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SPATIAL AND SEASONAL VARIATIONS OF WATER QUALITY ASSESSMENT IN INLE LAKE, MYANMAR

May Thet Su Kyaw Tint[1*], Naoko Tokuchi[2] and Eiji Nawata[3]
[1]Graduate School of Agriculture, Kyoto University, Kyoto, Japan
[2]Field Science Education and Research Center, Kyoto University, Kyoto, Japan
[3]International Strategy Office, Kyoto University, Kyoto, Japan
[*]Corresponding author: may.tint.68w@st.kyoto-u.ac.jp

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ABSTRACT

Inle Lake is the second largest freshwater lake located in southern Shan State, Myanmar. Assuming that the lake water quality is becoming degraded because of human activities, including agriculture and tourism, the water samples were monthly collected from eight locations inside the lake for 10 months, and its physiochemical parameters were examined to establish appropriate sampling methods for monitoring lake water quality by observing the spatial and temporal variations. The results showed that there were two clusters according to cluster analysis (CA); cluster 1 included St. 1 and St. 2, and cluster 2 included the rest of the stations (St. 3 to St. 8). The recorded values changed significantly according to the seasons and were generally higher during the agricultural season (March-October) than the tourism season (November-March), suggesting that the agricultural practices, such as fertilization, influenced the temporal variations. The proper sampling locations should probably be St. 1 and/or St. 2 in cluster 1and St. 6 in cluster 2 and that the changes in water quality should be observed twice a year: in April during the agricultural season and in December during the tourism season for monitoring in the future.

Key words: floating garden, human activities, tourism, sedimentation, water pollution

INTRODUCTION

Wetlands provide ecosystem services that benefit both human and non-human living beings, which include a huge range of biodiversification, habitats for plants and animals, water resources, fishery, agricultural activities and tourism opportunities (Dixon and Wood 2003; Jenkins et al. 2010; Zhong et al. 2019). Those benefits depend on the freshwater quality (Filik Iscen et al. 2008), and unfortunately, the degradation of the quality of freshwater in the lake ecosystem have been influenced by intensive human activities such as agricultural and industrial ones and sewage contaminations, as well as the increase of recreation and tourism activities (Barakat et al. 2016; Hemond 1988; Rahmani et al. 2013; Zhong et al. 2019).

Inle Lake is the second largest freshwater lake and located in the Nyaung Shwe Township in Myanmar, and it has been providing numerous ecosystem services by its environmental, touristic, economic, and agricultural values. In addition, it is also the habitat of diverse species of amphibians and fishes, flora and fauna (Lwin and Sharma 2012). The lake also provides fresh water by regulating the water flow and by supporting natural water filtration (Karki et al. 2018). Previous studies reported that the water quality of Inle Lake was threatened by especially sedimentation and anthropogenic activities such as agricultural practices in and around the lake and tourism industry (Akaishi et al. 2006; Lwin et al. 2012).

One of the primary sources of sedimentation of the lake is deforestation in the surrounding mountains and the surface erosion from the watershed areas (Htwe et al. 2015a; Sidle et al. 2007; Thin et al. 2020). Moreover, the expansion of the agriculture industry in and around the lake had a major impact on the water quality of the lake. The local inhabitants have practiced the traditional method of floating agriculture, which is one of the main forms of livelihood, including the cultivation of tomato and other vegetables (Myint and Maung 1996; Than 2007). The residents around the lake also practice on-land cultivation, which consists of crops on the flat areas between the lake and the mountains, comprising of paddy fields and upland fields of other major crops such as sugarcane, potato, groundnut and others (Htwe et al. 2015b). The associated adverse impacts consist of water pollution from the use of fertilizers and pesticides on floating gardens inside the lake and on-land agricultural industry around the watershed areas of the lake (Butkus and Myint 2001; Lwin et al. 2012).

Furthermore, the government officially declared 1996 as the year of tourism, which was also called the “Visit Myanmar Year”, to boost the tourism sector. Since then, the number of visitor arrivals in Myanmar has increased gradually and has contributed to the improvement of the local economy (Akaishi et al. 2006; Ingelmo 2013). According to the Ministry of Hotel and Tourism, the total number of tourists’ arrivals in Myanmar increased from 416,344 in 2000 to 3,551,428 in 2017 (Myanmar Tourism Statistics, MoHT, 2017). Additionally, the total number of tourists’ arrivals in Inle Lake has also risen from 131,102 in 2014 to 249,989 in 2017. Due to the blooming of tourism, the number of hotels in and around the lake and in the township area gradually increased from 36 in 2000 to 103 in 2017.

The urbanization associated with increasing tourism and industrialization in the area was one of the main factors for lake water quality change (Akaishi et al. 2006; Lwin and Sharma 2012; Su and Jassby 2000). Akaishi et al. (2006) indicated that the physiochemical water quality degraded, which was associated with agricultural activities in and around the lake including the floating cultivation, which were supposed to release pollutants such as K^+ and NO_3^- into the lake. It is considered that tourism growth has negative effects on the water quality of the lake. Moreover, other related factors may include sewage disposal, petroleum products from motorboats and waste products from households and hotels, resulting in water pollution and eutrophication (Sidle et al. 2007; Thin et al. 2020).

Thus, monitoring is urgently needed to assess the changes in water quality for sustainable water management. However, to monitor the lake water quality for a long term implies in high labor costs and time-consuming work. Hence, the present study sought to clarify the most appropriate locations and timing for sampling in order to make efficient monitoring of water quality in the lake by studying the changes in water quality of Inle Lake according to the spatial and temporal variations around the lake.

MATERIALS AND METHODS

Site description. Inle Lake is located in the Nyaung Shwe Township, Taunggyi District, Southern Shan State in the Republic of the Union of Myanmar. The Inle Lake is located between 20° 18' and 20° 53' N latitudes and between 96° 50' and 96° 57' E longitude, at an average elevation of 890m, and the drainage area of the lake is 3683 km^2 (Htwe et al. 2015b; Su and Jassby 2000). The lake sits in a tropical monsoon climatic region with an annual rainfall of 1217 mm in 2017 (Fig. 1). Inle Lake has three seasons: dry (March-June), rainy (July-October) and winter (November-February) (Re et al. 2018). The agricultural season occurs during both dry and rainy seasons, from March to October. The tourism period occurs during the winter, from November to March. The tourism period and the non-agriculture season happen at the same times. There are 29 inflows: 17 streams from the East, 11 streams from the West and 1 stream from the North. The only outlet, Nan Pilu stream, is in the south and the lake water flow mainly from North to South.

