Land use Impact on the Spatial and Seasonal Variation of Contaminant Loads to Abou Ali River and Its Coastal Zone in North Lebanon

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Abstract

Assessment of contaminant loads to surface water bodies is important for the proper use and management of these water resources. Many pollution assessment studies have focused on heavily polluted rivers of industrialized countries as well as major rivers in other less developed countries. Studies concerning relatively small rivers in developing countries are rather limited although water quality in such rivers may be impacted by human activity and land use patterns resulting in considerable ecological changes. This study assesses the land use impact on water quality in the Abou Ali River Basin and its coastal zone in North Lebanon, based on multiple indicators, primarily concentrations of nutrients, metals and pesticides. The assessment was conducted during the dry season in 2002 and wet season in 2003. The water quality of the Abou Ali River is not significantly degraded (as generally perceived) and exhibits slight seasonal differences in the interaction between land use and water quality. The worst water quality is apparent in the Tripoli area where the total pollution of the upstream flow accumulates exacerbated by local wastewater discharge. The steep profile of the Abou Ali River flushes contaminants towards the estuary and the sea. Future work requires the development of the approach that assists in evaluating current and future environmental conditions at a river/estuary/sea interface within a rigorous framework.

Keywords: *Abou Ali River, water quality, coastal zone, land use impact.*

1. Introduction

Water issues in most developed countries are currently related to aquatic ecosystem protection, risk-based toxicity and effects assessment at the organism level, endocrine disruption and the synergistic and cumulative effects of toxic contamination (Rabeni and Wang, 2001; Gomes and Lester, 2003; Janssen *et al.*, 2003; Soldan, 2003). On the other hand, developing countries are still faced with issues such as fecal contamination and impacts on public health. Moreover, developing countries suffer from the 1) lack of human and financial resources and 2) ineffective and outdated institutional frameworks (Massoud *et al.*, 2003). National priorities are invariably focused on economic development, often at the expense of the environment. The lack of resources prevent planning agencies and local authorities from collecting comprehensive land use and water quality data which in turn hinders the optimal utilization of surface waters. In this context, numerous

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studies have focused on heavily polluted rivers in industrialized countries as well as major rivers in other less developed countries. In contrast, relatively small rivers in developing countries are rather limited although water quality in such rivers may be impacted by human activity and land use patterns resulting in considerable changes (Papakonstadinou and Beltsios, 1996; Dassenakis *et al.*, 1998).

Freshwater ecosystems and coastal areas are increasingly at risk from pollution impacts on a global scale with land-based discharges being the preponderant pollution source (Greiner *et al.*, 2000; Storelli *et al.*, 2001; Wells *et al.*, 2002). Most watersheds encompass various land uses such as residential and commercial development, recreational and agricultural activities, manufacturing and industrial processing and each has an impact on water quality (Johnson *et al.*, 1997; Jarvie *et al.*, 1998; Sliva and Williams 2001; Wang *et al.*, 2001; Albek, 2003; Meador and Goldstein, 2003; Ren, 2003). Along coastal regions, surface water drains to one outlet in a watershed eventually reaching an estuary. Thus, upstream land-based activities affect the water quality at that point. Chemically or biologically contaminated rivers have negative impacts on coastal zone communities. Although water quality studies have been conducted at a basin level for a long time, most of these studies focus on areas in the vicinity of pollution sources or use mathematical models to estimate pollutants loading from non point sources (Payraudeau *et al.*, 2001; Liu *et al.*, 2003). Considering the complex interactions between land use, rivers, and associated coastal zones, an integrated approach incorporating environmental, socio-economic, institutional, and legislative aspects is essential (Bhuyan *et al.*, 2003).

2. Situation and Problem Statement

Water pollution is a problem confronting many developed and developing countries and Lebanon is no exception (Massoud *et al.*, 2003a,b). As there is currently no treatment of industrial waste effluents or community sewage in Lebanon, these effluents are discharged to surface, coastal, or ground waters, or used for irrigation. In addition, municipal and hazardous solid waste management remains inadequate in many areas in the country. As a result, the pollution of water resources is continuously increasing with population growth and industrial development without adequate control measures and proper management practices. In a preliminary characterization of Lebanese coastal waters and rivers, wastewater discharge and solid waste disposal were identified as the two most predominant and damaging activities to the socio-economics and environmental conditions (El-Fadel *et al.*, 2000). The survey revealed that the area along the coast of Tripoli and El-Mina in North Lebanon showed the highest affected region due to such activities. In particular, the Abou Ali River is being used for the discharge of municipal and industrial wastewaters, and the uncontrolled disposal of municipal solid waste in the river proper as well as in a landfill located at the mouth of the river. As such, it was selected as the primary project area.

3. Objectives

The present research project falls within the framework of sustainable development that is linked with the:

- Mediterranean Action Plan (MAP) and revised Barcelona Convention

- Global Program of Action for the Protection of the Marine Environment against Land-based Sources of Pollution
- Principles of integrated coastal zone and river basin management

Considering the current environmental situation in the project area and the primary importance of the Abou Ali River to the future development in North Lebanon, a basin wide assessment of the river and tributaries during both dry and wet seasons along with a land use assessment were conducted. The objectives are primarily to identify the catchment priority areas or hot spots and determine the impact of land use practices that contribute most to Abou Ali River and its coastal zone degradation using chemical, physical and biological indicators. Ultimately, the project aims at developing planning and managerial instruments that are essential to the management and protection of the Abou Ali River basin and its associated coastal area.

