

# Evaluation of Stormwater Detention Pond to Prepare Recreational Water Quality

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## Research

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# Abstract

Jenteh Detention Pond (JDP) composing of north and south ponds was designed for lessen extreme floods and disaster relief. This water monitoring project was motivated by concerning hygiene contamination once the JDP is opened as a recreational water park. The Surface Water Classification and Water Quality Standards (Taiwan Environmental Protection Agency) and Bacterial Water Quality Standards (United State EPA) were evaluated and then applied to examine the yearly samples: total coliform (TC), dissolved oxygen (DO), ammonia-nitrogen (NH<sub>3</sub>-N), and total phosphorus (TP). Significant correlation (0.442-0.946) between precipitation and the TC was concluded so that the South Pond should be alerted for the potential fecal contamination, once encountered torrential rains or extreme floods. Elevated DO over 130% of the corresponding saturation implied deteriorated water quality in the South Pond. High TP (0.36± 0.19 - 1.89± 0.52 mg/L) in both ponds revealed possibility of eutrophication. However, because JDP was not designed as a full-body-use recreational park, the fecal indicator in the bacterial water quality standards did not prevent the two ponds from leisure activity except flooding days. With overall statistical analysis, the water quality found be generally adequate by attaining the reference base line of Category C in the surface water classification.

## 1. Introduction

Detention ponds are defined as stormwater management structures that are best practice to collect runoff, reduce flow to provide flood protection, and improve water quality (US EPA, 2018). Also, detention ponds predominantly receiving flood or stormwater often were anticipated with pollutant removal characteristics, by analyzing water quality upstream and downstream (Patterson, 1998; Guo and Adams, 1999; Beaudry, 2014). An US EPA report summarized results from field-scale and pilot-scale detention basin retrofit device, which indicate decontamination including *E. coli* and nutrients (nitrogen and phosphorous) can be controlled with media installation (US EPA, 2018). Different methods were applied for determination of any impairment from upstream runoff to detention ponds. *Gammarus minus* was collected as a bioassay during 12 rain events, and the *in situ* bioassay proved that the urban runoff was not toxic to the bioassay. The tested water quality comprised of metals and temperature downstream and upstream (Lieb and Carline, 2000).

With intentional or unintentional, contaminants could enter water body of a detention pond, so that led to this research on the examination of the potential contaminants prior to discharge to surface water bodies. Jenteh Detention Pond (JDP) was established in 2013 for flood control and disaster relief in the San-Yei River (SY River) watershed, Tainan, Taiwan. Whenever a flood peak is observed, the JDP is expected to become a water storage reservoir to reduce the flood flow from the SY River, so that the flooding disaster can be avoided for the neighborhood. Additionally, JDP plays a role of a natural grit chamber in order to block the sedimentation upstream and to reduce clogging of the water flow downstream (Kuan, 2014).

The Tainan city government has been planning the JDP to be a water recreational park in the riverbank of SY River since 2019. Thus, in addition to the disaster relief, the JDP should provide leisure and environmental education functions as a scenic point by adequately clean water body (Tainan City Government, 2019). Motivated by the new recreational function of the JDP, a year-round water quality investigation was conducted to ensure adequately clean water could be provided to the future tourists.

The primary water source of JDP is the overflow discharge of the SY River (Fig. S1). According to the Tainan City Government (2019), before the JDP was constructed, flooding was a severe problem once summer torrential rains was observed. Since the JDP was constructed, the flood problem was controlled except the ones occurred in 2018 and 2019. In 2018, a severe flood caused by a torrential rain was not controlled by the JDP. Thus, the flood overflowed from the SY River flew all over a university campus nearby and many neighborhoods downstream. The spill volume of the water from the JDP caused damage of property lost around \$1,570,000 in the university campus. The torrential rain disaster in 2019 also caused an unexpected water overflow from the JDP and the SY River to the neighborhood community and the university campus again.

After the two-year flooding events were reported, the JDP seems not able to achieve disaster relief and more constructions such as expansion of the height of the dikes and dams have been conducted. No water-related disease was reported at those time, but the notoriously polluted water quality of the SY River and the effluent to the JDP make the neighborhoods concerned. Even though ahead of the flooding incidents, two water purification plants have been constructed to control the water quality in the SY River and indirectly maintain the water quality in the JDP. One is Wandai Water Purification Plant, located by the North Pond; and the other is Rende Drain Water Purification Plant, close to the South Pond (Fig. 1). The purposes of the two water purification plants are to intercept the SY River flow and then discharge qualified clean water back to the SY River. Thus, the water in the JDP from the SY River is expected to meet certain criteria.

Even though the influent of the JDP was indirectly treated as the river water purified with the two plants described above, the water quality in the JDP has not been regularly examined. Before the water recreational park is open, appropriate water quality criteria need to be surveyed and determined.