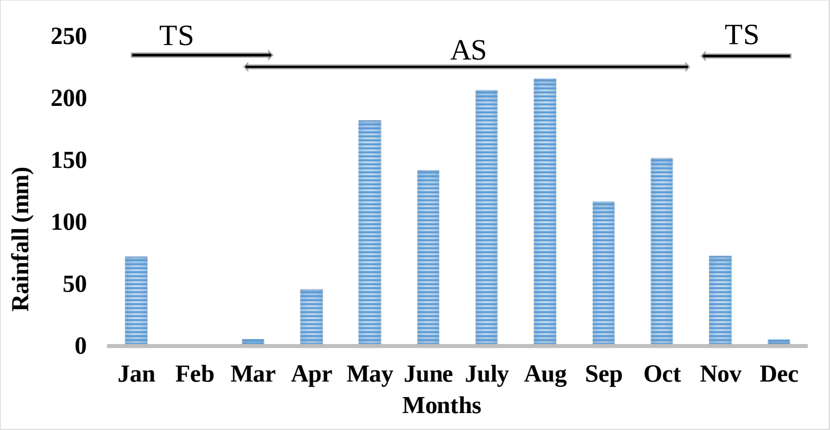

Fig. 1. Monthly rainfall in Nyaung Shwe Township (2017)
AS: Agriculture season, TS: Tourism season

Water sampling. The water samples were monthly monitored at eight locations around the lake (Fig. 2), during the period from August 2017 to May 2018. The water quality samplings were conducted at two inflow streams (St. 2 and 4), one near populated areas (St. 1), one at the center of the lake (St. 3), one near the floating garden areas (St. 5), one at open water area of the lake (St. 6), one near the weaving village (St. 7) and one near the outlet (St. 8). The names and the characteristics of the eight stations are shown in Table 1. A previous study was carried out in 2004 to observe the lake water quality by measuring the physical and chemical parameters in Inle Lake (Akaishi et al. 2006). There were 5 same sampling locations with the present study and those stations are St. 1, St. 2, St. 3, St. 4 and St. 7. Eight water samples were collected from the lake surface with plastic bottles and sent to the Department of Agricultural Research (DAR) in Yezin, Myanmar.

Table 1. Names and the characteristics of the sampling stations in Inle Lake

Station	Name	Characteristics of the location	Geographic coordinate
St.1	Tourism hub	Very populated area (near township area)	20°39'33.18"N 96°55'29.16"E
St.2	Inlet 1	Flows through the tourism hub area	20°38'15.47"N 96°55'17.35"E
St.3	Center	The center of the open water area of the lake	20°34'15.78"N 96°55'04.20"E
St.4	Inlet 2	The inflow is located near the banks of the lake	20°32'15.48"N 96°53'57.61"E
St.5	Floating garden	Inside the floating island (Tomato cultivation area)	20°29'55.70"N 96°55'03.58"E
St.6	Open water	Open water area of the lake	20°29'53.72"N 96°54'59.71"E
St.7	Weaving village	Near the dyeing and textile production area	20°26'43.18"N 96°53'45.30"E
St.8	Outlet	The outflow section of the lake	20°26'15.20"N 96°54'06.62"E

The pH was measured by a pH meter (F-51, HORIBA Ltd.) and the electrical conductivity (EC) by a Conductivity meter (DS-51, HORIBA Ltd.). Major cation concentrations, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+), and other elements, such as iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn), were analyzed using an atomic absorption spectrophotometer (NovAA 400, Analytik jena Ltd.). The concentrations of Fe, Mn, Cu and Zn were low, and these data were not shown. Carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and chloride (Cl^-) were analyzed by the titrimetric method using a titrator. SO_4^{2-} was analyzed by the turbidimetric method with a UV-VIS spectrophotometer (Janway 6305, Keison products Ltd.). Total suspended solids (TSS) and total dissolved solids (TDS) were determined using a water bath and oven. Nitrate (NO_3^-) was analyzed by a devarda's alloy with Kjeldahl distillation unit. Hardness was calculated as the sum of Ca^{2+} and Mg^{2+} concentrations.

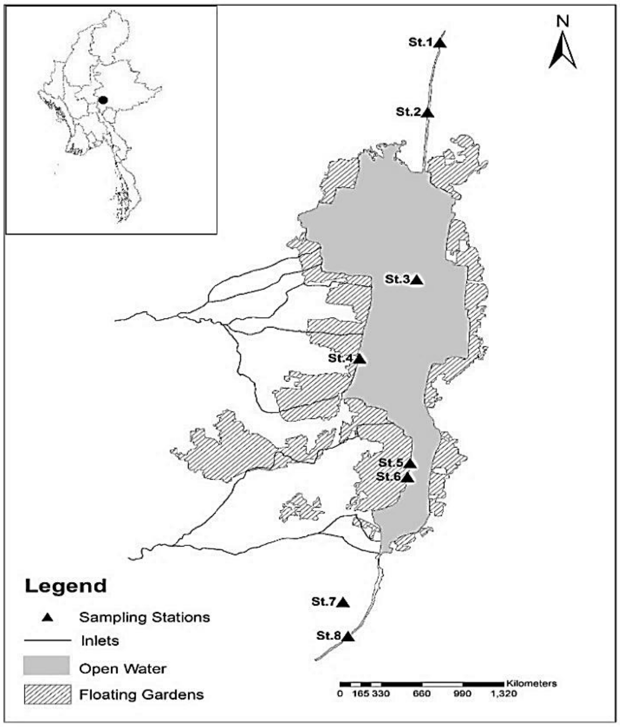

Fig. 2. Map of Inle Lake and the location of sampling stations (St.1-8). The dot in the map of Myanmar (upper left corner) shows the study area.

