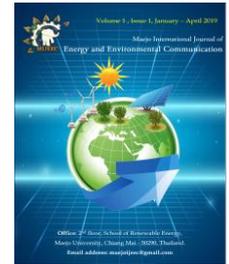




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ARTICLE

Study on Dynamic Behaviors of Water Quality and Mechanisms of Eutrophication in Kandawgyi Lake, Yangon City, Myanmar

Khine Lwin Aye¹, Tomoaki Itayama¹, Kyaing², Kyi Pyar Shwe², Kou Tasaki³,
Yuhei Hayata⁴, Akihida Tada^{1*}

¹ Graduate School of Engineering, Nagasaki University, Nagasaki, Japan.

² Department of Civil Engineering, Yangon Technological University, Yangon, Myanmar.

³ Engineer, TAISEI CORPORATION, Kansai Branch, Chuoh-ku, Osaka, Japan.

⁴ Engineer, KAJIMA CORPORATION, Kansai Branch, Chuoh-ku, Osaka, Japan.

*Corresponding author, E-mail address: atada@nagasaki-u.ac.jp

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ABSTRACT

Kandawgyi Lake is a famous recreational place in Yangon; however, the water quality deterioration and algae blooming occurred in recent years due to the economic development and people's unawareness. In this study, the dynamic behaviors of water quality and mechanisms of eutrophication is investigated. During one-year field observation's results showed that the lake's water quality had been polluted by domestic wastewater depend on the high value of BOD and COD. Moreover, it was found that the thermal stratification exists about 1.0 meters water depth of the lake and anoxic water mass exists near the bottom of the lake. Besides, the one-year water depth observation showed the seasonal changes of water depth and, the water depth prediction by using the IOM mass balance model indicated better agreements in a dry season than a wet season. From the results of this study, it was thought that internal loading of nutrients could be the main reason of the algae blooms. Therefore, we proposed the bottom sediment removal as the most effective method to improve the water quality. Furthermore, small constructed wetlands at each inlet drains also can be an effective method as a countermeasure for the prevention of the next sediment accumulation.

1. Introduction

In many rural and urban areas, lakes and reservoirs are essential sources of water and livelihoods. The nutrient enrichment ultimately promotes algae and phytoplankton, causing several problems such as lack of oxygen and the outbreak of algal blooms (Nabar et al., 2014). The location of the study area (Kandawgyi Lake) is presented in Figure 1. It is located in Bahan Township at a latitude 16° 47' North and a longitude 96 ° 10' East in the south part of Yangon City in

Myanmar. The surface area of Kandawgyi Lake is 647,497 m² and the average water depth is about 1.83 m. Kandawgyi Lake was developed as a reservoir for Yangon City in 1879 and utilized as a drinking water source for a population of 35,000. However, after the Hlawga reservoir was constructed entirely in 1924, the role of the Kandawgyi reservoir was finished. At present, Kandawgyi Lake and the surrounding area are developed as an urban park (YCDC, 2014).

On the north bank of the lake, seven urban drain inlets are collected domestic wastewater and stormwater overflow from the catchment area. Also, wastewater from the surrounding restaurants and hotels discharged directly into the lake. The lake has one outlet (small movable weir) on the southwest bank; however, this weir is usually closed; thus, water pollutants are accumulated and no exchange water in the lake. As a result, water quality deteriorated, and algae blooming occurred in the whole lake. Also, according to the previously conducted research studies, Kandawgyi Lake was classified as eutrophic condition based on the spot observations (Soe, 2013). Moreover, our first paper reported Kandawgyi Lake as a hypereutrophic state according to the high Chlorophyll-a (Chl-a) value of 196µg/L on average based on the long term observation. Furthermore, cyanotoxin microcystins (MCs) occurred in Kandawgyi Lake and order as the averaged concentration of MC-RR, MC-LR, and MC-YR were 24.5 µg/L, 7.3 µg/L and 4.3 µg/L, respectively. The variations of MC variants were independently among the sites according to the low mixing condition of the lake water in horizontally (Khine et al., 2020).

The practical and sustainable water quality management of urban lake is an important issue because of the inflow and outflow with the fluctuations in water levels. It also corresponds to the hydrological condition that is more complicated than a natural lake (Hostetler et al., 1990). Thermal stratification, which can prevent the penetration of dissolved oxygen into deeper layers, has a significant role in the water quality status of lakes and reservoirs with its influence on physical and biological processes (Elo et al., 1998, Dobiesz et al., 2009).

