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Spatial Variation of Water Quality in Boeng Tamouk Lake, Northern-part of Phnom Penh, Cambodia

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Abstract: *The lakes around Phnom Penh are used as the natural treatments of wastewater before discharging into the river. Thus, the pollutant load in the wastewater concerns the water quality in the natural lakes. This study aims to assess the spatial variation of water quality in Tamouk Lake, which is located in the northern part of Phnom Penh and partly receives the wastewater from Phnom Penh, at the pre- and post-storm events. The Spatio-temporal maps of water quality (TSS, DO, EC, pH, COD, PO4, and NO3) were generated from 11 points by using the geostatistical interpolation method (SK). The selected sampling points cover the pollution at inlets, outlets and open water in the lake. The sampling procedure was carried out in two different events, which were on 28 May (pre-storm event) and on 7 June 2019 (post-storm event). The water quality parameters were classified into 5 classes based on the single factor pollution index score (P_i). Then, the overall pollution level in the lake was evaluated based on the comprehensive pollution index (P). According to the MoE's standard (Ministry of Environment), the EC and pH exceeded the limited standard. Based on the pollution index score, the parameters DO and COD stayed in class III for both events. The TSS was slightly concerned (class II) at the post-storm event. PO4 was a moderate pollutant at the pre-storm event (class III). The NO_3 was found to not share its contribution to pollution for both events. The spatial maps of water quality indicate that the spatial distribution of the water quality parameters increased dramatically nearby the inlet at the pre-storm event, but slightly increased nearby the outlet of the lake during the post-storm event. However, only TSS rose steeply in the lake during the post-storm event. The water quality parameters of Tamouk Lake were found to exceed the limited standard of effluence. Therefore, the study would support the receiving water-monitoring program or determine the total maximum daily load in order to maintain the standard of water quality in this lake. The output of the study on the basic parameters could be a good indicator for further investigation including the assessment of bio/chemical pollution.*

Keywords: simple-kriging; Tamouk Lake, pollution index

1. INTRODUCTION

Most lakes around the cities in some developing countries function as the storage in biological treatment to collect the wastewater from the drainage system (Verma and Negandhi, 2011). Hence, the pollutant load in wastewater from the multiple sources such as both domestic and commercial industries polluted the water quality in those lakes. These pollutants were pathogenic microorganisms, phosphorus and nitrogen, hydrocarbons, heavy metals (Zn, Cu, Cd, Pb, Cr etc), endocrine disruptors, and organic matter (Akpor *et al.*, 2014).. Tamouk Lake has been selected as one site of wastewater treatment (Johkasou) by JICA since 2015 (JICA, 2016a) due to the fact that this lake is the largest lake in the northern part of Phnom Penh and has the low level of the population density in the area. Additionally, the developing status in the area is still immature (JICA, 2016a). Since the lake functions as the storage to receive wastewater from the drainage system in the northern part of Phnom Penh, the water quality in Tamouk Lake has become more concerning due to the pollutant load in wastewater discharge.

The water quality is such a key factor which is hard to identify as its characteristic vary based on numerous factors such as street sweeping, land-use change, and climate change (Pitt and Shawley, 1982; Vaze and Chiew, 2002; Yee, 2005). The water quality data in the lake, moreover, is often collected from the points (Li and Heap, 2011). Thus, the spatial variation maps of water quality parameters are of great importance since they can be used to identify the pollution of the unknown point (Li and Heap, 2011). The objective of this study is to assess the spatial variation of water quality parameters (Total suspended solid (TSS), pH, Electrical conductivity (EC), Dissolved oxygen (DO), Chemical Oxygen Demand (COD), Phosphate (PO4), and Nitrate (NO3)) in the Tamouk Lake by using simple Kriging interpolation method.

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2. METHODOLOGY

Study area

The study was conducted in Tamouk Lake or Kob Srov Lake situated in Prek Pnov district of Phnom Penh, Cambodia. Tamouk Lake or Kob Srov Lake is the largest natural lake and the major reservoir of wastewater treatment in the northern area of Phnom Penh city. This lake is surrounded by 2 inlets, 2 outlets, and three water gates as shown in the map (Fig 1). As reported by JICA in 2016, this lake covers 3270 ha and the depth water is 3.0-4.5 m in the dry season and accumulate 2-3 m more in the rainy season. Moreover, the Tamok sewage system is a separate system that covers the treatment area of 6,019.2 ha with the population of around 481,000 (population projection to 2035). The total length of trunk sewer is 66.1 km (diameter from 200 mm to 1,650 mm), and the pumping stations were installed at nine locations, seven of which were pumping stations were manhole type and two were installed at the inlet of Tamouk Lake (JICA, 2016a).