Regarding the data analysis, the actual data of the water quality (Table 2) were normalized as the data of some parameters, mainly the Cl^- concentrations among all stations were extremely high compared to the other research data of Akaishi et al. (2006) and my own (2019, unpublished) and the cause of this discrepancy is unknown. The latter data in 2019 were those by one time measurement, and the water samples were collected in May. The analytical measurements were done in Kyoto University, Japan and the analytical methods were different from the Department of Agricultural Research (DAR) in Myanmar. Thus, it is considered that the normalized data should be used for the analysis. Normalization was done to restrict the data to a certain range obtained by the formula: x = (x-xmin)/(xmax-xmin), where xmin means the minimum value of each station and xmax refers the maximum value of each station. The analysis of variance (ANOVA) and post hoc test was used to compare the sample means. The mean comparison between agriculture and tourism seasons was done using paired *t*-test. The hierarchical cluster analysis (CA) was applied to identify homogenous groups of stations. RStudio (Version 1.0.153) was used for all the statistical analysis in this study.

Table 2. Comparison of water quality data in 2004, 2017 and 2019 in Inle Lake

Elements	**St.1**			**St.2**			**St.3**			**St.4**		
	2004	**2017**	**2019**	**2004**	**2017**	**2019**	**2004**	**2017**	**2019**	**2004**	**2017**	**2019**
pH	7.20	7.12	7.97	7.20	7.13	8.22	7.00	7.13	8.91	7.00	7.22	8.10
EC (µScm^{-1})	378	343	566	324	338	396	260	257	302	327	263	495
Ca^{2+} (mgl^{-1})	50.20	61.05	58.80	48.80	60.28	42.25	36.10	34.41	16.62	43.80	43.82	50.18
Mg^{2+} (mgl^{-1})	14.60	8.94	30.94	12.00	9.15	20.94	11.80	8.44	26.05	14.50	9.61	31.57
Na^{+} (mgl^{-1})	9.63	8.95	10.95	4.50	8.72	10.26	7.71	6.34	9.59	13.40	6.34	6.79
K^{+} (mgl^{-1})	6.44	3.15	4.43	5.65	3.00	2.99	5.51	4.04	2.68	3.80	2.64	4.43
Cl^{-} (mgl^{-1})	3.67	105.09	14.40	2.51	106.76	14.87	2.26	97.23	13.39	2.55	93.18	10.62
SO$_4^{2-}$ (mgl^{-1})	0.77	14.28	16.97	0.16	15.82	8.53	3.10	14.53	3.00	6.90	15.66	0.91
NO$_3^{-}$ (mgl^{-1})	DL	1.55	9.17	0.01	1.49	7.12	DL	1.19	0.54	DL	1.11	0.00
TA (mgl^{-1})	140.00	295.40	ND	129.00	277.60	ND	100.00	246.90	ND	117.00	274.20	ND
TH (mgl^{-1})	186.00	69.98	ND	171.00	69.42	ND	139.00	42.90	ND	169.00	52.84	ND
pH	ND	7.14	7.69	ND	7.17	7.82	7.00	7.22	ND	ND	7.18	8.11
EC (µScm^{-1})	ND	236	493	ND	295	383	264	259	ND	ND	256	344
Ca^{2+} (mgl^{-1})	ND	39.80	53.31	ND	38.35	31.02	39.80	39.35	ND	ND	39.55	27.03
Mg^{2+} (mgl^{-1})	ND	9.00	33.52	ND	8.99	29.83	24.50	8.66	ND	ND	8.66	26.58
Na^{+} (mgl^{-1})	ND	5.34	3.24	ND	4.49	4.03	12.60	5.40	ND	ND	7.39	5.16
K^{+} (mgl^{-1})	ND	2.94	2.81	ND	2.99	1.77	4.72	1.97	ND	ND	2.56	1.83
Cl^{-} (mgl^{-1})	ND	98.08	5.07	ND	89.01	6.00	2.05	100.19	ND	ND	90.88	7.48
SO$_4^{2-}$ (mgl^{-1})	ND	14.48	0.71	ND	14.38	0.83	0.96	17.20	ND	ND	14.66	2.04
NO$_3^{-}$ (mgl^{-1})	ND	1.37	0.00	ND	1.37	0.00	0.45	1.18	ND	ND	1.45	1.72
TA (mgl^{-1})	ND	262.30	ND	ND	260.10	ND	117.00	258.50	ND	ND	224.10	ND
TH (mgl^{-1})	ND	48.78	ND	ND	47.33	ND	200.00	48.01	ND	ND	48.21	ND

Source: Akaishi et al. 2006 (November 2004), The present study (2017), Unpublished data (2019), ND: No Data.
The 2019 data was one time measurement and collected the samples in May.

RESULTS AND DISCUSSION

Spatial and seasonal variations of water quality in Inle Lake. The hierarchical cluster analysis (CA) was performed for grouping the water monitored stations (Fig. 3). The dendrogram showed that the cluster 1 included St. 1 and 2 that are located near the township area, and it was shown in Table Apd-1 that those 2 stations showed the highest values of most parameters, such as Ca^{2+}, TSS, TDS, and hardness. The cluster 2 was composed by the rest of the stations, including the floating garden area, the station near a weaving village and the outlet of the lake.

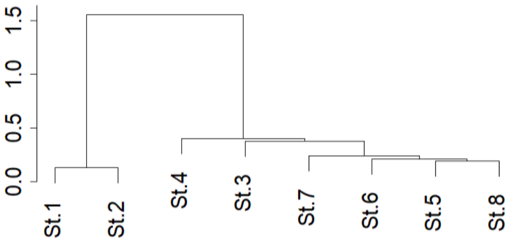

Fig. 3. Dendrogram revealing spatial similarities of the stations of Inle Lake by CA

The main sources of the Ca, Mg and hardness were erosion and sediment loadings from the bedrock, which consists mostly of limestone and calcareous sandstone in the drainage basin (Bhateria and Jain 2016; Thin et al. 2020). The composition of the TSS and TDS may include sand, silt, clay, minerals, sediments and organic matters, as well as sewage effluent (Bhateria and Jain 2016; Butler and Ford 2018). The elements Ca^{2+}, TSS, TDS and hardness were significantly higher in St.1, St.2 and St.4 (Table Apd-1), which are the main inlets of the lake. The sediment loads from the surface erosion, which are transported in through the inlets from the adjacent watershed area of the lake, summed up to the sewage contamination from the populated areas might impact the variation of those elements.