Besides, excessive nutrients may also result in eutrophication; and harmful algal blooms, which are one of the consequences of dissolved oxygen depletion, and the establishment of an anoxic environment at the bottom of lakes and reservoirs (Huang et al., 2019). The first paper found out that the average value of total nitrogen (TN) was 2.21 mg/L and the average value of total phosphorus (TP) was 0.56 mg/L. It was thought that nitrogen limitation status based on the low TN: TP ratio in the lake. However, the sources of the nutrients are not fully understood and challenging to propose counter measurement methods for eutrophication in the lake. Therefore, this study focuses on the seasonal changes of lake water quality and water depth to understand the eutrophication process in this lake.

2. Material and methods

2.1. Field Observations and Sample Collections

2.1.1. Water Quality Characteristics

The water sampling survey was conducted once a month from February 2018 to October 2019 at the three observation points No.14, No.15, and No.17, as shown in Figure 1. The three points, No.14 (near the inlet points), No.15 (center of the lake), and No.17 (near the outlet), were selected considering the flow direction pattern in the lake. Samples

were collected in the middle of each observation month from 9 a.m. to 11 a.m. every time. After collecting the samples from the water surface, it was kept in a cool box and transported to the Environmental Engineering Laboratory at Yangon Technological University. The target water quality indicators were water temperature, pH, biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

2.1.2. Vertical Distribution of Water Quality

To measure the vertical distribution of water quality, multi-item water quality measurement sensors (Model – AAQ1183, JFE ALEC Co. Ltd.) used at four observation points (St-1, St-2, St-3, St-4) as shown in Figure 1. The target water quality indicators were water temperature, dissolved oxygen (DO), pH and Chl-a at every 0.3 m interval of water depth.

2.1.3. Water Depth Measurement at St-4

A small memory pressure gauge (DEFI-D10, JFE ALEC Co., Ltd.) was sunk on the bottom at St-4 and the water depth variation was measured every 15 minutes. The observation period was from September 21st in 2018 to October 6th in 2019. The data from November 21st to December 14th in 2018 is missing due to the malfunction of the pressure gauge. Photo 1 shows the pictures of Kandawgyi Lake, which was taken from the south and south-west of the lake. All of these pictures showed the same way of eutrophication status like green water-colored that could be a high concentration of Chl-a. It is easy to grasp the shooting locations from Figure 1.

2.2. Chemical Analytical Methods

The thermometer and pH-meter used to measure the water temperature and pH at field observation. BOD and COD measured at Yangon Technological University and used by dilution method and titration methods, respectively (APHA, 1998).



