11

Ecological Studies of Wetland Ecosystem in Manipur Valley from Management Perspectives

S.C. Rai and Adon Raleng
Department of Geography
Delhi School of Economics
University of Delhi, Delhi
India

1. Introduction

Wetlands are complex ecosystems often occupying the interface between land and water. Wetlands function as part of the landscape with or without the presence of humans. They have value because many of their functions have proved to be useful to humans but are at the same time ecologically sensitive and adaptive systems. The increasing demand and pressures on wetlands without understanding their nature and dynamics have often led to their degradation, thereby threatening livelihood of the communities' dependent upon these resources. The world's freshwater lakes of today are vanishing at a much faster rate than they used to be a century ago. In some cases, even the area is lost (Raleng, 2010). Current emphasis on wetland management has two objectives: firstly to conserve biotic diversity and secondly to maximize economic gains. This explains why in recent years much attention has been directed towards the formulation and operation of sustainable management strategies for wetlands[1]. Wetlands comprise lakes, rivers, marshes, bogs and similar areas and they are generally regarded as areas of land that remain waterlogged for a substantial period of the year. Wetlands fulfill a wide range of essential functions include flood proofing, natural sewage treatment, shoreline anchoring and dissipation of erosive forces, sediment trapping, nutrient retention and removal and recharging of aquifers. In addition, many food chains depend upon wetland productivity and form important habitats for fisheries and wildlife. Wetlands are important for maintaining

[1] Wetlands are the only single group of ecosystems to have their own international convention. The call for wetland protection gained momentum in the 1960s, primarily because of their importance as habitat for migratory species. A series of conferences and technical meetings culminated in the "Convention on Wetlands of International Importance Especially as Waterfowl Habitat" (better known as the Ramsar Convention) which came into force in 1975. In 1985 there were 38 signatories, in 1991 this increased to 60, and by 1993 the total number was 75 countries (Dugan, 1993). Currently 153 nations have joined the Ramsar Convention as Contracting Parties and more than1600 wetland sites around the world covering 145 million hectares; have been designated for inclusion in the Ramsar List of wetlands of International Importance (Ramsar Convention Secretariat, 2006). India has designated 25 wetland sites as Ramsar Sites of International Importance.

biodiversity and securing livelihood for local communities. The wetlands are most productive life support system in the world.

Wetland ecosystems are among the most threatened of all environmental resources. These bodies are getting more and more polluted due to anthropogenic activity leading to changes in land-use/cover characteristics and subsequently hydrologic processes, specifically through the large-scale conversion of forests to other land-uses (Jain et al., 2000; Mao & Cherkauer, 2009). After large areas of natural wetlands in all parts of the world were totally lost by drainage and landfills or were highly degraded by other human activities, the values and functions of natural wetlands are now being rediscovered (Gopal, 1991). At present, most of the wetlands of India and elsewhere are threatened to extinction mainly because of cultural eutrophication and conversion into agricultural land. Substantial changes in land-use/cover have occurred over north-eastern part of India in the past few decades with the shortening of *jhum cycle*, spread of settlement and increasing use of land resources for agriculture and economic development. Shifting cultivation, also known as "Slash and Burn" or "Swidden agriculture" and as "Jhum cultivation" in north-east India, where it is a predominant activity for the majority of the population, is often described as an inefficient, destructive practice, which contributes to deforestation and lowland sedimentation (Sillitoe, 1998). Reducing the *jhum cycle* during recent years has put pressure on resources and thus the productivity of land degradation, increased levels of soil erosion, hydrological imbalances and forest degradation all of which have caused reductions in yields and insecurity of food sources (Toky & Ramakrishnan, 1981). Understanding the characteristics of hydrological processes and regime change is important for driving the solutions to rational use of the lake water and limiting the environmental degradation in the region.

In India, studies on wetlands have not yet gained importance though few beautiful fresh water lakes of the Himalaya viz., Dal Lake of Kashmir, Khecheopalari Lake of Sikkim and Nainital Lake of Uttarakhand are losing their charms and reducing their areas at alarming rate. The data on lakes are not scientifically compiled, so it is difficult to provide solutions to lake problems. Several earlier studies have focused on ecological, wetland ecosystem management, rather than on the catchment's scale hydrologic impacts of land-use/cover change. Singh (1989) studies wetland ecosystem management perspective of fish, wildlife and environment in Loktak Lake. Singh & Shymananda (1990) studied management of Loktak Lake. Wetland ecosystems are among the most threatened of all environmental resources. It is important to understand the ecosystem processes in a wetland and the factors responsible for maintaining characteristics which impart particular value to it. There is a broad understanding of land-use change but their associations with the hydro-ecological consequences are not understood properly. So, there is a need to understand the relationship of these changes and those problems. Therefore, in view of this, the present study is focused on ecological studies of wetland ecosystem in Manipur valley from management perspectives, which need immediate conservation.

2. The Loktak Lake ecosystem

Loktak Lake, the largest natural lake in north-eastern India, occupies the southern part of Manipur valley, which runs north-south through the centre of Manipur state. Due to its importance in the socio-economic and cultural life of the people, it is considered as "The life-line of Manipur". A large population living in and around it depends upon the lake resources for their sustenance. Its biological richness, and uniqueness of habitat, has resulted in its designation as a "Wetland of International Importance" under the Ramsar Convention, a distinction it shares with just five other lakes in India. The lake is famous for its floating mats of vegetation locally called *phumdi*, which are heterogeneous mass of soil, vegetation and organic matter at various stages of decomposition and for being the only refuge of the endangered S*angai* (Manipur brow-antlered deer) which is closer to extinction (LDA & WISA, 1998).