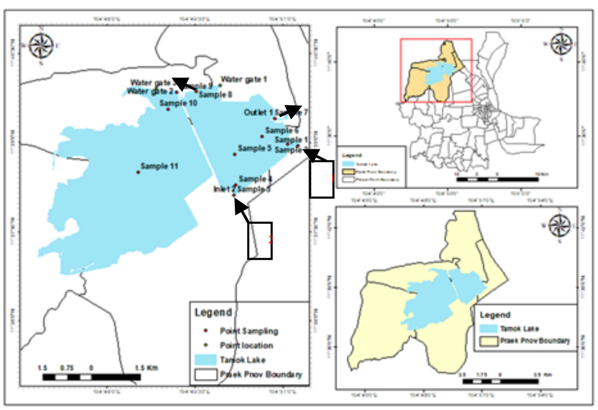

Fig 1. The location of Tamok Lake and flow direction

Sampling methods and location selection

- *Water quality Parameters Selection*

The water quality parameters such as Total Suspended Solids (TSS), pH, Electric Conductivity (EC), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Phosphate (PO4), and Nitrate (NO3) were selected to consider in this study (Table 1) because those parameters were essential parameters, which were check in general. pH is a water quality parameter that is able to indicate the acidity or alkalinity in the water of lake. Dissolved Oxygen demand (DO) is a water quality parameter that is able to indicate the level of oxygen dissolve in the water of lake. If the oxygen level in the water optimum, it justifies that the water is of good quality. Electrical conductivity is the measure of the amount of electrical current that a material (salinity and ion) can carry or its ability to carry a current. Electrical conductivity is also known as specific conductance. Conductivity is an intrinsic property of a material. Nitrate is a water soluble molecule made of nitrogen and oxygen. It is formed when nitrogen from ammonia or another source combines with oxygenated water. Nitrate is naturally found in plants and many foods, and is tasteless and odorless. Nitrogen is a major nutrient for microbial life and is therefore very important with regards to its effects on the environment. Total suspended solids (TSS) is the dry-weight of suspended particles that are not dissolved, in a sample of water that can be trapped by a filter that is analyzed using a filtration apparatus. It is a water quality parameter used to assess the quality of a specimen of lake water. The chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. Phosphate occurs in runoff from the road surface, runoff from fertilized lawns and golf-courses, human wastes, food-processing wastes, wastewater from the pulp and paper industry, and partially treated or untreated sewage. Phosphate is commonly found in household detergents and other cleaning materials.

The field monitoring was conducted two times: the pre-storm event and post-storm event. The field survey was conducted during the pre-storm event on 28 May 2019. After that, the second field survey was conducted during the post-storm event on 7 June 2019. 11 points from the depth of 10 cm in Tamouk Lake were established for both field surveys

Table 1. Water quality parameters and site location consider in Tamouk Lake

Date	Parameter	Site location
28/05/2019	EC, DO , pH, COD, PO4, NO3, TSS	Inlet, outlet, and middle of the lake
07/06/2019	EC, DO , pH, COD, PO4, NO3, TSS	Inlet, outlet, and middle of the lake

Fig 2 shows the occurrence of storm event during the site monitoring in the Tamouk area. There was one storm event appearing in the gaping time between the first site monitoring and second site monitoring. For assumption, there was no additional water from the storm events and surface runoff from other areas in the northern part of Phnom Penh to compare the water quality parameters such as EC, COD, PO_4, TSS, pH, DO, and NO_3 of both site monitoring (early rainfall and lately rainfall).