Photo 1. Current Condition of Kandawgyi Lake

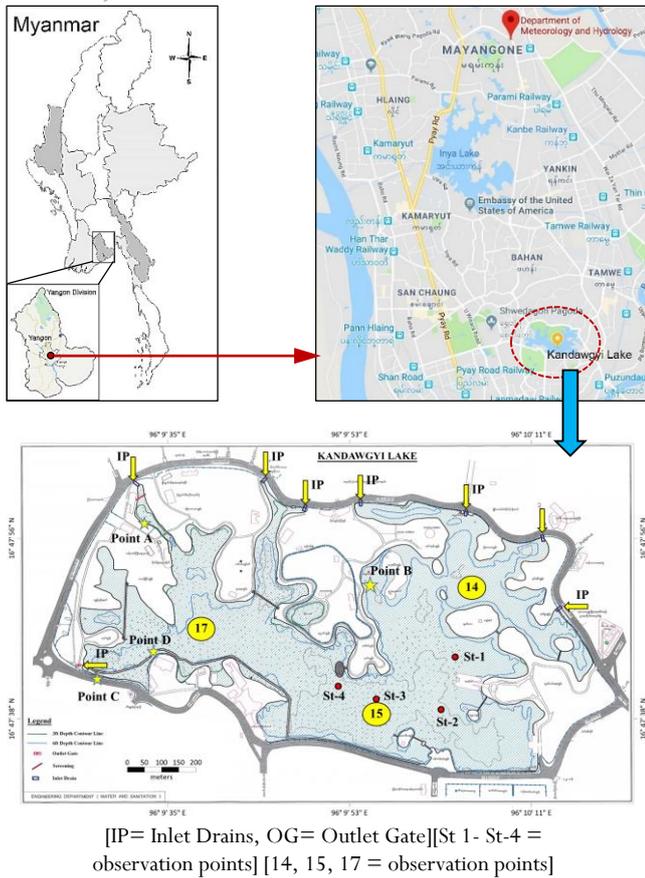


Figure 1. Location of Kandawgyi Lake

2.3. Water Depth Prediction Model

The weather information such as daily atmospheric temperature and rainfall were collected from the Department of Meteorology and Hydrology (the KABA-AYE Weather Station), which located the northern part of the lake (refer to Figure 1). Figure 2 showed the daily changes of maximum atmospheric temperature and rainfall conditions of the study area. The two solid lines showed the maximum atmospheric temperature (red) and minimum atmospheric temperature (orange). Besides, a light blue bar showed daily recorded rainfall. In this study, the inflow-outflow model (IOM) was slightly modified from the mass balance method to predict the variations of water depth in the lake. Blaney and Criddle method used to calculate the lake evaporation since the input data was only atmospheric temperature and suitable for data limitation case studies (Zhan et al., 2009).

2.3.1. IOM Mass Balance Model

In principle, the mass balance method is a simple method for measuring open water evaporation, and it was calculated based on the change in the volume of water stored and the difference between inflow and outflow.

Equation (1) shows the water balance equation of the lake and Equation (3) describes the calculation of the evaporation rate in the lake by using the Blaney and Criddle method.

$$\frac{dV}{dt} = (Q_{ri} + Q_{gi}) - (Q_{ro} + Q_{go}) + (P - E)A_s \quad (1)$$

$$h = \frac{V}{A_s} \quad (2)$$

where; E is the evaporation rate from the water body (mm/d), P is a daily rainfall (mm/d), Q_{ri} is the surface inflow rate, Q_{ro} is the surface outflow rate, Q_{gi} are the groundwater and seepage inflow rate, Q_{go} is the groundwater and seepage outflow rate, V is the water stored volume into the lake, A_s is a lake surface area, h is water depth of the lake.

$$E = f_d * (0.46 * \bar{T}_i + 8.00) \quad (3)$$

where; \bar{T}_i is a mean temperature (average of minimum and maximum temperatures), f_d is a mean daily percentage of annual daily hours based on latitude.

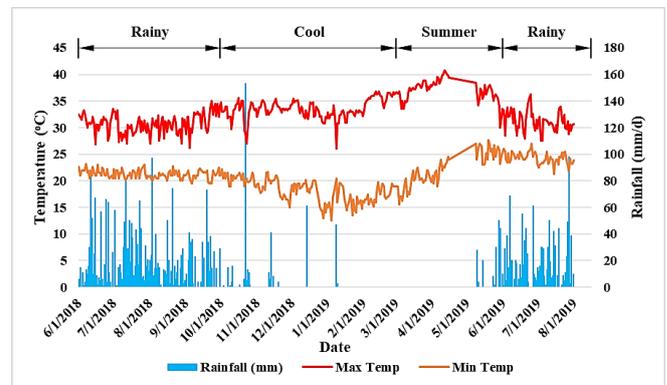


Figure 2. Daily Atmospheric Temperature and Rainfall at the KABA-AYE Weather Station

2.3.2. Evaluation of Model Accuracy

The water depth prediction model was evaluated by using the statistical indicators. The calculation of residuals, the standard deviation of residual and regression analyses were applied to evaluate the model performance in this study. The residual standard deviation used to measure the difference between the measured and predicted values. The smaller value of the residual standard deviation shows the model's prediction and accuracy is high. Besides, the coefficient of determination (R^2) was applied for testing the proportion of variance in the measured data explained by the model. The value of (R^2) range between 0 and 1, with higher values indicating less variance, and values greater than 0.5 typically considered acceptable (Phogat et al., 2016, Stefanie Jachner et al., 2007). The applicable equations were given by:

$$Residual = (M_i - S_i) \quad (4)$$

$$S_{res} = \sqrt{\frac{1}{N-2} \sum_{i=1}^N (M_i - S_i)^2} \quad (5)$$

$$R^2 = \left[\frac{\sum_{i=1}^N (M_i - \bar{M})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^N (M_i - \bar{M})^2 \sum_{i=1}^N (S_i - \bar{S})^2}} \right]^2 \quad (6)$$

where: S_{res} = Residual standard deviation
 M_i = Measured Water Depth (m)
 S_i = Predicted Water Depth (m)
 N = Datapoints
 R^2 = coefficient of determination
 \bar{M} = mean value of measurement water depth
 \bar{S} = mean value of predicted water depth

