Water quality assessment of Lebanese coastal rivers during dry season and pollution load into the Mediterranean Sea

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ABSTRACT

The chemical and microbiological properties of Lebanese perennial coastal rivers were studied during the dry season extending from July to September 2004. The results indicate significant levels of pollution in all eight rivers. Although many physical and chemical variables were within WHO guidelines for drinking water, coliform levels were unacceptably high indicating pollution from untreated sewage. The most polluted rivers in most categories were the Abu Ali and Antelias. With the exception of bacterial and phosphate loadings, Awali River provides the highest amount of pollution to the Mediterranean mainly due to its high water flow, although it is one of the least polluted rivers. The urgent need for controlling wastewater dumping into river streams is emphasized. The data obtained should serve as a reference point to assess the efficiency of planned wastewater treatment plants.

Key words | bacteria, dry season, Lebanon, perennial rivers, pollution

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INTRODUCTION

Lebanon is a Middle Eastern country that is blessed by significant water resources, unlike its neighbors. However, the rain is mainly concentrated in winter months. A significant portion of the rain falls on the western slopes, ranging from 892 mm on the coast and reaching 1210 mm at higher altitudes, as compared to 705 mm in Biqaa (Hajjar 1997) and all the way down to 200 mm in North Biqaa. Steep slopes, in addition to the fissured porous rock of the Lebanese mountains, result in significant losses of fresh water. As a result, of the total 8.8 billion m^3 of rainwater falling on Lebanon, only 2.2 billion m^3 are available for use (Qumair 1998). While water is abundant in winter, significant water shortages are still experienced around the country for the rest of the year. In addition, water quality in many areas is questionable. This has resulted in several outbreaks of disease mostly in the remote areas of the country.

Within the context of assessing water quality in Lebanon, some studies have addressed the water quality in spring water (Jurdi 1992) and others have addressed the Litani River water quality due to its strategic importance (Jurdi *et al.* 2001). In addition, some studies have addressed the heavy metals present in river sediments (Korfali & Davies 2003). Most of these studies have indicated varying levels of pollution and others have emphasized the importance of designing and implementing a complete water policy (El-Fadel & Zeinati 2000; El-Fadel *et al.* 2000; El-Fadel *et al.* 2001).

To face the problems of wastewater disposal, Lebanon has devised plans to initiate 20 coastal wastewater treatment plants that would serve 65% of the population of Lebanon. Several other small inland stations would raise the total number of stations built to around 100, serving 80% of the population by 2020 (Chedid 2004). These plants are expected to significantly reduce pollution levels in fresh water systems and in sea outfalls. Their total efficiency will be easily assessed by checking river water quality improvement before and after the plant construction. This study should present the worst scenario for water quality, since it deals with the dry season when pollutants are at a

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maximum. Actual plant operation is not expected to start before 2006. Several political and financial hurdles are still standing in the way of initiating these projects.

For a better understanding of Lebanese perennial coastal rivers' properties, a list of their names, length, and average annual flow is listed in Table 1. The main inland Litani River is named Kassmieh on its coastal stretch and the flow indicated refers to the total flow of the Litani River. The final section, considered from the point where the river makes a turn to the west (Figure 1), is called the Lower Litani and is reported to have a flow of 130 Mm^3/yr (Jaber 1993).

An increase in human population and urbanization in recent years has resulted in a gradual deterioration of water quality in the Lebanese rivers. Water diversion for power generation, abstraction for expanding irrigation projects and increased residential consumption is significantly reducing available water quantities. Water quality is being drastically affected by untreated sewage and industrial waste dumping, in addition to agricultural runoff.

Unfortunately, apart from the study conducted by El-Fadel & Zeinati (2000) which assessed the impact of waste disposal on water quality in nine major rivers in Lebanon in the month of November 1999, limited information on the chemical and microbiological qualities of Lebanese rivers have been collected and published. Because of this, the present paper aims to assess water quality at the outlet of perennial coastal rivers, which are listed in Table 1 from north to south, during the dry season (July to September). Figure 1 represents a map of Lebanon including major river basins. (El-Fadel & Zeinati 2000).