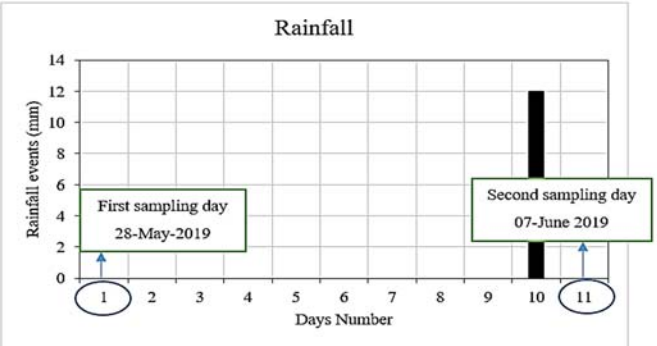

Fig 2. The occurrence of the storm event during the site monitoring

The 11 points for sampling (**Fig 1**) in the lake were selected in order to represent the environmental conditions over the Tamouk Lake in May and June 2019. The selection of these eleven points adhere to the following criteria:

- Four samples (1–4) were taken from the first zone of Tamouk Lake. Those points represent the Lake zone which receives and is influenced by the enormous amount of wastewater from the inlets 1 and 2.
- Two samples (5 and 6) represented the water quality conditions at the purification point of the Lake.
- Two samples (7 and 8) represented the water quality conditions at the outlets 1 and 2.
- Two samples (9 and 10) were collected to represent the water conditions influenced by the water from zone one.
- One sample (11) represented the water quality conditions in the middle of zone 2.

The Water quality standard

Table 2. Cambodia water quality standard for surface water (MoE, 1999)

Parameter	Unit	Standard Value
pH	-	5.0-9.0
TSS	mg/l	<120
DO	mg/l	2.0-7.5
COD	mg/l	<100
EC	µs/cm	<300
PO_4	mg/l	<6
NO_3	mg/l	<20

Table 2 represents the water quality standard in Cambodia by following the Sub-Decree of the Ministry of Environmental number 27.

Pollution index evaluation of water quality in the lake

- *Single Factor Pollution Index*

The single factor pollution index is a method used to evaluate the pollution level of the water quality parameters adopting with limited standard of Ministry of Environment (Yan *et al.*, 2015):

$$P_i = C_i / S_i \quad \text{(Eq. 1)}$$

where P_i is the pollution index of i units pollutant, C_i is the measured concentration of i units pollutant (mg/L), and S_i is the limits allowed by the Ministry of Environment of Cambodia in Sub-Decree on Water Pollution Control**.** The P_i value was particularly used to evaluate the pollution level of each water quality parameter in the surface water (Table 3)

Table 3. Standard of single factor pollution index (Yan *et al.*, 2015)

P_i	Class of pollution level
≤0.4	I Non-Pollution
0.41-1.00	II Slightly polluted
1.01-2.0	III Moderately polluted
2.01-5.0	IV Heavily polluted
≥5.01	V Seriously polluted

- *Comprehensive Pollution Index*

The comprehensive pollution index method is used to evaluate the complex issue of water quality which involves many different kinds of contaminants in surface water (Zhao et al., 2012). The detail of the comprehensive pollution index is below:

$$P = \frac{1}{n}\sum_{i=1}^{n} C_i / S_i \quad \text{(Eq. 2)}$$

where *P* is comprehensive pollution index, and *n* is the number of selected pollutants. Ultimately, the values determined for *P* could be used to classify the water quality level of the lake (Table 4).

Table 4. surface water quality classification (Zhao *et al.*, 2012)

Pollution index (P)	Water quality level
≤0.2	Ⅰ Cleanness
0.21-0.40	Ⅱ Sub-cleanness
0.41-1.00	Ⅲ Slight pollution
1.01-2.0	Ⅳ Moderate pollution
≥2.01	Ⅴ Severe pollution

Simple Kriging for interpolation

Kriging speculates that at least some of the spatial variation observed in natural phenomena can be represented by incidental processes with spatial auto interrelationship, and requires the spatial auto interrelationship to be explicitly modeled. Kriging can be used to illustrate and model spatial specimens, estimate values at the unmeasured point, and evaluate the uncertainty associated with a prophesied value at the unknown value. SK has a much more powerful significance on the hypothesis of stationary of the mean (Glacken and Snowden, 2001; Mpanza, 2015). Simple Kriging is estimated by following the equation below

$$\hat{Z}(s_o) = \sum_{i=1}^{n} \lambda_i Z(x_i) + \left[1 - \sum_{i=1}^{n} \lambda_i\right]\mu \qquad \text{(Eq 3)}$$

Where μ is a known stationary mean, λ_i is kriging weight and n is the number of sampled points used to make the estimation (n=11 samples).

