Jordan Journal of Civil Engineering, Volume **4**, No. **4**, **2010**

Influence of Industrial, Agricultural and Sewage Water Discharges on Eutrophication of Quttina Lake

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ABSTRACT

The influence of human activities on water quality of Quttina lake (an important water resource in the middle region of Syria), has been evaluated and correlated with pollution source situated at lake banks; namely, phosphate fertilizer factory, agriculture and wastewater drainages. Surface and deep water samples from different sites in the lake have been collected and analyzed during the period of April to October 2009 to study the effects of pollution sources on Quttina lake eutrophication. Water quality parameters include temperature, pH, EC, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), ammonium, phosphate and nitrates ions, total nitrogen and total phosphorous. The results have shown that these parameters varied from one site to another, where the highest concentrations were found to be in those sites close to phosphate factory discharges and in the northern part of the lake. Moreover, seasonal variations in pollution parameters were clear, especially for ammonium, phosphate and nitrates ions in addition to oxygen parameters (DO, COD and BOD). Moreover, mean total phosphorus concentration in Quttina lake surface water varied between 0.51 mg/l and 2.2 mg/1, where the highest values were found to be near the phosphate fertilizer factory discharges in addition to sites close to wastewater and agriculture runoffs situated at the western side of the lake. In addition, N:P ratio varied between 1.1 and 22.9 during the sampling period; the natural ratio being 16:1. On the other hand, the parameter distribution with depth in two sites has been studied. The results have shown that there are no clear differences between the deep and surface samples, and this is due to lake shallow depth and water flow. Furthermore, positive relationships have been found between total phosphors and nitrogen and oxygen indicators (BOD and COD), which indicates the increase of organic pollution and the algal bloom.

KEYWORDS: Water pollution, Quttina lake, Eutrophication, Phosphate fertilizer factory, Syria.

INTRODUCTION

Quttina lake is an important water resource for agriculture and industry in the middle part of Syria, which is situated close to Homs city (around 160 km north of Damascus). Orontes river originating from Lebanon is the main water inlet for the lake. There are several industrial activities located at the lake banks which use lake water in their processes. These are the phosphate fertilizer company, steam power plant and vehicle maintenance workshops, where most of their industrial wastes reach the lake. In addition, the lake is surrounded by several villages, where agriculture and sewage water drainages find their ways to the lake and affect its water quality. These activities have a clear impact on the lake water quality. Many studies have been conducted on the lake and the surrounding areas, where they focused on the emissions from the phosphate

Accepted for Publication on 15/10/2010.

fertilizer factory including trace elements, fluorine and radioactivity (Othman and Al-Masri, 2007; Al-Oudat et al., 2003; Meray and Al-Oudat, 2005). In addition, the lake pollution was studied in 1986 from the water quality point of view, where most of the water quality parameters were determined in water as part of the Ministry of Irrigation (MOI, 1986) monitoring program. However, the results were not fully discussed to correlate parameters with pollution sources. In addition, many factors affecting the water quality of Quttina lake have been changed since that times; namely, population, increasing industrial and agricultural activities and increasing water usages. Even though there is a governmental control on the discharges of the industrial activities into the lake, where the lake water is routinely monitored and the results are reported, there is still concern on the water quality of Quttina lake, especially since there is a clear and visible water eutrophication problem. Therefore, the lake has to be re-assessed.

Water eutrophication has become a worldwide environmental problem in recent years (EPA, 2008; Enrich-Prast, 2002; IUCN, 2003; ILEC, 1994; MPCA, 2008; EPA, 2008; Al-Farajat, 2009; Yang et al., 2008; Linkevicene et al., 2003; MEJ, 2004; Schindler, 1977; Walker, 2006; Whiteside, 1993; Okbah, 2005). Water eutrophication in lakes, reservoirs, estuaries and rivers is widespread all over the world and the severity is increasing, especially in the developing countries. In this paper, water eutrophication of Quttina lake has been evaluated by studying the seasonal variations of Total Phosphorus (TP), Total Nitrogen (TN) and other influencing factors such as temperature, salinity, NH_4, NO_3, PO_4 and related oxygen parameters (DO, COD and BOD). Sources of these parameters were also discussed.

METODOLOGY

Study Area

Quttina lake is located in the middle of Syria close to Homs city at about 160 km north of Damascus city (Figure 1). The lake is around 12 km length and reaches 5 km width at some places. The lake is located 500 m above sea level and the water depth is around 5-8 in winter. The lake was formed at its current capacity after constructing the lake dam in 1938. The lake was first formed by the old dam built by the Great Alexander. Parts of the old ruins dam are still present.

Sampling, Field Measurements and Laboratory Analysis

Surface and deep water samples were collected every two weeks from 11 sites distributed in the lake as seen in Figure 2. Two sites were chosen to have depth profiles (sites 3 and 7). The sampling campaign started in April and ended at the end of October 2009. Temperature, pH and conductivity (EC) were measured at the field using German made WtW meter. The samples were analyzed after sampling. The main parameters were determined using the standard methods for water analysis (Andrew et al., 1995). These parameters included Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Organic Carbon (TOC), nitrates (NO_3), phosphates (PO_4), ammonium (NH_4), Total Nitrogen (TN) and Total Phosphorous (TP).

RESULTS AND DISCUSSION

Water Quality Parameters

The mean values for all measured parameters are presented in Table 1. The lowest mean temperature value was found to be in April (15.9 ^{o}C) and the highest in the middle of July (28.09 ^{o}C). The variations in surface water temperature were very small from one site to another, with an exception of the water temperature in those sites located close to the fertilizer factory and steam power plant, where the temperature has increased by 3 degrees, which is in agreement with a previous study (Al-Oudat et al., 2003). Eutrophication can be enhanced where the temperature is in the range of 25-30^{o}C (Yang et al., 2008).

Water alkalinity was very clear in most of the water samples and periods, where pH values varied between 7.99 in September 2009 and 8.96 in October 2009. The obtained values in this study were higher than the values reported in previous studies (MOI, 1986; Al-Oudat et al., 2003), where the highest value observed was 8.25. This indicates that there has been a change in the water quality from the previous periods and that the water quality needs to be investigated again.