We applied the Surface Water Classification and Water Quality Standards (TEPA, 2017) to make comparisons between the monitored results with the baseline values (Table 1). Category A, B and C in the classification, specific to terrestrial surface water bodies such as lakes, were used to make the evaluation. Additionally, considering about possible partial body contact in the water leisure activity, Bacterial Water Quality Standards (US EPA, 2003) was applied to examine the risk of fecal contamination. Since all surface waters may potentially receive fecal indicator bacteria, one municipal water treatment plants upstream (Hu Wei Liao Water Resource Recycle Center), in addition to the two water purification plants near by the JDP, have been constructed to prevent human-derived pathogens and indicators from fecal pollution to the SY River and the JDP. Conversely, the Bacteria Water Quality Standards (US EPA, 2003) were made specific to recreational waters that designated for primary contact including swimming and

surfing, which tends to be beyond the JDP-associated leisure activities, which will be not full body contact. A fair evaluation for the JDP water quality needs to be surveyed and a final conclusion needs to be conveyed to the public as important references. Fecal indicator bacteria including total coliform have been used for representing potential pathogens in surface waters. However, the summary of the bacterial water quality standards as USEPA criteria are varied from state to state and class by class. For example, the Class D water body in New York, no more than 20% of total coliform samples may exceed 5,000 CFU 100 ml<sup>-1</sup>, which is close to Category B in TEPA (2017). In Florida, the primary contact standard is 1,000 total coliform CFU 100 ml<sup>-1</sup> as maximum for monthly average. Certain state such as Washington, only fecal coliform standards are provided for the recreational water quality.

Our objective is to evaluate a yearly monitoring results for the water quality of JDP and to investigate if it meets appropriate water quality standards. Two inland surface water quality standards were employed: Surface Water Classification and Water Quality Standards (TEPA, 2017) and Bacterial Water Quality Standards (US EPA, 2003). Three sampling sites (A, B, C) were designed but only samples from A and C were fully collected due to water availability (Fig. 1). The temporal domain covered the months from July 2019 to July 2020. Monthly water samples were collected and analyzed with the parameters of total coliform, dissolved oxygen (DO), pH, temperature, suspended solids (SS), ammonia-nitrogen (NH<sub>3</sub>-N), and total phosphorus (TP) with the methods promulgated by the government (TEPA, 2017). Moreover, potential cause of relatively poor water quality was studied. To illustrate, the total coliform number was evaluated with monthly precipitation records. Suggestions about when and how the JDP would be suitable for tourists to visit is given.

## 2. Materials And Methods

### 2.1. Site description

The JDP comprised of two ponds, North and South, nearby the SY River flowing from north to south (Fig. 1). The North Pond was built with an area of 6.72 hectares and with a water storage capacity of 133.6 thousand tons. The designed reduction flow of the peak flood from the SY River is about 2.0 tons s<sup>-1</sup>. Located downstream of the North Pond, the South Pond was built with 17.12 hectares and with a water storage capacity of 496.6 thousand tons. About twenty times over that of the North Pond, the designed reduction flow of the peak flood to the South Pond is about 40 tons s<sup>-1</sup> (Kuan, 2014). The JDP is anticipated to control peak floods one hour ahead of a flood disaster forecast (Tainan City Government, 2019). A water monitoring station was set near by the Wandai Water Purification Plant, so that water parameters including NH<sub>3</sub>-N and SS are monitored periodically.

### 2.3 Analytical methods

The total coliform number were cultured and analyzed with membrane filter method according to the standard method promulgated by the National Institute of Environmental Analysis (NIEA, 2013), adapted from standard methods (APHA, 2012). NH<sub>3</sub>-N was detected with electrometric measurement (NIEA, 2019).

NH<sub>3</sub>-N was analyzed with Indophenol-blue colorimetry (NIEA, 2005), adapted from standard methods (APHA, 1998). Suspended solids were measured with stoving method (NIEA, 2013), adapted from standard methods (APHA, 1998). Total phosphorous were measured with ascorbic acid and a spectrophotometer (NIEA, 2000), adapted from standard methods. Dissolved oxygen was measured with electrometric measurement (NIEA, 2012) referenced by standard methods.

## 3. Results And Discussion

### 3.1 Water quality of total coliform numbers

Due to the fact that the sampling site B became drought and no sample could be collected after October 2019, the year-round water quality analysis was completed mostly from two of the three initial sampling sites: Site A and C, representing the North and South Pond, respectively (Fig. 1). The monthly total coliform indicated that the population was dramatically increased, during wet seasons in both of the two ponds. In the wet seasons, the population in Site C frequently exceeded 5,000 CFU 100 mL<sup>-1</sup> (Fig. 2), which means Category B standard was violated in the South Pond (Table 1). Worthy being considered, a pattern about the coliform growth tends to be associated with the location, the pond capacity, and the flooding day. The highest number of the total coliform is often observed in Site C, which located downstream of the Site A. Also, the time series plot shows, since August 13 2019 (the flooding day), the highest coliform number was firstly observed on Site A, and then followed by Site B, and C; along with the flow direction from north to south. The pattern in 2019 revealed that the coliform number started to grow on the flooding day (August 13 2019) and then became gradually accumulated in Site B and C. Therefore, the highest coliform numbers detected in Site C can be explained: (1) during the flooding time, the South Pond might receive dirty water (with high levels of coliform) spilled from the North Pond and the SY River, and (2) due to the relative large sedimentation area in the South Pond, the concentration of the total coliform increased suddenly. When the flood water was not able to be captured by the South Pond, it leaked into the underground aquifer in a short period of time. Although flow capture efficiency was an important performance indicator of pollutant removal effectiveness of storm water detention ponds (Guo and Adams, 1999), the South Pond seems to have relatively short detection time, comparing with the North Pond.

