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Surface water quality and information about the environment surrounding Inle Lake in Myanmar

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Abstract Inle Lake is the second largest lake in Myanmar and one of the nine key sites for sightseeing there. An analysis of its water quality has not been published before. The objective of this study is to reveal the current situation and find any major problems with the lake. For this purpose, the natural and cultural environments were examined. Some physical and chemical aspects of the surface water were assayed in situ for 2 days in November 2004. The principal ions were analyzed in our laboratory. The main cation and anion species in the lake surface water are Ca^{2+} and HCO_3^-. Its high calcium content can be attributed to the limestone of Shan Plateau around the lake. The alkalinity of the lake water was 3829–4114 acid-neutralizing capacity (ANC) (pH 7.8–8.0); it can be attenuated by Ca^{2+}. The concentrations of PO_4-P, NO_2-N, and NO_3-N were relatively high; these could originate from domestic and agriculture uses. The trophic state is eutrophic. The concentrations of coliform bacteria indicated that the lake water was unfit to drink, but some people use it for drinking anyway. The bacteria could enter the lake through the direct latrine system used there. The thermal type of the lake is presumed to be warm polymictic. More extensive studies are needed because the lake is thought to be the most changing site in Myanmar as a result of both the tourism boom and increasing agricultural activity.

Key words Myanmar · Water quality · General information

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Introduction

The results of this study constitute the first set of data for physicochemical water quality and aid the development of water quality management of Inle Lake in Myanmar.

Geographic situation

Inle Lake is the second largest lake in Myanmar. It is situated in Shan State in northeastern Myanmar; 870 m above sea level (asl), 20°27′–20°40′ N, 96°52′–96°57′ E. The average length is 18 km from north to south, and the width is 11 km from east to west (Ma 1996). It is said that the area of Inle Lake has declined 15% since British colonial times (1886–1948). The general formation of the lake is Shan Plateau limestone. The lake flows mainly north to south (Fig. 1). The rate of siltation from inflowing streams is 623 000 m^3 $year^{-1}$, and clearing the natural vegetation for cultivation accelerates siltation (Ma 1996). It receives the basins of Shan Plateau drainage and runs off into Mobye Reservoir. The outlet volume is 46.6 $mg^3 s^{-1}$ (JICA 2002).

The lake sits in a tropical monsoonal area with an average annual rainfall of 953 mm (Ma 1996). Precipitation is mostly confined to the rainy season (May to October) (Fig. 2). Rain on Shan Plateau in both the cold dry season (November to February) and the hot dry season (March to May) is more frequent than that in other parts of Myanmar (FAO 1985). Water depth is 7 m in the rainy season and 4 m in the hot season (Butkus and Myint 2001). No data regarding the lake's level during the cold dry season have been recorded.

Biological diversity

Luxuriant submerged plants on the bottom and floating-leaved macrophytes on the surface cover much of the lake. The flora and fauna of the lake are quite diverse (Ma 1996).