Model Validation

Cross-validation was used to compare which interpolation methods provide the most accurate surface. Cressie (2015) gave a basic idea to delete some data and use the remaining data to predict the deleted observations (Cressie, 2015). For example, there are 11 sample points (Fig.1) in this study. The cross-validation deleted the point *sample 1* and calculated the value of point *sample 1* by using the data of the other 10-sample point in the map. The predicted and real values at the point *sample 1* were compared. This process was repeated for each sample in map (Fig.1). During the cross-validation procedure, the mean error (ME), root mean square (RMSE), average standard error (ASE), root mean square standardized (RMSSE) were also calculated. The comparison of cross validation result should be considered when the predictions are unbiased, standard errors are accurate, and predictions do not deviate much from the measured value.

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left[\hat{Z}(s_i) - Z(s_i)\right] \qquad \text{(Eq. 4)}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\hat{Z}(s_i) - Z(s_i)\right]^2} \qquad \text{(Eq. 5)}$$

$$RMSSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{\hat{Z}(s_i) - Z(s_i)}{\hat{\sigma}(s_i)}\right]^2} \qquad \text{(Eq. 6)}$$

$$\text{ASE} = \sqrt{\frac{\sum_{i=1}^{n}\hat{\sigma}(s_i)}{n}} \qquad \text{(Eq. 7)}$$

Where ME is the mean of the difference between measured values and predicted ones whose errors are unbiased. While the predictions of measurement values are unbiased, the mean prediction error should be near zero. RMSE, on the other hand, indicates how the model predicts the measured values to be close to the measurement values as possible. The smaller RMSE is better. The values of ASE are used in order to evaluate the prediction divergence. Therefore, ASE should be the same as RMSE, which can evaluate the divergence of predictions correctly. In essence, the average standard error should be close to zero. Root mean square standardized, which is used to be indicator the standard errors, are also accurate. The values of RMSSE should be close to 1. If the RMSSE are greater than 1, then the variability of the predictions is underestimated vice versa.

3. RESULTS AND DISCUSSION

Surface Water quality in Tamouk Lake

The water samples of 11 points in Tamouk Lake were analyzed by two laboratories. The parameters of pH, EC, DO and TSS were measured at ITC and the parameters of COD, PO4 and NO_3 were gotten from the MOE laboratory. Moreover, NO_3 was a parameter, which easy to concentrated, so, the parameter was analyzed around 1 hour after the sampling. The range of surface water quality parameters in Tamouk Lake was summarized in Table 5, which illustrates the Mean, Median, Standard Deviation, Minimum and Maximum concentration of the results for the 7 surface water quality parameters that were present in water of Tamouk Lake. The data obtained from the experiment thus allows the statistical values to be calculated and summarized.

According to Table 5**,** the range of pH obtained at both events exceeded the standard in Table 2**.** The TSS level during the pre-storm event was acceptable as it stayed in the given standard. The level, however, went beyond the limit at the post-storm event. Both events saw the excessive values of DO and EC compared to the standard. The excess of DO may have come from the oxygen released by the aquatic plants during the day. Likewise, that the EC levels highly exceeded the standard value was largely due to the ion and salinity levels in wastewater discharge found in many sources. Besides, there was a large number of COD value surpassing the standard range at the pre-storm event, unlike at the post-storm event when COD stayed in the range of standard. Notably, the values of PO_4 were contrary to of NO_3 as for both events, PO_4 were found to transcend moderately while the latter stayed below the limit.

