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POLLUTION IN QARAAOUN LAKE, CENTRAL LEBANON

Amin Shaban[1]
Nadine Nassif[2]

[1]Remote Sensing Center
[2]Marine Sciences Center
Lebanon National Council for Scientific Research
Beirut, Lebanon

Lebanon is well known by its water resources. Unfortunately, in the last three decades these resources were subjected to several geo-environmental problems, mainly surface water pollution. Most ponds and lakes are contaminated. Qaraaoun lake, the largest lake in Lebanon, is typical. The lake was constructed in 1962 in the Bekaa plain to harvest waters from the Litani River. It was designed for irrigation and hydropower, in addition to local domestic uses. Recently, several studies were conducted on this lake that tackled its water quality. All showed that the lake is polluted, but they did not describe the regime and sources of pollution. This study examined water quality to identify types and location of pollution in the lake. Together with land use classification, the pollution sources were delineated. Out of twenty-five sites, sixteen were described as "hotspots", since they show high values in most of the tested parameters. Lake contamination is extremely high; for example, in addition to anomalous values in physical characteristics, total coliform often exceeds 5000 Col/100ml, and nutrient percent reaches eight times over the international guidelines. All resulting values exhibited alarming water quality conditions. The two major sources of pollution are the Litani River, and the eastern side of the lake, where human activities contribute sewage and fertilizers.

INTRODUCTION

Water resources in Lebanon are available in sufficient quantities. The average annual precipitation is about 800 mm along the coastal stretch and reaches to some 1400 mm in the mountains. Moreover, snow covers around 2000-2500 km^2 annually. This creates fifteen rivers and about 800 major springs. Nevertheless, the water cycle is fast due to steep sloping terrain and the abrupt dip of rock strata, which in turn makes these resources improperly utilized (Shaban, 2003). In addition, the problem of water pollution has a significant negative impact on these resources. This is obvious in many rivers and springs (Abboud and Aker, 1986; ECODIT, 1989; Slim et al., 2000; Saad et al., 2003; Kheir et al., 1994; Khawlie, 2000b; NCSR-RSC, 2004).

Water harvesting, as an optimum solution, can help exploit these resources instead of allowing them to be lost to the sea. Dams on river courses and lakes that collect and store water from melting snow are very useful. The Qaraaoun dam is a typical example of water storage in Lebanon and it contains a large volume of water that forms Qaraaoun Lake. This lake is the terminal point of the upper Litani River basin. In this segment of the basin, there are sixteen major tributaries feeding the primary river course. It located at altitude of about 800-850 m and is situated between the following grid coordinates (Figure1):

-Longitude: 145200 and 147100

-Latitude: 183700 and 179000

Qaraaoun Lake is the largest man-made water reservoir in Lebanon and is located in the southern part of the Bekaa plain along the primary watercourse of the Litani River (175 km length). The lake is an elongated water body that lies parallel the mountain chains of western and eastern Lebanon. It has an area of about 5 km^2, maximum depth of about 45 m, a perimeter of 14 km, and a capacity of around 225 million m^3. The dam was constructed in 1965 following the studies done by Abd-El-Al (1953).

The lake was designed as a multipurpose facility to supply water for irrigation, hydropower production and domestic uses. In addition to electricity generation, two major irrigation projects in the command areas of the Qaraaoun Lake are currently under study or implementation. These are the South Bekaa irrigation project (irrigating about 23000 ha) and the South Lebanon irrigation project, designed to irrigate 15000 ha (LRA, 2002). Unfortunately, the lake water has recently become polluted as can be directly seen from the physical characteristics of the water, the floating leachates and the dead fish at its surface. Also, the sediments of the lake are severely polluted (Thomas, 2005)

Studies of the pollution problem in Qaraaoun Lake are few compared with those on river water and springs from other regions of the country. The studies which tackled the water quality of the Qaraaoun Lake are those done by: LRA, 1994; SIDA/ASDI, 2000, Jurdi et al., 2001; BANE, 2003 and El-Ghol, 2004. In these studies, emphasis was only on water quality assessment, with a little concern for pollution sources. This study aims not only to analyze water quality, but also to identify pollutant sources and their mode of transport to lake water. In addition to physiochemical and microbiological analysis of water and field verification, modern techniques of remote sensing were applied to facilitate identification of the main elements governing pollutant transport.

MATERIALS AND METHODS

Normally, in water pollution assessment, it is realistic to analyze all related physical, chemical and bacteriological parameters. The resulting information is indicative of the sources of pollution, which is essential for future mitigation or conservation efforts. In this study, physiochemical and