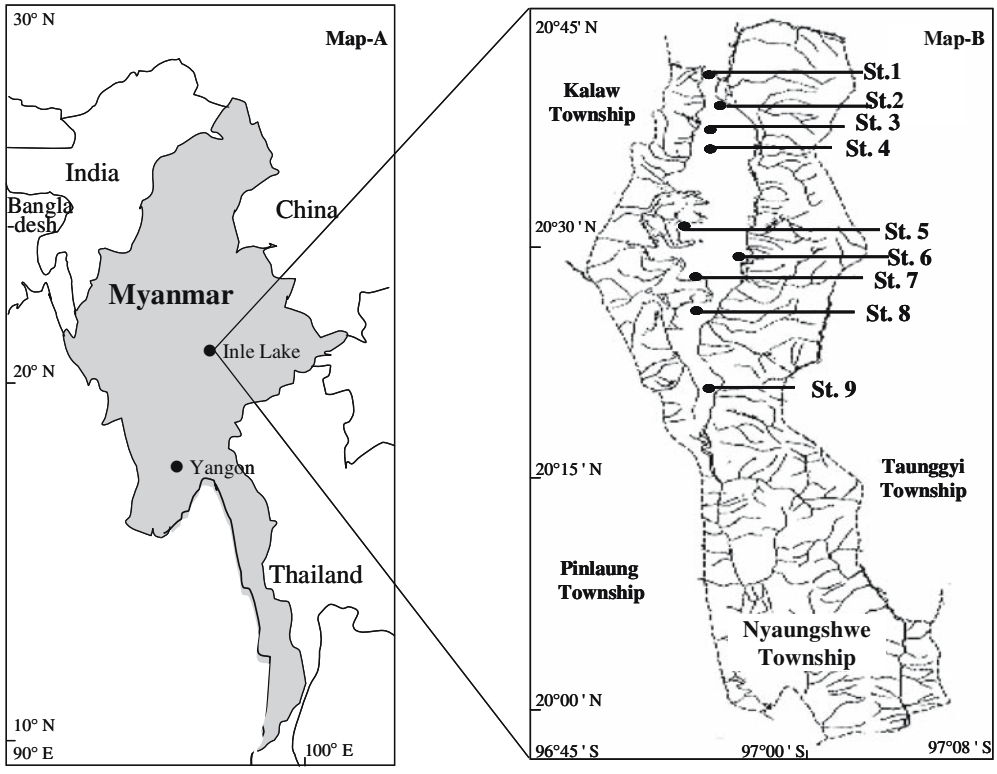

Fig. 1. Location and drainage system of Inle Lake in Nyaungshwe township, with sampling sites. *Figures on maps* indicate longitude and latitude. In Map-A, *solid lines* indicate country border. In Map-B, *solid lines* indicate streams in Nyaungshwe township and *dotted lines* indicate township boundary

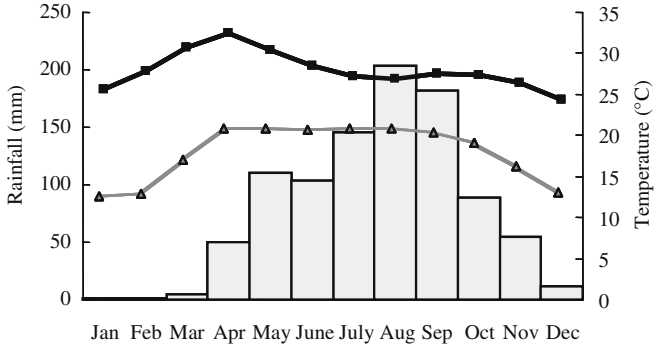

Fig. 2. Average monthly rainfall in Nyaungshwe township: monthly with maximum (■) and minimum (▲) atmospheric temperature. (From Ma 1996)

Fifty-three species of bird and 36 species of fish, including 16 endemics, were counted; additionally, threatened species, 4 birds and 5 mammals, were observed (Ma 1996). Mammals and endemic fishes listed in the *Red Data Book* face extinction (Butkus and Myint 2001).

Cultural background

Since the early 1950s, tourists from other countries have visited the lake (Thaw 1998). The trend has become significant since 1996, when the nation focused on increasing tourism. Moreover, in 2001, the Myanmar government determined Inle Lake as one of the nine key sightseeing sites for the development of tourism (Thaw 2001). The local government claimed that 20000 people visit Inle Lake annually. The attracting point is the unique culture of the natives, called the Inthas. For example, tourists like to see the floating gardens, leg rowers and flat-bottomed boats, floating markets, and cloth made from lotus stalks. The floating gardens are man-made islands composed of weeds and silt from the bottom of the lake. Inle is famous for silk clothing, too. Textiles, one of the major industries, use chemical dyestuffs as well as natural dyes (Butkus and Myint 2001). In addition, there are many pagodas and stupas built on the lake in the eleventh century. Goldsmithing, silversmithing, weaving, and other crafts also attract the tourists, and they enjoy trips on motorboats (Ba 2003).

The main business in Inle Lake is agriculture on the floating gardens. Tomatoes constitute about two-thirds of the region's agriculture (Butkus and Myint 2001). The farmers can harvest tomatoes from these gardens when the rest of the country is short of them. Seventy-five percent of the tomato yield is exported to other states and divisions of the country, and the cultivated area is increasing year after year (Fig. 3).

The farmers use chemical fertilizers, pesticides, and organic fertilizers for the tomato gardens. It is said that the volume used of some pesticides goes far beyond the recommended rate (Butkus and Myint 2001). The national government has admitted that the mass of the floating gardens contains nitrogen levels six to eight times higher than those in the soil (Daw and Kyaw 2000).