The seasonal variation of some parameters such as pH, Ca^{+}, K^{+}, Cl^{-} and NO_3^{-} were shown and those were significantly different in months with $p < 0.001$ (Fig. 4 to 8). The variations of the other parameters (Mg^{2+}, HCO_3^{-}, SO_4^{2-}, TSS, TDS, hardness and alkalinity) were provided in the Appendix 1. Among the above five elements, only Ca^{+} was significantly different among the stations ($p < 0.001$). The St. 1 and 2 had similar trends, which showed significant differences with other stations (St. 3 to 8), in almost every month of all parameters. The pH values in September and November were higher than those of the other months in all stations. The values in October, January and April were low and these showed significant differences with September and November (Fig. 4). Regarding the Ca^{2+} values, the higher values of St.3, 5, 6, 7 and 8 in September were found and it was significantly different with August, December, February, March, and May (Fig. 5). The values of K^{+} in August and April showed the same trends and were significantly higher than the other months such as November, January to March, and May in all stations. The values in October were significantly lower than August (Fig, 6). The values of Cl^{-} were higher during the period from August to December in all stations than those in the other periods, and lower in January, February and April (Fig. 7). The values of NO_3^{-} of all stations were higher in April and May than those in the other months excluding November (Fig. 8). The highly fluctuated water chemistry was observed in Inle Lake.

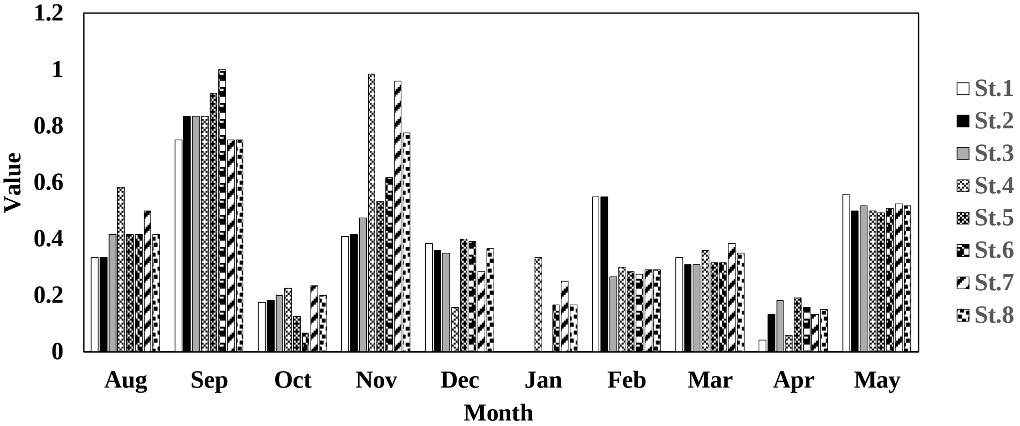

Fig. 4. Seasonal variations of pH among the stations. There are significant differences among some months and some stations, but in order to avoid complexity caused by many small letters, significant relations are shown in the text.

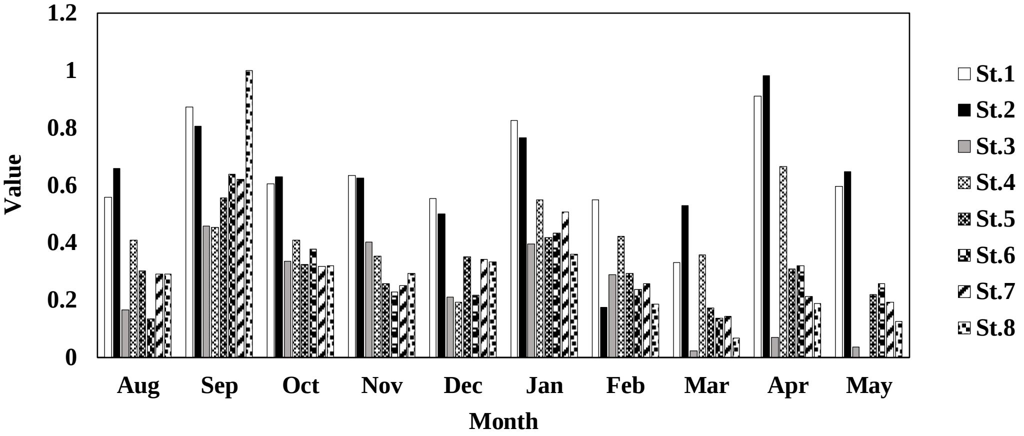

Fig. 5. Seasonal variations of calcium among the stations. There are significant differences among some months and some stations, but in order to avoid complexity caused by many small letters, significant relations are shown in the text.

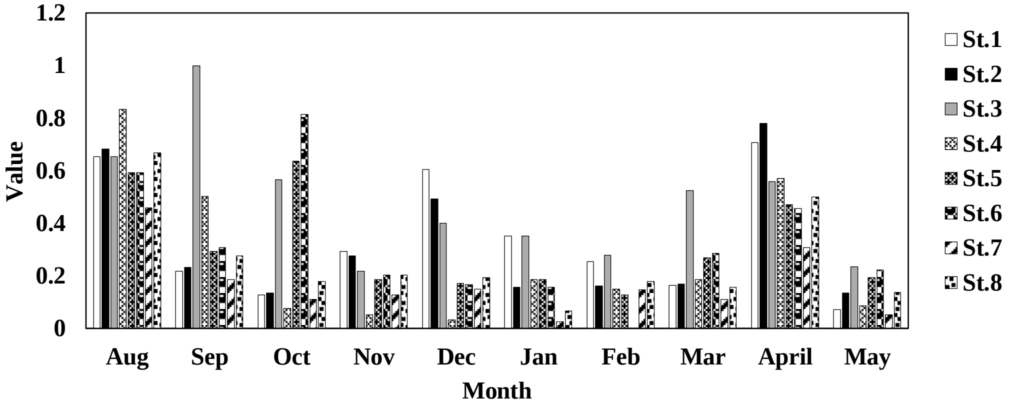

Fig. 6. Seasonal variations of potassium among the stations. There are significant differences among some months and some stations, but in order to avoid complexity caused by many small letters, significant relations are shown in the text.