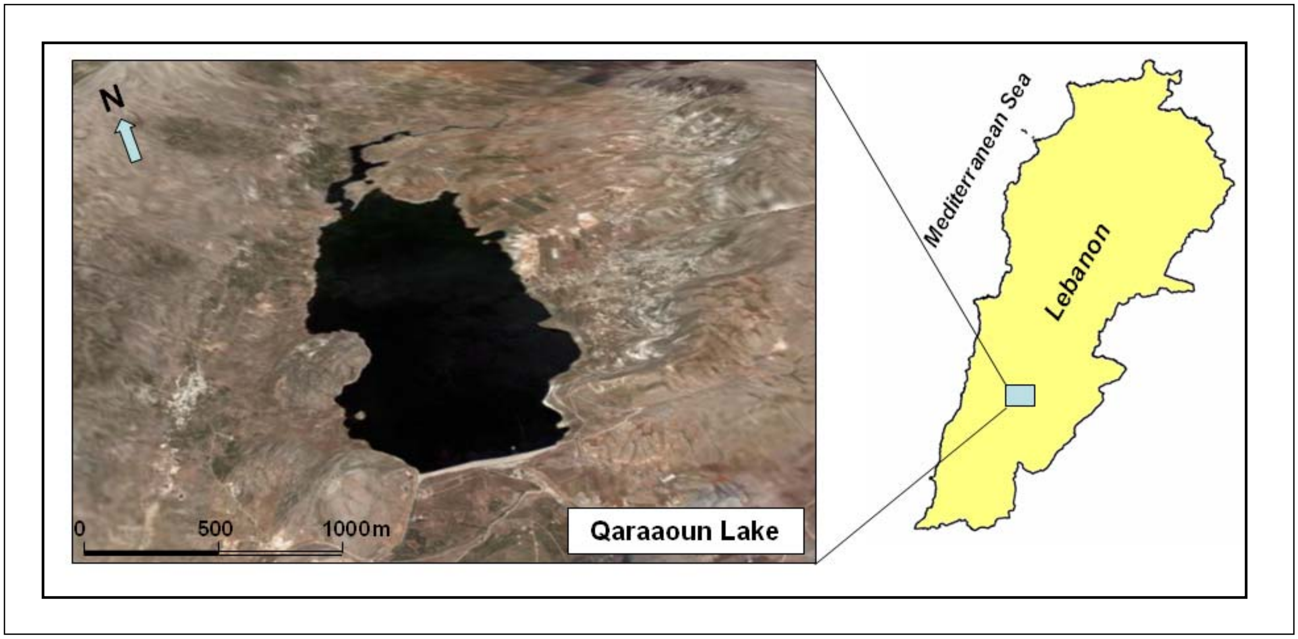

Figure 1. Location map of Qaraaoun Lake (image adapted from Google Earth).

microbiological characteristics of lake water were determined through field and laboratory investigations. Twenty-five sites were investigated (Figure 2). Sampling was carried out in the dry season of the year (August 2004). This was done to avoid the dilution of rainwater and associated high water flows into the lake from the Litani River as well as other streams. Selection of sites was often done applying the grid method of sampling. A defined spacing between sites was followed (approximately between 200-300 m). Some sites were selected with respect to location of streams outlets into the lake, as well as where obvious contamination sources were observed.

Three major phases were used in this study: In-situ physical investigation, laboratory testing, and satellite images analysis to assess land use in the area of study. All these phases were accompanied with field reconnaissance and verification. Each phase is described below and shown in Figure 3.

1. Physical investigation was conducted using in-situ testing with a portable submersible instrument or sonde, which has built-in programming and data logging. This sonde is manufactured by YSI in the USA. Model 600XLM has probes to measure temperature, specific conductivity, dissolved oxygen, pH and total dissolved solids. The instrument was immersed in lake water for fifteen minutes taking a measurement every minute. Data was downloaded to a computer and a mean value was calculated for each parameter.

2. Laboratory testing included two major elements of analysis as follows:

- Microbiology to measure total coliform and faecal coliform, and
- Nutrients including ammonium, nitrite, nitrate and phosphorus.

For the microbiology, each sample was diluted by factors of 10 or 100 for total coliform (TC) and faecal coliform (FC). One ml of non-diluted and 1 ml of each dilution were incorporated with medium in three Petri dishes and maintained at 45-47^{o}C. After solidification the dishes for TC were incubated at 36-37^{o}C for 24 hours. The dishes for FC were incubated at 44 $^{+}$ 0.5^{o}C for 24 hours. For the nutrients, samples were collected in plastic bottles of 300 ml sealed with water in place and emptied just prior to collection. Bottles were rinsed three times with lake water before