The origin and evolution of Loktak Lake may be ascribed to tectonic activity and neotectonism remarkably influenced by a long history of fluviolacustral processes. The Loktak Lake is situated about 38 km south of Imphal, the capital city of Manipur. It lies between longitudes 93˚ 46′ to 95˚ 55′ E and latitudes 24˚ 25′ to 24˚ 42′ N (Fig. 1). Overall 53 settlements in and around Lokatak Lake is located having 279935 persons, which accounted for 12% of the total population of Manipur state. The lake, along with its surrounding swamps (locally called *pats*) is an integral part of the floodplain of Imphal River. The oval-shaped Manipur valley (height: 746-798 m asl), bounded by mountains rising 2000-3000 m asl along with the Imphal River and its tributaries (Iril, Thoubal, Heirok, Khunga and Chakpi), and other streams (Nambul, Nambol and Ningthoukhong) that pour their silt-laden waters directly into Loktak Lake. Morphometric data are summarized in Table 1.

Maximum length (L)	26 km
Maximum breadth (B)	13 km
Shore line length (L)	126 km
Orientation	N – S
Surface area	287 km^2
Area covered by *Phumdis*	107 km^2
Area covered by islands	17.2 km^2
Area covered by encroached land of fish farm, paddy field etc.	89.3 km^2
Area of open water	73.5 km^2
Mean breadth	11.04 km
Shoreline development	2.10
Total volume of water	550.21M m^3
Maximum depth (Zm)	4.58 m
Mean depth (V:A)	1.92 m
Mean depth : Maximum depth (Z:Zm)	0.42
Development of volume	1.26
Area of catchment's	980 km^2
Surface area : Catchment's area	0.293
Index of lake permanence	1.92

Table 1. Morphometry of Loktak Lake

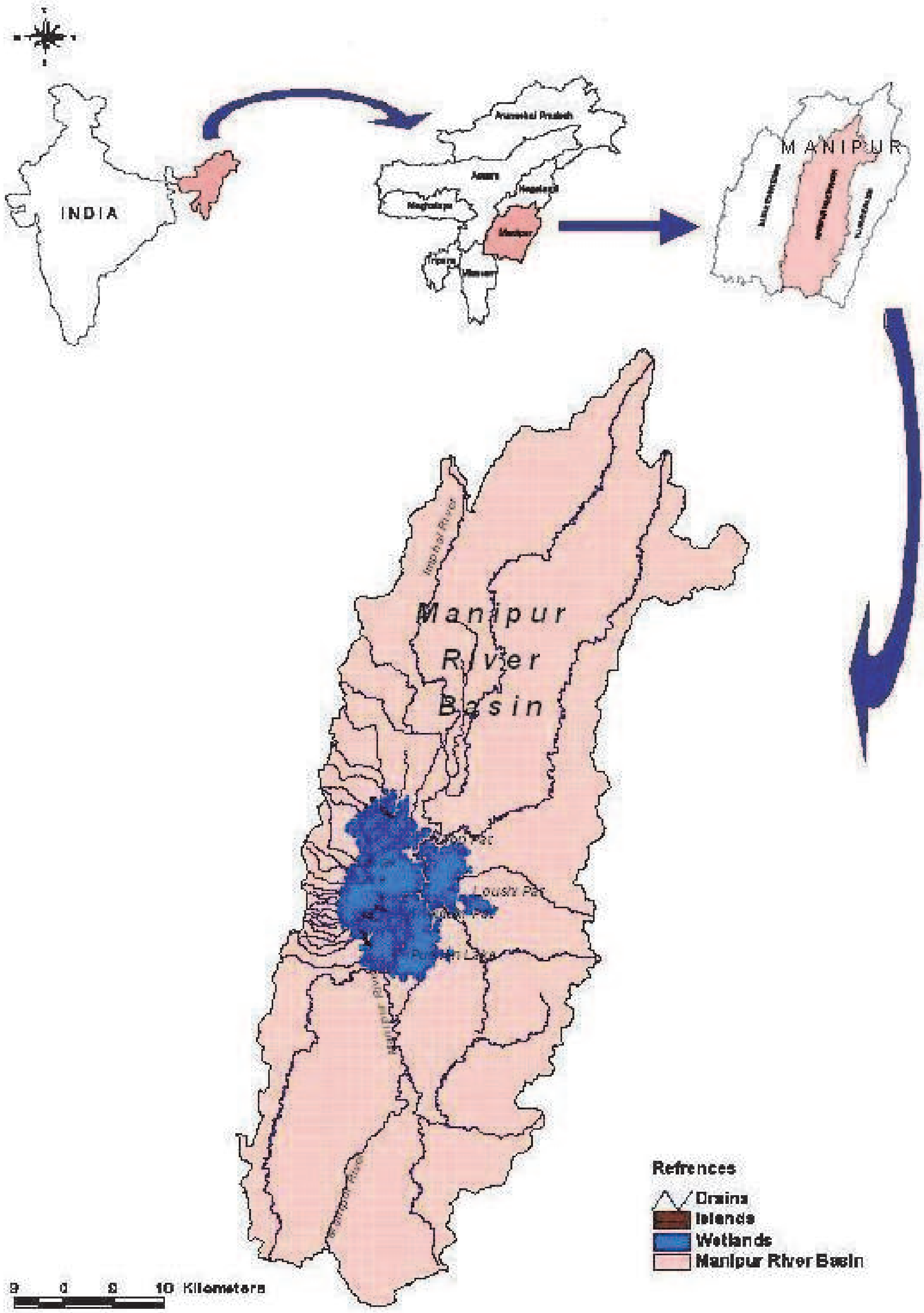


Fig. 1. Location of Loktak Lake

About two-thirds of Manipuri's population lives in the valley (one of the most densely populated areas in India with 415 persons per km^2). These communities are directly or indirectly dependent upon the lake itself. The productivity of the surrounding agricultural fields is on account of the nutrient rich waters of the lake. The wetland's enormous fish resources support large fishing communities in and around the lake area, in particularly villages of Moirang, Ithing, Karang, and Thanga, who completely rely for their livelihood on fish catches. About 60% of the fish catch of Manipur comes from Loktak Lake alone. Besides these vital functions, the lake is also being used for a major lift irrigation and power project.