3. Results and Discussion

3.1. Physio-Chemical Characteristics of Water Quality

Figure 3 shows the physical and chemical characteristics of water quality at three observation points, that is, No.14, No.15, and No.17. The light blue band in the figures represents Japanese water quality standards. Water samples were collected from the water surface in the middle of each observation month. This study recorded an average water temperature was 29.5°C. During the observation period, the values of pH measured above the Japanese water quality standard (6.0 - 8.5) and has an average value of 9.4. During the entire observation period, the COD value was higher than the Japanese water quality standard. On the other hand, the 40 % value of BOD was measured higher than the Japanese water quality standard. The value of COD was very high, based on an average of 112.84 mg/L, while the average value of BOD was 11.87 mg/L. Therefore, COD could be included as a part of algae biomass in the lake. However, compared with the COD, the role of BOD was deficient. Of course, the algal cell body cannot be degraded in 5 days easily. Thus, BOD might be related to the biodegradation of organic materials, rather than the degradation of the algal cell body.

3.2. Vertical Distribution of Water Quality at St-3

Figure 4 (a) shows the vertical distribution of water temperature at observation point St-3. During the observation period, a remarkable thermal stratification occurred at a depth of one meter in January, February, and April in 2019. In September, November, and December in 2018, the water temperature gradually decreased from the water surface to the bottom layer of the lake. In June, July, August, and October in 2019, the water temperature had a uniform distribution in the water column.

Figure 4 (b) draws the vertical distribution of DO at St-3. The value of DO gradually decreased from the water surface to the bottom for all observation periods. At the water surface, DO concentration occurred higher than the minimum DO requirement level (4 ~ 6 mg/L) for aquatic life.

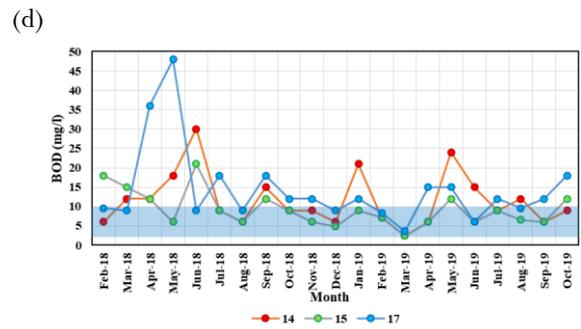
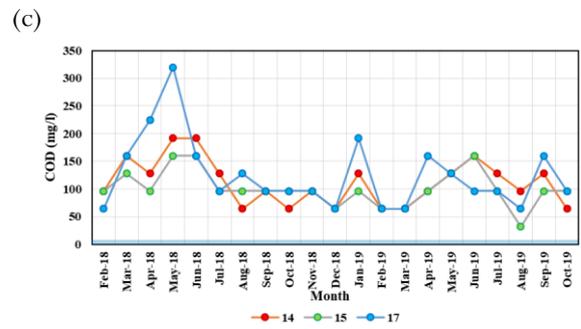
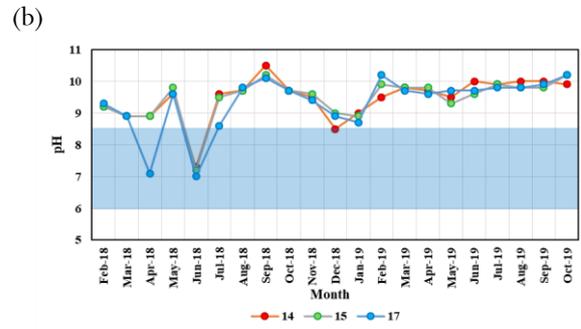
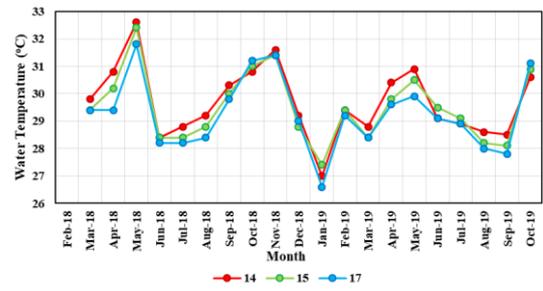


Figure 3. Physio-Chemical Water Quality Variations (a) Water Temperature, (b) pH, (c) Chemical Oxygen Demand (COD), (d) Biochemical Oxygen Demand (BOD)

However, anoxic water mass occurred at a depth of more than 1.5 meters for the observation periods of 13th January, 6th April, 1st June, 14th July, and 6th October in 2019.

Figure 4 (c) describes the vertical distribution of pH. On the water surface, the value of pH is high and it gradually decreased from the water surface to the bottom for all observation months. The uniform distribution occurred in the water column on 11th November in 2018. The highest value was found in April 2019. The observed results have shown a significantly high value of pH from the water surface to a depth of 1.0 meters and expected that these causes mainly depend on the abnormal occurrence of phytoplankton.