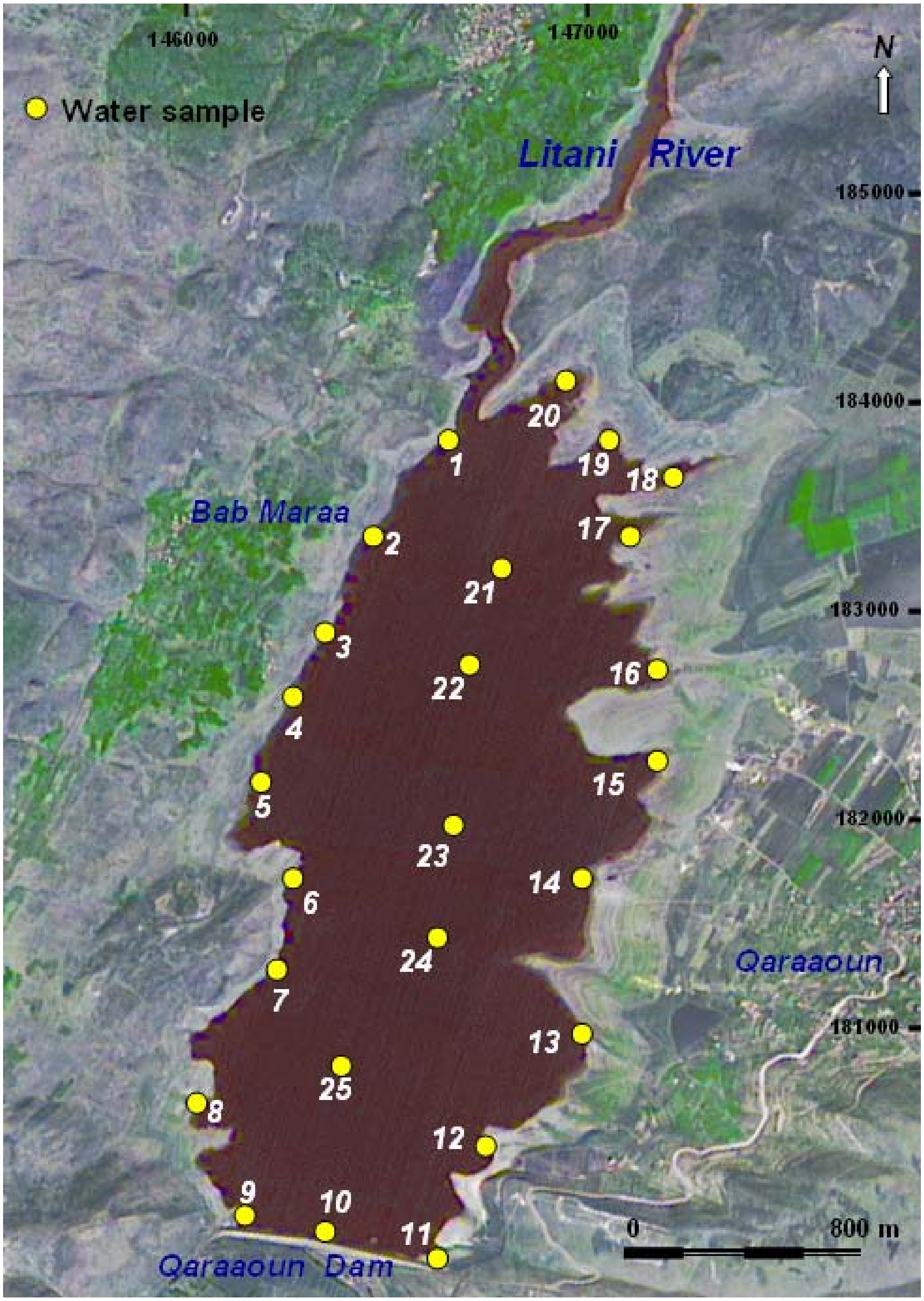

Figure 2. Investigated sites in Qaraaoun Lake (Land sat 7ETM+satellite images).

filling with the sample. Samples were kept cool until submitted to the laboratory.

3. Satellite image analysis was used to identify land use around the lake and it is indicative of the sources of pollution surrounding the lake. The satellite images are Landsat 7 ETM+ (30 m resolution) of January 2003. This task was conducted at the National Council for Scientific Research-Remote Sensing Center (CNRS) using ArcView software. Major features were digitized on screen, using ancillary data for the purpose of this study. All divisions of terrain elements were

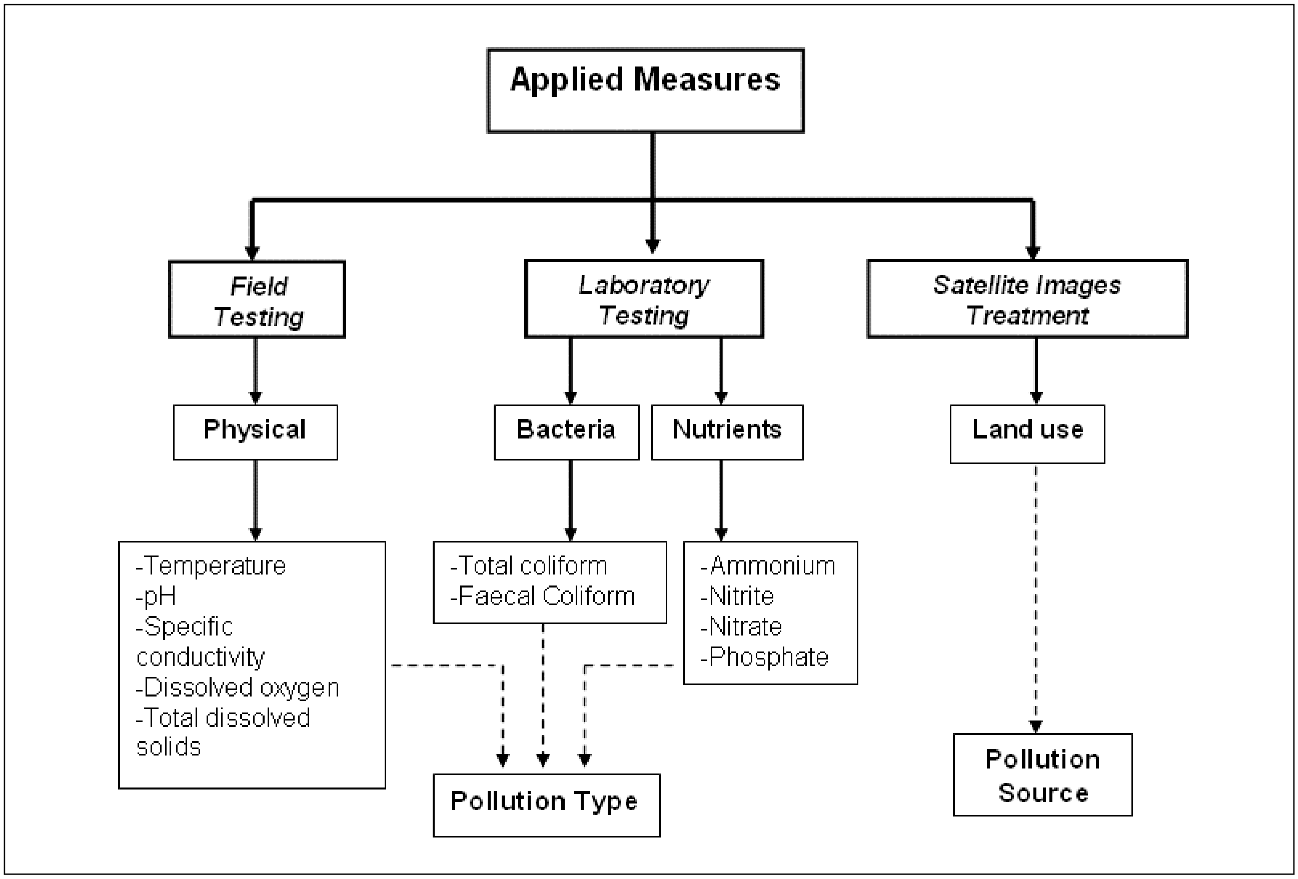

Figure 3. Applied measures to identify pollution type and sources in Qaraaoun Lake.

plotted and classified as follows: Vegetation cover of all types (e.g. fruit trees, shrubs, olive trees, etc.), urban and industrial sites, bare rocks and soil, in addition to soil and alluvial deposits.