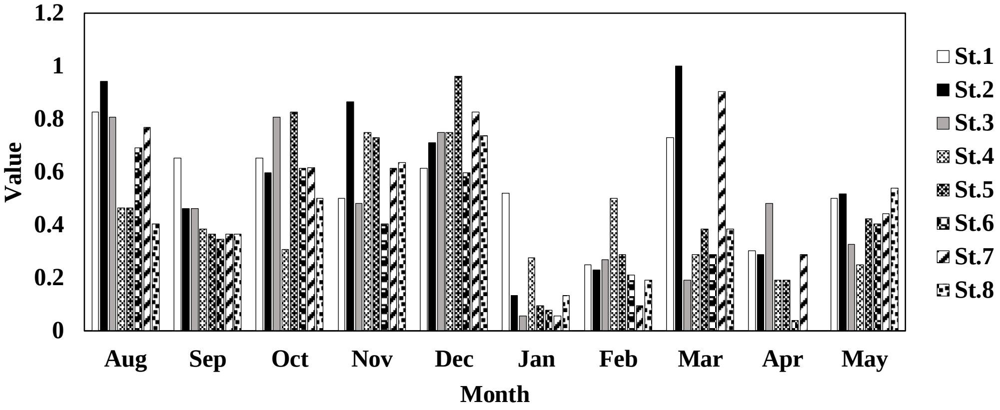

Fig. 7. Seasonal variations of chloride among the stations. There are significant differences among some months and some stations, but in order to avoid complexity caused by many small letters, significant relations are shown in the text.

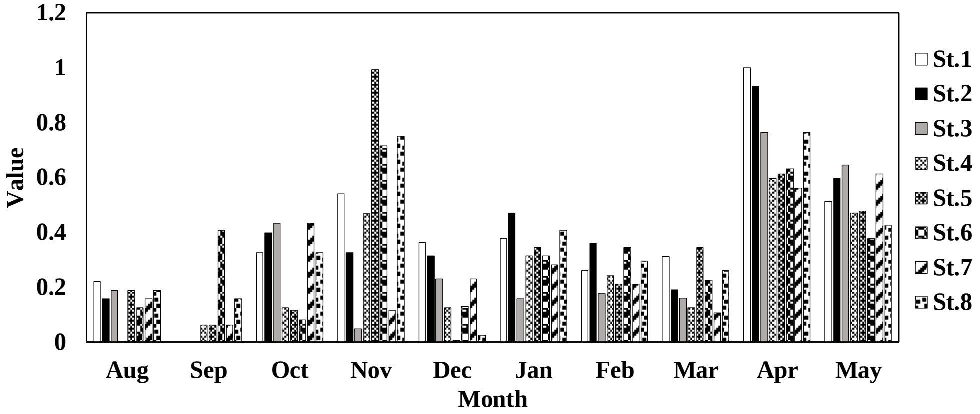

Fig. 8. Seasonal variations of Nitrate among the stations. There are significant differences among some months and some stations, but in order to avoid complexity caused by many small letters, significant relations are shown in the text.

Assuming that the activities of agriculture and tourism are the main factors influencing the lake water quality, the sampling months were divided into two seasons: agriculture and tourism seasons (Table 3). The result revealed that the element values in the agricultural season tended to be higher compared to the tourism season. There was a statistically significant difference between the two seasons with pH and Mg^{2+} ($p < 0.05$), K^+, HCO_3^-, TDS and alkalinity ($p < 0.01$) and SO_4^{2-} ($p < 0.001$).

The fertilization in agriculture areas is also one of major anthropogenic sources of K^+ and NO_3^- in surface water (Petzoldt and Uhlmann 2006; Skowron et al. 2018). The value of K^+ was significantly higher during agricultural season (Table 3), compared to tourism season. However, NO_3^- values were not significantly different between the two seasons due probably to the nutrient uptake by cultivated crops or phytoplankton in the surface lake water. The Cl^- generally originates from anthropogenic sources including agricultural practices, wastewater, and sewage discharges (Ludwikowski and Peterson 2018; Oberhelman and Peterson 2020). Based on the results of Cl^- values, the sewage contamination and waste disposal, agricultural activities, and tourism-oriented activities around the lake might influence the water quality during the whole year. The finding of the present study was consistent with the result of other research, in which water contamination from human activities, including agricultural runoff, affected the Cl^- contents in the Lake Tonle Sap, Cambodia. (Oyagi et al. 2017).

Table 3. The t-test results comparing agriculture and tourism season on water quality.

	Agriculture season		**Tourism season**		
	Mean	**SE**	**Mean**	**SE**	***t*-test**
pH	0.40	0.01	0.36	0.02	*
EC	0.58	0.03	0.54	0.04	ns
Ca^{2+}	0.40	0.06	0.35	0.05	ns
Mg^{2+}	0.57	0.02	0.49	0.03	*
Na^+	0.22	0.03	0.22	0.02	ns
K^+	0.38	0.04	0.21	0.03	**
CO_3^{2-}	0.15	0.02	0.15	0.02	ns
HCO_3^-	0.51	0.02	0.62	0.02	**
Cl^-	0.48	0.04	0.46	0.03	ns
SO_4^{2-}	0.24	0.01	0.31	0.01	***
NO_3^-	0.33	0.02	0.30	0.03	ns
TSS	0.18	0.04	0.13	0.05	ns
TDS	0.33	0.03	0.25	0.02	**
Alkalinity	0.59	0.03	0.73	0.03	**
Hardness	0.38	0.07	0.35	0.06	ns

*$p<0.05$, **$p<0.01$, ***$p<0.001$ SE: Standard Error

Representative sampling locations and times for long term monitoring. The representative stations for each cluster and months for each season were selected based on the CA and the variation of the data of pH, Ca^{2+}, K^+, Cl^- and NO_3^- (Fig. 4 to Fig. 8), which showed significant differences and are considered to be agriculturally important.