Table 5.Range of surface water quality parameters in Tamouk Lake

Date	Parameter	Mean	Min	Max	SD
28/05/2019	pH	8.932	7.901	9.633	0.623
	DO (mg/l)	11.011	9.14	11.69	0.684
	EC (µs/cm)	387.273	224	763	194.925
	TSS (mg/l)	28.636	1	97.5	27.432
	COD (mg/l)	38.954	10.2	112	38.845
	PO4 (mg/l)	6.264	2.9	14.5	4.009
	NO3 (mg/l)	5.127	2.8	9.2	1.815
7/6/2019	pH	8.724	7.754	9.651	0.808
	DO (mg/l)	7.772	4.13	11.35	1.983
	EC (µs/cm)	377.909	231	567	120.613
	TSS (mg/l)	59.01	10	152	49.109
	COD (mg/l)	22.315	9.01	49	15.825
	PO4 (mg/l)	4.794	1.8	8	1.838
	NO3 (mg/l)	6.455	2	15.3	4.122

Water pollution index

The single factor pollution index (P_i) and comprehensive pollution index score (P) are the values used to evaluate the pollution level by adopting the MoE standard. Table 6 shows pollution index score (P_i and P) and the water quality classification of Tamouk Lake.

Table 6. Comprehensive pollution index and water quality classification of Tamouk Lake

Parameter	Pre-storm event		Post-storm event	
	P_i	Class	P_i	Class
DO	1.468	III	1.036	III
TSS	0.239	I	0.492	II
COD	1.325	III	1.096	III
PO4	1.044	III	0.799	II
NO3	0.256	I	0.323	I
Comprehensive Pollution index (P)	0.8664	III	0.7492	III

These surface water quality parameters in the lake were divided into 5 classes by using the range of value in Table 3. Also, the overall water quality in the lake was evaluated by using the range of value in Table 4.

According to Table 6, the pollution index score (Pi) for overall water quality parameters indicates that the DO levels at both events (1.468 and 1.036, respectively) were moderately concerned (class III). Similar to DO, both COD levels (1.325 and 1.096) stayed in class III implying that the parameter COD was moderately concerned. During the pre-storm event, TSS was found to be a non-pollutant (0.239, class I) but a slight pollutant during the post-storm event (0.492, class II). In addition to these parameters, PO_4 was moderately concerned in the pre-storm event (1.044, class III); however, the value decreased to 0.799 leading to a claim that PO_4 was slightly concerned within class II. Interestingly, NO_3 was a non-pollutant by staying in class I for both events (0.256 and 0.323, respectively). Based on the P value, the quality of water in Tamouk Lake was moderately concerned for both pre- and post-storm events (class III).

Spatial maps of surface water quality

- *pH*

Fig 3 illustrates the spatial distribution map of pH under the pre- (a) and post-storm events (b) generated from the 11 sample points in Tamouk Lake. It can be seen that during the pre-storm event, the pH value nearby the second inlet was proximity to 7 implying, but the pH at the first inlet indicated that there are more basic. In addition, pH levels of both outlets were higher than the inlets for the post-storm event map (Fig 3 (b)). By referring to the pre-storm event map, pH was concerned (more basic) at the first inlet. Moreover, RMSE values (Table 7 and Table 8) of the pH maps were 0.407 for the pre-storm event map (a) and 0.519 for the post-storm event map (b). Therefore, RMSE value of map (a) was better than map (b).

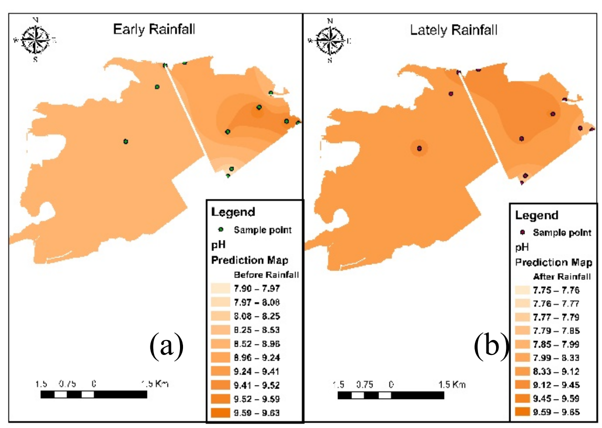

Fig 3. The Estimate Result of pH on surface water under the temporal change in Tamouk Lake, (a) pH result of the early rainfall, (b) pH result of the lately rainfall

- *Dissolved Oxygen demand (DO)*

Fig 4 illustrates the spatial distribution map of DO under the pre- and post-storm events generated from the 11 water sample points. post-storm event. DO levels at the both inlets for the pre-storm event were higher than the post storm. Moreover, RMSE values (Table 7 and Table 8) of the DO maps were 0.656 for the pre-storm event map (a) and 1.661 for the post-storm event map (b). The relationship between the measurements and prediction of DO in map (a) is better than in map (b)

