Research article

Study on the Water Quality of Indawgyi Lake Affected by Surroundings

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Received 30 December 2020 Accepted 19 May 2021 (*Corresponding Author)

Abstract Water quality assessment was carried out at Indawgyi Lake, the biggest lake of Myanmar. The main aim of this research is to evaluate the current status of lake water quality affected by the surroundings and man-made activities for three seasons (cold, hot and rainy) in 2019. Some physicochemical properties such as temperature, pH, ORP, EC, NTU, TDS and DO of surface and deep water samples from each point and totally four different points were analyzed in situ by water quality monitor U-53-G(Horiba). The concentrations of Cr, Mn, Fe, Cu, As and Hg were also examined by atomic absorption spectrometer (AAS) and total hardness, total alkalinity, salinity and chloride were measured by their respective methods. Nitrate and phosphate were detected by LaMotte, SMART 3 colorimeter. The condition of COD and BOD of the lake water were also investigated by standard incubating methods. In addition, counting of coliform was performed to detect pathogenic microorganisms of lake water. The resulting values were compared with the standard limits of World Health Organization (WHO) and it was concluded that the lake was urgently needed to sustain the long-life existence and its water qualities due to the findings of some physicochemical, biological, toxic and pathogenic affects produced by the surroundings.

Keywords physicochemical properties, lake water, concentration, pollution, standard guideline value

INTRODUCTION

Water pollution becomes a serious threat and its affect to human and environmental is very wide. Freshwater ecosystems contain rivers, streams, ponds, lakes and wetlands. Fresh water is a main resource of habitat for organisms and its quality is closely related with surroundings. Now freshwater biodiversity has been challenged by many kinds of anthropogenic affects. Indawgyi Lake is not only the largest lake of Myanmar but also the third largest inland lake in Southeast Asia. It is located in the Mizaram-Manipur-Kachin Rain Forest Ecoregin in which it is the subtropical moist broad leaf forest biome. It is situated in the Mohnyin Township, Kachin State of northern Myanmar and 180 km away from the south-west of Myitkyina. Its measures are 13 km long from east to west, and 24 km wide from north to south. Lake water flows from the south to the north and only one water outlet, Indaw chaung at the northeast of the lake which finally combines into the Ayeyarwady River. Indawgyi area was officially recognized as a wildlife sanctuary on August 9th 2004 and it has also been regarded as a Ramsar site on February 2nd 2016. The entire lake basin has been declared as Biosphere Reserve on June 15th 2017 by UNESCO Man and the Biosphere Reserve Programme-MA (Indawgyi Wildlife Sanctuary, 2018). It has total area 815 km^2 including the lake and lakeside which is 259 km^2 with grasslands and the surrounding forested watershed. It has 546 feet (166 m) above the sea level. Over 400 species of birds,

109 species of water birds and 93 species of fishes and shrimps rely on the lake (Indawgyi Wildlife Sanctuary, 2018).

There are 38 villages around the lake and some villages are on the bank of the lake. Ethnic groups living in nearby villages are mostly the Red Shan and the Kachin and they earned for their livings from the agriculture, fishing and mining. They grow rice, orange, mustard, pineapple and dog-fruit. Now the lake has been facing many issues such as deforestation, disposal of mine tailings, poor management of waste, depletion of fisheries, climate change and reducing lake area.

Some water researches have done on it but there has not been still found a research that determines for both of surface and deep water qualities from each site until now. Therefore the aim of this research was to study the qualities of Indawgyi lake water affected by the surrounding not only from surface but also from bottom as the short term one year assessment in 2019. Seasonal sampling date were January 13 (as cold season), May 1 (as hot season) and July 25 (as rainy season) in 2019 (Daung Hawng, 2019).