4. Description of The Study Area

4.1. Characteristics of Abou Ali River

Similar to most river basins in developing countries (Bjorklund, 2001), the Abou Ali River Basin in Northern Lebanon is disturbed by human activities. Around 800,000 inhabitants live in its catchment and induce a wide range of river alterations. The area of the basin is estimated at 484 km^2 of which 97 percent is mountainous. The river is 44.5 km-long and its basin encompasses nearly 236 towns distributed among several administrative districts. The basin's major urban complex is Tripoli, the second largest Lebanese city, with about 350,000 inhabitants. Figure 1 depicts the administrative boundaries of the study area with its major towns. Historically, the region predominantly agricultural, but the last three decades have witnessed a rapid increase in urban construction at the expense of agriculture. The river crosses the coastal mountains in a narrow valley with steep profiles (1,850 m at the origin) and runs in its lower portion on a length of about 3 km through Tripoli and the flat coastal plain. The funnel shape of the basin makes it ideal for flooding in its lower portion. Indeed the river has flooded twice, in 1942 and 1955, causing extensive property damage and loss of life. As a result, by the end of 1968, the downstream river course was straightened and an artificial, near rectangular concrete channel was constructed with vertical lateral retaining walls (nearly 5 m high). The channel has a total length of 2.5 km and its width varies between 24 and 29 m. The channel capacity was designed for 1,500 m^3s^{-1}, which will allow the safe routing of a 1,000 year flood event in combination with the upstream detention basin (CES *et al.*, 1998). Populations along adjacent streets use the flood channel for wastewater discharge and littering resulting in the accumulation of refuse on both sides of the channel (JICA and CDR, 2001).

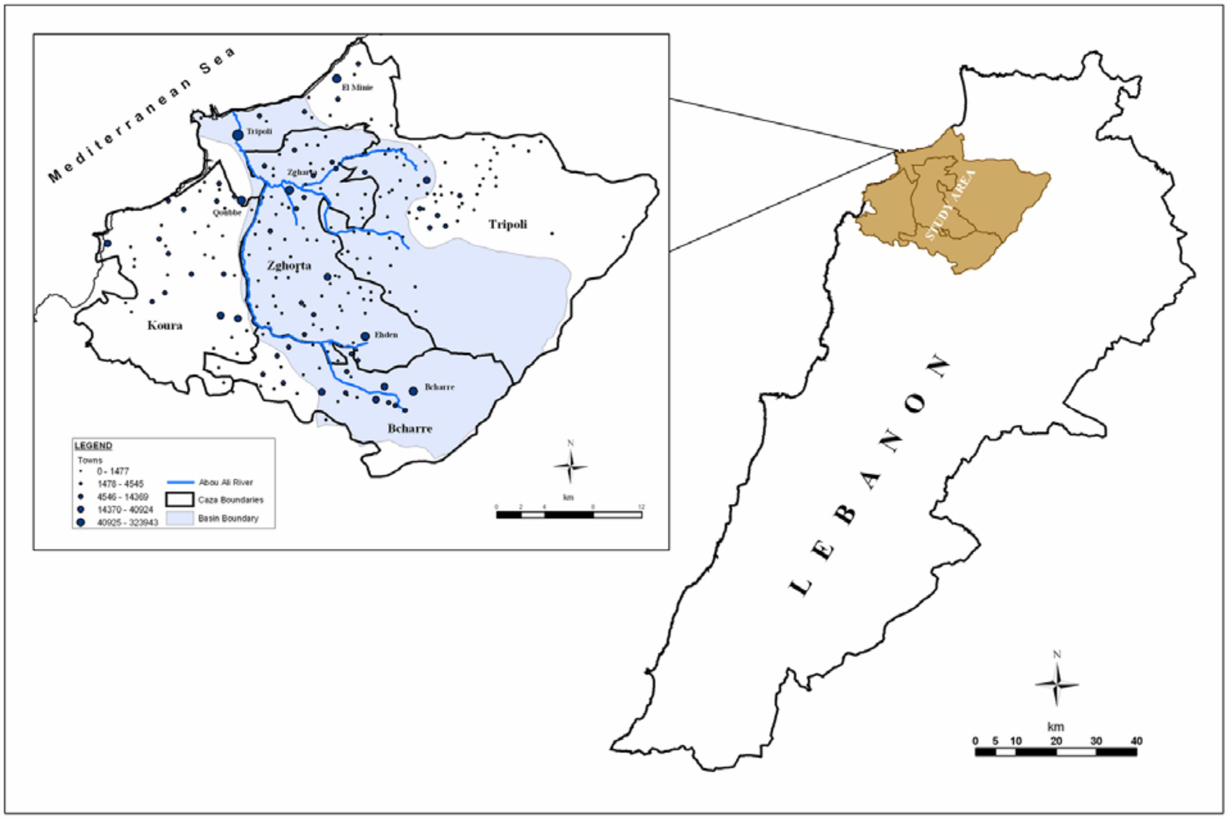


Figure 1. Administrative boundaries of the study area with its major towns

4.2. Land Use Patterns

Arable lands, forests, settlements and other spaces constitute the main land use categories in the Abou Ali river basin. Most agricultural land of the basin is located in the hinterland at more than 400 m above sea level. The land use is dominated by olive and citrus plantations at lower elevations and fruit bearing trees at higher altitudes (i.e. apples, cherries, apricots, peaches, etc.). Present industries include small facilities scattered throughout the study area comprising car repair workshops, food processing establishments, furniture and woodcrafts, and various commercial shops. Moreover, solid waste dumping sites are scattered throughout the area. Mining is not particularly developed and consists mainly of extracting construction materials (quarries). Figure 2 depicts major sites in the study area. The Northern area of the river mouth is targeted to become the industrial zone of the Tripoli district where a major wastewater treatment plant and waste disposal facilities will be constructed alongside various industrial facilities (CES, 1998). Table 1 presents a summary of the important water uses, climate and hydrogeology characteristics, and waste management practices in the Abou Ali River Basin.