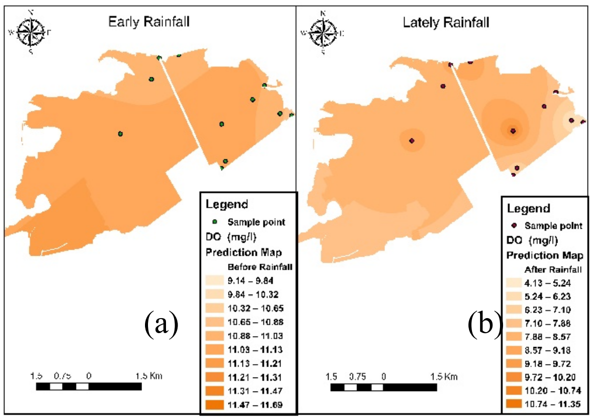

Fig 4. The Estimate Result of DO on surface water under the temporal change in Tamouk Lake, (a) DO result of the early rainfall, (b) DO result of the lately rainfall

- *Electric Conductivity (EC)*

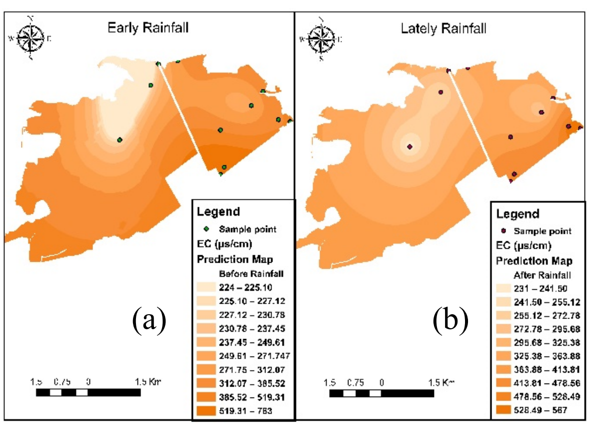

Fig 5. The Estimate Result of EC on surface water under the temporal change in Tamouk Lake, (a) EC result of the early rainfall, (b) EC result of the lately rainfall

Fig 5 illustrates the spatial distribution map of EC under the pre- and post-storm events generated from the 11 sample points in the Tamouk Lake. Moreover, RMSE values (Table 7 and Table 8) of the EC maps were 54.746 for the pre-storm event map (a) and 60.618 for the post-storm event map (b). The relationship between the measurements and prediction values of EC in map (a) is better than in map (b). In regard to the map (a), EC was highly concerned at the second inlet. In contrast, the EC levels were concerned at both inlets at the post-storm event (b).

- *Total Suspended Solid (TSS)*

Fig 6 shows the spatial distribution map of TSS under the pre- and post-storm events generated from the 11 sample points in the lake. According to the spatial map, the TSS level at the post-storm event was more concerned than the pre-storm event. The TSS maps comprised of five classes for the pre-storm event and 6 classes for the post-storm event. Based on Table 7 and Table 8, RMSE value of the TSS maps were 26.197 for the pre-storm event map and 39.548 for the post-storm event map. The relationship between the measurements and predictions of TSS in map (a) is better than in map (b).

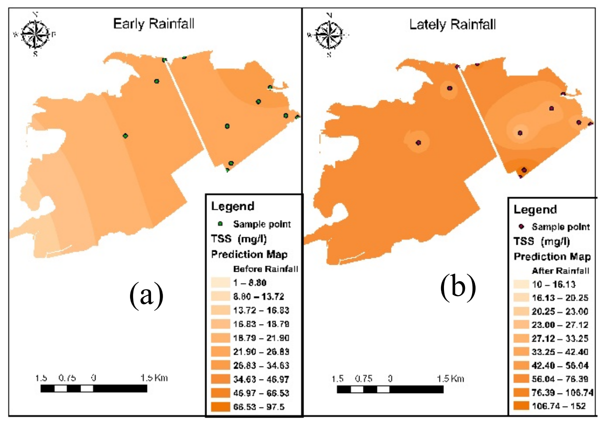

Fig 6. The Estimate Result of TSS on surface water under the temporal change in Tamouk Lake, (a) TSS result of the early rainfall, (b) TSS result of the lately rainfall

- *Chemical Oxygen Demand (COD)*

Fig 7 illustrates the spatial distribution map of COD under the pre- and post-storm events generated from the 11 points in the lake. Based on Table 7 and Table 8, RMSE values of the COD maps were 27.306 for the pre-storm event map (a) and 11.879 for the post-storm event map (b). The relationship between the measurements and estimations of COD in map (a) is better than in map (b).