To verify if that the increase of the total coliform is correlated with the flooding time, correlations between the coliform number and previous 7-day rainfall average were estimated (Fig. 3). The correlations were calculated between the total coliform numbers and moving averages of the past 7-day precipitation. The scatter plot and the correlation coefficient ( $r_{\text{north(A)}}$ : 0.946 and  $r_{\text{south(C)}}$ : 0.442) indicated significant association between the early precipitation and the later raised coliform numbers. Therefore, the peak flood occurred on August 13 2019 indeed caused the exceeding coliform growth. The water quality indicated by the total coliform number was seriously affected by rainfall, so the South Pond may not be recommended for leisure activity after a big rainfall is just observed.

A yearly distribution of the coliform detected in the two ponds is described with a box plot (Fig. 4). Perhaps due to a relative large sedimentation capacity, the water quality in South Pond (C) was not stable, revealed by a relatively large coliform population distribution. The interquartile range (IQR) between Site C and A was 1,392 and 372 CFU 100 ml<sup>-1</sup>, and the maximum count in Site C and A was 8,700 and 4,500 CFU 100 ml<sup>-1</sup>, respectively. Also, the water quality varied tremendously between the wet and dry seasons. To illustrate, the total coliform units grew tremendously in the summer flooding days but dropped to around 1,000 CFU 100 ml<sup>-1</sup> in the other seasons.

### ***3.2 Water quality indicated with the Surface Water Classification***

To make a fair evaluation of the JDP water quality, we applied the Surface Water Classification and Water Quality Standards (TEPA, 2017) to make comparisons between the monitored results with the baseline values (Table 1). The associated parameters with the relevant environmental standards pertaining to protection to the living environment including DO, pH, SS, NH<sub>3</sub>-N, TP, and temperature were measured (Fig. 5). Some of them were not conducted until 2020.

The classifications of terrestrial surface water bodies are intended to specify the scope of application but not to restrict the uses, the relevant environmental standards were made pertaining to protecting living environment and human health (Table 1). Category A, B and C were selected in the classification specific to terrestrial surface water bodies such as rivers and lakes. Category A water bodies may be used for class 1 public water, which can be used for swimming pool after only several simple purification processes are completed. Category B water bodies may be used for Class 2 public, Class 1 aquaculture water, which associated with raising organism (trout, sweet fish and perch) involving food, restoration, conservation, or sport. Category C water bodies may be used for functions such as Class 3 public water and Class 2 aquaculture water. Because the water in the JDP is not designated for public use, neither for swimming or any full body contact activity, Category C was chosen as base line for the current application but Category B was the goal for primary-contact water leisure activities. Therefore, the water quality data are displayed with marked levels of Category A, B, and C (Fig. 5).

During the dry seasons, DO values detected were often greater than 130% of saturation based on the corresponding temperature in Site C (Fig. S2). The data implied a worse water quality. Although in natural water bodies, DO of over saturation could be observed due to water-dropping aeration or photosynthesis, over 130% of saturated DO is a symptom of deteriorated water quality (TEPA, 2010). Algal bloom is assumed to be observed following by DO of 130% over saturation. The 130% over saturated DO was detected in Site C during September - December in 2019 and June - July in 2020. Additionally, during September - December in 2019, pH was remarkably high (over 9.0) and beyond Category B. Additionally, SS in Site C hardly attained Category B. NH<sub>3</sub>-N in Site C attained Category B. TP cannot attain any category levels in both of the two ponds.

DO and NH<sub>3</sub>-N have been listed as critical pollutants to be controlled in the SY River watershed, due to the small business and urban residential water use upstream (TEPB, 2020; PCEC, 2019). In the watershed,

pollution sources contribution analysis showed that 78.1% was caused by municipal waste, 15.8% from industrial, and 6.2% from livestock (TEPB, 2020). The high TP measured in the two ponds might be the result of incompletely treated effluent from the SY River. For example, detergent waste from the residential water discharged to the SY River could be one of the pollution sources. The observed high TP could cause an outbreak of eutrophication. TP levels was measured as  $0.36 \pm 0.19$  mg/L and  $1.89 \pm 0.52$  mg/L, in North and South Pond, respectively. Nearby the North Pond located the Wandai Water Purification Plant and the Rende Drain Water Purification Plant, which were constructed for the purpose of maintaining water quality in the SY River. However, both of the water plans were designed with aerated gravel-packed contact beds, which were useful in treating SS, BOD, and  $\text{NH}_3\text{-N}$ , but not in controlling TP. TP removal is recommended to put into consideration for better water quality in JDP. The water quality in the confined water system could be deteriorated due to potential eutrophication, which would affect the expected water function including leisure amusement. To avoid the eutrophication, an applicable TP control strategy could be necessary. Production of aquatic plant would be reduced as much as 50% in case of dissolved phosphorous can be reduced to around  $0.025 \text{ mg L}^{-1}$ , which is about the level required with Category A (lower than  $0.02 \text{ mg L}^{-1}$ ) (Deevey, 1970). Also TP was recognized as a growth limiting factor of algae such as cyanobacteria, which is famous of forming harmful algal blooms. Controlled TP into water body was suggested as the most effective way to limit potential algal growth (Thomas, 1969). US EPA (2018) reported media installation as retrofit device in detention basins exhibited greater than 56% of phosphorous removal, but the cost is the consideration for the widespread use of media such as ferric oxide (the most expensive) and the switchgrass (the least cost).