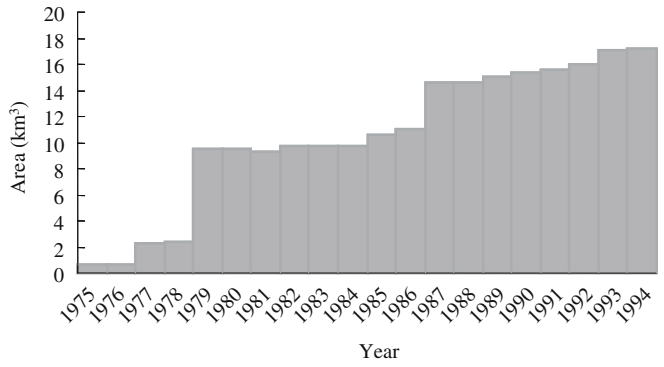

Fig. 3. The area of tomato gardens in Nyaungshwe township. (From Ma 1996)

The lake is important for transporting products around it and into distant townships. United Nations Development Programme (UNDP) suggested that approximately 40% of the people in Nyaungshwe township were landless in 1999 (FAO 2004). They use canoes at all times and sell many products on their boats, called floating markets.

Many fish and other aquatic products are provided to surrounding townships. FAO estimated that the annual production of the fisheries in Nyaungshwe township is 550–650 tons, and grass carp farming inland in Inle Lake contributes to the livelihood of an unknown number of people. In addition, FAO indicated that the consumption of fish was three times higher than that of meat (FAO 2004). Therefore, fish provide the main source of animal protein in Myanmar.

In 2004, the local government counted 107 732 people in 16 484 families in 318 villages on and around the lake. Many people use lake water for washing and bathing. Some people in the floating villages also drink the lake water. Others dig draw wells and tube wells for drinking water. Each home has water containers for drinking and cooking. Many of these containers are earthenware pots or plastic tanks covered with a plate and a cup. The pagodas have filter-type water-purifying equipment, although they also have earthenware containers. All accommodations for tourists use factory-purified and bottled water because if tourists accidentally drink the water that natives drink, it makes them ill.

Many toilets in the area are ground pit latrines, which have bored holes in the back; some have a hole above the lake surface through which excretions are dropped directly into the lake. Even some factories and accommodations that have septic tank systems do not adequately treat the sewage. UNDP suggested that 72% of households in Nyaungshwe township in 1999 used unsanitary open pits or had no latrines (FAO 2004). No wastewater treatment is done, and domestic drainage flows directly into the lake from around the area.

Aquatic environmental problems

Conditions that we consider to be problems are silting action of the inflow streams, overcrowding by water hyacinths, extinction of unique species, disturbance created by boat trips for tourists, fertilizer and pesticide pollution from the floating gardens, and sewage contamination.

It was reported that the water quality has declined at an increasing rate, and the government initiated the Inle Lake Preservation Project (Butkus and Myint 2001). The project's committee consists of the Shan State Peace and Development Council, Nyaungshwe township local authorities, and the Myanmar government (Irrigation, Agriculture, and Forestry Departments). The project focuses primarily on protection of birds and other fauna and management of fish resources.

Materials and methods

Field investigations of some physical and chemical parameters were carried out in Inle Lake on November 23–24, 2004 (during the cold dry season). Chemical and physical water quality was surveyed at one of the inflow streams [station (St.) 1], near densely populated areas (St. 2, 6, 7, 8, 9), near upstream (St. 3, 4), and a remote area with a fine wide view (St. 5). Nine water samples were taken from the surface (St. 1–9), and two samples were taken from 1-m depth, approximately 0.5–1 m above the bottom (St. 1, 2) (see Fig. 1).

Water temperature and conductivity were measured *in situ* with a conductivity meter (Hanna waterproof Dist HI 98311) corrected to 25°C. The pH and dissolved oxygen (DO) were measured with a pH meter (Horiba D-24T) and a dissolved oxygen meter (Orion dissolved oxygen meter 810). The populations of coliform bacteria (coliform) and *Escherichia coli* were estimated by a rapid test kit (AOAC 110402, Compact Dry EC Nissui).

Water samples were collected with a high-rate water sampler (SUS 304) and tapped into plastic bottles. The samples were filtered with a 0.45-μm membrane filter for the following chemical analyses.