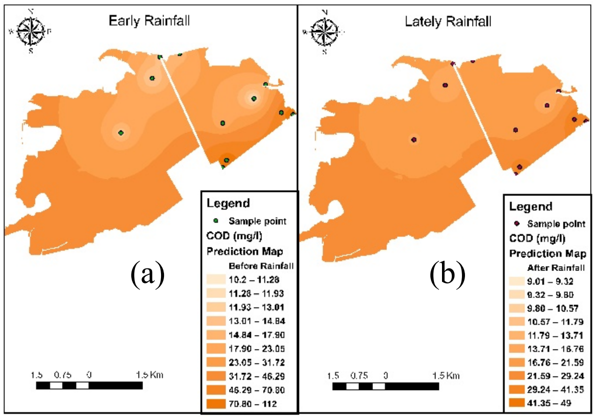

Fig 7. The Estimate Result of COD on surface water under the temporal change in Tamouk Lake, (a) COD result of the early rainfall, (b) COD result of the lately rainfall

- *Phosphate (PO_4)*

Fig 8 illustrates the spatial distribution map of PO_4 under the pre- and post-storm events generated from the 11 water samples of the lake. According to the spatial maps, the PO_4 level of pre-storm event was more concerned than the post-storm event. According to the statistical indicator in the Table 7 and Table 8, the RMSE of PO_4 maps were 4.038 for the pre-storm event map and 1.753 for the post-storm event map. The relationship between the measurements and estimations of PO_4 in map (b) is better than in map (a).

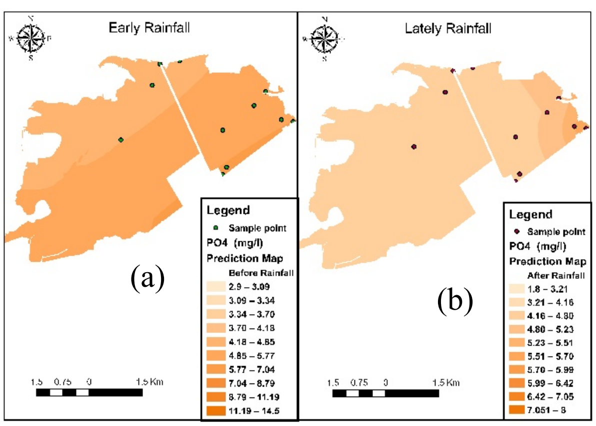

Fig 8. The Estimate Result of PO_4 at surface water under the temporal change in Tamouk Lake, (a) PO_4 result of the early rainfall, (b) PO_4 result of the lately rainfall

- *Nitrate (NO_3)*

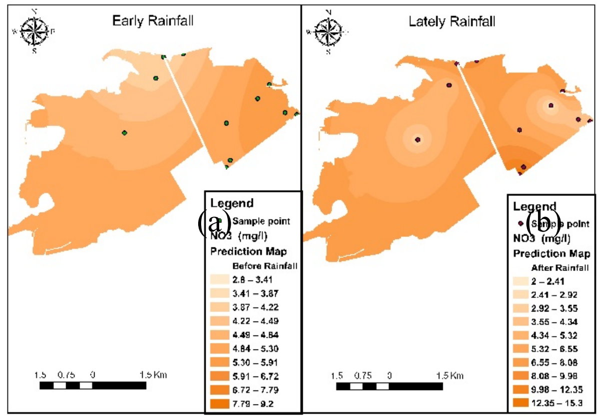

Fig 9. The Estimate Result of NO_3 on surface water under the temporal change in Tamouk Lake, (a) NO_3 result of the early rainfall, (b) NO_3 result of the lately rainfall

Fig 9 illustrates the spatial distribution map of NO_3 under the pre- and post-storm events generated from the 11 points in the lake. Based on the Table 6 and Table 7, the RMSE value of NO_3 maps were 1.749 for pre-storm events and 3.280 for post-storm event. The relationship between the measurements and estimations of NO_3 in map (a) is better than in map (b).