This paper aims to provide the most comprehensive picture of the status of the Lebanese coastal rivers to date. The importance of this work stems from the fact that it will provide baseline data necessary for assessing the efficiency of planned wastewater treatment plants across the country. In addition, it quantifies the pollutant loading into the Mediterranean, paving the way for a total evaluation of sea pollution emanating from river waters in Mediterranean countries.

SAMPLING AND ANALYTICAL METHODS

Sampling locations, collection and preservation

Samples were collected at river outlets within 1 km of outflow to the sea. This is with the exception of the Kabir River, which was sampled in the town of Hekr Addahiri close to the town of Sammaqiye, because of sea encroachment into its basin near the shore.

Water samples were collected in triplicates on a monthly basis during the dry season (July through September, generally in the middle of the month) using autoclaved bottles, which were previously washed by an acid solution (1:1 HCl / water) then by distilled water. Samples were generally taken at about one-third of the total depth below the surface of water where possible. After collecting, samples were stored at 4°C in an icebox and analyzed

Table 1 | Lebanese perennial coastal rivers' properties (Ecodit 2001)

Name	Length (km)	Catchment area (km^2)	Annual flow (Mm^3/year)
Kabir	60	297	190
Bared	23.5	288	282
Abu Ali	44.5	478	262
Ibrahim	30	310	508
Damour	37.5	304	307
Awali	48	230	299
Kassmieh	170	2168	793