SiO_2 was determined by the molybdosilicate method (APHA et al. 1998). Major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) were analyzed by the direct air-acetylene flame method (APHA et al. 1998) with an atomic absorption spectrophotometer (Shimadzu AA-660). Anions (Cl^-, SO_4^{2-}, NO_2^-, NO_3^-, PO_4^{3-}) were determined by a high performance liquid chromatograph (APHA et al. 1998) (Shimadzu LC-10AD) with a UV detector (Shimadzu SPD-6AV). Total organic carbon (TOC) was determined by the high temperature combustion method (APHA et al. 1998) using a TOC meter (Shimadzu TOC-V CSN).

Hardness was calculated based on Ca^{2+} and Mg^{2+} concentrations (APHA et al. 1998). Alkalinity was calculated based on concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, NO_3^-, and Cl^- (WHO 1992).

$$[CaCO_3/\text{mg l}^{-1}] = 2.497\,[Ca^{2+}/\text{mg l}^{-1}] + 4.118\,[Mg^{2+}/\text{mg l}^{-1}]$$

$$[\text{Alkalinity/ANC}] = (2[Ca^{2+}] + 2[Mg^{2+}] + [Na^+] + [K^+]) - (2[SO_4^{2-}] + [NO_3^-] + [Cl^-])$$

Table 1. Physicochemical water quality of Inle Lake on December 23–24, 2004; site locations correspond to Fig. 1

A. Unit	Site	Depth (m)	Temp. (°C)	EC (μS cm^{-1})	TOC (mg l^{-1})	DO (mg l^{-1})	DO (%)	pH	Alkalinity (mg l^{-1})	*Escherichia coli*	Coliform (CFU ml^{-1})
1	One of the inflow streams	0	21.0	321	48.2	4.0	53	7.0	134	2	80
		1	21.0	338	44.5	3.4	45	7.0	133	3	107
3	Reach near inflow	0	22.6	324	–	6.0	81	7.2	129	0	94
4	Reach near inflow-2	0	25.8	327	42.9	6.5	93	7.0	117	0	18
6	Open water	0	24.7	260	34.3	8.6	120	7.0	100	23	23
2	Nyaungshwe town	0	22.6	378	51.9	2.4	33	7.2	140	5	99
	(tourist hub)	0	21.9	374	–	2.3	–	7.4	–	–	–
		0	21.0	374	–	2.2	–	7.2	–	–	–
		0	21.5	374	–	1.6	–	7.2	–	–	–
		1	21.9	376	51.4	3.5	48	7.6	138	3	102
		1	21.9	374	–	–	–	7.4	–	–	–
		1	21.9	374	–	1.4	–	7.4	–	–	–
		1	21.6	373	–	2.9	–	7.2	–	–	–
5	Silversmith area	0	21.1	305	–	2.2	29	7.2	109	2	64
7	Paung Daw Oo Pagoda	0	21.7	253	–	1.8	24	7.0	103	1	85
8	Nampan Market area	0	23.3	255	41.6	4.7	64	7.0	140	1	99
9	Lotus textile area	0	23.5	264	32.9	0.6	8.2	7.0	117	1	137
	Maximum value		25.8	378	51.9	8.6	120	8.0	140	23	137
	Minimum value		21.0	253	32.9	0.6	8.2	7.8	100	0	18

B. Unit	Depth (m)	SiO_2 (mg l^{-1})	Hardness (mg l^{-1})	Ca^{2+} (mg l^{-1})	Mg^{2+} (mg l^{-1})	Na^{+} (mg l^{-1})	K^{+} (mg l^{-1})	Cl^{-} (mg l^{-1})	SO_4^{2-} (mg l^{-1})	PO_4-P (mg l^{-1})	NO_2-N (mg l^{-1})	NO_3-N (mg l^{-1})
1	0	5.15	175	50.4	12.0	5.51	6.81	2.65	0.172	0.0195	0.028	0.024
	1	9.27	190	43.4	19.8	7.66	4.12	3.17	0.647	0.0216	0.822	0.239
3	0	5.82	171	48.8	12.0	4.50	5.65	2.51	0.163	0.0191	–	0.008
4	0	2.42	169	43.8	14.5	13.4	3.80	2.55	6.90	0.0166	DL	DL
6	0	3.58	139	36.1	11.8	7.71	5.51	2.26	3.10	0.0111	0.036	DL
2	0	8.30	186	50.2	14.6	9.63	6.44	3.67	0.766	0.0240	0.007	DL
	1	8.79	184	49.6	14.7	12.3	5.56	4.38	1.14	0.0281	0.909	0.350
5	0	2.97	190	36.6	23.9	7.95	5.46	0.779	0.171	0.0112	0.033	–
7	0	4.00	165	30.0	21.9	9.73	3.24	2.99	2.39	0.0078	0.024	DL
8	0	3.76	140	35.2	12.6	6.04	6.02	2.65	0.859	0.0180	0.024	0.011
9	0	8.06	200	39.8	24.5	12.6	4.72	2.05	0.956	0.0218	0.692	0.454
Maximum value		9.27	227	50.4	24.5	13.4	6.81	4.38	6.90	0.0281	0.909	0.45
Minimum value		2.42	123	30.0	11.8	4.50	3.24	0.78	0.163	0.0078	0.007	0.01