An attainment percentage table was constructed to present a fare evaluation of the JDP water quality (Table 2). In North Pond, 100% of the total coliform, pH, SS, and  $\text{NH}_3\text{-N}$  attained Category B, and 92% of DO observations attained Category C. In South Pond, only 44-100% among the total coliform, DO, pH, SS, and  $\text{NH}_3\text{-N}$  achieved Category B and C. TP in the two ponds were not able to attain any of the categories. In brief, the South Pond revealed modest water quality, according to the elevated DO and pH during the dry seasons, as well as the exceedingly high total coliform numbers during the wet seasons. On the contrary, Site A at the North Pond displayed a normal DO variation during the same study time. North Pond is ready to be designed in the recreational park with the relatively good water quality. South Pond had problems of over saturated DO and TP exceedances. Although the total coliform violated Category B in the Surface Water Classification and Water Quality Standards (TEPA, 2017) during the flooding days, the level as the fecal indicator bacteria listed in the bacterial water quality standards did not prevent the pond from leisure activity (US EPA, 2003). As far as the water leisure activity does not involve swimming, the current monitored water quality is adequate as the reference base line of Category C was mostly attained.

### ***3.3 Water indicated with the Bacterial Water Quality standard***

According to US EPA (2003), fecal bacteria have been used as an indicator of potential presence of pathogens in surface water and risk of disease. Among the fecal bacteria, fecal coliforms, enterococci,

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and *Escherichia coli*, are used as the primary indicators. Although scientific advancement in the fields of microbiology, statistics, and epidemiology have emphasized that culturable enterococci and *Escherichia coli* have a higher degree of association with outbreaks of certain diseases than fecal coliforms and total coliforms (US EPA, 2012), only total coliform is listed in the Surface Water Classification and Water Quality Standards for us to make comparisons (TEPA, 2017). Therefore, we evaluated the JDP water quality also with the available bacterial water quality standards, which applied total coliforms in the certain EPA Regions (US EPA, 2003). The reviewed US EPA standards (2003) were scientifically related to protection of human health in waters designated for primary contact recreation, including swimming and surfing. For example, in New York State, no more than 20% of the total coliform samples may exceed 5,000 CFU 100 mL<sup>-1</sup>, and water bodies beyond the level cannot be considered recreational purposes. In Utah, the secondary contact recreational uses same as the primary contact level are 1,000 – 5,000 CFU 100 mL<sup>-1</sup>, designating certain waters as “swimmable.” In California, no sample allowed to exceed 10,000 CFU 100 mL<sup>-1</sup> in recreational waters. These standards are defined as a concentration level above which the health risk from ingestion of contaminated surface water is unacceptable high. The waterborne diseases have been demonstrated with evidence of gastrointestinal disorders form ingestion of polluted surface water. Based on the above references, fecal contamination in the JDP was not an issue that can prevent it from being leisure water activity, since even the highest number during the flooding did not exceed 10,000 CFU 100 mL<sup>-1</sup> (Category C in TEPA, 2017). The nearest wastewater treatment plant, Hu Wei Liao Water Resource Recycle Center, upstream of the JDP, performed a controlled discharge of indicators from fecal pollution. The discharges of indicators from fecal pollution were relatively stable, except during the flooding days.

## 4. Conclusions

According to significant correlation between precipitation and the total coliform number, the South Pond should be alerted for the possible violation of Category C and potential fecal contamination, once encountered torrential rains or extreme floods. Significant correlations (0.442–0.946) between early-day precipitation and total coliform (as high as 8,700 CFU 100 ml<sup>-1</sup>) was concluded. The high coliform numbers observed in the JDP was associated with the river flow direction, the storage capacity, and considerable precipitation. Elevated DO over 130% of the corresponding saturation implied deteriorated water quality in the South Pond. High TP ( $0.36 \pm 0.19$ – $1.89 \pm 0.52$  mg/L) in both ponds revealed possibility of eutrophication. However, as far as the primary contact does not involve activities such as swimming, the current fecal indicator bacteria (total coliform) did not prevent the water body from providing leisure functions. At least during the studied period, the North Pond was adequate for recreational use to the public. The associated water quality was evidently good with the Category B attainment, based on the TEPA water quality standard (2017). The two water purification plants were able to control DO and NH<sub>3</sub>-N most of time, but TP is suggested to be evaluated due to the existing exceedances in the two ponds. In order to avoid eutrophication, TP is recommended to being controlled. Certain media installation as detention basin retrofit device is recommended (US EPA, 2018).