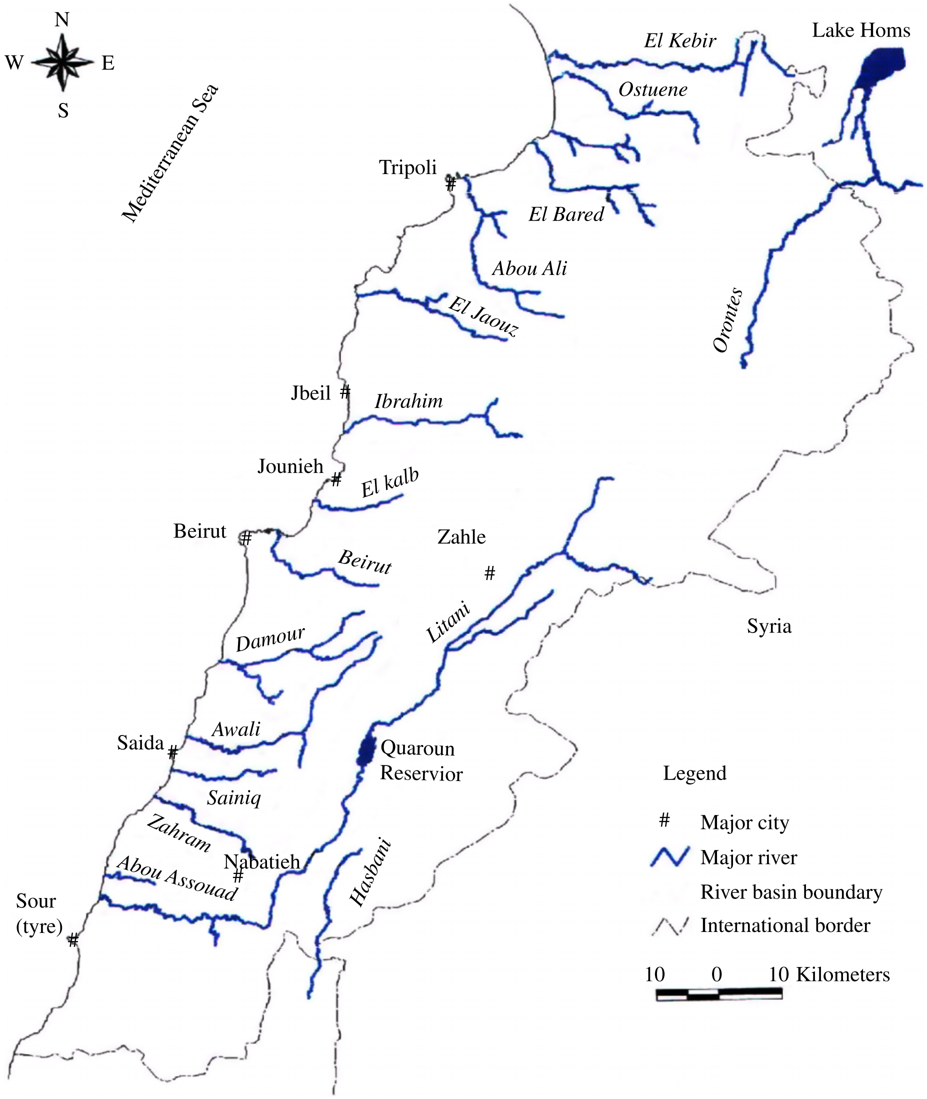

Figure 1 | Map of Lebanon showing major rivers. Reproduced from El-Fadel & Zeinati 2000 ©. Also published in El-Fadel *et al.* 2000 and El-Fadel *et al.* 2001.

within 24 hours. At the time of sampling, the river temperature and flow were taken.

Analysis of physical and chemical parameters

In the laboratory the level of dissolved oxygen (DO), % saturation, pH, conductivity, temperature, total dissolved solid (TDS), salinity, biological oxygen demand (BOD), nitrate, sulfate and phosphate were analyzed.

DO, % saturation, pH, conductivity, TDS and salinity are measured using sension 378 Laboratory Multiparameter meter from Hach. Nitrate, sulfate and phosphate measurements were done by Hach DR/2500 laboratory spectrophotometer using standard methods (Hach 2004).

Nitrate analysis by DR/2500 is done using method 8039 (Powder Pillows or AccuVac Ampuls). It is the cadmium reduction method (a technique-sensitive method). In fact cadmium metal reduces nitrates in the sample to nitrites. Nitrite ions react in an acidic medium with sulfanilic acid $(NH_2)C_6H_4SO_3H$ to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution. Test results are measured at 500 nm. (N.B: gentisic acid: 2,5 dihydroxybenzoicacid.) Results are in function of mg/l NO_3^--N.

Sulfate analysis by DR/2500 is done using method 8051 (Powder Pillows or Accuvac Ampuls). SulfaVer 4 method is based on the turbidity due to the presence of sulfate. Sulfate ions in the sample react with barium in the sulfaver 4 and form a precipitate of barium sulfate. The amount of turbidity formed is proportional to the sulfate concentration. SulfaVer 4 also contains a stabilizing agent to hold the precipitate in suspension. Test results are measured at 450 nm and the results are in function of mg/l SO_4^{2-}.

Phosphate analysis by DR/2500 is done using two methods: method 8190 (acid persulfate digestion method) phosphates present in organic and condensed inorganic forms (meta-, pyro- or other polyphosphates) must be converted to reactive orthophosphate before analysis. Pretreatment of the sample with acid and heat provides the conditions for hydrolysis of the condensed inorganic forms. Organic phosphates are converted to orthophosphate by heating with acid and persulfate. This method must be followed by one of the reactive phosphorus (orthophosphate) analysis methods for determining the phosphorus content of the sample. The method 8048 is the second method used (Powder Pillows or AccuVer Ampuls), it is a phosver 3 (ascorbic acid) method: Phosphorus active (orthophosphate) reacts with molybdate in an acid medium to produce a mixed phosphate/molybdate complex. Ascorbic acid reduces the complex giving an intense molybdenum blue color. Test results are measured at 880 nm and the results are in function of mg/l PO_4^{3-}.

Microbiological analysis

For microbiological analysis, *E. coli* and total coliform counts were performed with membrane filtration methods (m-ColiBlue24). In 24 hours, Hach's m-ColiBlue24 broth gives simultaneous results for total coliforms and *E. coli*. *E. coli* colonies are shown in blue while the rest of the coliforms are shown in red. For some rivers, dilutions were made to make the count more feasible.