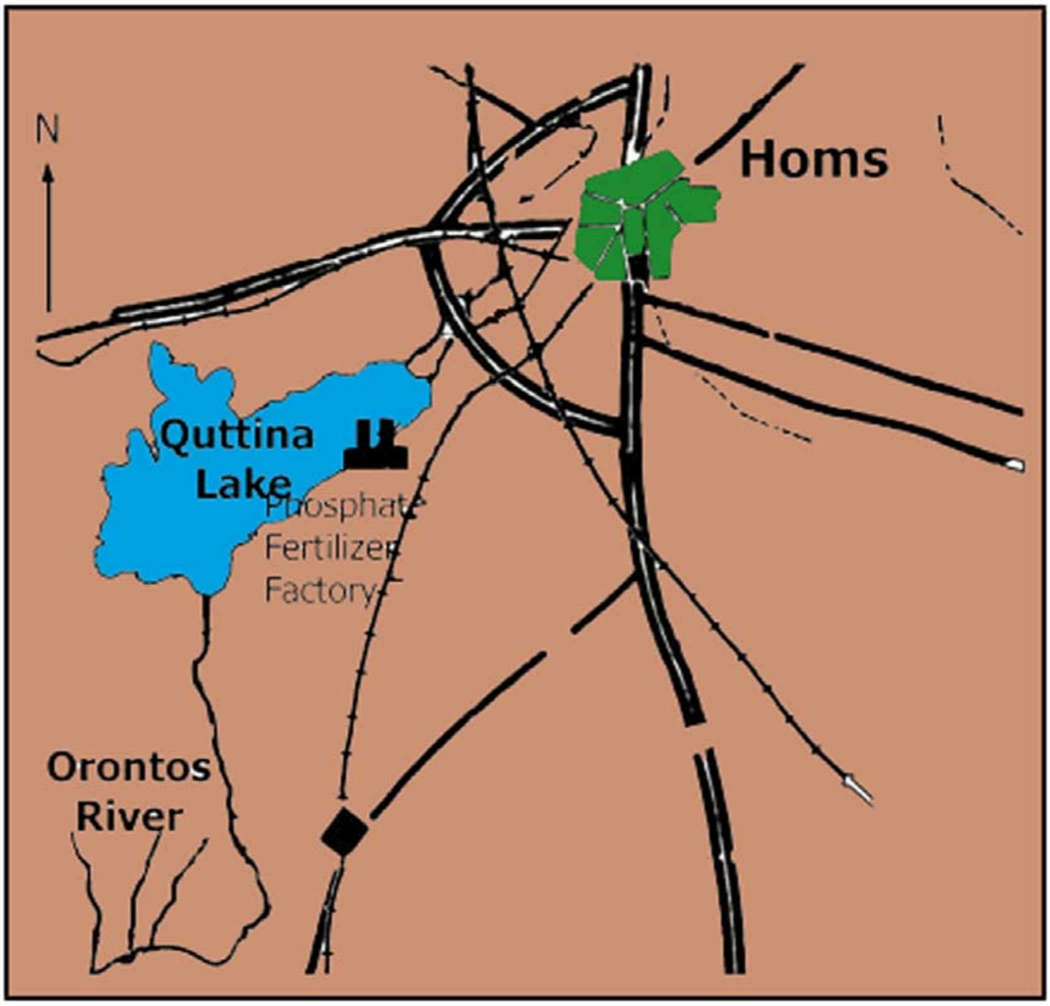

Figure 1: Quttina lake and surrounding villages

Water conductivity (EC) reflects the quantities of dissolved salts and salinity. Mean conductivity values varied between 354 μ S/cm at the end of October 2009 and the highest value reached in mid-October 2009 (435 μ S/cm). The lowest value was observed in site 3, which is close to the inlet of the Orontes River into the lake, where the water is fresher. Conductivity variations with time are highly correlated with water input to the lake due to dilution. However, EC was relatively higher in those locations close to the fertilizer factory (sites Nos. 16, 17, 18 and 19) and the agriculture and sewage drainages in site 7 (Figure 3).

Oxygen parameters (DO, COD and BOD) have been determined to assess the biological and industrial pollution of the lake. Mean DO values varied between 7.30 mg/l in the dry months and 14.88 mg/l in April. The lowest value was close to clean limit (higher than 7 mg/l). There was a clear relation between DO and