There are 14 hills appearing as islands in the southern part of the lake. Only four of them, viz., (i) Thanga island, (ii) Karang island, (iii) Ithing island, and (iv) Sendra island are inhabitat. These islands are connected to the lake shore through motorable roads and bridges except Karang island, which is isolated from the other three and can be reached only by boat. The lake can be broadly divided into northern, central and southern zones. The three zones are characteristically different in terms of biodiversity and pressure of human activities. Therefore, these three zones i.e. Northern, Central and Southern were considered for the sampling site. Six sampling sites, two each in every zone, all in the lake periphery except one site (Site IG, which is an island). The three disturbed sites were selected in the study are Moirang (Site MO); Khathinungei (Site KI) and Mayang Imphal (Site MI) whereas the comparatively undisturbed sites are Hayel (Site HA), Khordak (Site KH) and Ithing (Site IG).

3. Land-use/cover change

Land is used to meet a multiplicity and variety of human needs and to serve numerous and diverse purposes. When the users of land decide to employ its resources towards different purposes, land-use change occurs producing both desirable and undesirable impacts. Land-use is the utilization of all developed and vacant lands on a specific space at a given time. The increasing pressure due to population and human activities of land resources to meet the increasing demands are contributing to significant transformation of land for a variety of land-uses.

Shifting cultivation is the characteristic feature of agriculture in the hilly catchments of the Loktak Lake. This form of land-use practices occupies a distinct position in the tribal economy, with about 74% of the tribal population deriving its sustenance from this traditional mode of agriculture. But due to rapid increase in population, the shifting cycle which until a few decades was more than 20 years has reduced to less than five years. This reduction has led to land degradation and increased soil erosion leading to sedimentation of water bodies consequently reducing its water holding and overall carrying capacity. The analysis of land-use/cover change is essential to formulate the suitable plan for lake conservation.

The data for land-use\cover of Loktak Lake catchment have been derived from secondary sources. The temporal land-use/cover data of Loktak Lake catchment of 1990 and 2004 including structural component data of 2004 have been obtained from Loktak Development Authority and Manipur Remote Sensing Application Centre, Imphal. The land-use/cover map has been prepared by using high resolution data like IKONOS satellite, for some area and merge data of 2.5m resolution using LISS-III (Linear Imaging Self Scanner) and PAN (Panchromatic) data. By comparing the temporal land-use data of 1990 and 2004, major land-use/cover changes that occur between the two periods were obtained. Intensive field investigations were carried out for ground verification.

A detailed land-use/cover inventory was developed to assess the current status of the lake catchment and presented in Table 2. The land-use/cover pattern in the lake catchment as a whole showed about 13.99% and 14.85% area under built-up land in 1990 and 2004, respectively. Agriculture is the main occupation of both the people living in the hill and valley area of Loktak Lake. The total agriculture land in the valley accounts for 36.28% and 35.62% in 1990 and 2004, respectively. On the other hand, shifting cultivation or *Jhum* cultivation is a very popular practice in the hill catchments. This type of cultivation is also known as slash and burn cultivation and account for 3.01% and 1.74% in 1990 and 2004, respectively. The total forest land in the lake catchment covered about dense forests have more than 40% canopy and accounts for 1.43% and 0.56% of the total area of the catchment in 1990 and 2004, respectively. The area where canopy cover is less than 10% is considered as degraded forest and its area accounts for 8.95% and 3.35% of the total area of the catchment in 1990 and 2004, respectively. Scrub land is observed mostly in the periphery of dense forest. The total areas under this class accounts for 9.35% and 5.80% in 1990 and 2004, respectively. Open forest represents the forest areas which were earlier deforested and presently natural regeneration is going on. The total areas under this class accounts for 0.37% and 9.76% in 1990 and 2004, respectively. The area under marshy/swampy class accounts about 0.60% and 0.84%, whereas hills/hillocks about 0.72% and 0.67% in 1990 and 2004, respectively. Area under water bodies such as ponds, reservoirs, rivers and aquaculture ponds are clubbed together and accounts for 0.93% and 2.24% in 1990 and 2004, respectively. The total area under wetlands accounts for 24.33% and 24.84% in 1990 and 2004, respectively (Table 2). The detailed descriptions of wetlands are presented in Table 3.

Land use Classes	1990		2004		Variations (%) (1990-2004)
	Area				
	(ha)	(%)	(ha)	(%)	
Built-up land	14558	13.99	15448	14.85	0.86
Agricultural land	37735	36.28	37055	35.62	-0.66
Shifting cultivation	3131	3.01	1811	1.74	-1.27
Dense forest	1493	1.43	586	0.56	-0.89
Open forest	391	0.37	10160	9.76	9.39
Degraded forest	9312	8.95	3514	3.35	-5.58
Scrub forest	9732	9.35	6042	5.80	-3.55
Marshy/swampy land	631	0.60	509	0.48	-0.12
Hill / hillocks	755	0.72	705	0.67	-0.05
Aqua-ponds/water bodies	974	0.93	2331	2.24	1.31
Wetland	25312	24.33	25839	24.84	0.51
TOTAL	104000	100	104000	100	-