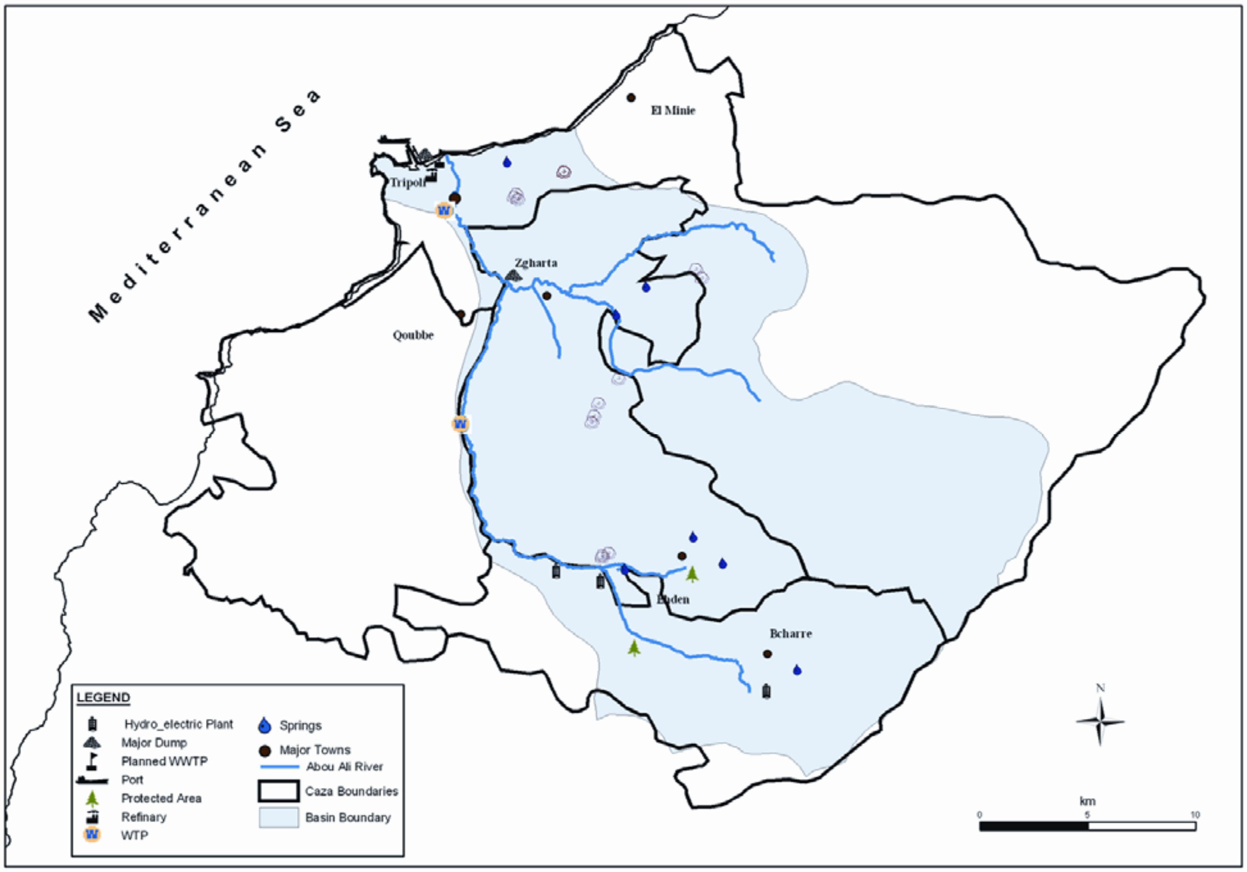


Figure 2. Major sites in the study area

Table 1. Summary of major uses, hydro-geology, climate, and waste management in Abou Ali river Basin (CES *et al.*, 1998; SOER, 2001; JICA and CDR, 2001)

Major uses	*Hydrogeology*
• Water supply, hydropower generation, irrigation, fishing, tourism and recreation, and ecosystem maintenance. • Two water treatment plants with a capacity of 40,000 and 5,000 m^3d^{-1}, respectively receive their water from the river and supply the Tripoli and Koura regions. • Three hydroelectric plants have been constructed along the river with a combined nominal capacity of 12.1 MW.	• The basin was formed by carboniferous deposits, during the Tertiary, Jurassic and Cretaceous periods. • Soils have mainly evolved from weathered rock and, to a lesser extent, volcanic material and accumulated plant residues. Most of which are base-saturated calcareous soils, except for the sandy soils formed on the basal cretaceous strata. • Flow constitutes about 7 to 12 percent of the total surface water flow of Lebanon with an annual flow rate of 8.32 m^3s^{-1} and total annual quantity of 262 MCM.
Climate	*Waste management*
• Mediterranean climate with moderately warm and dry summer and fall, and moderately cold, windy, and wet winter. • Almost 80 to 90 percent of its total precipitation occurs between November and March. • The months from June to September are generally very dry. • Scattered rainfall events begin to occur in October, increasing in intensity until peak wet season events from December to March. • The coastal plain is subtropical, with a mean temperature of 27°C in summer and 14°C in winter, and decreases approximately 3°C for each vertical 500m. • Mean annual rainfall is about 1,600 mm for the headwaters of the basin, decreasing to 700 mm from north to south. • The difference between day and night temperatures averages about 7°C. • Prevailing winds are from the West and Southwest, while winds from the East and Northeast occur less frequently (85 vs. 15 percent).	• At present, there are no wastewater treatment plants within the catchemnt area of the Abou Ali River. • There is no evidence of controlled and regular service for sludge disposal from cesspools or septic tanks. • Many settlements do not have a completed sewage collection network. • Existing networks discharge wastewater directly without prior treatment into the sea through pipelines and channels or indirectly via coastal streams. • The two most commonly employed practices of MSW management include open dumping and open burning. • Almost all municipalities practice industrial waste co-disposal with MSW. • In Tripoli, the average generation rate of solid waste is about 0.65 kg/capita/day, thus resulting in a total of 382 tons/day that have long been dumped (25 years) in an open area (65,000 m^2) on the mouth of the Abou Ali River encroaching more than 150 m into the sea.