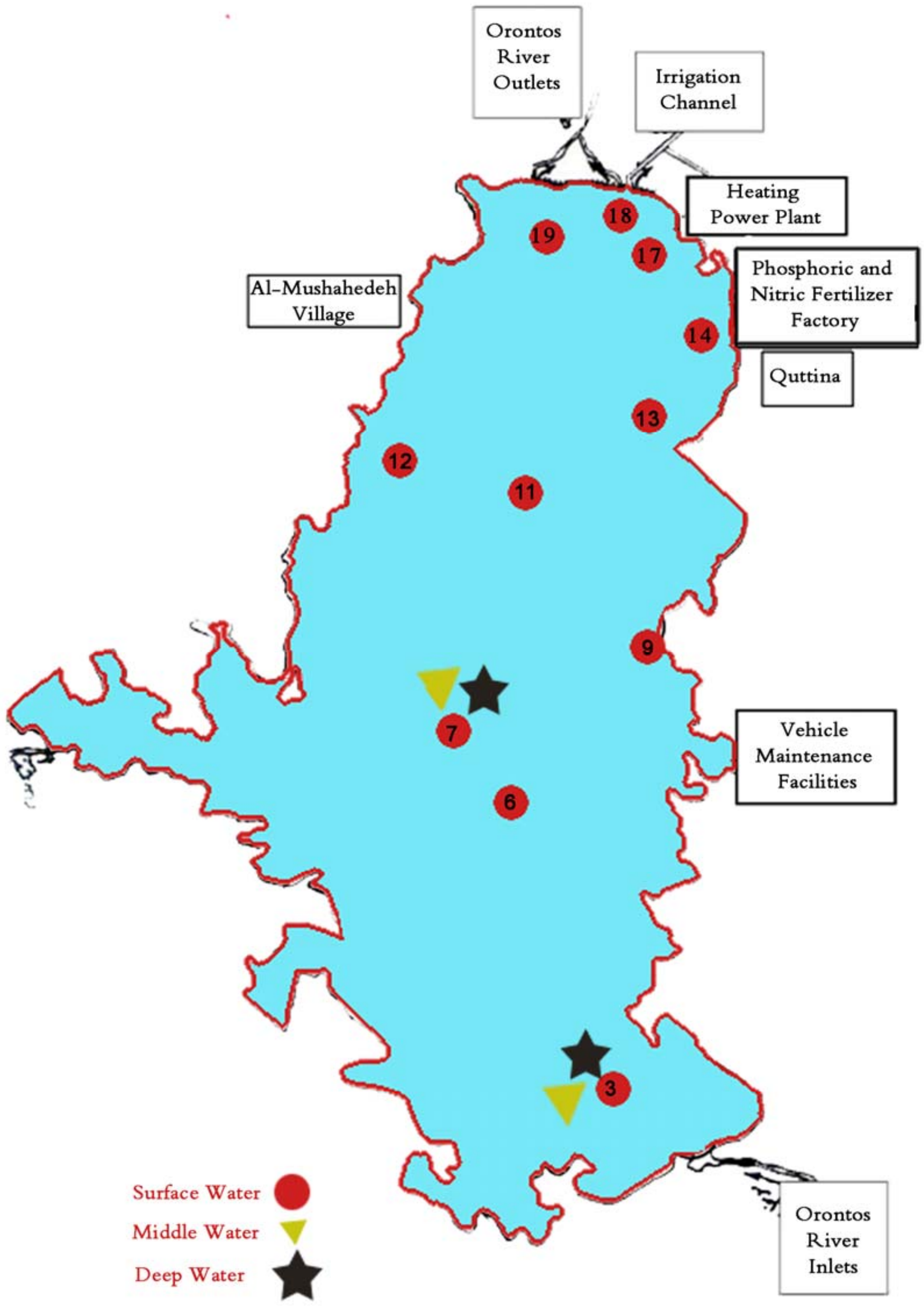

Figure 2: Sampling locations and pollution sources

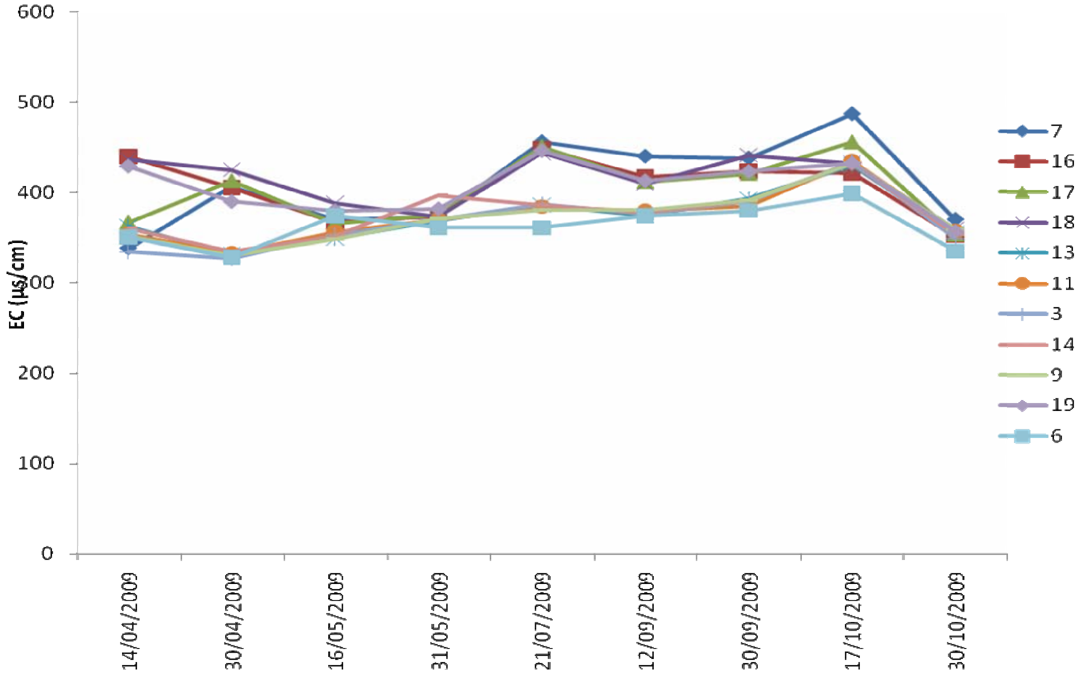

Figure 3: Monthly variation of EC in Quttina lake water

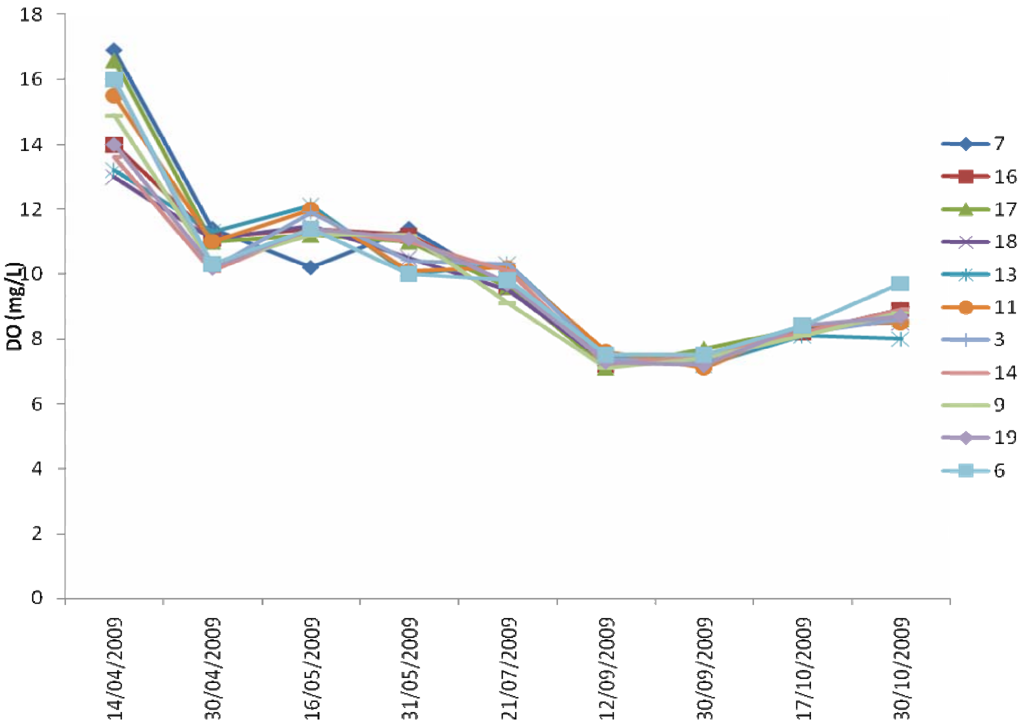

Figure 4: Monthly variation of DO in Quttina lake water

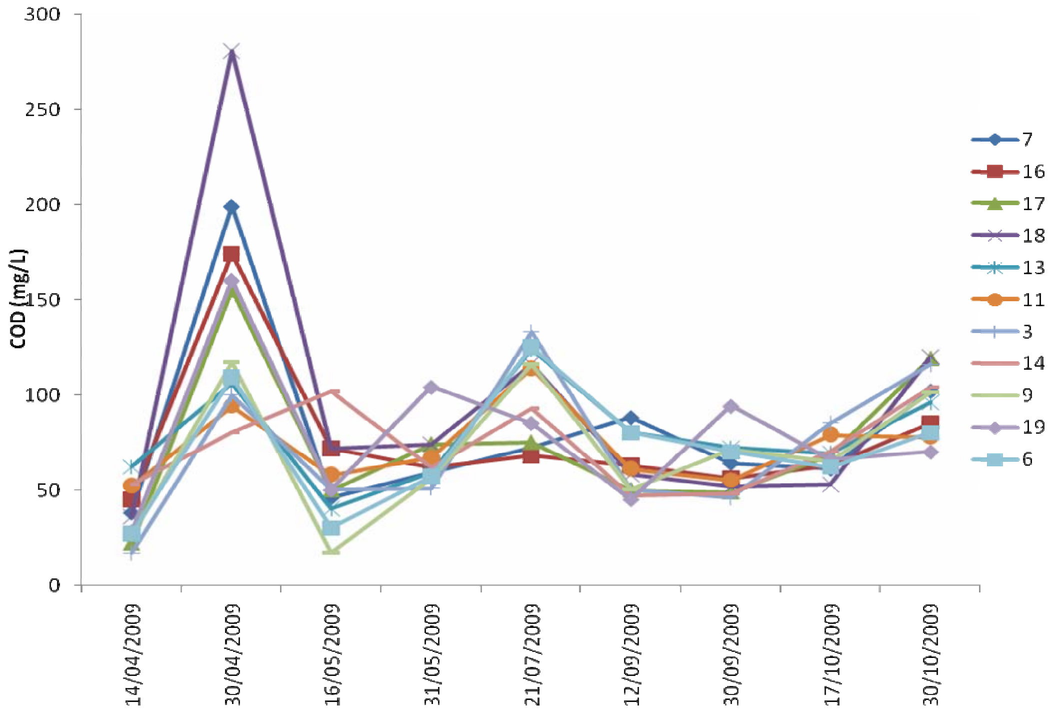

Figure 5: Monthly variation of COD in Quttina lake water

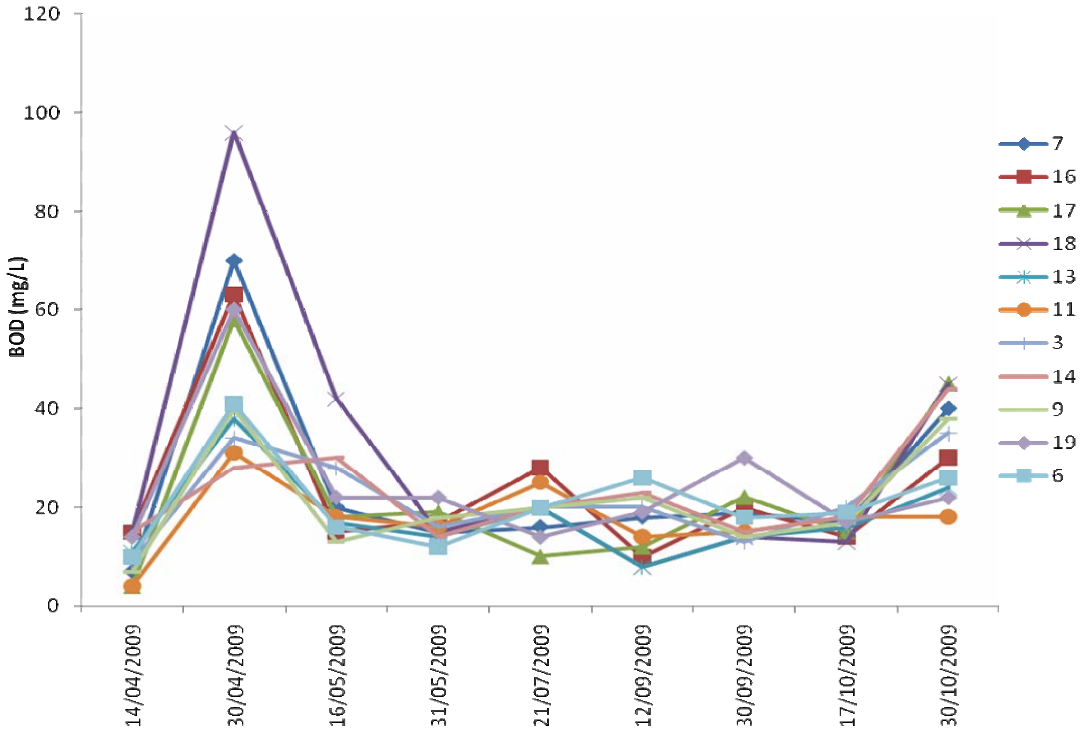

Figure 6: Monthly variation of BOD in Quttina lake water

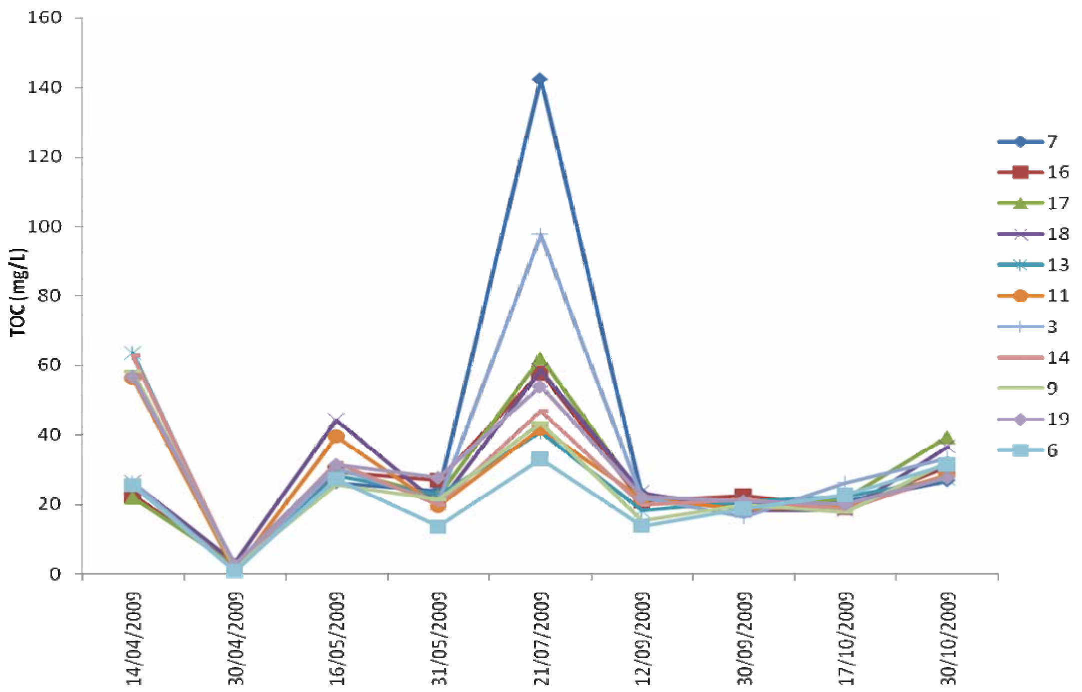

Figure 7: Monthly variation of TOC in Quttina lake water

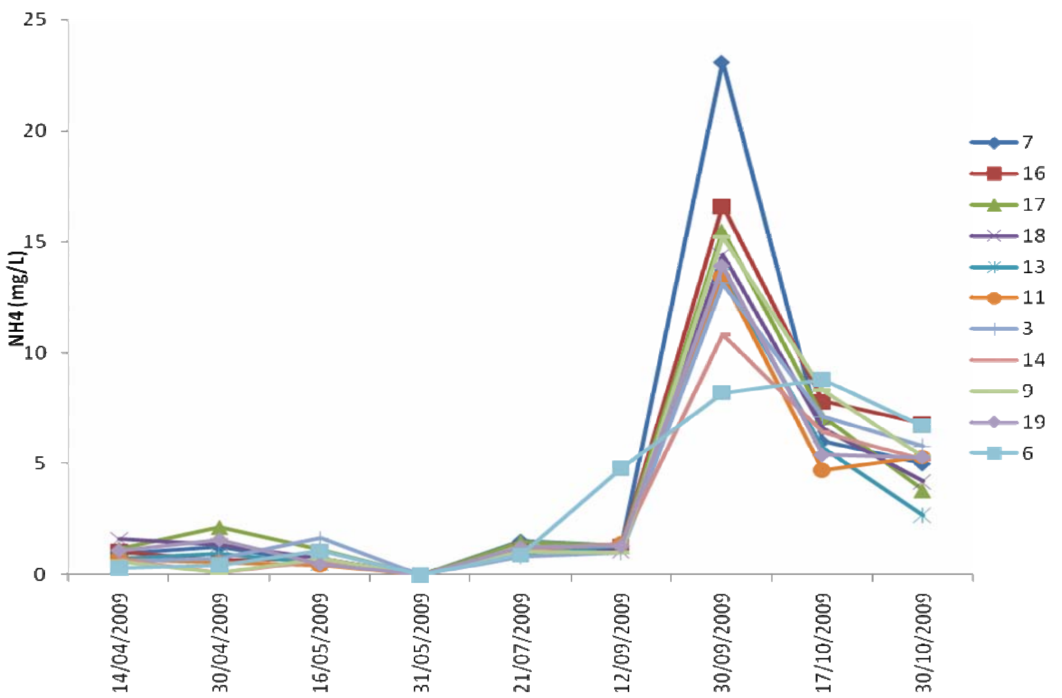

Figure 8: Monthly variation of NH_4 in Quttina lake water

temperature as can be seen in Figure 4. DO concentration in water decreases when there is a contamination from sewage water, and this was observed in our case such as the increases in locations 7 and 6 due to discharges of sewage water from villages situated at the western bank of the lake. In addition, mean Chemical Oxygen Demand (COD), which gives an indication of organic pollution caused by industrial activities, varied between 53.35 mg/l in the middle of May and 143.18 mg/l at the end of April. The highest value (281 mg/l) was found in those sites close to the fertilizer factory (Figure 5), while the lowest one (17 mg/l) was measured at the entrance of the Orontes River (site No. 3), which indicates a clear evidence of the effect of the phosphate fertilizer factory on the lake. On the other hand, COD has increased in the wet months (April and end of October) because of water dilution by rainwater and water flow into the lake from the Orontes River.