Data from the physiochemical and microbiological water analyses, represent water quality of the top part of water column (i.e. depth < 3m). These data are one time measurements in the dry season (August, 2004). Several measuring dates in the dry season were not necessary because no significant inflows were observed to the lake during the dry season. This method was used in similar studies (Jurdi et al., 2001; El-Ghol, 2004) which found no remarkable variations in physiochemical and microbiological parameters between different dates of the dry season in the lake.

The data from the sonde measurements as well as nutrient and bacteria analysis are shown in Table 1. Values for these parameters were compared with international standards to identify anomalous values, which may lie above or below acceptable water quality levels. Any anomalous reading of a specific parameter is a reflection the source type of the pollutants that flow into the lake.

Physical characteristics

1. Temperature (T) measures the intensity (not amount) of heat stored in a volume of water. Abrupt differences in temperature indicate multisource water effluents into the lake. This is obvious from the temperature variation at the lake/land boundary, which points to the presence of water seeps to the lake that might transport pollutants. Particular temperature differences should be measured locally depending and referenced to a background value, which was the case for this study. Recorded values of temperature in Table 1 indicate the overall water regime in the lake.

Table 1. Water characteristics of the Qaraaoun Lake Col/100ml.

Site No.	Physical characteristics					Bacteria		Nutrients			
	Temp. C°	pH	Sp. cond. µs/cm	DO mg/l	TDS mg/l	TC Count/100 ml	FC Count/ 100ml	NH_4-N mg/l	NO_2-N mg/l	NO_3-N mg/l	PO_4-N mg/l
1	29.70	7.68	618	3.26	318	16500	338	2.02	0.30	5.33	0.97
2	28.40	7.61	601	3.07	326	15500	375	1.08	0.07	5.21	0.90
3	27.80	7.74	575	3.11	311	14850	391	0.91	1.73	3.11	0.88
4	26.90	7.84	569	4.18	316	9500	186	0.75	1.08	1.19	1.06
5	26.10	7.91	481	5.53	350	6450	154	0.21	0.04	2.39	0.64
6	25.20	8.12	351	6.16	196	3225	19	0.08	0.06	1.05	0.69
7	24.60	8.07	335	6.19	173	3100	18	0.06	<0.01	2.24	0.48
8	24.10	8.25	384	7.61	159	2950	76	0.08	<0.01	2.65	0.98
9	23.20	8.02	369	6.74	237	5500	124	1.16	2.03	3.71	1.09
10	23.90	8.01	378	5.19	154	3550	56	0.85	0.52	0.93	0.38
11	24.70	7.81	595	3.88	386	2750	261	1.14	0.73	3.55	0.22
12	25.30	7.74	463	4.83	297	10250	441	3.04	1.98	5.81	3.15
13	25.90	7.22	580	4.22	281	25250	419	3.16	1.63	6.22	7.35
14	26.80	7.18	612	3.51	403	16500	485	2.67	2.41	5.91	2.76
15	27.50	7.35	684	2.97	562	13500	397	0.42	1.82	3.28	3.29
16	27.80	7.31	693	2.02	511	11000	402	0.53	2.11	2.06	2.24
17	28.90	7.42	721	2.25	529	12500	437	0.66	0.67	3.46	2.19
18	29.10	7.08	709	2.10	526	13000	395	0.71	0.14	4.14	2.67
19	29.40	7.17	875	1.27	559	12200	206	0.62	0.25	6.88	3.55
20	29.60	7.41	817	2.81	598	17500	159	0.05	0.16	6.18	4.08
21	29.00	7.63	418	8.93	241	6500	36	1.06	0.09	0.89	0.67
22	27.90	7.28	406	8.87	230	5350	16	0.04	<0.01	1.34	0.14
23	26.70	7.17	386	9.98	156	4800	5	0.006	<0.01	1.06	0.26
24	25.50	7.43	338	11.25	173	5600	4	0.03	<0.01	0.76	0.28
25	24.60	7.28	346	5.83	180	6250	2	0.17	0.04	0.89	0.41

2. pH values tend to be basic (>7) and are at acceptable levels. However, some sites exhibit high values that approach 8 or above. This is indicative of effluent sources of water to the lake.

3. Specific conductivity in the selected sites has a mean value of 532 and standard deviation of 160. About 70% of the specific conductivity values are higher than the acceptable level (i.e. 400 μs/cm according to the EEC). These levels are found in two parts of the lake. The first is the upper western part (e.g. sites 1-5) and the second is on the eastern flank (e.g. sites 11-20). For the first group, it is clear that there is a descending trend in conductivity from where the river water enters the lake. This show high conductivity is derived from the upstream reaches of the Litani River. The higher conductivity in the eastern part is attributed to the relatively thick alluvial deposits, which are rich in metals and thus contribute to the higher conductivity.

4. Typical concentrations of dissolved oxygen (DO) in surface water are less than 10 mg/l. It has diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge. Measurements of DO in the lake show high standard deviation (S_d =2.66), which indicates the influence of dilution from the river water. Normally, DO is an indicator of the concentration of nutrients and organic matter. Low DO levels are frequently accompanied with high concentrations of decaying organic matter and higher temperatures in the water (Kegley, 1997). In Qaraaoun Lake, a clear decrease in DO levels was noticed in the effluent of the river (i.e.

sites 1-4), as well as at the eastern shore of the lake (i.e. between sites 11 and 20). This can be attributed to a higher concentration of organic matter there. The lowest DO was found at sites 15-20, where the circulation of lake water is relatively slow and is characterized by a number of meanders and small-scale bays.

5. Total dissolved solids (TDS) such as sodium, chloride, magnesium and sulfate contribute to elevated filterable residue values. High TDS waters may interfere with the clarity, color and taste of manufactured products. Results from the lake show a correlation between the levels of conductivity and TDS. TDS was found to be in the range of 0.40 – 0.85, with a mean value of 0.60.

Microbiological characteristics

The total coliform (TC) group is the collection of microorganisms that live in large numbers in the intestines of man and warm and cold-blooded animals. It includes faecal coliform (FC) and non-faecal coliform. The first group has a common member, *Escherichia Coli,* while the second is naturally present in soils and vegetation.