5. Methodology

The study encompassed primarily the assessment of land use patterns and water quality implications. The emphasis was placed on field-based assessment, supplemented, where possible, with available secondary sources such as catchment study reports, environmental assessment studies, Geographic Information System (GIS) coverages, together with local knowledge.

5.1. Sampling Sites

Sampling activities covered Abou Ali River from the source to the mouth and was conducted during the dry season in 2002 and wet season in 2003. The results were analyzed in seasonal and spatial contexts in order to assess stream responses to runoff and low/high flow conditions. At first, a reconnaissance survey was conducted to define point and non-point sources of pollution and sampling locations. Sampling sites were chosen to serve as the best possible compromise between representativeness and operational constraints. Major selection criteria include:

- Mouths of major streams and tributaries
- Above/below land uses presumed to be sources of pollution
- Undeveloped tributaries and areas to provide spatial controls
- Readily and safely accessible
- Coverage of the river basin

In many locations it was difficult to collect samples particularly, the section of the river that flows in Tripoli due to the flood protection channel. A total of 19 samples were collected and labeled S1 to S19 (Figure 3). The average flow rate of the river for the month of October (dry season) is 0.8 m^3/sec and for the month of March (wet season) is 17.2 m^3/sec. Table 2 summarizes the general conditions encountered at each location.