Over the 130 years aged of the lake, the sediment continuously received a high amount of organic materials and could be accumulated with the phosphorus (other nutrients also). Therefore, the internal loading is essential for eutrophication processes in this lake (Søndergaard et al., 2003, Van der Molen et al., 1994). Besides, the microbial activity and stratification pattern leads to the anoxic water near the water-sediment interface. As a result, dissolved phosphorus released into the water column from the sediment (Horppila et al., 2017). It enhances the eutrophication and may create a shift from P to N limitation. It was evident from low TN: TP ratio and high average TP value of 0.56 mg/L measured from our first paper (Khine et al., 2020). Furthermore, some research studies illustrated that the high value of pH in eutrophic lakes leads to an increase in internal phosphorus loading (Pettersson et al., 1998, Cooke et al., 1993, Jensen et al., 1992). Thus, the process of internal loadings is also one of the critical factors for nutrient source and algae growth in this lake.

3.3. Seasonal Water Depth Variations and Predictions

Figure 5 shows the time-series measurement of water depth for a one-year duration. Water depth recorded every 15 minutes was averaged to get the daily average of water depth variations. The water depth increased about 15cm from September to November in 2018 and decreased 26 cm in November from 2018 to January 2019. It was continuously decreased 38 cm from January to May in 2019 and steadily increased from May to September in 2019. The recorded water depth showed seasonal fluctuations for a one-year duration.

Figure 6 illustrates the conditions of the predicted water depth for Case-1 and Case-2, as shown in Table 1. To predict the changes of water depth in the lake, two conditions were considered as Case-1 for a dry season and Case-2 for a wet season, respectively. For the former, there was no inflow runoff into the lake while the latter had inflow runoff into the lake. However, Q_{ri} and Q_{ro} were neglected for both conditions since the inflow runoff discharge did not measure in this lake. According to the information from the Yangon City Development Committee, the outlet gate is always closed; thus, the surface outflow rate did not consider in this study. The groundwater does not have much interference with the storage capacity of the lake, and hence, seepage inflow and outflow rate can be considered as relatively equal. Therefore, daily rainfall (P) measured at the KABA-AYE Weather Station and calculated daily evaporation rate (E) were considered as input data for the IOM mass balance model.

Table 1 shows the initial conditions for Case-1 and Case-2 in detail calculation steps. The time step was taken as a one-day interval for water depth calculation due to the daily recorded atmospheric temperature and rainfall data from the weather station. For the conditions of Case-1, Figure 6 (a)

showed good agreement between predicted and measured water depth for a dry season.