FC may be separated from the TC group by their ability to grow at elevated temperatures and are associated only with faecal materials. Therefore, *Escherichia Coli* is the major practical indicator of faecal contamination (Edberg, et al., 2000). According to WHO (1996); EEC (1980) and USEPA (1986), drinking water must be free from FC bacteria or *Escherichia Coli*.

The maximum level of TC in the lake was found to reach about 25250 col/100ml, which is in sample 13. However, since the raw human sewage lies in the order of 10,000,000 col/100ml (Chapman, 1996), this means that about 0.25% of water in site 13 is raw sewage. The standard deviation is relatively high (S_d= 5859) indicating the high dilution of water in the lake. For the FC, the high level was concentrated in the Litani River flow (i.e. sites 1-3), with a descending trend southward to the western flank of the lake. FC also shows higher levels at sites 1-3 and 12 to 18 (Figure 4).

In Qaraaoun Lake, the maximum recorded value for FC was 485 col/100ml, while the minimum was 2 col/100ml The standard deviation is also high (S_d = 174.7). The higher recorded levels were found in the same sites as those of the TC. In the middle of the lake, FC was relatively low. This indicates mainly high deposition of sewage on the lake shores. Figure 4 shows the distribution of FC levels in the lake. In this figure, five major levels were proposed depending on the minimum and maximum recorded values in the lake.

Nutrients

Nutrients refers broadly to those chemical elements essential to life, but more specifically to nitrogen and phosphorus in a water pollution context. In this study analyzed nutrients included ammonium, nitrite, nitrate and phosphorus.

The mean values of the measured nutrients in the lake were almost higher than acceptable guidelines. Table 2 shows the nutrient measurements taken from the lake. While there is an obvious increase in levels of ammonium, nitrite and phosphorus, acceptable concentrations are found for nitrate**.** The higher concentration of the main nutrients is found at the river inflow and at the eastern flank of the lake. The trend of nutrient levels from the measured sites approximately coincides with those for the bacteria. Also there is a correlation between the trends of the four nutrients.

Land use

From the satellite images (Landsat 7 ETM+), a number of land features were described and

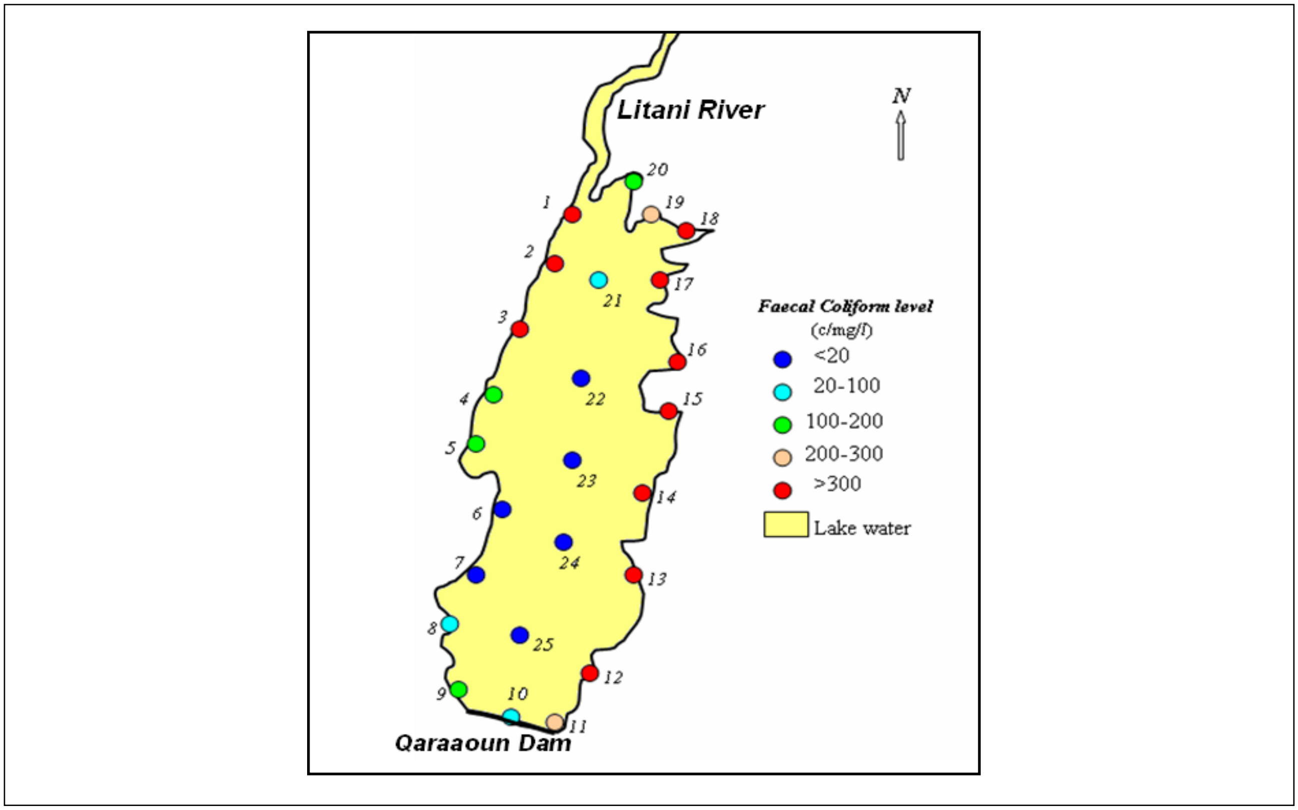

Figure 4. Faecal coliform distribution in Qaraaoun Lake.

digital cartography was applied to produce a land use map (Figure 5). The map covers the area surrounding the lake, and includes the catchment boundaries that drain to the lake.