According to the CA, the two clusters were grouped. The cluster 1 included St. 1 and St. 2, located near the populated tourist's hub, and the highest values of most parameters were found in these two stations. Thus, it is more likely that tourism influences the water quality of these stations. On the other hand, the cluster 2 contained the rest of the stations. The trends of the stations were checked, and then, the one with the largest variations among the stations was selected as the most appropriate station for each season. With the largest variations, it is easy to detect changes. The St. 1 and 2 had the similar trends among the stations regarding the seasonal variations. The St. 6 had the largest variations which had the similar trends with other stations on the pH, Ca^{2+}, and Cl^-. Thus, the St.1 and/or St.2 from the cluster 1, and the St. 6 from cluster 2 were considered to be the appropriate stations for monitoring.

Regarding the comparison of the influences of agriculture and tourism, the values of elements such as pH, Mg^{2+}, K^+, HCO_3^-, TDS, alkalinity and SO_4^{2-} were significantly higher in agricultural season (March to October) than tourism season (November to March) (Table 3). Therefore, the observation of lake water quality should be done twice a year. Regarding the seasonal variations, April and May during the agricultural season and November and December during the tourism season had similar trends among the stations in most of the parameters. The influential elements of agriculture and tourism, i.e., K^+, NO_3^- and Cl^- of those four months were checked again to select the most appropriate months for each season. The values of K^+ and NO_3^- in April were much higher than those in May, and the Cl^- values in December were higher than those in November. It is indicated that water quality of April is highly influenced by agricultural activity and that of December can be representative month for tourism. Thus, the changes in water quality should be monitored in April for agricultural season, and in December for tourism season.

CONCLUSIONS

The spatial and temporal variations of the water quality of Inle Lake were clarified to select appropriate sampling locations and time periods for future monitoring in this study. The elements Ca^{2+}, TSS, TDS and hardness were significantly higher in the stations at the main inlets of the lake. It is possible that the sediment loads of the surface erosion summed up to the sewage contamination might impact the variation of those elements. The result also show that the St.1 and St.2 included in the Cluster 1 based on the CA were found to show the highest values of some parameters and thus, the tourism might influence the water quality of these stations. Then, the record values were higher during the agricultural season compared to the tourism season, indicating that the fertilization of agriculture areas might have impact on the lake water quality. Overall, the lake water is mainly contaminated by the impacts of sedimentation and human activities, including agricultural practices and tourism.

Inle Lake needs to be maintained, considering the variations in water quality and for the preservation of the biodiversity of the lake. The present study could contribute to future planning sampling design, which can reduce labor costs, times, and monitoring sites. The continuous monitoring and analysis of the lake water are required to meet the future long-term changes. In order to achieve that the proper sampling locations should probably be St. 1 and/or St. 2 from cluster 1 and St.6 from cluster 2. Moreover, the lake water quality should be measured at least twice a year: in April for agricultural season and in December for tourism season. Then, it is also recommended to adjust the amount and frequency of fertilizer usage following Good Agricultural Practices (GAP), such as application of organic fertilizers, in the agriculture sector in order to preserve the lake water quality.

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Appendix-1

Table Apd-1. Mean and SE of water quality parameters among the stations of Inle Lake (August 2017 – May 2018)

Parameters	**St. 1**	**St. 2**	**St. 3**	**St. 4**	**St. 5**	**St. 6**	**St. 7**	**St. 8**
pH	0.35±0.07	0.36±0.07	0.36±0.07	0.43±0.09	0.37±0.08	0.39±0.09	0.43±0.08	0.40±0.207
EC	0.71±0.08	0.70±0.06	0.50±0.208	0.52±0.06	0.45±0.07	0.60±0.07	0.51±0.06	0.50±0.07
Ca^{2+}	0.64±0.06^{a}	0.63±0.07^{a}	0.24±0.05^{b}	0.38±0.06^{bc}	0.32±0.03^{bd}	0.30±0.05^{be}	0.31±0.05^{bf}	0.32±0.08^{bg}
Mg^{2+}	0.51±0.10	0.54±0.08	0.44±0.08	0.61±0.08	0.52±0.08	0.52±0.07	0.47±0.06	0.47±0.05
Na^{+}	0.32±0.04	0.31±0.05	0.22±0.01	0.22±0.09	0.18±0.04	0.15±0.04	0.18±0.08	0.26±0.08
K^{+}	0.34±0.07	0.32±0.08	0.48±0.08	0.27±0.09	0.31±0.06	0.32±0.08	0.17±0.04	0.26±0.06
CO_3^{2-}	0.18±0.03	0.17±0.03	0.16±0.02	0.20±0.09	0.12±0.02	0.09±0.03	0.14±0.02	0.10±0.03
HCO_3^{-}	0.65±0.05	0.59±0.11	0.50±0.04	0.53±0.08	0.57±0.04	0.62±0.05	0.55±0.06	0.57±0.07
Cl^{-}	0.56±0.06	0.57±0.10	0.46±0.08	0.42±0.06	0.47±0.09	0.37±0.07	0.50±0.09	0.39±0.07
SO_4^{2-}	0.20±0.08	0.22±0.09	0.20±0.08	0.22±0.09	0.20±0.08	0.20±0.08	0.24±0.10	0.20± 0.08
NO_3^{-}	0.39±0.08	0.37±0.08	0.28±0.08	0.25±0.06	0.34±0.09	0.33±0.07	0.28±0.06	0.36±0.08
TSS	0.32±0.08^{a}	0.30±0.06^{ag}	0.05±0.01^{bh}	0.26±0.07^{ah}	0.07±0.02^{ch}	0.08±0.02^{dh}	0.10±0.03^{egh}	0.08±0.03^{fh}
TDS	0.37±0.03^{a}	0.41±0.07^{a}	0.22±0.04^{b}	0.31±0.03^{a}	0.27±0.03^{a}	0.28±0.04^{a}	0.26±0.04^{a}	0.26±0.04^{a}
Alkalinity	0.75±0.03	0.70±0.09	0.61±0.06	0.69±0.07	0.66±0.03	0.65±0.03	0.65±0.04	0.55±0.07
Hardness	0.63±0.05^{a}	0.69±0.05^{a}	0.21±0.05^{b}	0.36±0.06^{bc}	0.30±0.03^{bd}	0.28±0.05^{be}	0.29±0.04^{bf}	0.29±0.08^{bg}

Mean±SE: SE= Standard Error

Different letters indicate statistically significant differences ($p<0.05$) between the stations.
The values were normalized by the formula: x= x-xmin/xmax-xmin.