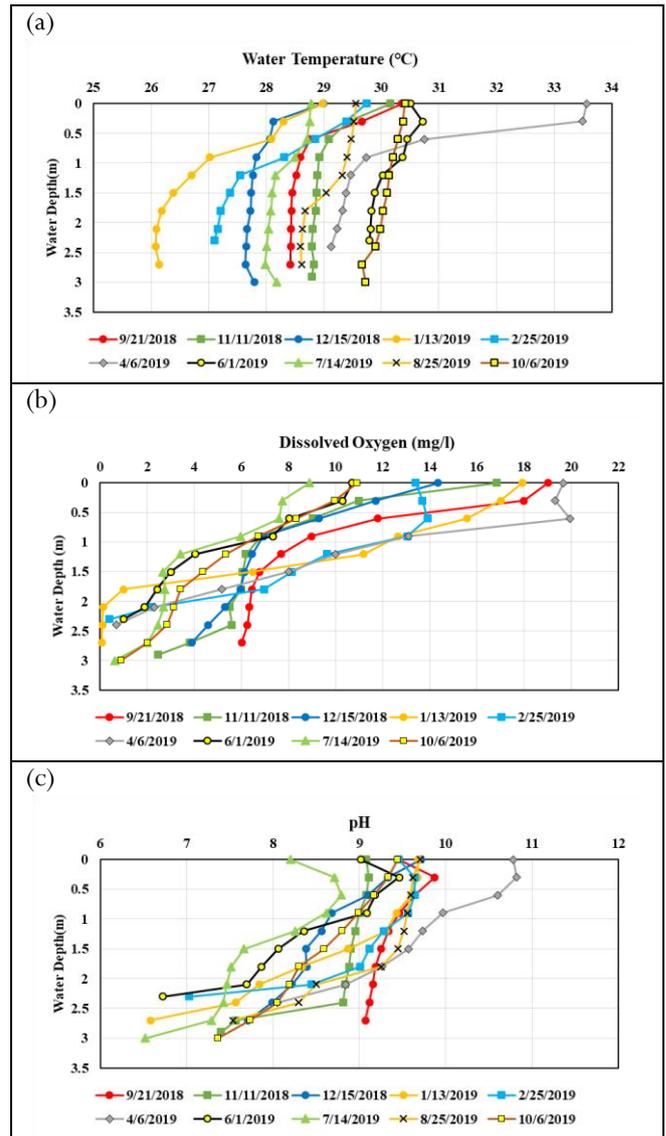


Figure 4. Vertical Distribution of Water Temperature (a) , Dissolved Oxygen (B) and pH (c) at St-3

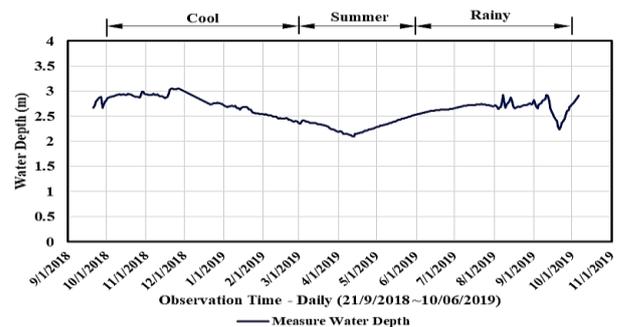


Figure 5. Seasonal Changes of Water Depth at St-4

It was overall average different about 0.85 cm between the predicted and measured water depths. On the other hand, Figure 6 (b) showed an overall average depth difference of

about 1.65 cm between the predicted and measured water depth for a wet season. As shown in Figure 6 (b), the predicted water depth for a rainy (wet) season was higher than the observed one. A cause of discrepancies in a rainy season might be the input weather information used the recorded data from the weather station, which located about 7.75 km far from the lake. As shown in Figure 7, the coefficient of determination (R^2) for Case-1 was 0.99 (p-value < 0.001) and 0.93 (p-value < 0.001) for Case-2, respectively. For Case-2 calculation, the maximum water depth used as 2.75 m according to the water depth fluctuation measurement records.

According to the overall statistical indicators, the variance between predicted and measured water depths for Case-1 and Case-2 was minimal and evaluated as the prediction model has high accuracy. Kandawgyi Lake was determined as a hypereutrophic condition based on the high value of Chl-a. In addition, the average measurement value of TN was 2.21 mg/L and TP indicated that high eutrophication conditions in this lake (Khine et al., 2020). Therefore, it was realized that inflow water, which contains high nutrients, comes into the lake even though the internal loading plays a vital role in enhancing the eutrophication in this shallow lake. To understand this, the daily inflow discharge from surrounding the restaurants and hotels, we calculated by multiplying the deviation of water depth with a constant value of the lake's surface area.

Table 1. Initial Conditions of Case-1 & Case-2

	Case-1	Case-2
Initial Day	01/02/2019	01/06/2019
Final Day	06/04/2019	31/07/2019
Initial Water Depth (m)	2.54	2.53
Remarks	Dry Season	Wet Season

The calculated residual standard deviation (S_{res}) for Case-1 was 0.01 and the calculated daily inflow discharge was 6,475 m³/d. On the other hand, the calculated residual standard deviation (S_{res}) for Case-2 was 0.02 for Case-2 and calculated daily inflow discharge was 12,950 m³/d. The calculated discharge indicated that the few amounts of inflow water comes into the lake. This evidence is beneficial to evaluate the sources of the nutrients in the lake. Furthermore, as we mentioned in the introduction part, the wastewater discharged from the restaurants and hotels should not be neglected. Of course, we have to measure and reduce the external nutrient loading in order to reverse the eutrophication of lakes (Phillips et al., 1994). However, that measure is not enough because the internal load of phosphorus remained and supply the food for algae growth. In that case, sediment removal to be a sound technique to reduce the phosphorus loading and to restore the natural and artificial

lakes with a high internal load of phosphorus (Pettersson et al., 1998, Dzialowski et al., 2008, Søndergaard et al., 2001). Moreover, small constructed wetlands can be used at