The main terrain classes that may contribute pollutants were considered. These are urban and industrial sites, bare soil, and vegetation cover. Field reconnaissance verified the extracted information from the satellite images and reported obvious land uses on the lake. Within the area of the lake, the following land use percentages were found: 8% urban, 2% industrial, 39% bare rocks and soil (mostly alluvial deposits), 31% irrigated land and 20% non-irrigated land. In addition to land use, surface water channels were plotted on the map to show possible routes of pollutant transfer to the lake.

Pollutants and source correlation

Correlation between pollutants and sources were based mainly on studying physical and anthropic parameters in combination with the resulting data from physiochemical and

Table 2. Nutrients levels in the Qaraaoun Lake

Nutrient	NH_4-N	NO_2-N	NO_3-N	PO_4-P
Mean value	0.86	0.26	3.20	1.65
International standards*	0.05-0.5	0.1	5-10	0.4
Maximum	3.16	2.41	6.88	7.35
Minimum	0.006	<0.01	0.76	0.14
Standard deviation	0.93	0.85	2.01	1.68
With respect to the acceptable level	3 times	2.5 times	0.40 times	4 times
Relatively high leveled sites	1-4, 9-19, 21	1, 3,4,9-20	1,2,12-14,19,20	4, 8,9,12-20

microbiological analysis. Using this information pollutant sources on land are assigned as follows:

1. Anomalous values which are not in the range of the international guidelines base on the physiochemical and microbiological tests, are considered "hotspots."

2. Hotspots are superimposed on the land use map

3. Description of the type of pollution that has anomalous readings (for example due to high levels in phosphorus or FC)

4. Extracting a relationship between the location of the hotspots and the closest suspicious land area that may contribute to pollution (e.g. high level of faecal coliform from the nearest human settlement)

5. Utilizing the physical elements that surrounded the lake, which in turn may play a role in transporting pollutants. Such as, for example, a steam or sloping land.

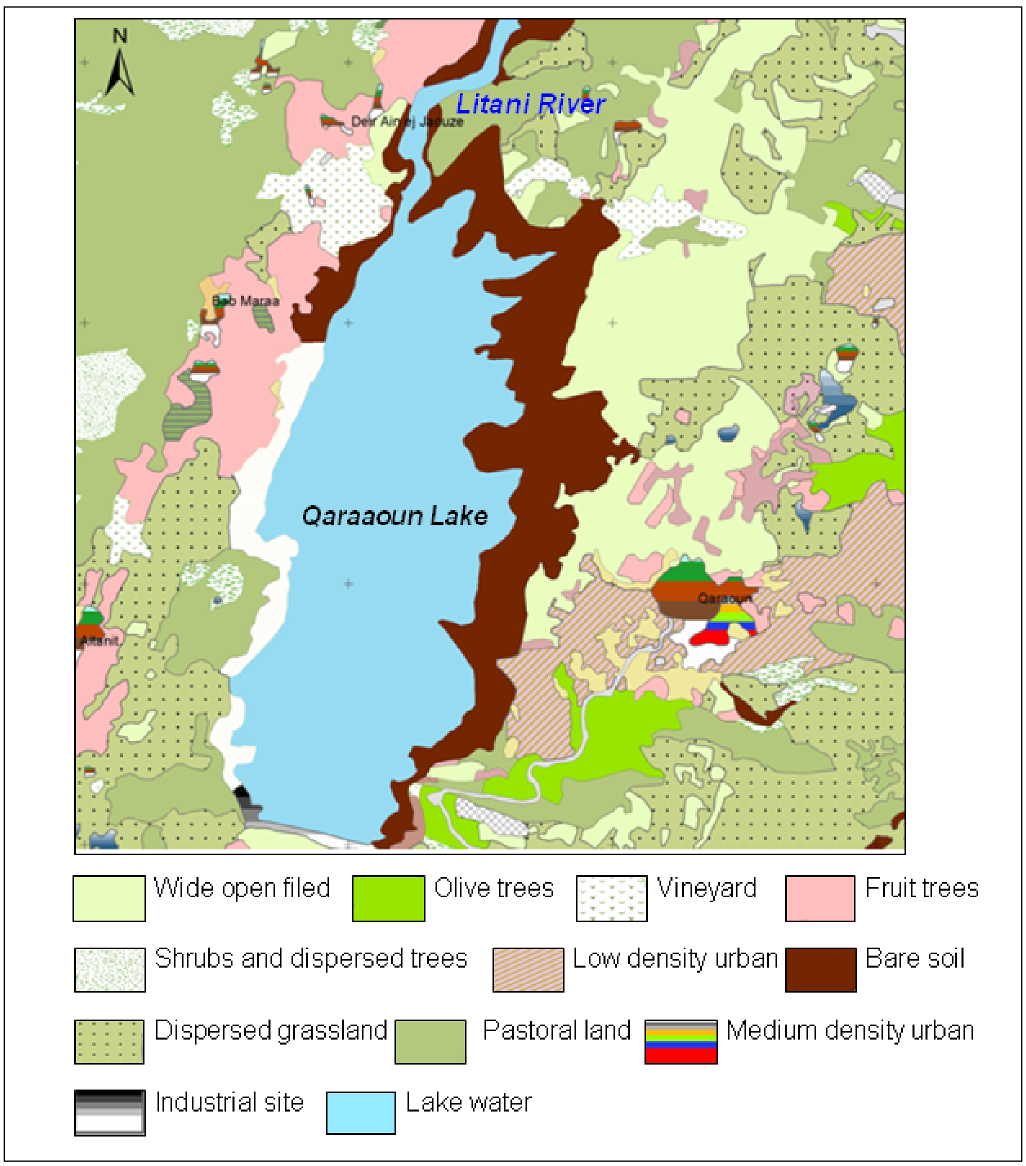

Figure 5. Land use map of Qaraaoun Lake (extracted from satellite image Landsat 7 ETM+, 2003).

Since there were different elements that may influence the pollution of the lake water a principal components analysis (ACP) was conducted. It is a technique used to reduce multidimensional datasets in order to simplify quality evaluation.