Source: Loktak Development Authority (LDA)

Table 2. Area under different land-use/cover in Loktak Lake

Habitat type	Area	
	(ha)	(%)
Open water	2634	10.19
Dense phum	9176	35.52
Moderate phum	1058	4.09
Sparse phum	1744	6.75
Aqua-ponds	6911	26.75
Agriculture	32	0.12
Island with vegetation	288	1.11
Island without vegetation	66	0.25
Settlement	80	0.30
Phum ring area	3841	14.87
Total	25830	100

Source: Loktak Lake Development Authority

Table 3. Structural components of wetland area, 2004

During the 15-years period, the major land-use/cover changes are the expansion of built up area, open forest, aqua-ponds/water bodies and wetland (Table 2). There was increased in built up land up by 0.86 % which was the result of rapid urbanization in the Loktak catchment. The urban population in the catchment has grown at an annual rate of 3.5% during 1991-2001. The increased in open forest area by 9.39% in 2004 and decrease in degraded forest area by 5.58% shows that the activities of afforestation program have been taken up by Lake Development Authority (LDA) for catchment treatment that reduces the shifting cultivation area by 1.27% and ultimately led to the process of natural regeneration in the catchment area. However, there was decreased in dense forest area from 1990 to 2004 by 0.89% which was the effect of past deforestation that need some span of years to regenerate again. The evidence of regeneration is very much clear from the open forest area which increased up to 9.39% in 2004. There has been an increase in the water bodies\aqua-ponds by 1.31%. This is mainly due to conversion of agriculture and marshy/swampy land into aqua-ponds as a result of inundation after the construction of Ithai barrage. This process led to the decreased of agriculture land and Marshy/swampy land by 0.66% and 0.12%, respectively (Table 2). Off the valley's 22 lakes, 9 have silted up and drained for cultivation in the last two or three decades. Loktak Lake itself has shrunk from 495 km^2 in 1971 to just 289 km^2 (Singh, 1989), whereas increase in the number of athapham in lake resulted in prolific growth of *phumdis*. The *phumdis* cover in the lake has increased significantly from 57% in 1989 to 74% in 2002. *Phumdis* in the central zone have increased at an annual rate of 5.7% (Raleng, 2010).

4. Hydrological analyses

The Loktak Lake has been the subject of study since 1950s with the primary objective of flood control and optimal use of water resources for accelerated economic development in the region. Water regime of Loktak Lake is determined by the inflow from various streams and direct precipitation on the lake surface. Overall 34 streams from the western hills and the Manipur river via Ungamel and Khordak channels drain into the lake. The hydrological analysis of the lake is investigated in detail viz., discharge and sediment etc.

4.1 Water Inflow and outflow

The annual average rainfall recorded in the lake watershed was 1392 mm during 2001. Total annual inflow of water into the lake was estimated about 1687 M cusecs. The surface inflow from 34 rivers/streams of the western catchment accounts for 52% of the total inflow into the lake. The total outflow of water from the lake was estimated about 1217 M cusecs. Water abstracted for the hydropower generation by National Hydroelectric Power Corporation (NHPC) accounts for 70% of the total outflow from the lake. Link channels account for 14% of water outflow, while loss of water through evapotranspiration and evaporation was estimated about 9.5% and 6.5%, respectively.

There has been a drastic change in the water exchange pattern between the Manipur river and Loktak Lake after construction of Ithai Barrage. The inflow was reduced to 91 M cusecs and outflow to mere 20M cusecs (Table 4).

Parameters	1958-59 (M cum)	2001-01 (M cum)	Reduction (%)
Inflow	103	91	11
Outflow	315	20	93

Source: Loktak Lake Development Authority, Manipur

Table 4. Reduction in water exchange pattern between Loktak Lake and Manipur river

4.2 Sedimentation

Loktak Lake is gradually silting and the major contributor is sediment from the surrounding catchment. The annual average sediment input into the lake is estimated as 650,000 metric tones. Western catchment accounts for 65% of the total sediment inflow into the lake and the rest 35% from the link channels. The high amount of sediment from the western catchment is mainly due to land-use/cover change and *jhum* cultivation etc. Out of 45 micro-watersheds of the western catchment, Thongjarok yields the maximum sediment load of 58 t/ha and the minimum of 2 t/ha by Merakhong (Table 5). Sedimentation has been observed in the peripheral areas of the lake especially at the mouth of the western streams and link channels, resulting in the reduction in the water holding capacity of the lake, and flooding in the peripheral areas. It has been observed that the silting rates have increased by 34.44% during 1993 to 2003 and by 69.94% during 1967 to 2003. High sediment deposition in the lake turns the lake turbid and deteriorating water quality.

Rivers	Discharge (MCM)	Sediment Load (t)	Area (ha)	Sediment Yield (t/ha)	N (t/yr)	P (t/yr)	K (t/yr)
Potsangbam	22	20752.18	1928.00	10.80	27	6	20
Awang khujairok	9	4229.91	843.40	5.00	54	8	41
Thongjarok	30	133440.83	2302.30	58.00	57	9	45
Merakhong	-	12097.18	5947.20	2.00	-	-	-
Nambol	104	65911.02	9540.00	6.90	243	34	198
Nambul	161	50204.90	19893.00	2.50	2338	270	2081

Source: Loktak Development Authority (LDA), Manipur

Table 5. Sediment Yield during 2000-01

4.3 Flooding

A total area of 63.50 km^2 from different zones of Loktak Lake has been identified to be highly flood prone. The causes of flooding in the wetland system can be mainly attributed to unsystematic operation of Ithai barrage. Silted drainage system, developmental activities, change in land-use practices, loss of forest cover and presence of natural barriers like *Sugnu Hump* and alignment of Chakpi river with Manipur river further compounds the problem. Characteristics of floods in the northern zone are different from that of the southern zone. Many of the drains in the northern zone have heavily silted up and are choked with thick *Phumdi* resulting in reduction of their flushing capacity. This causes flooding in the upstream courses.