Biological Oxygen Demand (BOD) is an indication of water contamination by organic materials and bacteria, especially from sewage water. Mean BOD values varied between 10 mg/l in mid-April and the highest value (96 mg/l) found in those samples collected close to phosphate fertilizer discharges of the sewage water (site No. 18) and discharges of the western villages sewage (site No. 7) (Figure 6). In addition, there is a clear peak for both COD and BOD at the end of April 2009, where a high algal bloom was also observed. Variations with time of both BOD and COD can define the starting date of the algal bloom in the lake.

Mean Total Organic Carbon (TOC) varied between 1.95 mg/1 in May and 61.65 mg/l in mid-July (Figure 7). The highest value reported here was close to vehicle maintenance workshops (142.4 mg/l) (site No. 7), where oils and lubricants find their ways to lake water (Figure 7). Dilution of contaminants by rainwater and increase of water flow of the Orontes River are the main reasons of lower values.

Ammonium concentration is an indicator of new biological pollution and the use of fertilizers. Ammonium concentrations varied between 0.79 mg/l in the middle of May 2009 and 14.34 mg/l at the end of September (Table 1). Generally, the lowest value was at the entrance of the Orontes River (site 3) (0.31 mg/l), and it increases to reach a value of 23 mg/l in site No. 7, which is close to sewage drainages of western villages (Figure 8). In addition, seasonal variations were very clear, where the values were relatively higher in most locations and increase when the water level in the lake increases (in April and late October). On the other hand, nitrate concentration varied between 0.21 mg/l in the middle of September and 10.25 mg/l in the middle of July (Figure 9). The lowest value was found in site No. 3 and the highest value was at the northern part of the lake close to the fertilizer factory discharges (18.5 mg/l). The measured values are relatively low but they are still higher than the values reported in a previous study, where concentration varied between 5-7 mg/l (Al-Oudat et al., 2003). In addition, the low levels of NO_3 in water may be due to microbiological processes that occur due to growing algae and plants in the lake that consume this ion and enhance the process of denitrification according to the following equation:

$$5CH_2O + 4NO_3^- \Leftrightarrow 4HCO_3^- + CO_2 + 2N_2 \uparrow + 3H_2O$$

This also can be correlated with the increase in water pH in the same period of NO_3 decrease; lower values of NO_3 concentration correspond to the increase in algal bloom in the lake.

Phosphorous is an important indicator of fertilizer pollution in the water bodies, and since it is consumed by bacteria, it is also an important indicator of biological pollution. Phosphorus can be present in organic and inorganic compounds. Phosphate ions as inorganic compounds are the main ions to be released by the phosphate fertilizer industry and agricultural releases. Phosphate ions varied between 1.11 mg/l in the middle of September and 2.60 mg /l at the end of April. The highest values were observed in locations close to fertilizer factory discharge (5.27 mg/l). Seasonal variations have shown the clear increase due to soil erosion by irrigation and rainfall water close to agricultural areas (site 6) (Figure 10).