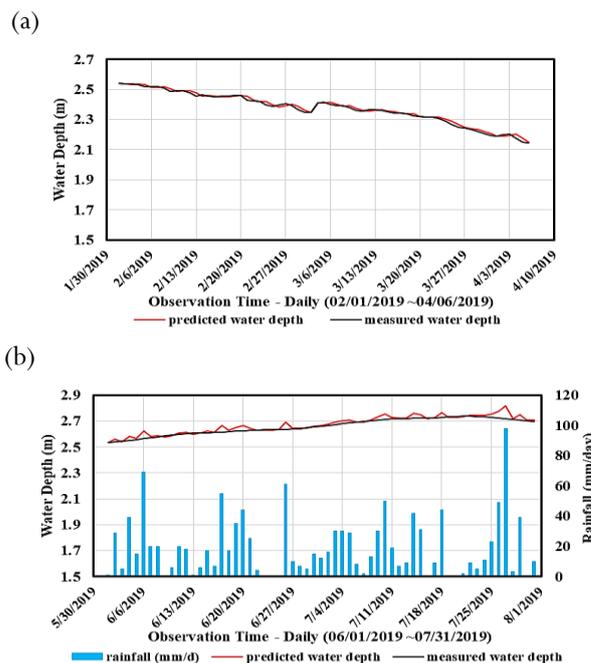


Figure 6. Comparison between Predicted and Measured Water Depth at St-4

- (a) Case-1: Changes of Water Depth in Dry Season
- (b) Case-2: Changes of Water Depth in Wet Season

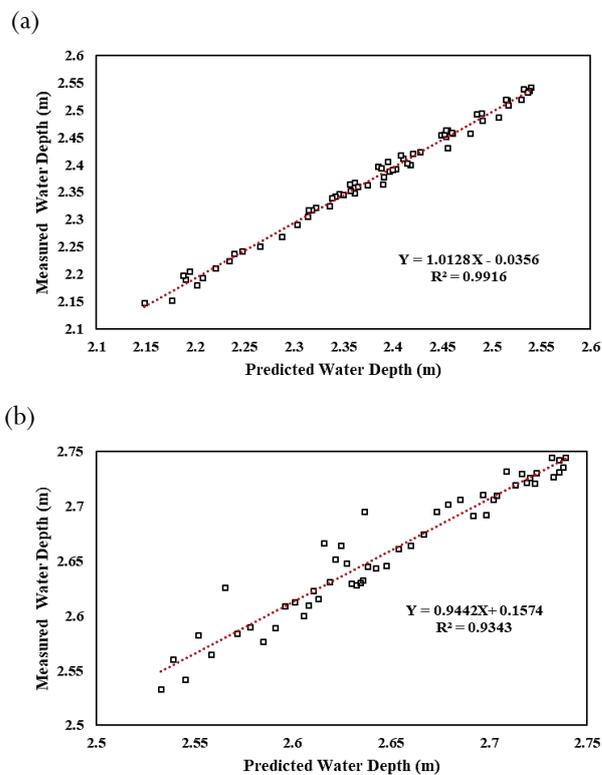


Figure 7. Regression Plots of Observed and Predicted Water Depth at St-4

(a) Dry Season, (b) Wet Season

each of the inlets drains into the lake to reduce the organic matter and nutrient loading (Coveney et al., 2002, Gorgoglione et al., 2018).

4. Conclusion

In this study, continuous field observations recognized that the high value of pH, BOD and COD depended on the influence of domestic wastewater inflow loading from the catchment area and surrounding restaurants into Kandawgyi Lake. According to the vertical distribution measurements, we found out thermal stratification and the high value of pH in the water column. The anoxic water mass also exists near the bottom of the lake. As a result, phosphorus released from the bottom sediment. The one-year water depth observation showed the seasonal changes of water depth in the lake. Additionally, the IOM mass balance model demonstrated better results for water depth prediction in a dry season rather than a wet season. It was thought that very few inflow water with a high value of nutrients coming into the lake based on the water depth observation survey. To approach the water quality management planning, overall finding results suggested that bottom sediment removal and small constructed wetlands should be developed.

Nomenclature and Abbreviation

YCDC	Yangon City Development Committee
IOM	Inflow-outflow model
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
S_{res}	Residual standard deviation
M_i	Measured Water Depth (m)
S_i	Predicted Water Depth (m)
R^2	Coefficient of determination

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References

American Public Health Association, 1998. In Standard Methods for the Examination of Water and Waste Water, 20th eds, APHA: Washington, DC.

Cooke G.D., Welch E.B., Newroth S. A.P.R., 1993. Restoration and Management of Lakes and Reservoirs, 2nd eds., Lewis Publishers, Boca Raton.

Coveney M.F., Stites D.L., Lowe E.F., Battoe L.E., Conrow R., 2002. Nutrient removal from eutrophic lake water by wetland filtration. *Journal of Ecological Engineering* 19: 141-159.