## Declarations

## Acknowledgements

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## Tables

Table 1

Relevant environmental standards pertaining to protection of the living environment: Terrestrial surface water bodies (Rivers and Lakes) (TEPA, 2017)

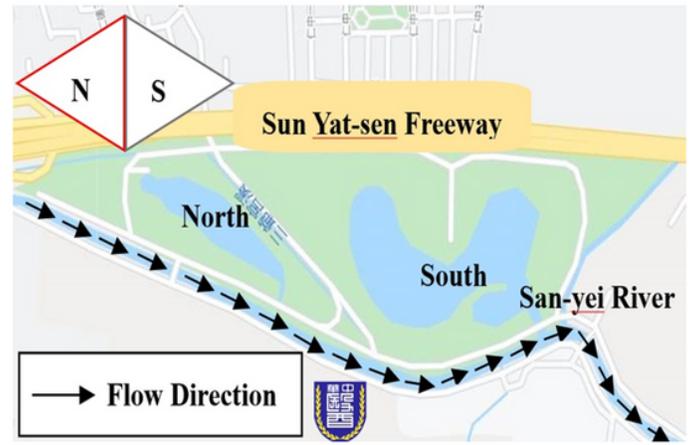
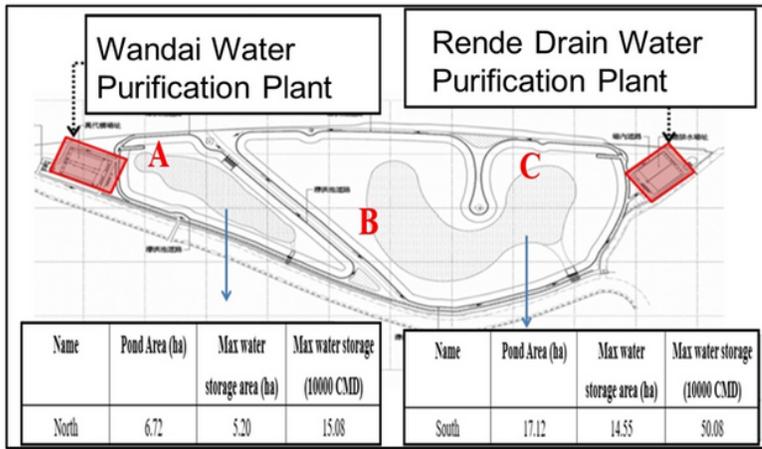
Category	Baseline value						
	pH	DO (mg/L)	BOD (mg/L)	SS (mg/L)	Total Coliform (CFU/100mL)	NH <sub>3</sub> -N (mg/L)	TP (mg/L)
<b>A</b>	6.5- 8.5	≥6.5	≤1	≤25	≤50	≤0.1	≤0.02
<b>B</b>	6.5- 9.0	≥5.5	≤2	≤25	≤5,000	≤0.3	≤0.05
<b>C</b>	6.5- 9.0	≥4.5	≤4	≤40	≤10,000	≤0.3	—
<b>D</b>	6.0- 9.0	≥3	≤8	≤100	—	—	—
<b>E</b>	6.0- 9.0	≥2	≤10	No floating objects or oil pollutants can be observed	—	—	—

Table 2

Attainment percentage for Category A, B, and C in the two ponds.

Location	Site A (North Pond)	Site C (South Pond)
Parameter		
Total Coliform (A: n = 23 C: n = 16)	100% Category A attainment 100% Category B attainment 100% Category C attainment	81% Category A attainment 81% Category B attainment 100% Category C attainment
DO (A: n = 26 C: n = 21)	46% Category A attainment 65% Category B attainment 92% Category C attainment	76% Category A attainment 81% Category B attainment 81% Category C attainment
pH (A: n = 26 C: n = 21)	96% Category A attainment 100% Category B attainment 100% Category C attainment	67% Category A attainment 81% Category B attainment 81% Category C attainment
SS (A: n = 14 C: n = 9)	100% Category A attainment 100% Category B attainment 100% Category C attainment	44% Category A attainment 44% Category B attainment 44% Category C attainment
NH <sub>3</sub> -N (A: n = 11 C: n = 5)	64% Category A attainment 100% Category B attainment 100% Category C attainment	25% Category A attainment 100% Category B attainment 100% Category C attainment
TP (A: n = 10 C: n = 6)	0% Category B attainment	0% Category B attainment

## Figures



(a)

(b)

Figure 1

JDP site illustration: (a) locations of the sampling sites A (north pond), B, and C (south pond) on the JDP; and the two purification water plants, and (b) Locations of JDP and SY River. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