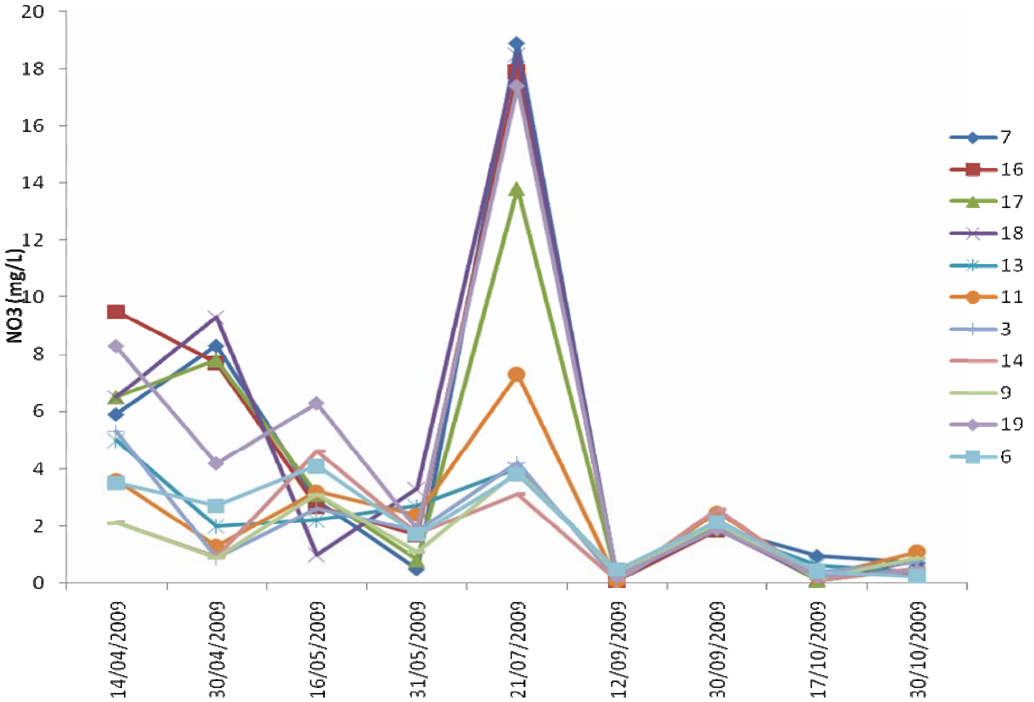

Figure 9: Monthly variation of NO_3 in Quttina lake water

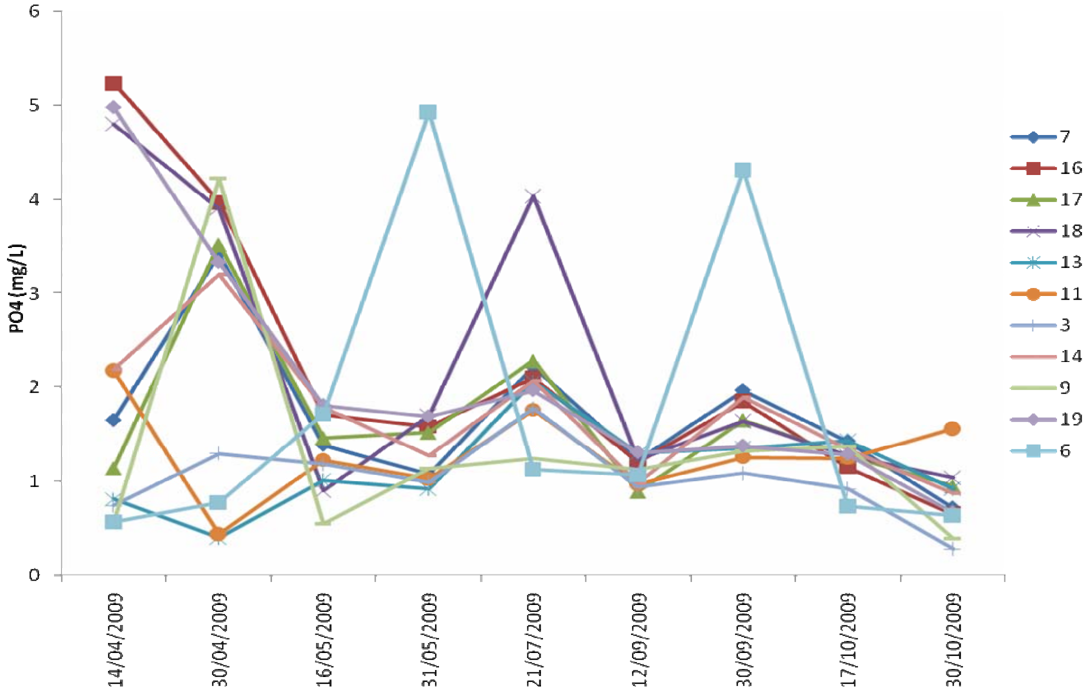

Figure 10: Monthly variation of PO_4 in Quttina lake water

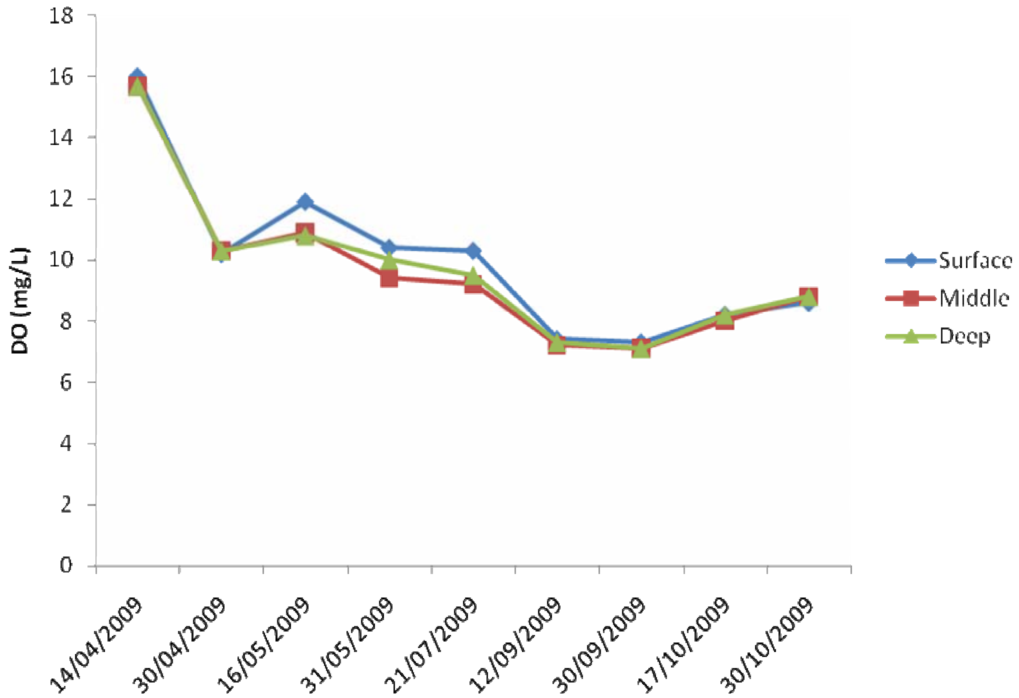

Figure 11: Monthly variation of DO depth profiles in Quttina lake water (site 3)