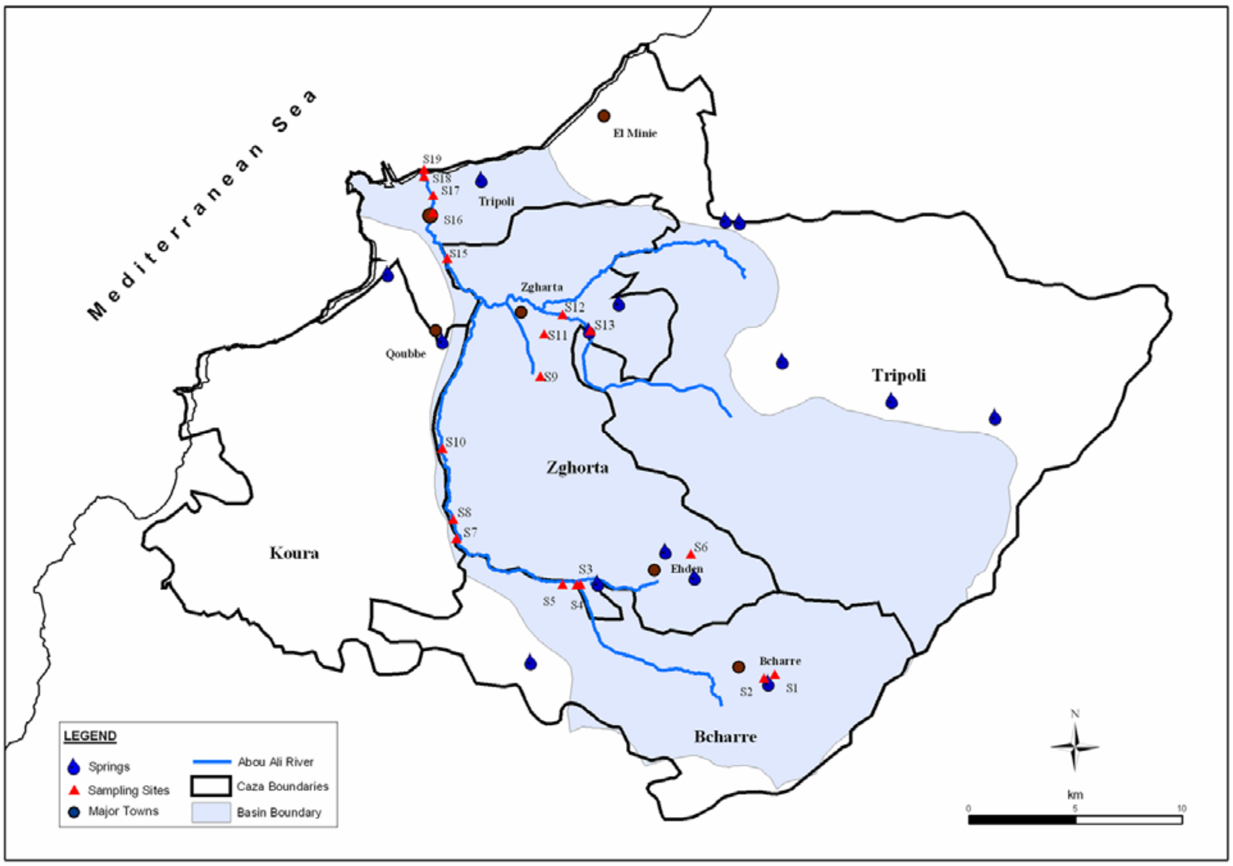


Figure 3. Sampling sites along Abou Ali River

Table 2. General description of the sampling sites

Site #	Description
1	Qaudisha Grotto, closed area, arable land
2	Downstream of the Bcherre hydroelectric plant, arable land
3	Upstream of the Blaouza hydroelectric plant
4	Blaouza hydroelectric plant, arable land
5	Downstream of Blaouza hydroelectric power plant
6	Mar Sarkis spring, recreational area (restaurants)
7	Upstream of the Abou Ali hydroelectric power plant
8	Downstream of the Abou Ali hydroelectric plant
9	Closed alcohol factory, 2 chicken slaughter houses and olive oil press, agricultural area
10	Olive trees, a pig farm
11	Agricultural area
12	Agricultural area and recreational area
13	Recreational area, agricultural area, low flow
14	Recreational area and agricultural area, low flow
15	Residential and agricultural area
16	Beginning of Tripoli
17	Midway of Abou Ali river in Tripoli
18	End of the river
19	Estuary (dump site)

5.2. Analytical Procedures

In preparation for water quality sampling, sampling and processing equipment were thoroughly cleaned. Equipment for trace element analysis was washed in dilute (0.1 percent) low phosphate soap and tap water, then rinsed with dilute (5 percent) nitric acid solution and deionized water. Organic-sampling and processing equipment was washed in the same manner with the addition of a final reagent-grade methanol rinse. Glass collection bottles were also washed in low phosphate soap and tap water, followed by deionized water, and dried out for 1-hour at 180^{o}C. One-time use polyethylene bottles were rinsed with stream water. Except during processing, all samples were kept refrigerated from the time of collection until analysis. Samples were transported to the American University of Beirut laboratories for chemical analysis. Water temperature, pH, Eh, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) were measured on site using a Hach Model 44600 Conductivity/TDS Meter and DO by membrane electrode method with a concentration range of 0.00 to 19.99 mg/l. Water samples were analyzed for constituents such as nitrate-nitrogen, ammonia-nitrogen, orthophosphate, chlorides, sulfates, alkalinity, total and calcium hardness, metals and orgnaochlorine pesticides. Metals were analyzed by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) following EPA method 200-8. Samples for pesticide analysis by gas chromatography/electron capture detector (GC/ECD) were further processed using USEPA method 505 for extraction. Table 3 lists the indicators measured and their units, the analytical techniques used, and the corresponding abbreviations.

Table 3. Analysis methods for various indicators (APHA-AWWA-WEF, 1998)

Parameter	*Type of analysis*	*APHA reference method*
PH	Potentiometry	4500-H^+ B
TDS	Potentiometry	2510 B
EC	Potentiometry	2510 B
BOD	Potentiometry	5210 B
COD	Closed reflux/Colorimetry	5220 D
Chlorides	Argentometric titration	4500-Cl^- B
Calcium hardness	EDTA[2] titration	3500 Ca D
Magnesium hardness	EDTA titration	3500-Mg E
Alkalinity	Acid titration	2320 B
Sulfates	Colorimetry	4500-SO_4^{2-}E
Nitrates	Colorimetry	4500-NO_3^- E
Ortho-phosphates	Colorimetry	4500-P E
Sodium	Flame emission photometry	3500-Na D
Potassium	Flame emission photometry	3500-K D
Fecal coliforms	Membrane filtration	9222D
Total coliforms	Membrane filtration	9222B
Pesticides	GC/ECD	EPA-508
Metals	ICP-MS[3]	EPA 200-8

[1] NA = Not Applicable
[2] EDTA = Ethylene diamine tetra acetic acid
[3] ICP-MS = Inductively Coupled Plasma-Mass Spectrometer

In order to estimate variability in sampling and laboratory techniques, quality control (QC) samples were submitted for analysis. Selected water samples were analyzed in duplicate to evaluate analytical precision. Spiked samples for both pesticides and metals were measured to test for accuracy. Blank samples were carefully selected to be free of the constituents of concern. For most metal analyses spiked samples' results agreed within 20 percent or better. Likewise the percent recovery of most standards was high. The results from duplicate analyses were averaged for use in this study (relative percent difference < 10%). Calibration blank and standards were run every 10 samples and at the end of the run with a percent recovery ranging between 95 and 110.

6. Results and Discussion

6.1. Seasonal Variation: Physical and chemical indicators of river water samples

No trend was observed in pH seasonal or spatial variations which is an indication of the lack of any systematic discharge of strongly acidic or alkaline wastes (Figure 4). The concentrations of dissolved oxygen ranged between 1.4 and 10.9 mgl^{-1}. A seasonal DO cycle in which concentrations are greater in the colder, winter months and lower in the warmer, summer months was observed. This can be attributed to lower stream flow during the summer that greatly affects reaeration which in turn affects DO values. Moreover, DO concentrations are reduced when an increase in temperature occurs as oxygen saturation levels are temperature dependent. The concentration of BOD_5 generally increased along the Abou Ali River (downstream) with slight fluctuations near agricultural and urban zones. Seasonal variations were most explicit in the estimates of COD (Figure 4) which can be attributed to increased stream flow and dilution during the winter.