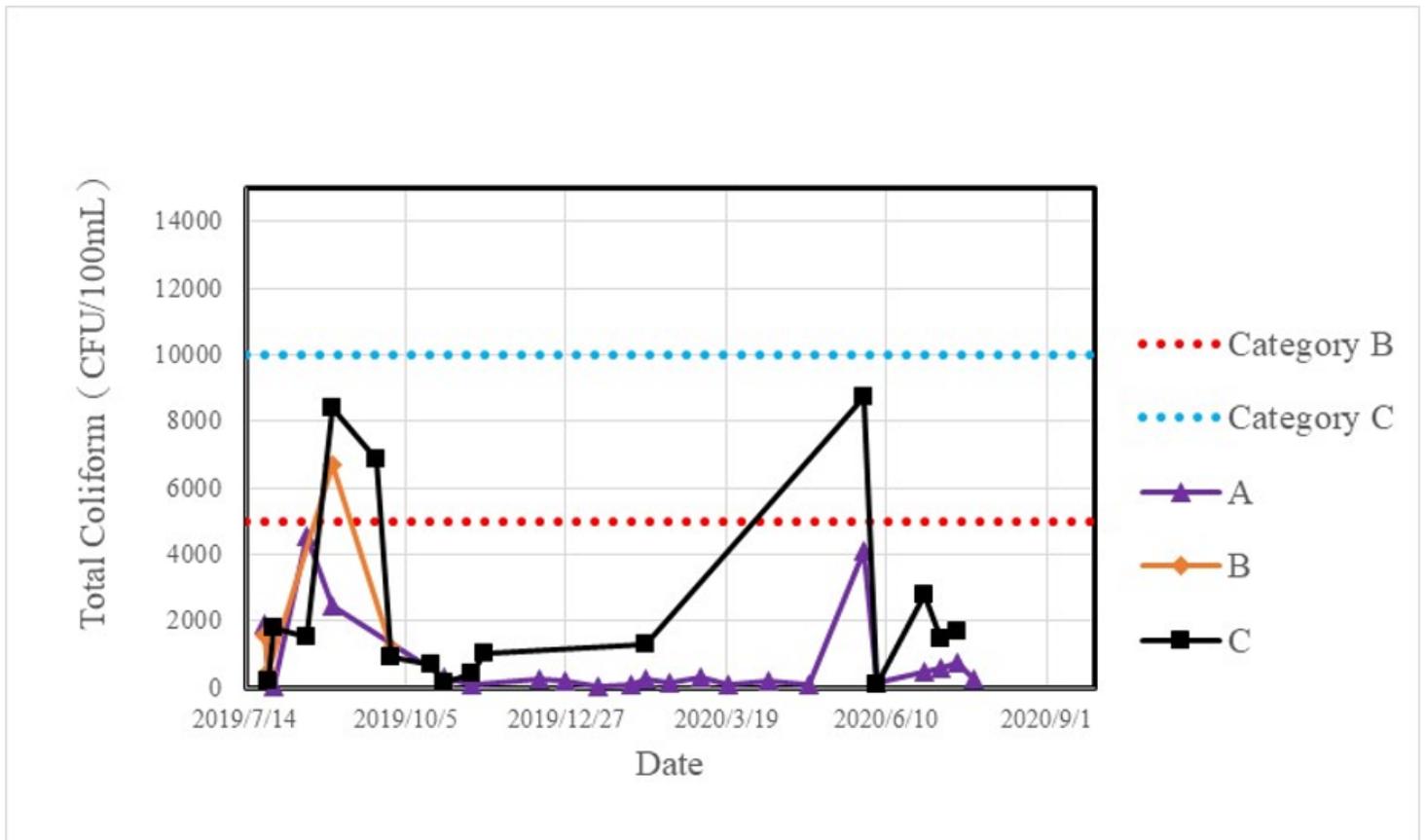
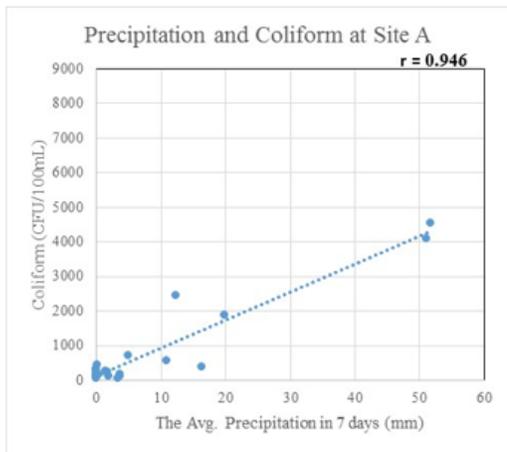
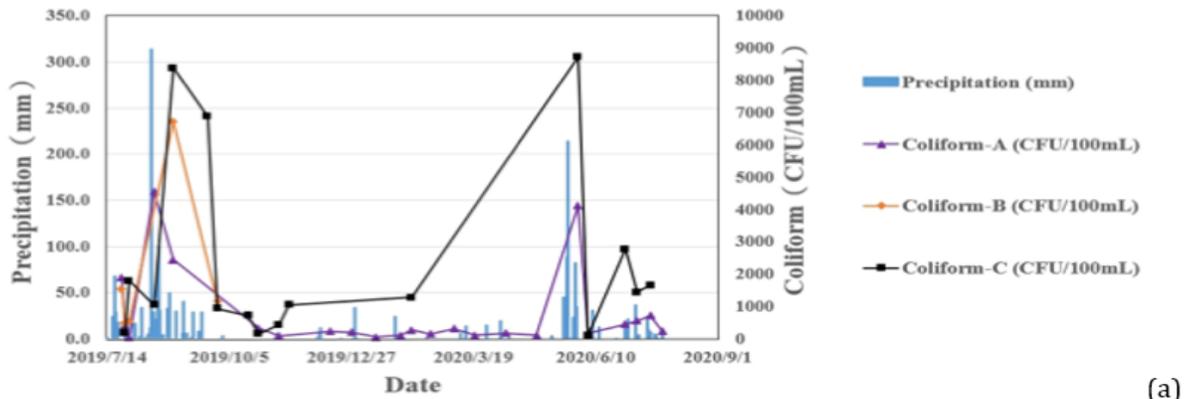