5. Water quality analyses

Water quality characteristics of Loktak Lake have been analyzed in detail. Water samples from six sites were collected seasonally i.e., rainy, winter and summer. All analyses were completed within ten days following standard method (Jain et al., 1999). The analysis carried out on various physico-chemical parameters reveals that the lake water of all the sites was circum-neutral to alkaline. The data reveals that pH of lake water ranges from 6.27 to 8.50. The lake water in different sites is severely affected and has also become considerably vulnerable to pollution with a wide range to contaminations. Dissolved oxygen concentration ranges from 6.80 to 9.32 (mg/l) and electrical conductivity in between 98 to 530 (µmoh/cm). Concentration of Chloride ranges from 8 to 30 (mg/l) and Phosphate-phosphorous concentrations fluctuate in between 0.002 to 0.260 (mg/l).

Seasonal variation in water quality characteristics of Loktak Lake have been analyzed in detail (Table 6). Most of the selected parameters reflected the seasonal pattern showing higher values in the rainy season. The pH was recorded highest at Site MI during summer season and lowest at Site KI during winter seasons. Analysis of variance showed that the pH varied significantly at sites and seasons but their interaction was not significant (Table 7). Water temperature ranged from 9.7 °C and 29.4 °C in the temporal cycle, highest during summer and lowest during winter season. Variation in temperature was significant between seasons but not between sites. The turbidity of the lake at various sites ranged from 35 cm to 145 cm. The highest turbidity (145 cm) was recorded in the rainy season at Site MO. Variation in turbidity was significant between sites and seasons, and their interaction was also found to be significant {LSD (0.05) =1.9}. Alkalinity was lowest in the winter season at all sites. The total alkalinity varied significantly among the sites and seasons and their interaction was significant (Table 7) (LSD (0.05) = 2.4}. Electrical conductivity showed marked variation among seasons and sites with higher values ranging from 194 to 530 (µ moh/cm) during rainy season, followed by summer (116 to 428 µ moh/cm) and winter season (98 to 150 µ moh/cm). It varied significantly among the sites and seasons, and their interactions was significant {LSD (0.05) =2.4}. Free carbon dioxide was highest in rainy season and ranged from 4.4 to 63.3 (mg/l) at various sites of the lake across the season. It varied significantly among the sites and seasons, and their interactions was also significant {LSD (0.05) =2.4}. Dissolved oxygen concentration range from 6.8 to 9.32 (mg/l). It varied significantly between sites and seasons and their interaction was also found to significant {LSD (0.05) =0.3}. Chloride concentration was highest in rainy season in all the sites and ranged from 8 to 30 (mg/l). It varied significantly among the sites and seasons and their interaction was significant {LSD (0.05) =4.1}. Phosphate-phosphorus concentrations fluctuate between 0.21 mg/l to 0.86 (mg/l) at various sites of the lake. Overall high amount of phosphate phosphorous was observed during rainy season. Its concentration increased considerably in rainy season may be attributed to the inflow of nutrients from the catchment area where fertilizers are extremely used for agriculture. It varied significantly among the sites and seasons, and their interaction was also significant {LSD (0.05) =0.03}. Total dissolved solid was recorded higher during rainy season at all sites and low during winter season. It varied from 52.7 to 480 (mg/l) and recorded highest at disturbed sites (360 to 480 mg/l). It varied significantly between sites and seasons, and their interaction was also significant {LSD (0.05) =2.2}. Biological oxygen demand was observed high in rainy season and low during winter season at all the sites. It ranged from 0.4 to 2.98 (mg/l) and varied significantly among the sites and seasons, and their interaction was also significant {LSD (0.05) =0.18} (Table 7).

Loktak Lake suffers from both natural and cultural eutrophication, which is indirectly the result of anthropogenic pressure and land transformation. A large amount of fertilizers residues are washed down the lake from the lake periphery paddy fields during the rainy season and accelerate pollution in the lake. The high silt contents that are brought down into the lake by the feeder streams and from jhumming prone catchment areas have silted up the lake bottom, thereby decreasing its water holding capacity. Changes in the pH of water may be the result of various biological activities (Gupta et al., 1996). The water temperature recorded higher during summer season is basically important for its effects in the biological reactions of the organism. The higher concentration of alkalinity value and free carbon-dioxide in the present study is similar with the report of Pandey & Kumar (1995). The high values of conductivity especially at disturbed sites during rainy season are associated with higher inflow from the surroundings. Total dissolved solids denote mainly the various kinds of materials present in the water. In the polluted waters the concentration of others substances increases depending upon the types of pollution. In present study, total dissolved solids had a cyclic pattern of seasonal changes and maximum during rainy season and minimum in winter. Johnson (1980) observed that total dissolved solid proportionately enhanced the electrical conductance in water and ran parallel to each other. The correlation between conductivity values and total dissolved solids (0.803) is similar with the above views. During the study period, water turbidity was found higher during the rainy season. It might be due to the high silt content of the water carried down into the lake by the feeder rivers and streams from the catchment areas. Such similar results were reported by Zutshi et al., (1980). Chloride concentration was found maximum during rainy season in all the six sites and on the contrary it was low during winter season. High chloride values were observed from the sites where anthropogenic pressure is maximum, which is related with animal wastes from cattle grazing and sewage disposed off by the household residing in the lake catchment. Excess of chloride over 5.5 mg/l in water was associated with contamination from animal organic matter (Khulbe, 1992; Jain et al., 1999). Phosphorous is an important factor in ecological studies and often regards as a limiting element in water ecosystem (Hecky & Kilhan, 1988). Main source of phosphorous in the lake was from domestic sewage, detergents, agricultural runoff. The high values of phosphate-phosphorus was recorded at disturbed site as compared to undisturbed site during rainy season, which might be due to rain draining into the lake with the nutrient rich soil deposited from the catchment areas of lake by its feeder streams and rivers. High level of free carbon-dioxide during rainy season was observed which may be attributed to its influx through rainwater in the form of carbonic acid. This is in conformity with the observation of Chakraborty et al.,