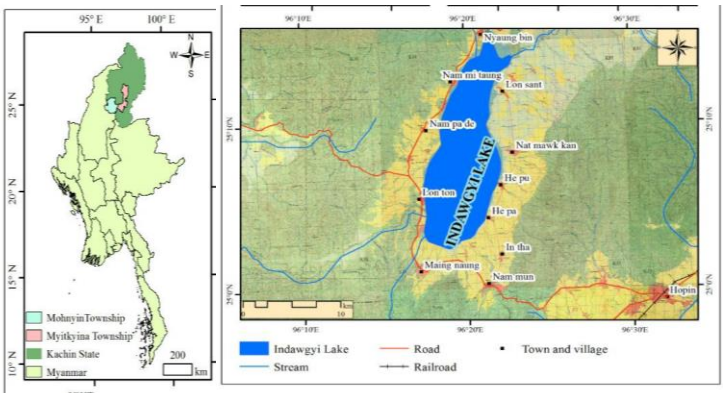

Fig. 1 Map of the Indawgyi Lake, Mohnyin Township, Kachin State, Myanmar

OBJECTIVE

The objective of this research is to evaluate the current status of physicochemical and biological properties of Indawgyi lake water which is polluted by the surroundings for three seasons (cold, hot and rainy) in 2019 and to contribute the local people to get the awareness on the relation between water quality and the environment.

METHODOLOGY

In this research, determination of physicochemical properties of Intawgyi lake water was carried out on 8 samples both of surface (sites 1, 2, 3 and 4) and bottom (sites 1(a), 2(a), 3(a) and 4(a)) of the lake water from 4 different sites. They were sampling site-1 (Near Nyaung bin Village), site-2 (Near Nantmee laung Village), site-3 (Near Center of the Lake), site-4 (Near Mamon kaing Village) respectively. Some villages are on the lakeside and near to the entrance of the permanent and seasonal inflowing steams. The depths of the water are different along the lake in everywhere randomly though the center is the deepest part, and so water-depth, location, collecting time and temperature were recorded for every sampling time. Some physicochemical properties of lake water such as pH, electrical conductivity (EC), nephelometric turbidity unit (NTU), dissolve oxygen (DO), total dissolve solid (TDS) and oxidation reduction potential (ORP) were measured by situ experiment by applying U-53-G (Horiba), (Trace20-HM 2000, Nanova). The concentrations of chromium (Cr), manganese (Mn), iron (Fe), copper (Cu), arsenic (As) and mercury (Hg) were also examined by atomic absorption spectrometer (AAS) and total hardness, total alkalinity, salinity and chloride were measured by their respective methods. Nitrate and phosphate were detected by LaMotte, SMART 3 colorimeter. The condition of chemical oxygen demand (COD) and biological oxygen demand (BOD) of the lake water were also investigated by standard incubating methods. In addition, counting of coliform was performed to detect pathogenic microorganisms of the lake water.


Sampling site-1 (Near Nyaung bin Village)


Sampling site-2 (Near Nantmee laung Village)


Sampling site-3 (Near Center of the Lake)


Sampling site-4 (Near Mamon kaing Village)