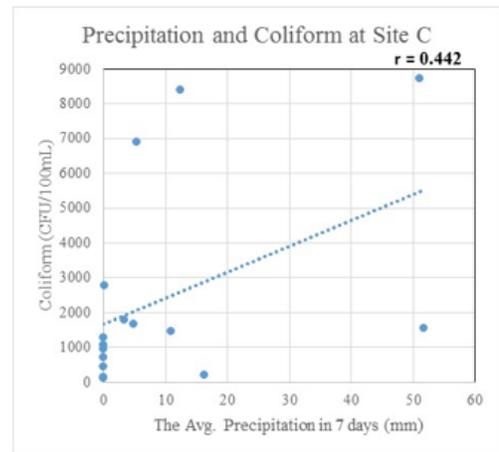
Figure 2

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Time series profile of the total coliform measured from the ponds: A (north), B (middle), and C(South).



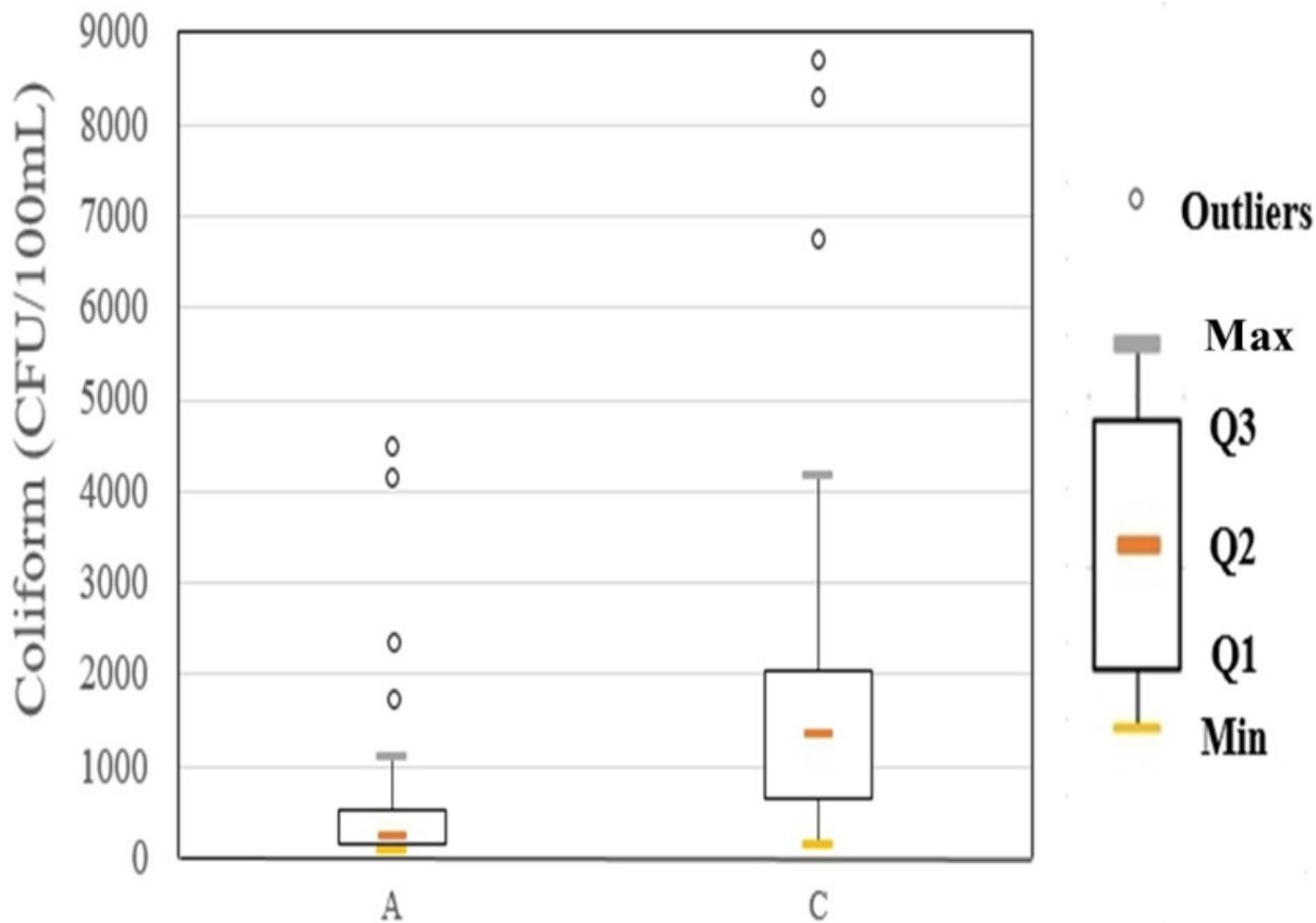
(b)