RESULTS

This work assesses the quality of eight coastal rivers that were still running in the dry season. Five rivers are north of the capital city Beirut while three others were south of the capital. In the tables below, rivers are listed in order from north to south. Special emphasis is made on the monthly variations within each river system. Although not showing on the map, the Antelias River flows into the sea between the Beirut and Kalb Rivers. It is important to note that the Awali River near the coast is mainly the outflow of power generating facilities working on water diversion from Qaraaoun Lake made by damming the Litani. Accordingly, water quality assessed would more accurately describe Qaraaoun Lake water quality rather than that of the Awali River. Tables 2 and 3 indicate the physical properties of the rivers studied.

According to Table 2 all the Lebanese rivers have basic waters with Damour being the most basic while Kassmieh and Antelias are the least basic ones. This is in line with the fact that limestone is abundant in river basins. With the exception of Damour, all the pH values lie within WHO (2004) limits for drinking water (6.5–8.5). The pH values obtained for Abu Ali compare well with the results reported by Massoud *et al.* (2004).

On average, Damour is the warmest river (28.2°C) while Awali is the coolest one (21.6°C). This could be attributed to the slow moving waters of Damour that are well exposed to the sun resulting in warmer waters and the fact that the Awali River waters are practically piped in from a height of 900 m from the Qaraaoun Lake in the Biqaa valley.

The temperature values obtained for Awali are significantly lower than those reported by Jurdi *et al.* (2002) for the Qaraaoun Lake: 25.9°C. However, further analysis of the data obtained for Qaraaoun, show a significant and sustained drop in temperature as the authors progressed towards the dam and the deeper end of the lake. When considering that water for the Awali is being taken from the bottom half of the lake, the temperatures obtained are quite reasonable. PH values obtained in Awali are higher than the reported 7.43 for Qaraaoun, while DO values are close to the reported average of 6.52 mg/l with the water movement through the turbines expected to increase the DO level.

Dissolved oxygen levels and % saturation shown in Table 2 indicate that Abu Ali and Antelias have a low saturation value but Damour has the highest one. These unusually high levels of DO in Damour could be due to increased algal growth, producing oxygen from

Table 2 | River temperature, pH values, dissolved oxygen and saturation for Lebanese coastal rivers during dry season

	July				August				September			
River	pH	T (°C)	DO (mg/l)	% sat	pH	T (°C)	DO (mg/l)	% sat	pH	T (°C)	DO (mg/l)	% sat
Kabir	8.32	28.4	5.70	64	8.30	28.5	6.75	79	8.26	24.4	5.64	68
Bared	8.42	24.9	6.90	78	8.35	25.0	6.97	82	8.45	24.0	7.28	89
Abu Ali	8.37	22.0	5.55	63	8.06	23.5	4.40	51	8.28	21.5	6.15	75
Ibrahim	8.34	21.5	7.05	80	8.41	24.5	6.94	81	8.38	19.5	6.70	83
Antelias	8.01	22.0	5.84	65	8.06	22.5	5.10	60	7.97	21.0	4.33	54
Damour	8.98	30.5	7.05	79	8.60	25.0	8.31	93	9.09	29.0	10.37	100
Awali	8.18	20.7	6.00	66	8.17	21.5	7.24	80	8.15	22.5	7.40	82
Kassmieh	8.20	29.4	6.15	68	8.06	28.4	8.53	94	7.73	25.0	6.84	76

photosynthesis (Ho *et al.* 2003). Similar results have been obtained by Tare *et al.* (2003) on the Ganga River in India showing increased DO levels due to photosynthetic activity despite high organic pollution levels. Such is probably the case for the Damour River which was clearly rich in algae. On the other hand, Abu Ali and Antelias seem to be overloaded with pollutants. The short river run between sources of pollution and the river outfall could be preventing algal growth from re-enriching the water with oxygen.