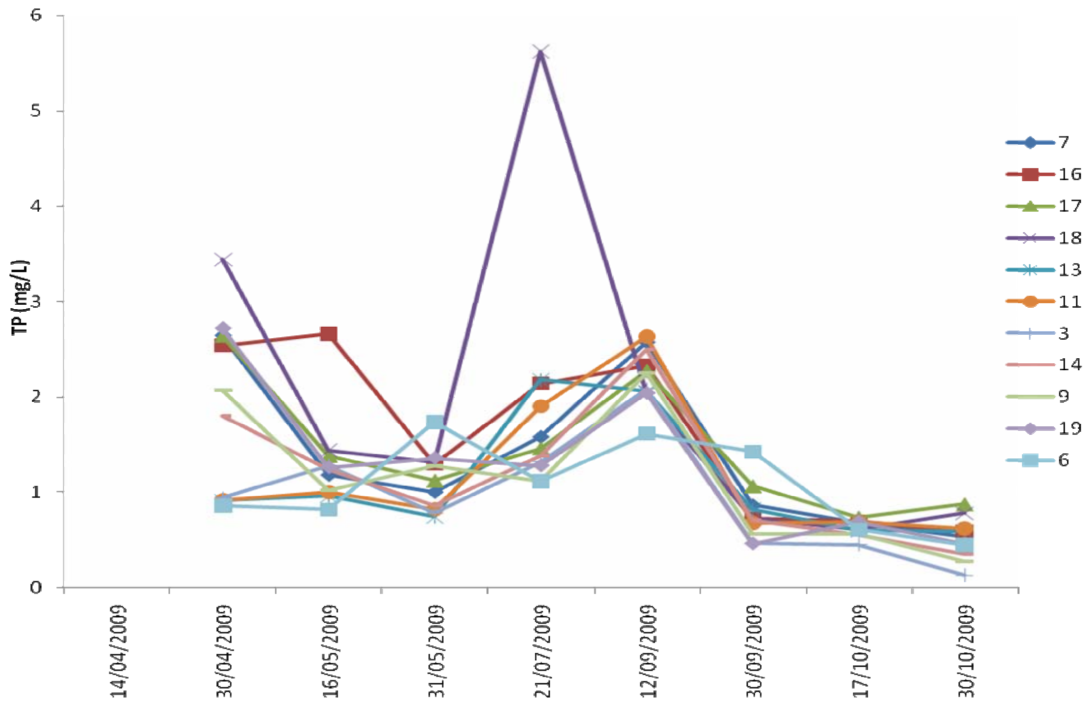

Figure 12: Monthly variation of TP in Quttina lake water

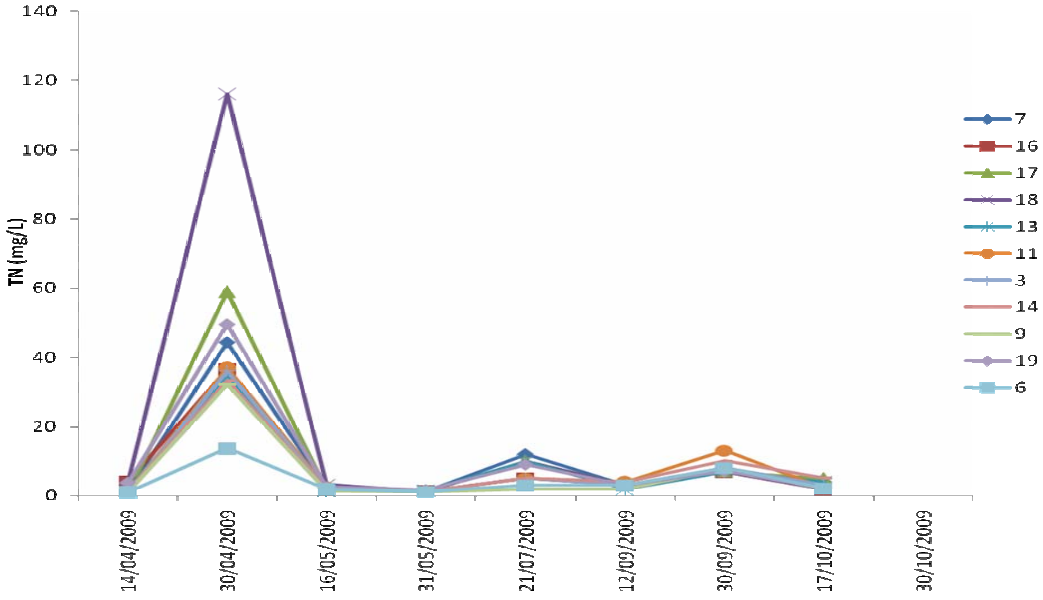

Figure 13: Monthly variation of TN in Quttina lake water

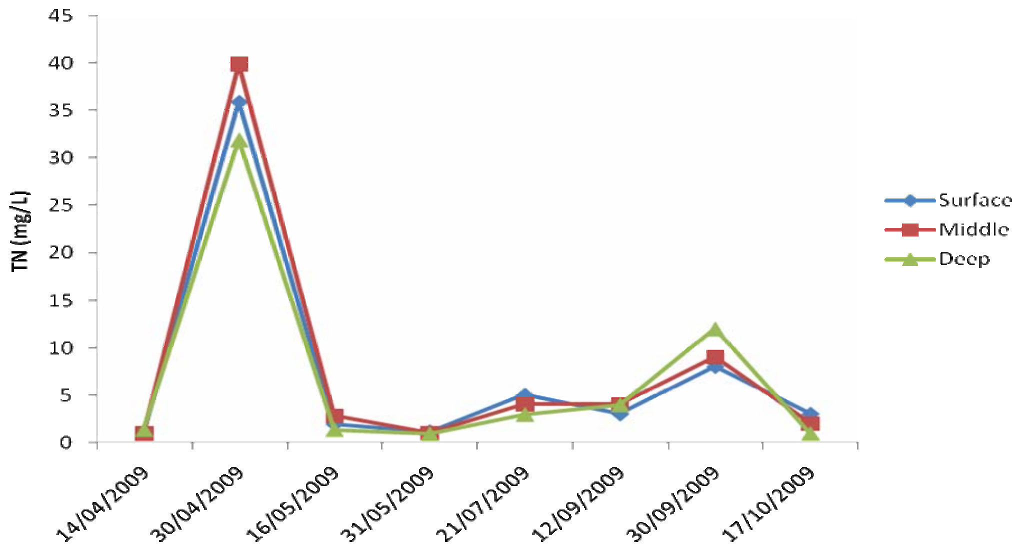

Figure 14: Monthly variation of TN in depth profiles in Quttina lake water (site 3)

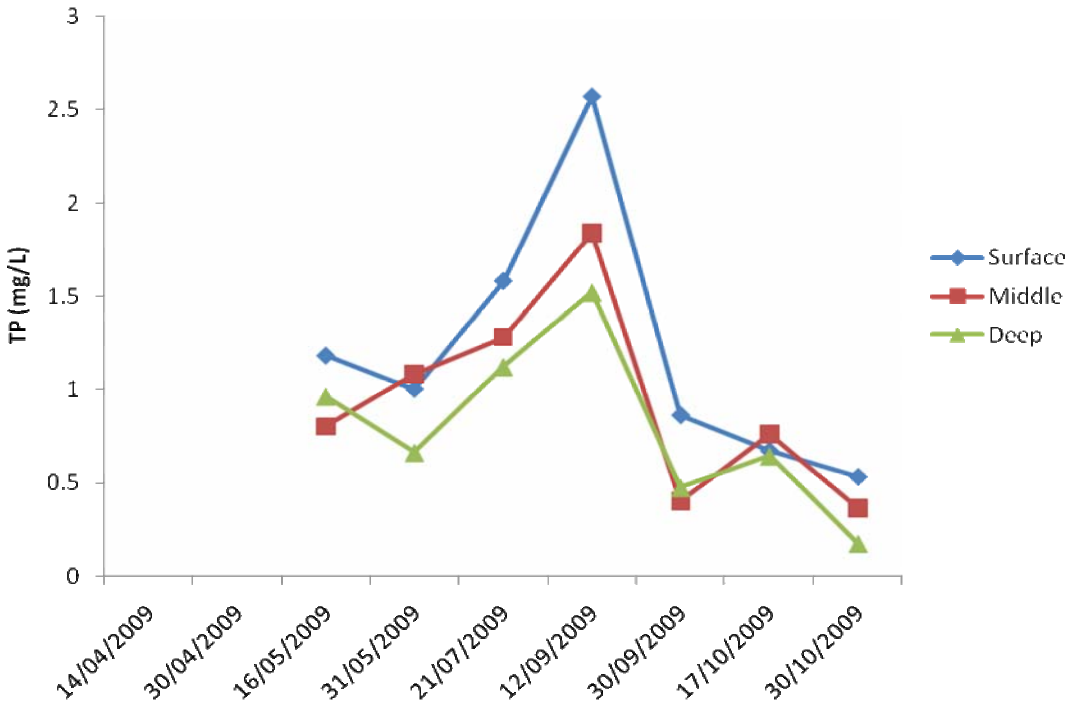

Figure 15: Monthly variation of TP in depth profiles in Quttina lake water (site 7)

Table 1: Mean water quality parameters values in Quttina lake

Sampling Date	TOC mg/l	PO_4 mg/l	NO_3 mg/l	NH_4 mg/l	DO mg/l	EC cm /S µ	pH	T °C	BOD mg/l	COD mg/l
2009/04/14	43.36	2.26	5.3	0.88	14.88	374	8.83	15.9	10.09	36.91
2009/04/30	1.95	2.59	4.18	0.91	10.73	365	8.41	18.55	50.82	143.18
2009/05/16	31.31	1.34	3.25	0.8	11.43	363	8.44	23.67	21.73	53.36
2009/05/31	21.73	1.62	1.78		10.72	374	8.84	26.01	16.18	65.91
2009/07/21	61.65	2.06	10.25	1.15	9.8	411	8.76	28.09	19.36	101.91
2009/09/12	20.15	1.11	0.21	1.56	7.34	395	8.3	26.29	16.36	61.09
2009/09/30	19.62	1.79	2.08	14.34	7.37	406	7.99	24.31	17.64	61.55
2009/10/17	20.59	1.22	0.34	6.72	8.26	435	8.84	18.32	16.73	67.36
2009/10/30	31.16	0.79	0.6	5.1	8.74	354	8.96	17.22	33.36	97.36

Table 2: Correlation factors (R^2)

	TN	TP	TOC	PO_4	NO_3	NH_4	DO	EC	pH	T	BOD	COD
TN	1.00											
TP	0.37	1.00										
TOC	-0.53	0.06	1.00									
PO4	0.68	0.48	0.02	1.00								
NO3	0.16	0.46	0.69	0.67	1.00							
NH4	-0.15	-0.67	-0.26	-0.21	-0.40	1.00						
DO	0.02	0.18	0.31	0.54	0.45	-0.57	1.00					
EC	-0.31	-0.05	0.14	-0.04	0.06	0.41	-0.47	1.00				
PH	-0.27	-0.30	0.42	-0.17	0.12	-0.41	0.39	-0.12	1.00			
T	-0.31	0.51	0.23	-0.07	0.25	0.03	-0.38	0.27	-0.37	1.00		
BOD	0.96	0.17	-0.50	0.24	0.00	-0.18	-0.08	-0.46	-0.09	-0.30	1.00	
	0.88	0.32	-0.26	0.32	0.25	-0.17	-0.20	-0.17	0.03	-0.07	0.89	1.00