Fig. 2 Sampling sites

RESULTS AND DISCUSSION

Table 1 Physicochemical and biological parameters of cold season

Parameters	Site 1	Site 1(a)	Site 2	Site 2(a)	Site 3	Site 3(a)	Site 4	Site 4(a)	Mni	Max	Aver	SD	n	WHO (2017)
pH	7.41	7.17	7.69	7.43	7.44	7.1	7.54	7.36	7.1	7.69	7.393	0.189	3	6.5-9.2
Ec (mmhos/cm)	0.13	0.13	0.2	0.2	0.14	0.14	0.14	0.14	0.13	0.2	0.155	0.030	3	1.5
Turbidity (NTU)	46.8	50.32	2.16	6.29	1.45	1.19	3.13	5.18	1.19	50.32	16.803	21.077	3	5
DO (mg/L)	8.01	7.17	6.45	7.44	6.53	6.46	7.96	4.29	4.29	8.01	6.661	74.518	3	-
TDS (mg/L)	86	85	88	92	91	91	93	96	85	96	90.3	3.694	3	600-1000
ORP (mV)	223	153	243	162	271	293	265	154	153	293	221	56.946	3	-
Total Alkalinity	120	100	200	140	140	140	120	120	100	200	138	29.761	3	-
COD (mg/L)	7.9	8	7.8	7.7	8	8.29	9.4	10.3	7.7	10.3	8.539	0.929	3	10
BOD(mg/L)	4.2	4	5.5	3.9	4.3	4.3	3.7	5.9	3.7	5.9	4.54	0.791	3	6
Salinity	0	0	0	0	0	0	0	0	0	0	0	0	3	-
Total hardness (mg/L)	60	60	68	64	64	64	66	66	60	68	64	2.828	3	500
Cl^- (mg/L)	4.96	3.19	3.19	1.42	4.96	3.19	3.19	1.42	1.42	4.96	3.19	1.338	3	200
Mn (mg/L)	0.01	0.01	0.01	0.01	0.01	0.1	0.01	0.01	0.01	0.1	0.028	0.032	3	0.4
Fe (mg/L)	0.16	0.3	0.03	0.16	0.02	0.03	0.03	0.09	0.02	0.3	0.103	0.099	3	0.3
Cu (mg/L)	0.06	0.06	0.06	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.055	0.005	3	2
Hg (mg/L)	0.02	0.03	0.05	0.01	0.04	0.02	0.02	0.04	0.01	0.05	0.029	0.014	3	0.006
Cr (mg/L)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0	3	0.05
As (µg/L)	0.095	0.04	0.024	0.003	0.016	0.011	0.141	0.065	0.003	0.141	0.044	0.048	3	0.01
NO_3^- (mg/L)	0.62	0.51	0.48	0.23	0.15	0.33	0.4	0.31	0.15	0.62	0.353	0.155	3	50
PO_4^{3-} (mg/L)	0.08	0.09	0.06	0.08	0.09	0.01	0.08	0.15	0.01	0.15	0.072	0.039	3	-
Depth (m)	0.05	1.45	0.15	2	0.55	5.25	0.3	3.54						
E-coli (CFU/100mL)	4	4	4	4	4	5	5	5						0
Temperature(°C)	20.76	19.89	23	22.65	22	21.65	22.9	21.66						
Time (hr)	12.29	12.27	2.22	2.24	3.14	3.17	4.48	4.52						

Table 2 Physicochemical and biological parameters of hot season

Parameters (units)	Site 1	Site 1(a)	Site 2	Site 2(a)	Site 3	Site 3(a)	Site 4	Site 4(a)	Mni	Max	Aver	SD	n	WHO (2017)
pH	9.04	8.49	8.31	8.06	7.9	7.66	9.04	8.18	7.66	9.04	8.338	0.502	3	6.5-9.2
Ec(mmhos/cm)	0.12	0.12	0.14	0.14	0.14	0.14	0.14	0.14	0.12	0.14	0.134	0.009	3	1.5
Turbidity (NTU)	6.02	7.29	1.86	2.53	2.06	1.81	5.76	8.22	1.81	8.22	4.558	2.660	3	5
DO (mg/L)	9.43	9.4	8.98	8.16	7.36	6.96	9.57	8.66	6.96	9.57	8.505	0.988	3	-
TDS (mg/L)	80	80	90	90	90	90	90	90	80	90	87	4.629	3	600-1000
ORP (mV)	141	198	224	247	217	240	139	196	139	247	198.8	41.223	3	-