BOD values (Table 3) show a significant decrease for Abu Ali, Ibrahim and Antelias between August and September while remaining relatively stable for the other rivers. Conductivity of the studied rivers, as shown in Table 3, is relatively stable across months: less than 13%

Table 3 | BOD, conductivity, and flow for Lebanese coastal rivers during dry season

	BOD (mg/l)		Cond (μs/cm)			Flow in m^3/sec		
Rivers	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep
Kabir	14.4	12.8	550	548	551	5	4.3	6
Bared	28.2	20.9	456	470	469	2.3	2	3.4
Abu Ali	39.3	14.7	498	604	561	7.2	3.3	2.3
Ibrahim	62.8	25.2	338	328	356	2.5	2	1.4
Antelias	53.2	23.2	638	569	625	1.32	1	0.6
Damour	21.3	24.9	370	421	384	0.2	0.1	0.4
Awali	33.4	27	462	410	372	9.8‡	9.1‡	9.1
Kassmieh	22.5	28.8	576	608	590	0.3	0.2	0.3

‡Values obtained from the Litani River authority.

difference between months, with the exception of Abu Ali which differs by 17.6% between July and August. The variation of TDS is presented in Figure 2. The lowest average TDS value for the dry season was obtained in Ibrahim (164 mg/l) while the highest was for Antelias (296 mg/l). All of these levels are within WHO acceptable limits for drinking water (<600 mg/l).

In order to complete the river description, river flow was measured at the sampling points and the results are shown in Table 3. Most rivers are actually slow moving streams in the dry season with the exception of Awali, which as mentioned before, is actually fed by the hydropower plant utilizing Litani River waters.

The nitrate, sulfate and phosphate levels were quantified and Figure 3 represents the values obtained for all rivers during the dry season. As shown in Figure 3, nitrate levels were highest in August for most rivers and then it drops again in September. This could be attributed to increasing agricultural fertilizing activities between July and August, which then decrease towards the end of the summer, resulting in a lower nitrate loading of river basins. Awali and Kassmieh are the richest in nitrates while Ibrahim has the lowest recorded level. This is in line with the fact that Ibrahim has increased industrial activity in its basin as compared to the mostly agricultural activities lining the paths of the other rivers (Ecodit 2001).

Sulfate analysis shows that Ibrahim has the lowest level while Damour has the highest. Although sulfate levels above 250 mg/l may alter the taste of water, no limiting guideline has been set by WHO. Nevertheless, none of the analyzed rivers exceeded the 40 mg/l sulfate level. Also, as shown in Figure 3, minimal variations between months are observed.

Phosphate levels (Figure 3) show a drastic difference between Abu Ali and Antelias vs. the other rivers. These results more accurately describe river status than those of nitrate and sulfate, since these two rivers are mainly constituted of untreated out-flowing wastewater. This fact is readily observed from water foulness at the sampling points. These conclusions are supported by the bacterial test results shown in Table 4. Significant levels of total coliform and *E. Coli* are found in all rivers, but the highest levels are obtained in Abu Ali and Antelias. The rivers to the south (Damour, Awali and Kassmieh) have consistently lower bacterial levels than the rivers to the north of Beirut. This fact may be attributed to the higher population concentrations to the north with the cities of Beirut, Jounieh, Byblos, Batroun, and Tripoli almost lining up one after the other all along the coast. This overall presence of *E. Coli* is a direct result of the

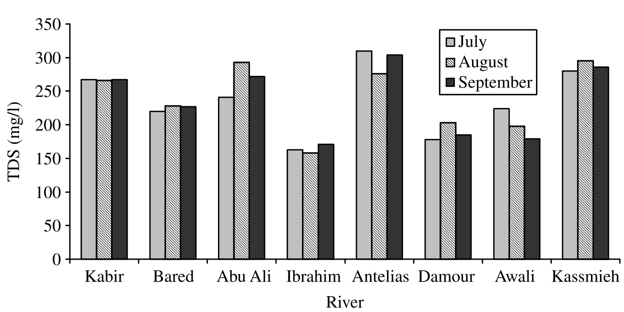

Figure 2 | Variation of TDS during the dry season.