TOC, total organic carbon; DO, dissolved oxygen

Table 2. Surface water quality in Inle Lake in 2001

Time	Place	N	E	Depth (m)	pH	EC (μS cm^{-1})	DO (mg l^{-1})
0955	BWC (north check)		96.60	4.0	7.8	370	4.0
1140	South limit of floating mats south of BWC	20.36	96.60		8.3	320	10.4
1240	Eastern side of resort	20.31	96.55	2.4	8.1	260	9.6
1540	Phaung Daw Oo Pagoda	20.28	96.53	1.7	8.3	320	9.8
1620	Plankton sampling point	20.33	96.54	3.9	8.0	310	8.6
1145		20.18			7.8	280	7.6
1555	Just upstream of covered bridge	20.16	96.54				3.6
1320	Plankton sampling point	20.33	96.54	4.5	7.8	275	6.8
1440	Open water			5.0	8.2	240	7.6
	Maximum value			5.0	8.3	370	10.4
	Minimum value			1.7	7.8	240	3.6

Source: Thein et al., unpublished data (2001)

Results and discussion

Water temperature ranged between 21° and 26°C (Table 1). The temperature variation was rather greater than that in 2001 (Thein et al., unpublished data, 2001; Table 2). Temperature presumably depended on solar radiation, as the lowest temperature was measured at dawn and the highest temperature was measured in the early afternoon. Temperatures were above 21°C even in the cold dry season. From data in 2001, DO at 1-m depth ranged from 3.5 to 8.3 mg l^{-1} and 5.9 mg l^{-1} even at the bottom (1.7-m depth) (Thein et al., unpublished data, 2001). The whole water column seems to be well mixed, which might result from stirring by frequent water transportation. Thus, we conclude that Inle Lake does not have stratification and, as the lake is shallow, it can be assumed to be a warm polymictic lake (WHO 1992).

Dissolved oxygen (DO) range was 0.6–8.5 mg l^{-1} (8.2%–120%). More than half the samples are below the limit (DO 5.0–9.0 mg l^{-1}) for fisheries and aquatic life according to the EU criterion (WHO 1992). These severe conditions for aquatic life can lead to declines in the numbers of fish (FAO 2004). Such a wide range, especially the high value of DO, might be caused by the agitation from the busy motorboat traffic for tourists. To elucidate the cause of fluctuation, a biological analysis such as the composition and state of aquatic life is needed in addition to the chemical analysis we performed.

Conductivity (EC) range was 253–378 µS cm^{-1}. Total organic carbon (TOC) ranged between 33 and 52 mg l^{-1}. Those values in the northern part (St. 1, 2, 3, 4) were higher than in the southern part (St. 6, 7, 8, 9). The highest value was seen in the Nyaungshwe town area (St. 2), which is the tourist hub for visiting Inle Lake. It is thus considered that human activity, especially tourists, largely affects the EC and TOC values. However, higher sampling density and population data around the sampling sites are needed to corroborate the relationship between human activity and water quality.

The pH varied only from 7.8 to 8.0. It can be presumed that the limestone around the area gives the water its alkaline state. On a worldwide scale, the lake acidification issue has been considered and sensitivity is characterized in terms of acid-neutralizing capacity (ANC) (WHO 1992). The minimum value of the lake water was 3829 ANC, which indicated that Inle Lake is insensitive to acidification (WHO 1992). The water can be attenuated mainly by calcium ions from the limestone of the Shan Plateau catchment area.