Total Alkalinity	140	120	160	160	160	160	160	160	120	160	150	14.880	3	-
COD (mg/L)	8.7	9.2	8	7.5	9.5	11	14	18	7.5	18	11.14	3.575	3	10
BOD(mg/L)	3.8	4	2.5	2.7	5	6	6.5	7	2.5	7	4.7	1.709	3	6
Salinity	0	0	0	0	0	0	0	0	0	0	0	0	3	-
Total hardness (mg/L)	62	92	80	76	82	78	72	74	62	92	77	8.619	3	500
Cl^- (mg/L)	4.96	4.96	3.19	7.09	10.64	4.96	8.87	7.09	3.19	10.64	6.559	2.435	3	200
Mn (mg/L)	0.15	0.12	0.01	0.09	0.13	0.1	0.14	0.14	0.01	0.15	0.104	0.045	3	0.4
Fe (mg/L)	0.05	0.05	0.01	0.01	0.01	0.01	0.03	0.03	0.01	0.05	0.026	0.018	3	0.3
Cu (mg/L)	0	0	0.001	0.001	0.03	0.003	0.17	0.17	0	0.17	0.0545	0.077	3	2
Hg (mg/L)	0	0	0	0	0	0	0.01	0.01	0	0.01	0.003	0.005	3	0.006
Cr (mg/L)	0.005	0.005	0.02	0.02	0.005	0.009	0.005	0.007	0.005	0.02	0.0101	0.007	3	0.05
As (μg/L)	0.013	0.014	0.027	0.044	0.062	0.074	0.075	0.086	0.013	0.086	0.0494	0.029	3	0.01
NO_3^- (mg/L)	0.42	0.6	0.08	0.2	0.24	0.12	0.12	0.07	0.07	0.6	0.252	0.188	3	50
PO_4^{3-} (mg/L)	0.03	0.07	0.05	0.11	0	0.03	0.14	0.08	0	0.14	0.065	0.046	3	-
E-coli (CFU/100mL)	4	4	5	5	5	5	5	5						0
Depth (m)	0.65	1	1.25	2	1.75	5.15	0.6	2.30						
Temperature(°C)	28.07	27.73	28.39	28.41	28.14	27.88	29.36	29.26						
Time (hr)	12.17	12.19	12.58	1	2.37	2.39	4.12	4.13						

Table 3 Physicochemical and biological parameters of rainy season

Parameters (units)	Site 1	Site 1(a)	Site 2	Site 2(a)	Site 3	Site 3(a)	Site 4	Site 4(a)	Mni	Max	Aver	SD	n	WHO (2017)
pH	6.9	7.46	7.46	6.09	8.15	7.85	7.94	6.5	6.09	8.15	7.259	0.732	3	6.5-9.2
Ec (mmhos/cm)	0.09	0.09	0.13	0.13	0.14	0.14	0.13	0.13	0.09	0.14	0.121	0.021	3	1.5
Turbidity (NTU)	96.9	12	13	27.4	7.91	9.83	12.3	11.8	7.91	96.9	29.595	30.086	3	5
DO (mg/L)	4.4	4.4	4.5	4.2	4.6	3.8	4.3	5.9	3.8	5.9	4.58	0.610	3	-
TDS (mg/L)	60	60	80	80	80	80	90	90	60	90	77	11.650	3	600-1000
ORP (mV)	390	405	216	434	442	373	281	286	216	442	348.5	82.285	3	-
Total Alkalinity	100	120	160	160	160	160	140	200	100	200	150	30.237	3	-
COD (mg/L)	9.8	10.6	9.2	9.5	13.5	15	17	20	9.2	20	13.38	3.998	3	10
BOD (mg/L)	7.8	8.3	8.5	9.3	10	12	15	17.5	7.8	17.5	11.37	3.523	3	6
Salinity	0	0	0	0	0	0	0	0	0	0	0	0	3	-
Total hardness (mg/L)	52	50	72	60	74	64	64	66	50	74	62.6	8.548	3	500
Cl^- (mg/L)	0.2	0.2	0.09	0.09	0.15	0.12	0.1	0.1	0.09	0.2	0.134	0.0467	3	200
Mn (mg/L)	0.06	0.06	0.02	0.02	0.06	0.09	0.1	0.1	0.02	0.1	0.063	0.0320	3	0.4
Fe (mg/L)	0.3	0.3	1.12	1.12	0.12	0.12	0.08	0.08	0.08	1.12	0.444	0.450	3	0.3
Cu (mg/L)	0.08	0.15	0.05	0.05	0.12	0.11	0.09	0.09	0.05	0.15	0.094	0.034	3	2
Hg (mg/L)	0.001	0.001	0.003	0.003	0.002	0.002	0	0	0	0.003	0.0015	0.001	3	0.006
Cr (mg/L)	0.02	0.02	0.05	0.05	0.03	0.03	0.03	0.04	0.02	0.05	0.034	0.011	3	0.05
As (μg/L)	0.01	0.011	0.012	0.003	0.01	0.01	0.029	0.05	0.003	0.05	0.0188	0.0153	3	0.01
NO_3^- (mg/L)	0	0	0.1	0.11	0.03	0.03	0.14	0.15	0	0.15	0.071	0.062	3	50
PO_4^{3-} (mg/L)	0.03	0.03	0.03	0.03	0.05	0.05	0.13	0.13	0.03	0.5	0.191	0.207	3	-
E-coli (CFU/100mL)	5	5	5	5	5	5	5	5						0
Depth (m)	0.65	1.65	0.55	2.9	0.45	8.5	0.75	3.33						
Temperature(°C)	27.82	27.58	30.36	30.13	30.33	30.27	30.33	30.37						
Time (hr)	1.32	1.34	2.39	2.4	3.28	3.3	4.58	4.59						