The values from the 25 sites reveal that the first axis comprises 68% of the variance and is mainly due to the bacteriological and chemical parameters measured (Figure 6). The second axis represents 14% of the variance and indicates less influence of these parameters. The ACP also shows that there is a significant difference in impact between the sites. For example sites 12 and 14 are especially marked by the presence of nitrates whereas sites 1, 7 and 14 are especially marked by the presence of coliforms and of nitrates. Sites 8, 10, and 21, and especially sites which are located at the river are polluted chemically and are the least contaminated by bacteria. The ACP shows that only sites 1, 2, 7, 13, 15, 18, 19, and 20 are influenced by the presence of nitrates and total coliforms. Sites 3, 12, 14, and 16 have a nitrite abundance. That means that there is a perceptible difference between the various sites chosen, and that the source out of nitrates can have different origins all along the river from the Litani. This difference seems to be influenced by the geographical location of the intake points.

In addition, there is a positive correlation ($p < 0.05$) between the faecal coliforms and the total coliforms (0.745), between the total coliforms and the nitrites (0.735) and between the faecal coliforms and the nitrates (0,675). A correlation also exists between the total coliforms and the phosphates (0.794).

Moreover, there is a positive correlation in ammonia, which supposed to be derived from urea.. However the difference is less significant between nitrites and the phosphates and it is not significant between nitrates and nitrite. It is noted that the faecal coliforms have an exclusively faecal habitat and that the nitrates can also come from feces by oxidation of ammonium (Gaudreau and Mercier, 1998).

Relying on the ACP application, it can be concluded that all sites on the river banks are polluted,

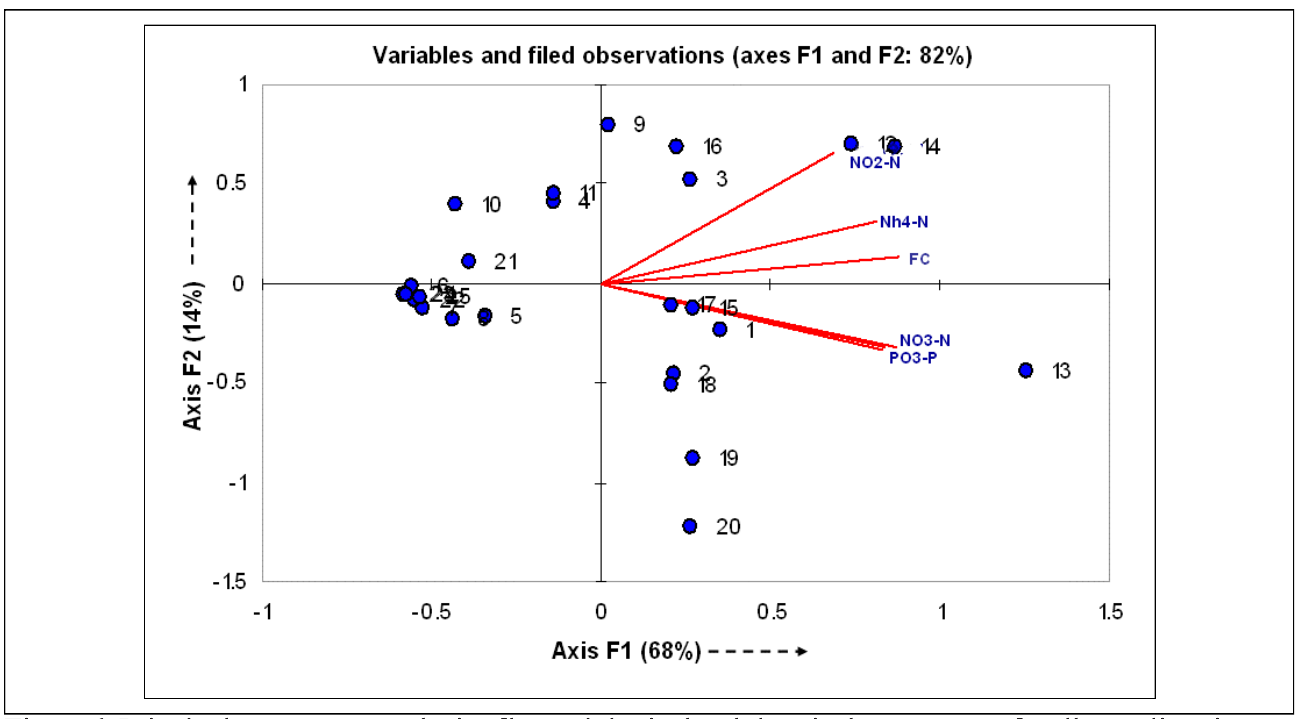

Figure 6. Principal component analysis of bacteriological and chemicals parameters for all sampling sites.

except those located at the middle of the river channel, which are much less polluted. This indicates the major role of pesticides and artificial fertilizers in pollution in addition to the presence of cattle close to the river. River water is considered a temporary indicator of pollution. For long-term follow-up, sediment analysis is of great importance a water pollution study.

Although most sites in the lake are polluted, of the twenty-five sites, fourteen can be considered hotspots, since each one comprises a variety of excessive concentrations. These are sites from 1 to 3, 9 and from 11 to 20. For the remaining sites, they are influenced by contamination, but to a level lower than that in the hotspots. The pollution seen at these site is attributed to the migration of pollution from the neighboring hotspots.

It is clear that the degree of pollution is different from one hotspot to another. The number of anomalous parameters is not the same at all hotspots. For example, site 13 has anomalous values in all tested parameters. This is not the case for site 15 (Table 3).

Contaminated samples indicate the source type, but do not necessarily indicate the location where the pollutants come from as noted by many studies on this topic (Jaafar et al., 1994; Dandan, 1999 and SIDA/ASDI, 2000). The use of land use information was extremely significant in this study.