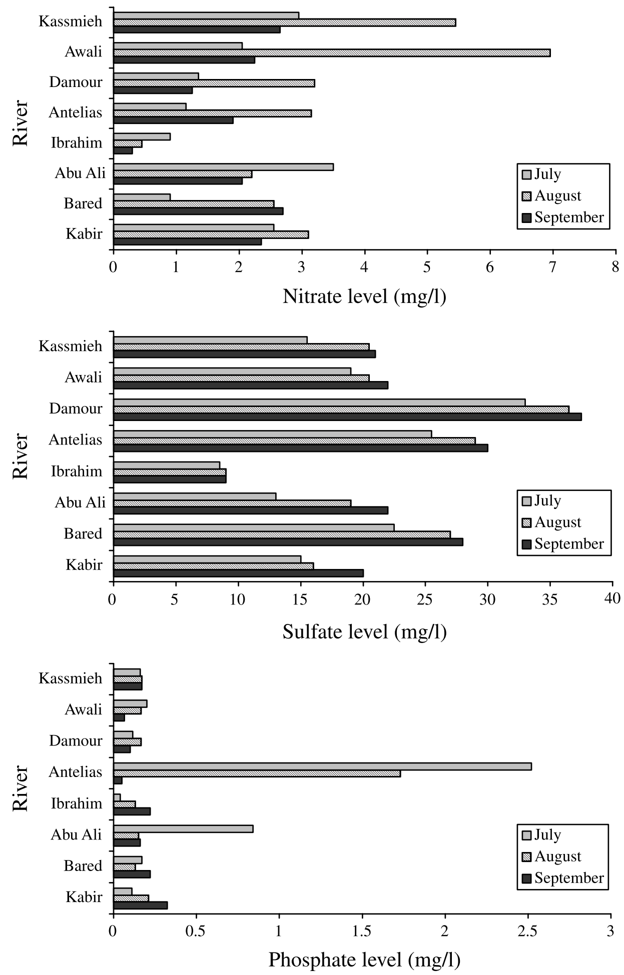

Figure 3 | Nitrate, sulfate and phosphate levels for Lebanese rivers during the dry season.

Table 4 | Bacteriological results in coastal rivers during the dry season

	CFU/10 ml					
	July		August		September	
River	Total coliform	*E. coli*	Total coliform	*E. coli*	Total coliform	*E. coli*
Kabir	230	10	900	20	77	10
Bared	350	90	610	17	70	20
Abu Ali	12,000	5,000	26,500	3,000	1300	200
Ibrahim	4,900	50	3,500	200	60	3
Antelias	105,000	3,400	28,000	6,000	11,000	5,000
Damour	470	6	490	15	110	4
Awali	140	0	710	1	40	1
Kassmieh	40	9	80	0	290	10

fact that, to date, wastewater is still flowing untreated into rivers and valleys across the Lebanese territories.

DISCUSSION

With increasing global warming, rain levels are being reduced in marginal countries to which Lebanon belongs. Increasing population is resulting in significant water shortages all around the country and Lebanon needs to turn to maximum efficiency in the use of its available resources of fresh water. This need is more pronounced during the dry months of the summer. This study indicates that despite the lack of wastewater treatment plants, the pollutant levels of all rivers remain within acceptable WHO limits for drinking water. According to Prat & Munne (2000), even with the presence of water treatment plants, excessive use of river water and the lack of natural flow are hindering the natural biological recovery of river waters. Eutrophication was obvious in many of the studied rivers and according to Dassenakis *et al.* (1998), nitrate and phosphate levels were found to decrease because of an elevated rate of consumption by plants aided by low water flow. This could drastically reduce the effect of remote suburban population centers on river pollution levels. Unfortunately, high population density in the coastal areas, land cost and offensive odors close to population centers would be major barriers to the implementation of any constructed wetland design or the application of any open channel system for natural wastewater treatment there.

Our results for the Abu Ali River are comparable to those obtained by Massoud *et al.* (2004). The river flow in our case seems to be higher resulting in slightly lower overall pollution levels in most categories. This is with the exception of the significantly higher BOD levels in August.