Model evaluation

Water quality parameters were generated from the data during the experiment (summarized in Table 3). The statistical result that indicates the accuracy of the spatial variation of water quality parameters were summarized in the Table 7 and Table 8. Four different statistical indicators can justify the accuracy of the interpolation methods such as Mean Error (ME), Root Mean Square Error (RMSE), Root Mean Square Standardized error (RMSSE) and Average Standard Error (ASE). Furthermore, RMSE is a value that is commonly selected to evaluate the accuracy of the estimated value.

Table 7. The cross-validation result of surface water quality at pre-storm event

Parameter	ME	RMSE	RMSSE	ASE
pH	0.009	0.407	0.774	0.52
DO	0.068	0.656	1.103	0.595
EC	3.104	54.746	1.385	59.394
TSS	1.48	26.197	0.886	29.572
COD	-0.84	27.306	0.655	38.111
PO4	0.111	4.038	0.992	4.189
NO3	0.093	1.749	0.996	1.768

Table 8. The cross-validation result of surface water quality at post-storm event

Parameter	ME	RMSE	RMSSE	ASE
pH	-0.076	0.519	0.726	0.713
DO	-0.179	1.661	0.867	1.897
EC	15.553	60.618	0.59	96.171
TSS	6.119	39.548	0.571	64.352
COD	1.3	11.879	0.671	17.027
PO4	-0.517	1.753	0.953	1.838
NO3	0.543	3.28	0.766	4.642

According to the explanation the cross-validation result in Table 7 and Table 8 above, the RMSE value of the pH maps were the smallest value (0.519 and 0.529) for both event (pre-storm event and post-storm event). However, RMSE (54.746 and 60.618) of the EC maps were the highest value for both events. The DO maps were the second accuracy (RMSE values are 0.656 and 1.661) when the pH maps for both events were the first. For the maps of pre-storm event, the NO_3 map was the third accuracy map (RMSE=1.749), the PO_4 map was the fourth (RMSE=4.038), the COD map the fifth (RMSE=27.306), and the TSS map the sixth (RMSE=26.197). On the other hand, the TSS map was the fifth accuracy (RMSE=39.548) and the COD map was the sixth accuracy (RMSE=11.879) for the post-storm event. Then, the NO_3 map became the fourth accuracy (RMSE=3.28) and PO_4 map was the third accuracy (RMSE=1.753) for the post-storm event.

4. CONCLUSIONS

To sum up this study, the spatial variability of 7 different surface water quality parameters was generated and elaborately evaluated. The water quality parameters of the Tamouk Lake were classified into five classes based on the score of Pi. Moreover, the overall pollution level of the lake was evaluated according the characteristic of P score. In accordance with Ministry of Environment (MOE) standard, the water quality parameters in the lake were found to exceed the limited standard especially pH and EC, apart from the NO_3 which stayed in the standard. Based on the pollution index score, the parameter DO and COD stay in class III for both pre- and post-storm events. The TSS was slightly concerned (class II) at the post-storm event. PO_4 was a moderate pollutant at the pre-storm event (class III). On the other hand, NO_3 was a non-pollutant for both events (class I). Based on the P score, the overall water quality of the lake was moderately concerned (class III) for both events. According to the resulting maps, it is evident that the spatial distribution of the water quality increased dramatically nearby the inlet at the pre-storm event, but drew a slight increase nearby the outlet of the lake during the post-storm event. However, it is noticeable that only the TSS parameter increased steeply in the lake during the post-storm event. The spatial distribution maps indicate that the water quality parameters in the lake rose at the post-storm event relative to the pre-storm event. The water quality fluctuation maps underscore that the pollutant load increase was more noticeable in the lake, which potentially resulted from the increasing wastewater discharge due to land reclamation and population growth. As the water quality of Tamouk Lake surpassed the limited standard, the study, therefore, would support the receiving water monitoring program or determination the total maximum daily load to maintain the standard of water quality in this lake. The output of the study on the basic parameters could be a good indicator for further investigation including bio/chemical pollution assessment.

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