Coliform bacteria occurred at 18–137 colony-forming units (CFU) ml^{-1}, and *E. coli* was also found in the surface water. Because residents use the water for drinking and cooking, the health risks must be considered. The acceptable level of *E. coli* or coliform bacteria in drinking water is 0 CFU per 100 ml (WHO 2004b); the level in Inle Lake exceeded that. A local health worker said that diarrhea occurs annually in this area. It is reported that at Lake Bhopal in India, which belongs to the same monsoonal region, coliform bacteria increased at the onset of summer toward 24,000 CFU ml^{-1} and dropped during the monsoon season to 120 CFU ml^{-1}; the water quality in that lake is also declining (Iqbal et al. 1995). In both cases, it is considered that infectious agents such as pathogenic bacteria from untreated sewage overflowing from open latrines cause diarrhea. WHO stated that 88% of diarrheal diseases are attributed to an unsafe water supply and inadequate sanitation and hygiene. If sanitation improves, diarrhea morbidity is reduced by 32% (WHO 2004a). The water usage is similar to lakes in India and Sri Lanka; some microbiological contamination is also reported there (Brick et al. 2004; Mertens et al. 1990). People there often use boiled water for drinking. However, it is reported that boiling was not effective to cleanse the water because of lack of sufficient heating time (Brick et al. 2004). Thus, the most important way to decrease hygiene risk is by conserving water resources. So, adequate sanitation promotion is strongly recommended to protect both health and the environment.

PO_4-P range was 0.0078–0.028 mg l^{-1}. In most surface waters, the concentration of PO_4-P ranges from 0.005 to 0.020 mg l^{-1}, so that a high concentration is largely responsible for eutrophication (WHO 1992).

NO_2-N range was 0.07–0.909 mg l^{-1}. In the usual case, freshwater is below 0.001 mg l^{-1}, although in Inle Lake the range greatly exceeded that level. High concentrations of nitrite are often associated with unsatisfactory microbiological water quality (WHO 1992); thus, this finding supports our results for *E. coli* and coliform bacteria.

NO_3-N range was 0.01–0.45 mg l^{-1}. In lakes, levels in excess of 0.2 mg l^{-1} NO_3-N indicate possible eutrophic conditions (WHO 1992), and several sampling points exceeded this value (see Table 1). With the biological considerations – dense water hyacinths (Kyaw 1996) have become a major problem, perch and carp are the dominant species of fish, and some aquatic weeds are almost disappearing in response to light limitations because of plankton growth (FAO 2004) – its category was supposed to be eutrophic or hypereutrophic (WHO 1992). Nitrogen, phosphorus, and potassium compounds used as chemical fertilizers on the floating tomato gardens (Ma 1996; Daw 2000) can cause pollution of the water. Sewage from excreta is also rich in nutrients and increases the problem. The effects of eutrophication can be highly detrimental to lake water quality and severely limit the uses of a lake (WHO 1992), so in Inle Lake the trophic condition probably has bad effects on both human life and the aquatic biota. To firmly establish the trophic category of the lake, data on transparency, chlorophyll, and total phosphates are needed in accordance with WHO recommendations (WHO 1992). Further, as the season of tomato farming is March to September, it is likely that higher loads of N and P are going to be observed during this season.

DO at the surface near Paw Daw Oo Pagoda decreased to 0.8 mg l^{-1} in 2004 from 9.8 mg l^{-1} in 2001 (Table 2) (Thein et al., unpublished data, 2004). The lower DO value indicates that the water quality has been decreasing. The continued expansion of tomato cultivation can be worsening the pollution.

The main causes of pollution are probably excessive human activity such as domestic uses, agriculture, recreation and tourism, fishing, and aquaculture.

Conclusions

Inle Lake is considered a warm polymictic lake. The major problem suggested was eutrophication, and the data indicate the lake is affected by human activities.

Inle Lake needs to be managed for water quality and biodiversity. It needs both water quality monitoring and water treatment, especially for agricultural drainage and sewage from toilets, to stop eutrophication and to preserve the health of the many waterborne residents around the area. In addition, more detailed analysis is needed to clarify the correlation between human activities and water pollution. Continuous monitoring for evidence to definitely sup-

port the causes of heavy siltation and biological sedimentation is also required.

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