Jurdi (1992) indicated that between 50 and 72% of potable water sources in Lebanon, including springs, wells, storage tanks and networks, do not conform to the WHO standards for bacterial contamination in the dry season. Some of the related values are those indicated for springs in the dry season giving: 17°C, 507 μs/cm, 1.8 mg/l nitrate, 11 mg/l sulfate, and 0.23 mg/l phosphate. Our results indicate that most of the rivers studied have higher levels of pollution due to sewer water addition before they reach the sea.

In order to evaluate the inflow of pollutants to the Mediterranean, Table 5 shows the input per second for each of the studied rivers. These results show that despite being one of the least polluted rivers, Awali provides the highest level of pollution to the Mediterranean due to its high flow,

Table 5 | Pollutant loading from active coastal rivers in the dry season

Rivers	BOD (g/sec)	Nitrate (g/sec)	Phosphate (g/sec)	Sulfate (g/sec)	TDS (g/sec)	E.Coli * 10^{-5} (CFU/sec)	Coliform * 10^{-5} (CFU/sec)
Kabir	69.4	13.6	1.1	86.7	1,360	68	2052
Bared	63	5.3	0.4	66.3	578	109	881
Abu Ali	115.1	11	1.6	76.8	1,146	11,662	56,604
Ibrahim	86.5	1.1	0.3	17.4	322	166	5,546
Antelias	37.3	2	1.4	27.5	290	4,693	46,928
Damour	6.8	0.4	0.03	8.3	44	2	83
Awali	281	34.9	1.3	191	1,863	6.2	2759
Kassmieh	5.4	1	0.04	5.1	76.5	2	36
Total	664.5	69.3	6.17	479.1	5,679.5	16,708.2	114,889

with the exception of Coliform bacteria and phosphate. Some of the most significant results obtained indicate a total loading of 5.7 kg/s of dissolved solids in addition to 0.48 kg/s of sulfate. The supply of 16,708 CFU/sec of *E. coli* is also very significant. It is expected that with the installation of wastewater treatment plants these numbers should be significantly reduced.

The pollutant loading into the Lebanese Mediterranean beaches has resulted in many of them being declared unsuitable for swimming despite the significant dependence on tourism existing in Lebanon. This shore evaluation is presented annually by the local magazine *Environment and Development*. However, due to the lack of government control and awareness on the part of bathers, swimming is still taking place in most polluted locations with significant adverse effects on swimmers. The acute effects are manifested in skin diseases while the long term effects lack the methodological long term studies to evaluate the extent. The most significant levels of pollution are generally observed near the river mouth. This study in combination with pollution level studies (especially bacterial ones) in the sea can help pinpoint the pollution point source so that appropriate measures can be taken to deal with the most urgent ones.

Most of the microbial pollution is attributed to human fecal matter. This is due to the fact that Lebanon is one of the most densely populated countries. Animal farms in the coastal regions are not very common and their contribution was not evaluated. Their specific impact was not within the scope of the current study.

While this study has assessed the water quality in perennial coastal rivers, further work is needed to assess the levels of heavy metal pollution before these waters can be redirected for human consumption. With the lack of major heavy industries in the Biqaa area, current studies aimed at channeling the Awali River waters to supply domestic water to Beirut seem to be a suitable solution for the time being. The water loss in the Awali River basin will only affect 1–2 km of its basin near the river mouth. While further work on damming other rivers and capturing their waters should be initiated as soon as possible, if water needs for the growing population are to be met, the environmental concern must still be taken into account before the construction of such projects.

CONCLUSIONS

- The waters of all perennial Lebanese Coastal rivers were found to be clearly polluted with faecal coliform indicating significant raw wastewater input.
- Nitrate, sulfate and phosphate levels are generally within acceptable WHO limits.

- A baseline set of data has been presented that would serve to assess future improvements made by wastewater treatment plants.
- The need to properly use all available fresh water resources is emphasized.
- A detailed analysis of monthly variations of various parameters is presented covering the dry season.
- Antelias and Abu Ali were found to be the most polluted rivers.

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