Sampling time for three seasons was afternoon but significant temperature difference could be seen in (Tables 1, 2 and 3). The highest water temperatures were found in the rainy season with the range 27.58-30.37 ˚C while the hot season was moderate with variation 27.73-29.36 ˚C and the cold season showed as the least temperature with change 19.89-22.9 ˚C. Ongoing from surface to the depth

along a vertical column, most of water samples showed their decreased temperatures but the difference was small. Therefore the whole lake water seems to be well mixed which result from stirring by frequent water transportation. Precipitation could be only seen in the early morning of cold season. Although alkaline pH values were found in the hot season with the range 7.66-9.04, the rainy season showed some acidic pH within the range 6.09-8.15. The lake reached its lowest water level due to the reduction of seasonally inflowing streams into the lake except annually streams and therefore lake water alone remained with the alkaline pH. In the rainy season, the lake and its all wetland areas were flooded and therefore possible mine disposal and sewage directly touched with the lake water. It was leading to have acidic pH value. DO is an important index of physical phenomenon and it is influenced by many factors that affect the oxygen solubility, temperature, water movement and salinity etc. DO range in the cold season was 4.29-8.01 mg/L, 6.96-9.57 mg/L in hot season and 3.8-5.9 mg/L in the rainy season respectively. It was denoted that the DO value declined in the depth water than top water and the highest amount was determined in the hot season of site 4, 9.57 mg/L (Table 2) and the lowest value was detected in the rainy season of site 3 (a), 3.8 mg/L (Table 3).