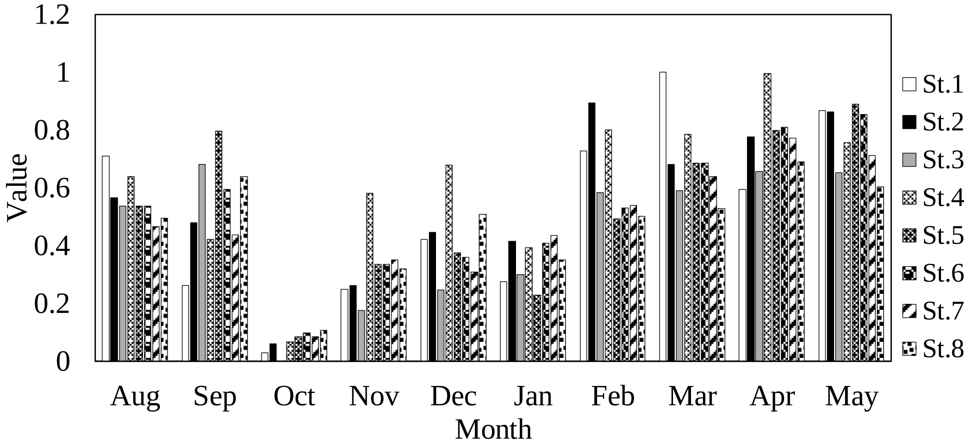

Figure Apd-1. Seasonal variations of Magnesium among the stations

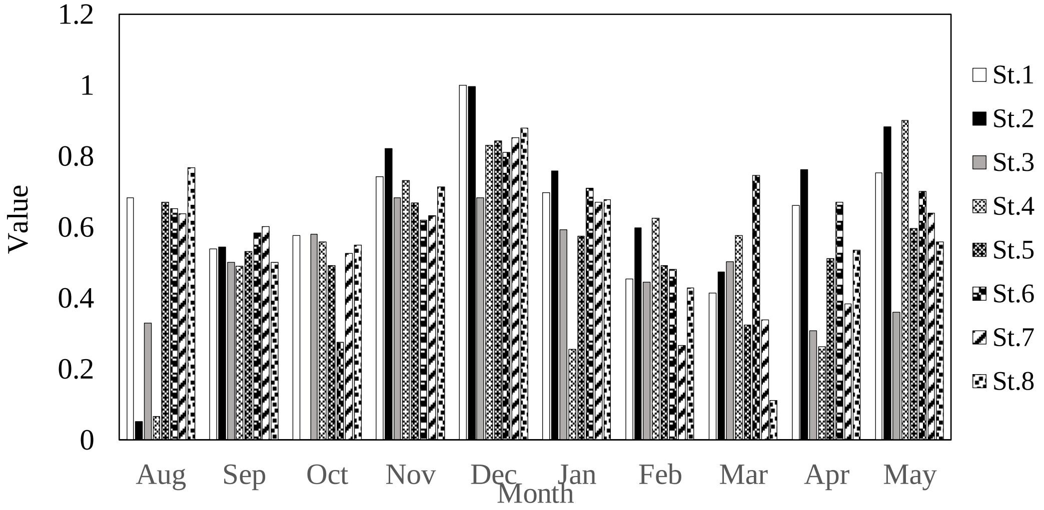

Figure Apd-2. Seasonal variations of bicarbonate among the stations

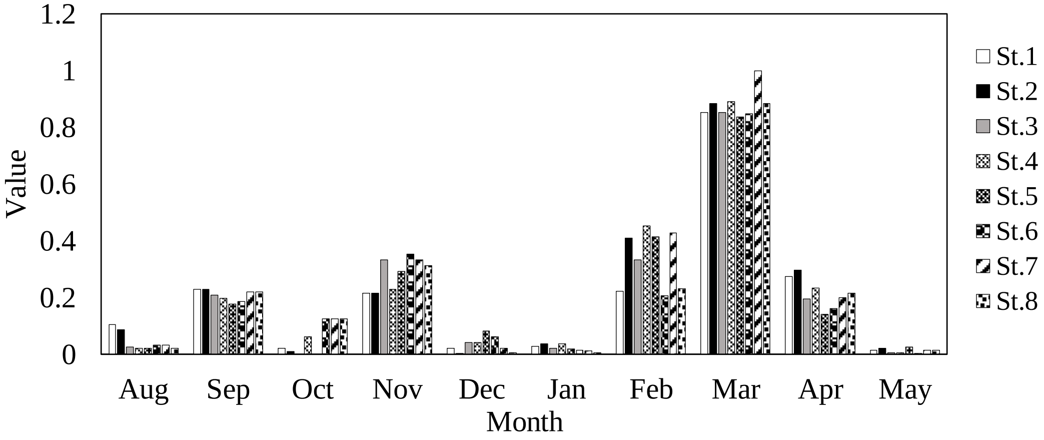

Figure Apd-3. Seasonal variations of Sulfate among the stations

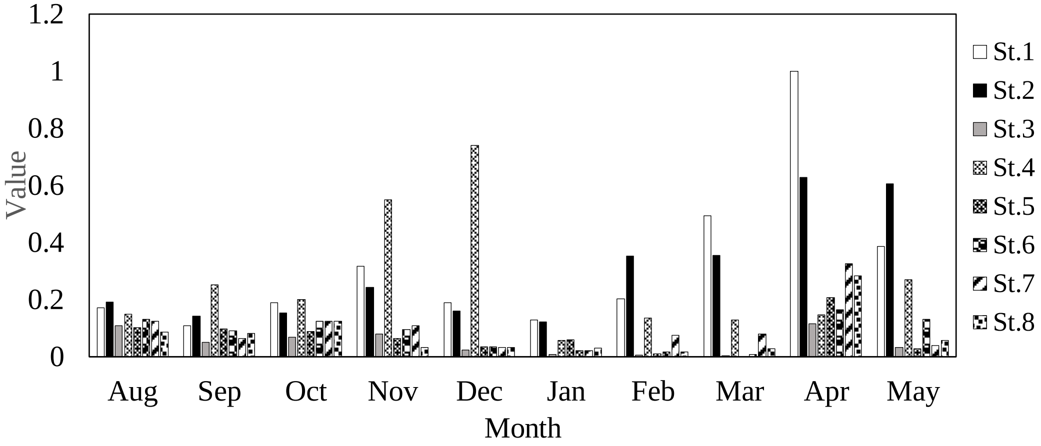