Dobiesz N.E., Lester N.P., 2009. Changes in mid-summer water temperature and clarity across the Great Lakes between 1968 and 2002. *Journal of Great Lakes Research* 35: 371-384.

Dzialowski A.R., Wang S.H., Lim N.C., Beury J.H., Huggins D.G., 2008. Effects of sediment resuspension on nutrient concentrations and algal biomass in reservoirs of the Central Plains. *Journal of Lake and Reservoir Management* 24: 313-320.

Elo A.R., Huttula T., Peltonen A., Virta J., 1998. The effects of climate change on the temperature conditions of lakes. *Journal of Boreal Environment Research* 3: 137-150.

Gorgoglione A., Torretta V., 2018. Sustainable Management and Successful Application of Constructed Wetlands: A Critical Review. *Journal of Sustainability* 10: 2-19.

Hostetler S.W., Bartlein P.J., 1990. Simulation of lake evaporation with application to modeling lake level variations of Harney-Malheur Lake, Oregon. *Journal of Water Resources* 26: 2603-2612.

Huang Y., Yang C., Wen C., Wen G., 2019. S-type Dissolved Oxygen Distribution along Water Depth in a Canyon-shaped and Algae Blooming Water Source Reservoir: Reasons and Control. *International Journal of Environmental Research and Public Health* 16: 1-14.

Horppila, J., Holmroos H., Niemistö J., Massa I., Nygrén N., Schönach P., Tammeorg O., 2017. Variations of internal phosphorus loading and water quality in a hypertrophic lake during 40 years of different management efforts. *Journal of Ecological Engineering* 103: 264-274.

Jensen H. S., Andersen F. O., 1992. Importance of temperature, nitrate, and pH for phosphate release from aerobic sediments of four shallow, eutrophic lakes. *Limnology and Oceanography* 37(3): 577-589.

Khine L.A., Itayama T., Nguyen T.D., Kyaing Kyi P.S., Whangchai N., Praphrute R., Tada A., 2020. Seasonal Variation of Water Quality and Microcystin Concentration in Kandawgyi Lake, Yangon City, Myanmar. *Engineering Journal, Chiang Mai University (In press)*.

Nabar B., Shirude M., Gupte A., 2014. Assessment of water quality of urban lakes for recreational purposes in thane district. *Journal of Environmental Science, Toxicology and Food Technology* 8: 46-50.

Phogat V., Skewes M.A., Cox J.W., Simunek J., 2016. Statistical Assessment of a Numerical Model Simulation Agro Hydro-chemical Processes in Soil under Drip Fertigated Mandarin Tree. *Journal of Irrigation Drainage Sys Eng* 5: 2-9.

Pettersson K., 1998. Mechanisms for internal loading of phosphorus in lakes, *Journal of Hydrobiologia* 374: 21-25.

Phillips G., Jackson R., Bennet C., Chilvers A., 1994. The importance of sediment phosphorus release in the restoration of very shallow lakes (The Norfolk Broads, England) and implications for biomanipulation. *Journal of Hydrobiologia* 275: 445-456.

Soe P.E., 2013. Study on the Eutrophication Status of Kandawgyi Lake. Master Thesis. Yangon Technological University.

- Jachner S., Van den Boogaart G., Petzoldt T., 2007. Statistical methods for the qualitative assessment of dynamic models with time delay (R Package qualV). *Journal of Statistical Software* 22: 1-30.
- Søndergaard M., Jensen J.P., Jeppesen E., 2003. Role of sediment and internal loading of phosphorus in shallow lakes. *Journal of Hydrobiologia* 506: 135-145.
- Søndergaard M., Jensen P.J., Jeppesen E., 2001, Retention and internal loading of phosphorus in shallow, eutrophic lakes. *Journal of The Scientific World* 1: 427-442.
- Van der Molen D.T., Boers P.C., 1994. Influence of internal loading on phosphorus concentration in shallow lakes before and

- after reduction of the external loading. *Journal of Hydrobiologia* 275: 379-389.
- Yangon City Development Committee (YCDC), 2014. The Project for the Improvement of Water Supply, Sewerage and Drainage System in Yangon City ,Vol VI Sewerage and Drainage Master Plan, Ch.3: 31-35.
- Zhan G., Lin Shelp M., 2009. Modified Blaney-Criddle method — an empirical approach to estimate potential evaporation using air temperature. In AB Fourie & M Tibbett (eds). *Proceeding of the Fourth International Conference on Mine Closure*, Australian Centre for Geomechanics: 461-471.