Sites	Season	pH	Temperature (°C)	Turbidity (cm)	Alkalinity (mg/l)	Conductivity (mho/cm)	Free CO_2 (mg/l)	Dissolved oxygen (mg/l)	Chloride (mg/l)	TDS (mg/l)	BOD (mg/)	Total Phosphorus (mg/l)
Mayang Imphal (MI)	W	7.34	10	97	65	150	53	7.1	11.0	52.7	1.43	0.67
	S	8.5	29.4	46	120	428	24.2	8.54	17	160	2.0	0.25
	R	7.8	22.2	140	140	530	63.3	7.4	25	460	2.8	0.84
Hayel (HA)	W	7.81	10	88	105	98	38.9	7.74	12	83	0.7	0.25
	S	8.1	29.3	35	151	116	38	8.89	12	103	1.1	0.21
	R	7.9	22.2	120	205	248	46.2	8.4	15	119	2.1	0.28
Khordak (KH)	W	6.99	9.7	72	98	115	35.7	7.9	8.0	52.7	0.86	0.41
	S	7.4	28.9	54	170	181	26.4	9.32	12.8	75	1.4	0.28
	R	7.2	22.6	118	250	223	40	8.4	13.0	110	1.9	0.51
Khathinungei (KI)	W	6.27	10	96	75	105	28	6.8	9.0	55	1.22	0.7
	S	7.8	29.3	60	128	160	15.8	8.51	12.0	140	2.8	0.40
	R	6.9	22	118	143	350	50	7.3	30.0	360	2.9	0.86
Moirang (MO)	W	7.64	10	95	85	119	12.6	6.9	12.0	60.8	1.49	0.55
	S	8.4	29.2	55	139	186	4.4	8.51	18	170	2.4	0.30
	R	7.9	22.6	145	145	327	59	7.4	28	480	2.98	0.83
Ithing (IG)	W	7.62	10	49	121	121	30.8	7.6	10	61.3	0.4	0.23
	S	7.9	28.2	48	118	120	30	9.2	13.9	99	0.8	0.20
	R	7.8	22	120	182	194	38.5	8.3	15	118	1.4	0.26

Table 6. Seasonal variations in water quality at different sites of Loktak Lake

Source of variation	d. f.	*F*	*P*
pH			
Site	5,36	11.67	0.001
Season	2,36	16.9	0.001
Site × Season	10,36	1.43	NS
Transparecy			
Site	5,36	22.9	0.001
Season	2,36	1990	0.001
Site × Season	10,36	54	0.001
Temperature			
Site	5,36	0.123	NS
Season	2,36	3535	0.001
Site × Season	10,36	1.04	NS
Conductivity			
Site	5,36	5195	0.001
Season	2,36	14598,	0.001
Site × Season	10,36	1064	0.001
Free carbondioxide			
Site	5,36	45.5	0.001
Season	2,36	279	0.001
Site × Season	10,36	31.9	0.001
Alkalinity			
Site	5,36	450	0.001
Season	2,3	2732	0.001
Site × Season	10, 36	116.4	0.001
Disvsoled oxygen			
Site	5,36	15.8	0.001
Season	2,36	49.3	0.001
Site × Season	10,36	9.6	0.001
Phosphate phosphorus			
Site	5,36	154	0.001
Season	2,36	247	0.001
Site × Season	10,36	22.9	0.001
Total Dissolved Solid			
Site	5,36	4335	0.001
Season	2,36	20981	0.001
Site × Season	10,36	2702	0.001
Chloride			
Site	5,36	24.3	0.001
Season	2,36	136.9	0.001
Site × Season	10,36	13.7	0.001
Biological oxygen demand			
Site	5,36	47.9	0.05
Season	2,36	118	0.001
Site × Season	10,36	2.7	0.05

Table 7. ANOVA for seasonal variations in water quality at different sites of Loktak Lake

(1959); Mansoori et al., (1995). The high dissolved oxygen content during summer season is largely attributed to increase in temperature with increase in photosynthetic activity of the aquatic plants and phytoplankton. Our results are consistent with Khulbe (1992). The presence of BOD in the Loktak Lake may be from polluted Nambul river and also from the domestic waste from local areas including from several huts lying inside the lake on the *phumdis*. High value of biological oxygen demand during rainy season might be due to high organic loads along with the rain runoff from the catchment area of the lake. Das & Pandey (1980) have also reported the same view for the lake Nainital of Kumaon Himalaya. The data based on the physico-chemical properties is an indicator of the water quality at the time of sampling. However, regardless of the high variation of the water quality, the results obtained can be representative of the spatial variation of the water quality throughout a wide range.