In the cold season, COD values of sampling points with the range 7.7-10.3 mg/L showed the lesser amount than WHO standard limit, 10 mg/L except for site 4 (a), 10.3 mg/L. Three site 3(a), 4 and 4(a) out of eight sites exceeded the standard limit in the hot season with the variation 7.5-18 mg/L and five sampling points except site 1, 2 and 2 (a) were above WHO limit in the rainy season with the range 9.2-20 mg/L. All BOD values of the cold season with the range 3.7-5.9 mg/L were observed under the WHO standard limit 6 mg/L though the hot season within the range 2.5-7 mg/L surpassed the standard limit in two sites 4 and 4(a) and also the rainy season in all sites varied 7.8-17.5 mg/L. It showed that lower BOD and COD of the lake water than WHO limits could be observed at cold season due to the relation with low temperature while most of the sampling sites of hot and rainy seasons indicated higher BOD and COD amount than the WHO limits due to the relation with their high temperatures. Though the acceptable WHO guideline value of nitrate for drinking water is 50 mg/L, excess of 0.2 mg/L in the lake water indicate the possible eutrophic condition (WHO,1992). Seven sampling points except site 3 in the cold season with the range 0.15-0.62 mg/L and three sampling points, site 1, 1(a) and site 3 expressed their exceeded levels in the hot season with the range 0.07-0.6 mg/L. All sampling points for the rainy season with the range 0-0.15 mg/L lie under 0.2 mg/L set by WHO. Due to the literature, the concentration of phosphate ranges 0.005-0.020 mg/L in most surface waters and higher than that support to the eutrophication (WHO, 1992). Most of the sampling points of three seasons (Tables 1, 2 and 3) showed exceeded phosphate level than WHO guideline limit. The lake has potential extent of nitrogen and phosphorous because a large outbreak of toxin producing cyanobacteria (blue green algae) in the whole lake, the excessive growth of aquatic plants, alkaline pH, oxygen depletion (DO) in bottom waters, decomposing macrophytes and algae in the sediment were also responsible for eutrophic condition. In addition, livestock and sewage from the agricultural run-off increased the amount of waste nutrients and then finally released the nutrients indirectly into the lake. Then more and more sedimentation set up and deposited especially in the north and south-edges of the lake which made the beds to rise up. Sediment caused water pollution, affected aquatic biota by smothering fish nursery area and wildlife by narrowing water channels and reducing lake basin area (Indawgyi Wildlife Sanctuary, 2018).

Among three seasons, the highest amount of total hardness 92 mg/L was observed at site 1(a) of the hot season with the range 62-92 mg/L and it was due to the evaporation of water by high temperature. All sampling points of three seasons showed the lower amounts of total hardness (Tables 1, 2 and 3) than the permissible limit, 500 mg/L prescribed by WHO for drinking water (WHO, 2017).The fresh water of the lake had not been detected the salinity. For all seasons, most of the sampling sites could be observed the concentrations of Fe under the guideline value 1.0 mg/L set by WHO for drinking water standard (WHO, 2017). The concentrations of Cu in all samples (Tables 1, 2 and 3) lie below the WHO guideline value 2.0 mg/L. The investigation of As pointed out as the lower levels in µg/L for all sampling points (Tables 1, 2 and 3) than WHO guideline value of drinking water