The analysis has shown that despite the dilution effect, NO_3-N concentrations increase in high flow periods (Figure 4). This is likely the result of runoff after fertilizer application during the Fall season. Likewise, nitrate concentrations increase from upstream to downstream. Ammonia-nitrogen and orthophosphates levels are uniformly low during the wet season (Figure 4). Although not significantly evident, the concentration of sulfates and chlorides was also generally increasing downstream. Alkalinity and Ca hardness showed a relatively strong seasonal effect. The river water is moderately hard with total and calcium hardness ranging from 150 to 400 mgl^{-1} as $CaCO_3$ and 70 to 260 mgl^{-1} as $CaCO_3$, respectively. This can contribute to the slight variation in the chemical composition of the river's water during the year.

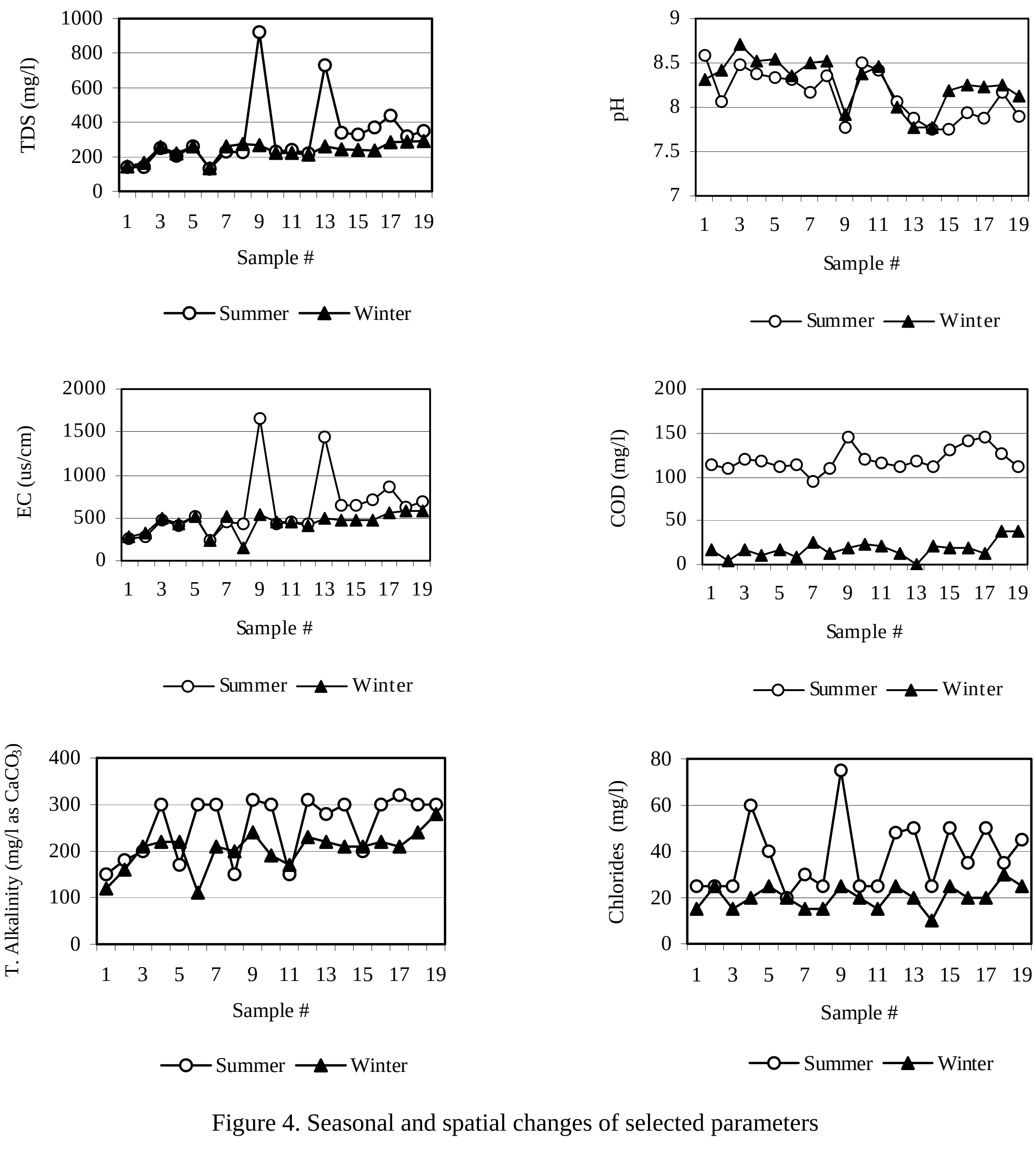


Figure 4. Seasonal and spatial changes of selected parameters

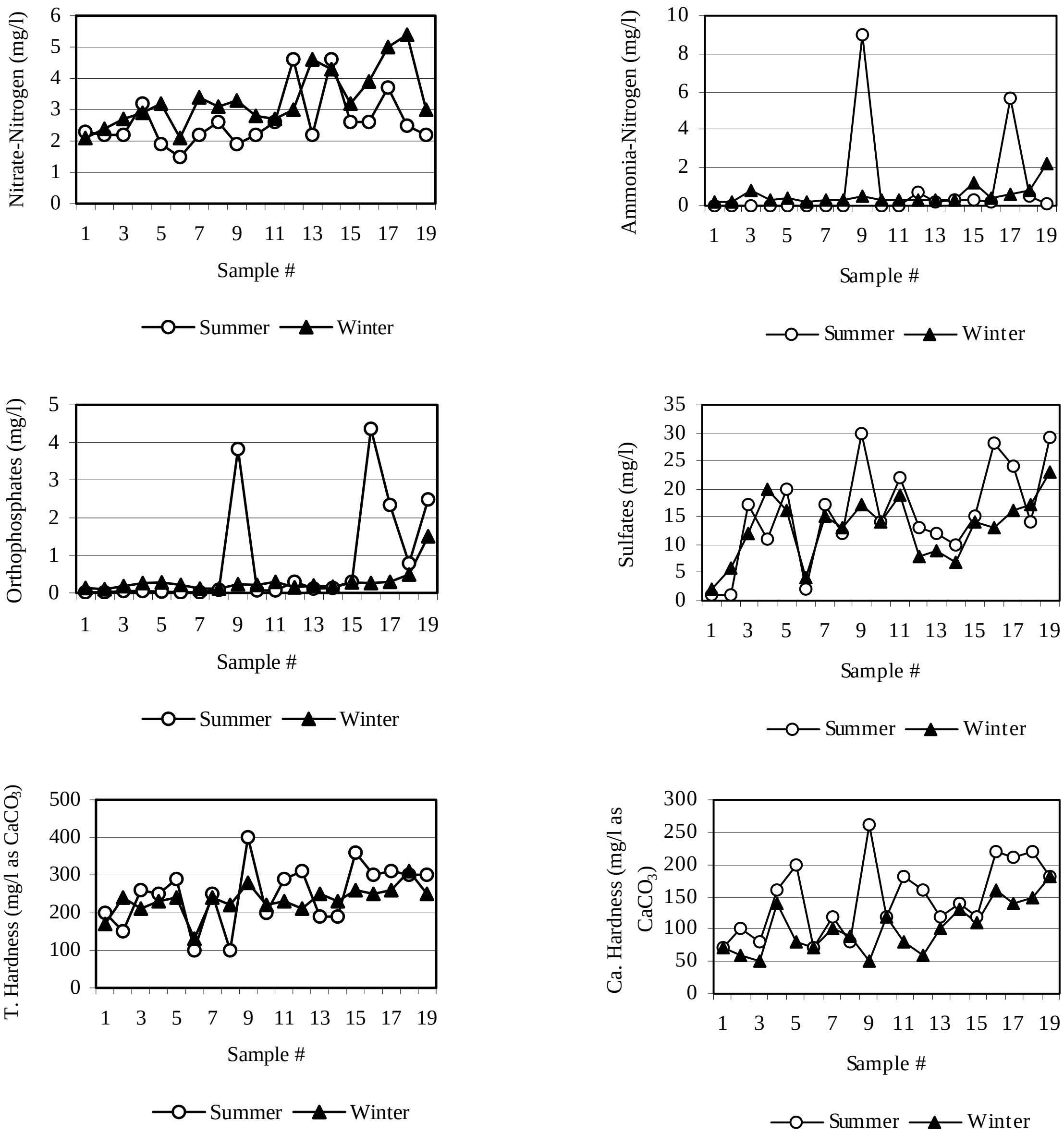
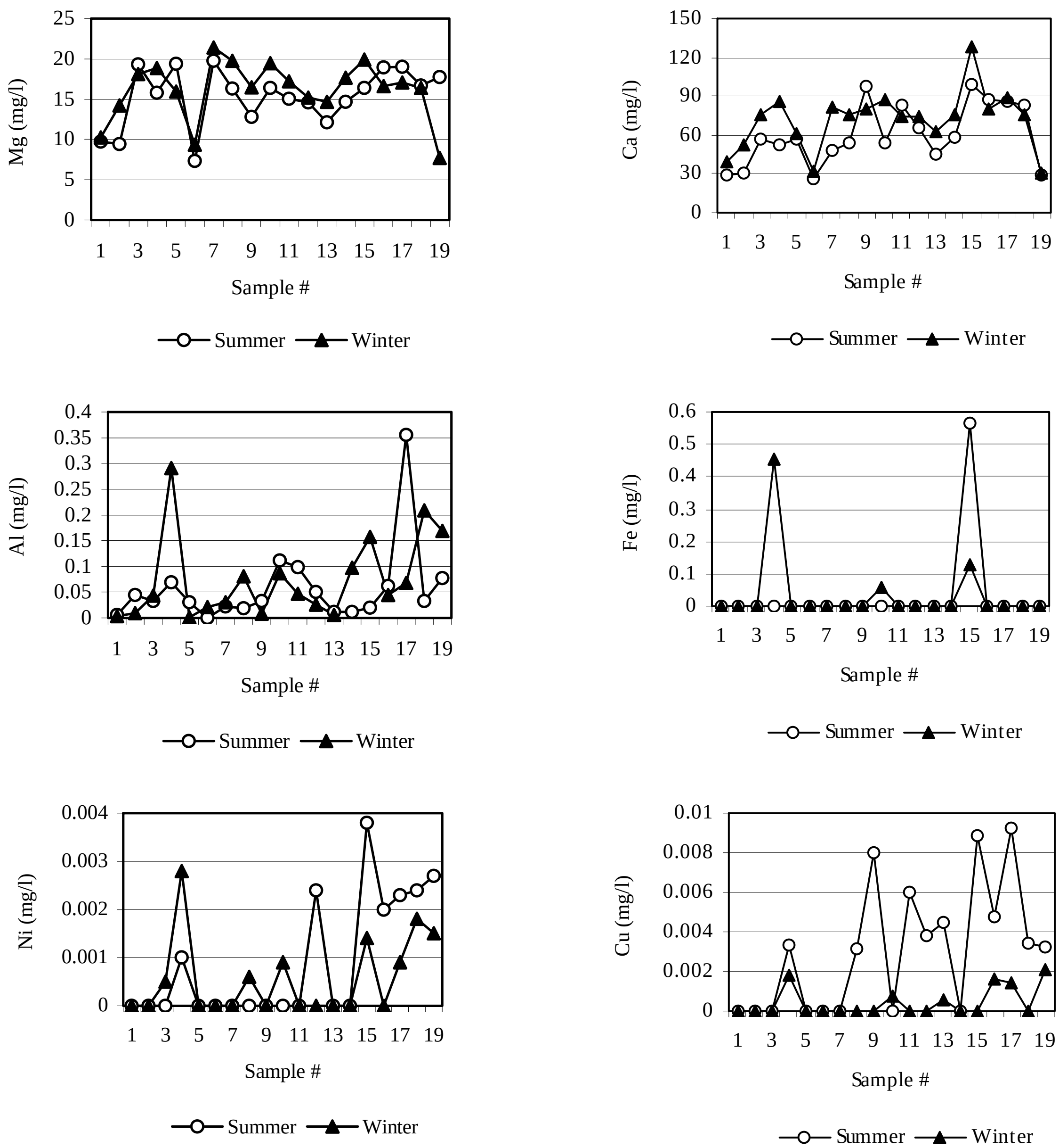