The type of pollution and location of the hotspots are the first two elements to be defined. The third is the route connecting the hotspot location with the nearest proposed source. For example, hotspot number 14, with high content of FC, is close to Qaraaoun village, where a stream connects the village to the lake. The village would be the major source of pollution at that spot.

It is important to include the elements which are hydrologically essential for pollutant transport. Not all these elements end up as a point source to the lake to produce a hotspot, such as a streams or man-made channels. Some were found as to be non-point-source hotspots (e.g. seeps through the alluvial deposits). This was done utilizing mainly field reconnaissance with topographic, geologic and land use maps.

CONCLUSION AND DISCUSSION

The Litani River basin is the largest in Lebanon (2170 km^2). Hydrology of the basin shows two principal parts, the upper and lower, with Qaraaoun Lake representing a valve point in between. The upper part is wider and derives waters from several tributaries to the primary course of the river, which is terminated at the lake. In this part, dense human activities exist, including many different agricultural activities and industries, all sharing integrally in the Lebanese economy.

In addition to hundreds of square kilometers of irrigated lands that rely on fertilizers, there are thousands of factories of different scales, and some ninety quarries. Proper infrastructure is totally lacking and therefore, wastewaters are dumped into the river courses. A recent assessment concluded that around 23 million m^3 of wastewater is dumped into the river tributaries each year (Ramal, 2005).

Although the location of Qaraaoun Lake is particularly fit to collect water from the river upstream, these waters are becoming highly polluted. The lake has recently become a wastewater collector. Human activities that exist near the lake exaggerate the problem, especially along the eastern shore where settlements are found.

The average FC in the lake is 216 mg/l. It is 288.8 mg/l at the river effluent and 360.2 mg/l at

Table 3. Interpretation of pollution sources in Qaraaoun Lake.

Site No*	Anomalous parameters	Effective land use	Effective transport elements	Proposed pollution source
1	Low dissolved oxygen (<3mg/l), high Faecal Coliform (>300mg/l) and above the acceptable	No remarkable land use influence	Litani River effluent into the Qaraaoun Lake	Direct discharge from the Litani River
2				
3				
9	Relatively high level of Faecal Coliform (124mg/l), and in nutrients (NH_4 = 1.16; NO_2 =2.03; PO_4 = 1.09 mg/l)	Presence of industrial site	Direct dump into the lake	located factory dumping industrial residues into the lake
11	High level of Faecal Coliform (261mg/l), high Ammonium level (1.14mg/l),	Grass lands for pastures, cultivated by olive trees, vineyard, fruit trees, and dispersed settlements in an open field	Stream Ouadi Ouraiq and slopping terrain towards the lake	Excessive fertilizers and animal wastes from the neighboring region of (Ech-Chmaiessat) and Aarid Halat
12	High level of Faecal Coliform (441mg/l), also in all nutrients values, notably in Ammonium (3.04mg/l)		Diffuse flow of pollutants through water seeps into the alluvial deposits	
13	High level of Faecal Coliform (over 400mg/l), and distinguished high levels in all nutrients	All these sites are facing relatively dense human settlements and activities. In addition, open areas cultivated by fruit trees are present	Each of these sites is connected with stream. These streams are almost conducted the human settlements. Moreover, there is a slop trend from these settlements towards the lake	The Qaraaoun village and the industrial activities (notably stone masons) are the most effective pollution sources. This is in addition to the cultivated areas with excessive fertilizers.
14				
15	Relatively high levels of TDS (over 500mg/l), even though high levels of Faecal Coliforms (around 400mg/l), plus unacceptable level of nutrients except in phosphorus			
16				
17	Specific conductivity over 700 µs/cm, TDS over 500mg/l, Faecal Coliform around 400mg/l, and high level of nutrients, notably in phosphorous (over 2 mg/l,)	Stone manufacturing (stone masons), some human settlements, grass lands and fruit trees	Major water courses and slopping terrain and diffuse flow through alluviums	Neighboring stone masons, animal wastes and fertilizers
18				
19	Specific conductivity over 800 µs/cm, TDS over 550mg/l, Faecal Coliform around 400mg/l, slight increase in nutrients except high values in phosphorous (over 3.5 mg/l,)	Fruit trees and grass land for pastures. Stone masons are present, but to a distance	Streams from remote areas	Animal wastes, and excessive fertilizers
20				Animal wastes, and excessive fertilizers, some dispersed settlements

the eastern side of the lake. It is less than 13 mg/l in the middle of the lake. This shows the sources of pollutants. Their anomalous levels of nutrients are concentrated at the same sites. Ammonium, for example, averages 0.994 mg/l at the river inflow point and 1.30 mg/l along the eastern shore of the lake, while it is around 0.032 mg/l in the middle.

Along a 14 km perimeter of the lake there are 16 hotspots where pollution levels are high. This represents some 75% of the lake body and means that a hotspot of pollution occurs for each 1 km. The lake is completely polluted. River water from upstream is contributing pollutants, as shown in many previous studies, but near the inflow point, levels are very high. The lake circulation dilutes and lowers the degree of pollution. This was shown from the high values of standard deviation (e.g. 0.93, 0.85, 2.01, 1.68, 2.66, 174.7 for ammonium, nitrate, nitrite, phosphorous, dissolved oxygen and FC; respectively) The velocity of water from the river inflow decreases entering the lake, allowing pollutants to settle to the lake floor as sediment deposits. Although not subjected to chemical analysis, field verification revealed high contamination in the lake floor from odor and color of collected sediments.

Pollution at the eastern shore is at its maximum for almost all parameters. This is in part to the slow circulation of water at the shore. The presence of a highly meandering coastline with several small bays helps magnify the problem. The sloping terrain from the east and the presence of several streams to the lake also contribute pollutants from this region into the lake. Both point and non-point pollution sources are found on the east side of the lake.

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ADDRESS FOR CORRESPONDENCE
Amin Shaban
Remote Sensing Center
National Council for Scientific Research
Beirut, Lebanon

Email: geoamin@gmail.com