(c)

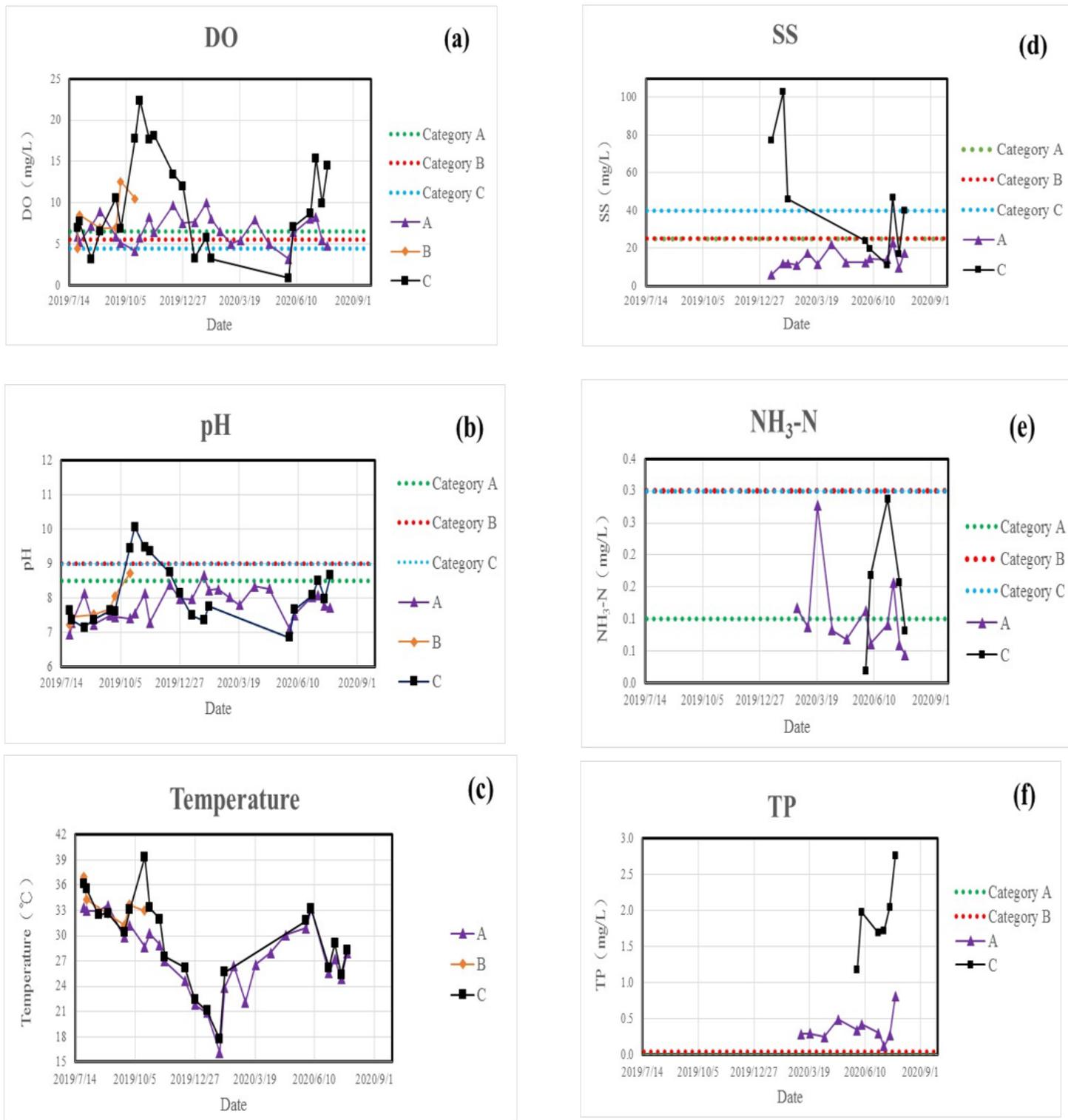
**Figure 3**

Correlation between precipitation and coliform: (a) time series of coliform and daily precipitation, (b) correlation of coliform and moving averages of the past 7-day precipitation at Site A, and (c) correlation of coliform and moving averages of the past 7-day precipitation at Site C.



**Figure 4**

Yearly distribution of the total coliform measured in the two ponds (North: A; South: C).



**Figure 5**

Time series profiles of the six parameters detected in the JDP: (a)DO, (b)pH, (c) temperature, (d) SS, (e) NH<sub>3</sub>-N, (f)TP. Categories A, B, and C defined in the Surface Water Classification and Water Quality Standards are marked in the figures. Site A located at the North Pond. Site B and C represented the South Pond.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [FINALSupplmFig1.FINALJDPsitelocation1.docx](#)
- [FINALSupplmFig2SaturatedDO1.docx](#)