6. Sustainable management lake ecosystem

The lake has many stakeholders. For the purpose of the present study only some of the important and relevant stakeholders are selected for study. Fishery is the most important occupation of communities in and around the lake, hence fishermen are the most important primary stakeholders of the initiatives. Phum hut dwellers, agricultural farmers of lake shore villages and hill villages, people originally displaced by reservoir flooding and livestock farmers are the other stakeholders. In order to stem and ultimately reverse current pressures on the lake ecosystem, a conservation strategy to promote the sustained use of wetland resources needs to be developed and implemented. The following management strategies warrant immediate attention as suggested by the selected stakeholders:

6.1 Research and monitoring

The most important questions regarding the ecological problems of Loktak Lake remain unanswered viz, the rate of nutrient enrichment, the pollution load, its point and non-point sources, hydrological details such as water retention, water loss or gain through seepage and most importantly, the likely impacts of the proposals considered for implementation both on biota and socio-economy. So, monitoring of lake from time to time is absolutely necessary.

6.2 Siltation control

This will involve soil conservation measures in the catchment, weaning shifting cultivators away from the damaging practice, and involving Sloping Agriculture Land Technology developed by some institutions.

6.3 Encroachment control

It has been pointed out that reclamation of wetland areas is being illegally undertaken by people of means, while others dispossessed of their holding because of submergence due to the damming of the lake are still being taxed. Illegal encroachers should be dispossessed of their holdings, which could then be distributed among the genuinely landless unemployed. Unless these human issues are resolved, all conservation efforts will be futile.

6.4 Control of over fishing

Fishing is the main occupation of island and many lakeshore villages. In recent times fishing has not become sustainable at all. Aquaculture should be encouraged in the catchment to reduce pressure on the fishery resources of the lake. The feasibility of paddy-cum-fish culture as an income generating activity as has been practiced by Apatani communities of Arunachal Pradesh in Apatani valley (Zero valley) could be examined. In addition, the introduction of sewage-fed fisheries would greatly reduce pollution from municipal wastes, and also enhance fish production. At this stage, it is essential that alternative or additional source of livelihood like piggery, duckery and revival of traditional handicraft and handloom industries though adequate incentives and technical and marketing support is necessary.

6.5 Environmental Impact Assessment (EIA)

An EIA of the Loktak Hydro-electric Power Project is must. The damming of the Loktak Lake water seems to have done more damage to the wetland ecosystem than was earlier envisaged; especially in terms of accelerating eutrophication and adversely affecting certain sectors of the traditional economy.

6.6 Water hyacinth control

Facilities to utilize the weed for biogas production, paper pulp and fiber, chemical products, and mulch and compost needs to be introduced. The spread of weevils in the lake for the eradication of hyacinth urgently needs to be investigated. The riotous growth of *Phumdi* also needs to be curtailed after a scientific assessment of the quantity to be removed.

6.7 Fertilizer usage control

Phum compost promises to undo various threats to the lake ecosystem. Removal of *phumdis* lead to better quality water and phum compost are free from the side effect that chemical fertilizers used by farmers, have on the lake ecosystem. Hence, promotion of phum compost at various levels and farm for mass production of phum compost need to be built. Weed infestation is directly related to the large fertilizer inflow into the wetlands. Alternative cropping practices need to be introduced with emphasis on, i.e. horticulture, sericulture, and perhaps apiculture, which could also enhance income levels. Today Loktak Lake has been placed on the informal list of threatened Ramsar Sites of the world. Only a concentrated effort on the part of official agencies, professionals, NGOs, and the local communities themselves, to comprehend the complexities of this delicately balanced, biologically-rich wetland ecosystem, and take appropriate action, can save Loktak Lake from demise.

6.8 Indigenous knowledge

Indigenous knowledge systems which through many years have evolved as a complex practice may be different from scientific conservation management. It would therefore be wise to conduct participatory research and studies to revive and recover traditional knowledge of indigenous management system of both in hill and valley villages as in the case of forest management in Caqueta, Columbia. The villages in the lake area are prone to water borne diseases. Close disease surveillance need to be kept. Mobile medical teams need to visit the villages during peak seasons and provide free medical camp. The hill villages need to given proper awareness regarding the negative effects of deforestation and forest fires not only to the lake ecosystem but also to their own lives. They should encouraged to form joint forest committees, which will control and monitor over exploitation of forest resources.

7. Conclusions

For sustainable development of any natural resources, it is very important that the stakeholders at various levels come together and participate in conserving and managing the resources. After a thorough analysis, it is very much clear that the deforestation particularly jhum cultivation and land-use/cover change has drastically affected the water quality of the lake. The water quality, in general, falls within class C to E as per the CPCB's designated best use criteria. The lake water is not fit for direct drinking without treatment but can be used for irrigation purposes. A comparative analysis of water quality of different sites indicates significant levels of pollution in the densely populated sites as compared to that of less populated sites because dissolved oxygen was low and bio-chemical oxygen demand and other parameters including nutrient levels were higher in the densely populated sites. It also indicates that out of the three zones (i.e. northern, central and southern zones) of the lake, the Northern Zone and Southern Zone shows significant levels of pollution. High intensity of fertilizer usage in the agricultural fields and practice of fish farming contribute significantly to water quality deterioration in the Northern Zone. The highly polluted rivers (like Nambul and Nambol rivers) also finally discharge pollutants in this zone. Southern Zone is polluted due to flow of all the pollutants finally in this zone and their accumulation due to poor flushing. So, while taking up any water management plan of Loktak ecosystem the highly populated sites of the Northern Zone and Southern Zone should be given priority at any cost. The stakeholders who are source of threat to the ecosystem need proper attention and monitoring. Also different types of participation can be practiced as per demand of the situation so that it leads to self management.

8. Acknowledgement

The authors are thankful to the Head, Department of Geography, Delhi School of Economics, University of Delhi, for facilities. We are also thankful to Dr. Alka Jain for her support, critical and constructive comments during the study period and Manipur Pollution Control board for laboratory analysis.