Table 3: Water pollution classifications (Ministry of Irrigation, 1986)

Parameter	Unit	1	2	3	4	5	6
N	mg/l	<0.5	<1	<2	<5	<10	>10
N (NH_4)	mg/l	<0.1	<0.2	<0.5	<2	<5	>5
P	mg/l	<0.05	<0.4	<1	<2	<3	>3
BOD	mg/l	<2	<4	<8	<15	<20	>20
COD	mg/l	<5	<10	<20	<30	<40	>40
DO	mg/l	>8	>6	>5	>4	>2	>2
pH	-	8-6.5	8-6.5	8-6.5	8-6.5	9-6	9-6
T	^oC	20>	25>	25>	30>	30>	30<
DO	mg/l	>8	>6	>5	>4	>2	>2
EC	cm /S µ	<400	<700	<1100	1300>	<1600	>1600
NO_3	mg/l	<1	<3	<5	<10	<20	>20
PO_4	mg/l	<0.025	<0.2	<0.5	<1	<2	>2

1: Very clean, 2: Clean, 3: Little polluted, 4: Low polluted, 5: Highly polluted, 6: Very highly polluted.

On the other hand, vertical distribution of pollution parameters has been studied in two sites; namely site No. 3 and site No. 7. There was no clear variation of the studied parameters with water depth. This is due to low water depth, which was not more than 2-3 meters during the study period, and due to the mixing of water by wind. Figure 11 presents an example of (DO) depth profiles.

Table 4: Total nitrogen, total phosphorus concentration and ratio in Quttina lake water

Sampling Date	**TP** mg/l	**TN** mg/l	**TN/TP**
2009/04/14	1.95	44.77	22.96
2009/04/30	1.29	2.08	1.61
2009/05/16	1.12	1.26	1.13
2009/05/31	1.29	6.91	5.36
2009/07/21	2.21	3.00	1.36
2009/09/12	0.77	8.09	10.51
2009/09/30	0.62	3.00	4.81

Water pollution parameters are somehow interrelated (Harrison, 1991). The measured values were statistically analyzed and the R^2 (correlation factor) values were calculated to assess the correlations between the parameters (Table 2). Only a linear relationship was considered in our study. There was a clear relationship between COD and BOD, where R^2 reached 0.89, and the DO is related to temperature. The relationship between PO_4 and NO_3 was also positive and R^2 was 0.67, due to natural correlation between the two elements (P and N), where the N:P ratio is about 16:1 in wet areas and decreases in dry areas. Both elements are produced by natural processes, but in our case the phosphate and nitric fertilizers are also other sources in the area.

Water quality parameters found in this study (Table 1) were compared with those for water classification of the Ministry of Irrigation (MOI, 1986) (Table 3). It is clear that the water of Quttina lake is very highly polluted (class 6), and the main causes of the increases in parameter values were the phosphate fertilizer factory and the sewage and agricultural drainages.

Total Nitrogen and Total Phosphorous and Quttina Lake Eutrophication

Water eutrophication is mainly caused by excessive loading of nutrients into water bodies like N and P. Excessive nutrients come from both point pollution such as wastewater from industry and municipal sewage, and non-point pollution like irrigation water, surface run water containing fertilizers from farmland,… etc. Increased nutrient load to water body is now recognized as a major threat to the structure and functions of near shore coastal ecosystems, and severe eutrophication problems associated with harmful algal bloom form a major manifestation (Yang et al., 2008). At present, excessive TN and TP in water are considered as the only factors inducing water eutrophication, but nutrient enrichment is only a necessary but not a sufficient condition for algal bloom. Eutrophication is not likely to occur if both TN and TP in water are low, but eutrophication may not occur in water high in TN and TP if other conditions such as temperature and current speed are not favorable. The influencing factors of water eutrophication include: (1) excessive TN and TP, (2) slow current velocity, (3) adequate temperature and favorable other environmental factors, and (4) microbial activity and biodiversity. Water eutrophication may occur rapidly when all of these conditions are favorable (Yang et al., 2008; Cheng and Lee, 2006). However, all of the above parameters can be observed in Quttina lake.

Mean TP in water varied between 0.51 mg/l and 2.2 mg/l (Table 4), and the highest values were observed in those sites close to fertilizer factory discharges. According to water classification, Quttina lake is a very highly polluted lake, where TP has reached 5.62 mg/l in site No. 18, which is higher than 3 mg/1 (class 6) (MOI, 1986) (Figure 12). Eutrophication occurs when TP concentration is higher than 0.3 mg/l (Yang et al., 2008), provided that other parameters-such as temperature- are high in the lake. Other authors reported lower values for algal bloom formation (0.01-0.015 mg/l) (Richardson et al., 2007; Cheng and Lee, 2006). Algal bloom is very clear in the hot spots measured in this study (close to the fertilizer factory and the agricultural drainages). In addition, seasonal variations of TP are also clear, where variations in discharges of water from phosphate fertilizer drainage systems and water level in the lake have been the main influencing factors. The highest value was found to be in April, which is the starting period of the algal bloom in Quttina lake.

Total N is also an important influencing factor for eutrophication. TN varied between 1.26 mg/l in May 2009 and 44.77 mg/l in April 2009, where the highest values were in sites 18 and 19 close to the fertilizer factory. According to water classification for TN, the lake water is highly polluted. Seasonal variations were very clear in most sites (Figure 13), where the concentrations increased when the water level increased and dilution took place.

Depth profiles of both TP and TN have shown little variations as can be seen in Figure 14 and Figure 15, due to low water depth and mixing of water by the wind. The area is known to be windy in most times of the year.

TP and TN ratio is also an important factor that should be considered for water eutrophication, where in natural cases the ratio N:P is around 16:1 and varies if artificial sources of these two elements are present (MPCA, 2008). N:P ratio in water varied between 1.1 and 22.9 during the period of the study (Table 4), where the highest value was observed in April, the starting period of the algal bloom. In addition, there was a clear positive relationship of TP and TN with oxygen parameters (COD and BOD) (Table 2), which also indicates the algal bloom occurrence due to water pollution. The increase in TP and TN with the increase of both COD and BOD is a clear evidence on algal bloom and water lake pollution, which are related to discharges of both N and P compounds from phosphate fertilizers and agricultural and wastewater drainages into the lake. This requires an urgent action to control these discharges.

CONCLUSION

Seasonal and partial variations of water pollution parameters in Quttina lake have been determined. A clear evidence was found on the water pollution of Quttina lake, as a result of the phosphate fertilizer factory. The levels of pollutants were found to be the highest at the northern part of the lake, which is close to this source of pollution. In addition, high levels in some sites were also due to agricultural and sewage drainages of some villages. These high levels have caused a wide eutrophication all over the lake. The study of seasonal variations of total N, total P, oxygen parameters (DO, COD and BOD) can be used to determine the starting date for the algal bloom in the lake, which is within the month of April. In addition, the N:P ratio varies from time to time, where the maximum value was in April. Total P is highly correlated with oxygen parameters; namely COD and BOD. Moreover, since the lake is too shallow and the area is windy, where waves are formed and move the water, there was no clear variation of the parameters with water depth. Finally, according to the results of water quality parameters, Quttina lake is considered a highly polluted lake.

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