Figure Apd-4. Seasonal variations of Total Suspended Solid among the stations

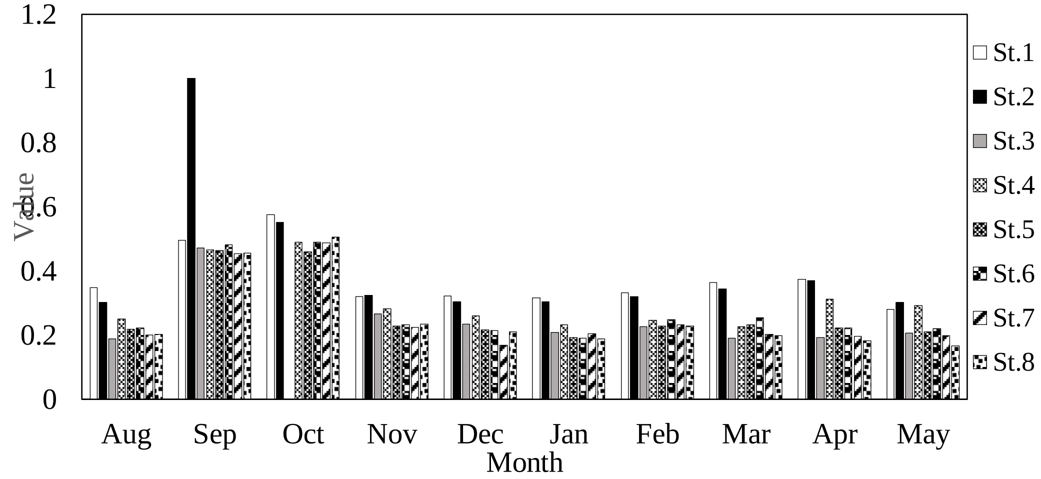

Figure Apd-5. Seasonal variations of Total Dissolved Solid among the stations

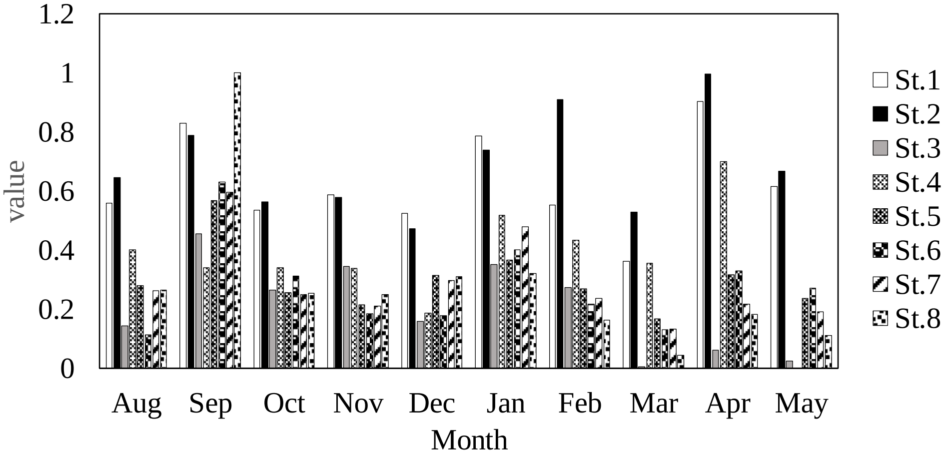

Figure Apd-6. Seasonal variations of Hardness among the stations

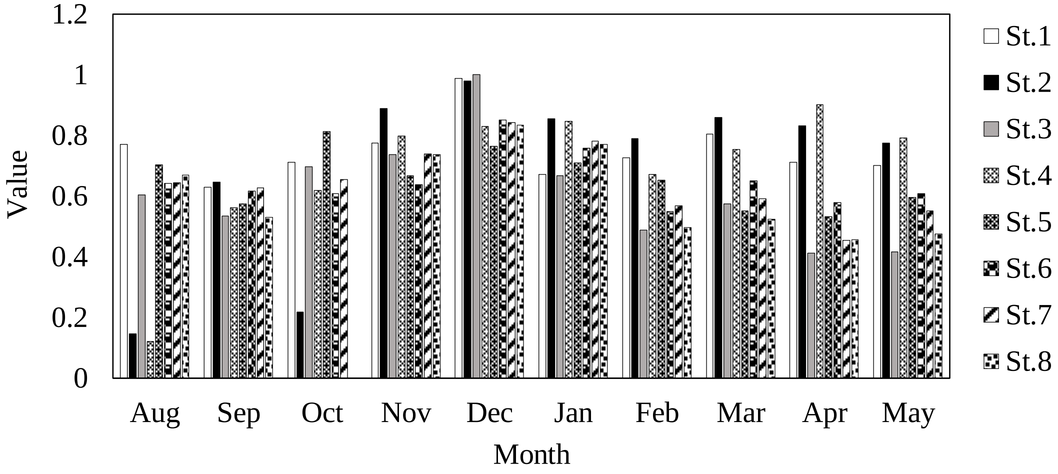

Figure Apd-7. Seasonal variations of Alkalinity among the stations