9. References

Chakrabati, P.K., Roy, R.D.P., Singh, S.B., (1959) A quantitative study of the plankton and the physico-chemical conditions of the river Yamuna at Allahabad in 1954-1955. *Indian J. Fish.*, 6(1), 186-203.

Das, S.M., Pande, J., (1980) Pollution, fish mortality and environmental parameters in lake Nainital. *J. Bombay Nat. Hist., Soc.*, 79, 100-109.

Dugan, P.J. (ed.) (1993) *Wetlands in Danger*. IUCN and World Conservation Union, Cambridge.

Gopal, Brij (1991) Wetland (mis) management by keeping people out: two examples from India. *Landscape and Urban Planning*, 20, 53-59.

Gupta, R.K., Sharma, M., Gorai, A.C., Pandey, P.N., (1996) Impact of coal mining effluents on the physico-chemical characteristics of Raja Tank, Jaria (Dhanbad). *J. Freshwater Biol.*, 8(2), 63-73.

Hecky, R.E., Kilhan, P., (1988) Nutrient limitation of phytoplankton in freshwater and marine environment. A review of recent evidence on the effect of enrichment. *Limnol. Oceanogr.*, 33, 796-822.

Jain, Alka, Rai, S.C., Pal, J., Sharma, E., (1999) Hydrology and nutrient dynamics of a sacred lake in Sikkim Himalaya. *Hydrobiologia,* 416, 12-22.

Jain, Alka, Rai, S.C., Sharma, E., (2000) Hydro-ecological analysis of a sacred lake watershed system in relation to land-use/cover change from Sikkim Himalaya. *CATENA*, 40, 263-278.

Johnson, M.E.C., (1980) Total solid content in two freshwater lakes. *Indian J. Bot*., 11 (2), 188-190.

Khulbe, R.D., (1992) *Studies on Water Pollution in Nainital and Bhimtal Lakes of Kumaun Himalaya.* II^nd Annual Progress Report, Ministry of Environment and Forests, Government of India, 187 pp.

King, D.L., (1970) The role of carbon in eutrophication. *J. Water Poll. Contr. Fed*., 42, 2035-2051.

LDA & WISA (1998) *Project Management Plan, Sustainable Development and Water Resource Management of Loktak Lake*. Loktak Development Authority and Wetland International- South Aisa.

Mansoori, H.A., Lavania, R.K., Tiwari, R.K., (1995) Hydrological study of Lakshmital lake Jhansi with special reference to plankton productivity. *Flora and Fauna,* 1(1), 39-42.

Mao, D., Cherkauer, K.A., (2009) Impacts of land-use change on hydrologic responses in the Great lakes region. *Journal of Hydrology*, 374 (1-2), 71-82.

Pandey, R. and Kumar, A. (1995) Comparative evaluation of potable water quality of tribal and non-tribal villages of Santhal Pargana, Bihar. *Ecology, Environment and Conservation*, 1(1), 71-74.

Ramsar Convention Secretariat (2006) *Participatory Skills. Ramsar Handbooks for the Wise Use of Wetlands*. Ramsar Convention Secretariat, Gland, Switzerland.

Raleng, Adon (2010) *Human Impact on Loktak Lake, Manipur*. Unpublished M. Phil. Dissertation, Department of Geography, University of Delhi, pp.125.

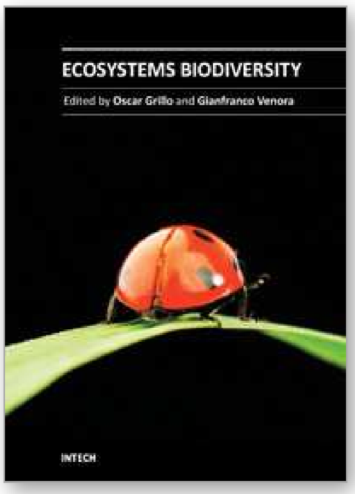
Sillitoe, P., (1998) It's all in the mound: fertility management under stationary shifting cultivation in the Papua New Guinea highlands. *Mountain Research and Development*, 18 (2), 123-134.

Singh, T.H., Shyamanda, R.K., (1990) Management *of Loktak Lake: An Enquiry into the Present Strategy and Possible Alternatives.* Manipur University, Imphal.

Singh, T.H., (1989) *Study of Wetland Ecosystem in Manipur Valley from Management Perspectives of Fish, Wildlife and Environment*. Department of Life Sciences, Manipur University, Imphal.

Toky, O.P., Ramakrishnan, P.S., (1981). Runoff and infiltration losses related to shifting agriculture (jhum) in north-eastern India. *Environmental Conservation*, 8, 313-321.

Zutshi, D.P., Subla, B.A., Khan, M.A., Vanganeo, A., (1980). Comparative limnology of nine lakes of Jammu and Kashmir, Himalayas. *Hydrobiologia*, 72, 101-102.



Ecosystems Biodiversity
Edited by PhD. Oscar Grillo

ISBN 978-953-307-417-7
Hard cover, 464 pages
Publisher InTech
Published online 16, December, 2011
Published in print edition December, 2011

Ecosystems can be considered as dynamic and interactive clusters made up of plants, animals and micro-organism communities. Inevitably, mankind is an integral part of each ecosystem and as such enjoys all its provided benefits. Driven by the increasing necessity to preserve the ecosystem productivity, several ecological studies have been conducted in the last few years, highlighting the current state in which our planet is, and focusing on future perspectives. This book contains comprehensive overviews and original studies focused on hazard analysis and evaluation of ecological variables affecting species diversity, richness and distribution, in order to identify the best management strategies to face and solve the conservation problems.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821