standard 0.01 mg/L. By comparison with WHO standard of Cr 0.05 mg/L, all sampling points contained the lesser amount (Tables 1, 2 and 3) than the standard values. Though all metal constituents showed with lower concentrations than the WHO limits, three heavy metals such as Hg, Cr and As could affect to the water quality with their impacts as possible as they contain. All EC values (Tables 1, 2 and 3) which lie under guideline limit 1.5 mmhos/cm set by WHO informed as the existence of low dissolved salts in the lake. Lake water also showed the lower TDS levels of all sampling points for three seasons (Tables 1, 2 and 3) than the WHO limit within 600-1000 mg/L. ORP indicates the state of oxidation and reduction process going on in water: a low value of ORP indicates high reduction while a high value for oxidation. The ranges were 153-293 mV in the cold season, 139-247 mV in the hot season and 216-442 mV in the rainy season respectively. Turbidity is caused by particular matter present in water such as clay, silt, colloidal particles, plankton and other microscopic organisms. In this research, higher amounts of turbidity units than the WHO standard limit 5 NTU were found in most of the sampling points of the cold, hot and rainy seasons were with the ranges 1.19-50.32 NTU, 1.81-8.22 NTU and 7.91-96.9 NTU but the outstanding values such as 96.9 NTU in site 1 of the rainy season maybe probably resulted by touching of detector to the bed. North-west corner of Indawgyi lake, site 1 and 1 (a) were especially suffering from the overloading of particulate matters because these two were very closed to the village and annual inflowing streams. This problem maybe probably the serious threat of pollution to the transparency of lake water in later. *Escherichia coli* was considered as the biological threat throughout the lake because it was found that 4-5 CFU/100 mL of all sampling sites (Tables 1, 2 and 3) along the west-lakeside from the north to the south due to direct latrine into the open water. *E. coli* in drinking water set by WHO is 0 CFU/100 mL (WHO, 2017). The result showed that it is necessary to carry out a proper water treatment for daily use and drinking water. Among three seasons, the rainy season does affect the most to the quality of lake water with the acidic pH, the highest turbidity, COD and BOD. The least affected season is the hot season which possesses the alkaline pH, the lowest turbidity, COD and BOD, the lowest contaminated mercury and chromium level than the other two seasons. Fish catches have decreased in the lake over the last five years of fisheries and late-rain in the rainy season were the current impacts to the environmental (Indawgyi Wildlife Sanctuary, 2018). It could be still noticed the relatively high transparency of the lake water about into 3.5m. But serious turbidity unit could replace the transparency of the lake water if the appropriate management was not applied to control the possible pollution sources in time. Natural aging process and filling to the lake with sediment slowly over time could support the eutrophication of the lake. The breeding of invasive species, water hyacinth and plants nutrients dominated many areas of the surface water and it could produce the reduction of the lake area for the aquatic biota. The use of detergents and soap, agricultural run-off, organic matter and sewage could increase the amount of nutrients and encourage the phenomenon of eutrophication. Starting point of plankton growth could be found on the surface water of the north-west part of the lake. In this area, reddish-yellow color water could be observed the whole year as shown in the Fig. 2. In conclusion, it could be said that physicochemical and biological properties of lake water quality was significantly suffered from the impacts of surroundings and needed to sustain its quality for the health of human and environmental.

CONCLUSION

This research was conducted as the assessment of the water quality of Indawgyi lake, the biggest lake in Myanmar and performed some physical, chemical and biological examinations of the surface and depth-water. The results obtained of the present work showed their significant variation with seasonal fluctuations. The current situation and challenges of Indawgyi lake water were increasing with sedimentation, potential eutrophication and pollution of water quality by chemical, physical and biological contaminants. The main causes of these problems were probably excessive human activity such as domestic uses, agricultural runoff, recreation, tourism, fishing, nutrient submerged and floating

plants from the surrounding. The lake is now needed to be control for water quality and long-live of biodiversity especially for agricultural drainage, gold mining effluents, excess nutrients and sewage from direct toilets to prevent sedimentation and eutrophication of the lake and to protect the hazard of water pollution for health of populations from the surrounding area.

ACKNOWLEDGEMENTS

We would like to thank to Department of Environmental Conservation, Myitkyina and Mohnyin and Wildlife Sanctuary, Indawgyi Lake for warm explanation, transportation, sampling, testing and giving permission to apply the laboratory.

REFERENCES

Akaishi, F., Satake, M., Otaki, M. and Tominaga, N. 2006. Surface water quality and information about the environment surrounding Inle Lake in Myanmar. The Japanese Society of Limnology, 7, 57-62.

Hawng, H. 2019. Determination of water quality of Indawgyi Late. MSc Thesis. Department of Chemistry, Myitkina University, Myanmar.

Indawgyi Wildlife Sanctuary an Fauna and Flora International. 2018. Indawgyi Wildlife Sanctuary management plan (Part-II). Appendices (2018-2019 to 2022-2023).

World Health Organization (WHO). 1992. Water quality assessment: A guide to use of biota, sediment and water in environmental monitoring. 2nd ed., Geneva, Switzerland.

World Health Organization (WHO). 2008. Guidelines for drinking-water quality. 3rd ed., Incorporating the First and Second Addend, Volume 1, Geneva, Switzerland.

World Health Organization (WHO). 2017. Guidelines for drinking-water quality. 4th ed., Incorporating the First Addendum, Geneva, Switzerland.