Figure 4. Seasonal and spatial changes of selected parameters (Cont'd)

The levels of metals in water exhibited slight spatial and seasonal variation although it's worth noting that exceptionally heavy rainfall events during the wet season in 2003 occurred. Seasonal variation was mostly significant for Cu and Zn (Figure 5). At high flow, Cu and Zn showed greater than 30 percent decrease at certain locations. There were no significant similarities in the distribution patterns of the various metals whish is attributed to the lack of heavy industries. Most pesticides analyzed were below the detection limit and 3 (Hg, As, Cr) out of the 18 metals were not detected. Traces of pesticides were encountered in some samples that are in close proximity to agricultural areas.



Mg (mg/l)
Sample #
Summer
Winter
Ca (mg/l)
Sample #
Summer
Winter
Al (mg/l)
Sample #
Summer
Winter
Fe (mg/l)
Sample #
Summer
Winter
Ni (mg/l)
Sample #
Summer
Winter
Cu (mg/l)
Sample #
Summer
Winter

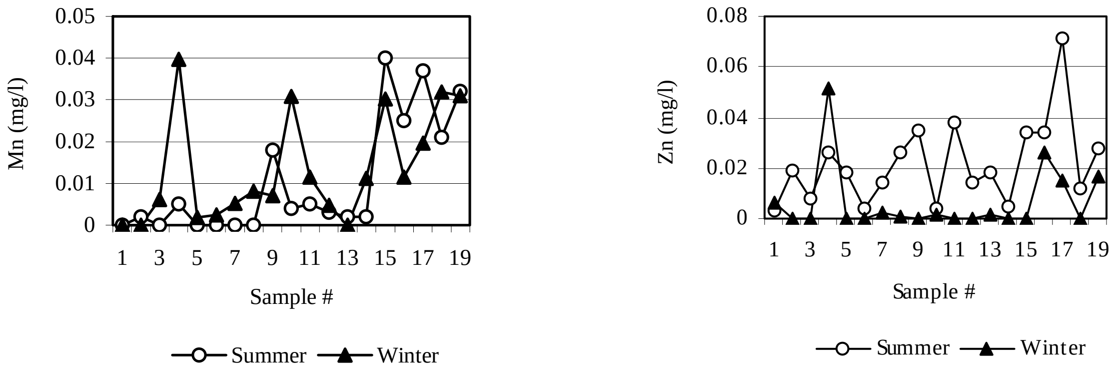


Figure 5. Seasonal and spatial changes of selected metals

6.2. Land Use and Water Quality Linkages

The determination of DO concentrations is a fundamental part of a water quality assessment since oxygen influences nearly all chemical and biological processes within water bodies. Concentrations below 5 mgl^{-1} may adversely affect the functioning and survival of biological communities and below 2 mgl^{-1} may lead to the death of most fish (Chapman, 1996). The results showed that DO levels were generally high probably due to the shallow rocky nature of the Abou Ali River which enhances aeration and hence saturation of water with dissolved oxygen. The lack of turbulent flow renders this process more difficult and may explain the observation of reduced values in some cases. Low values were detected at sites 9, 16, and 19 (Figure 6). The two chicken slaughter houses at site 9 in addition to the olive oil press might explain the measured low DO levels. The discharge of raw municipal wastewater on the outskirts of Tripoli (site 16) and likewise for site 19 where solid waste dumping exacerbates the problem might have resulted in low DO levels. The COD concentrations normally observed in surface waters range from 20 mgl^{-1} or less in slightly polluted waters to greater than 200 mgl^{-1} in waters receiving effluents. The level of COD in Abou Ali river water is relatively low due to the absence of heavy industry in the study area. Unpolluted waters typically have BOD values of 2 mgl^{-1} or less, whereas those receiving wastewaters may have values > than 10 mgl^{-1}, particularly near the point of effluent discharge. The levels of BOD_5 in the samples from the Abou Ali River ranged from 1.0 mgl^{-1} at the source (background sample) and 25.6 mgl^{-1} (Figure 7). Relatively high values were detected at sites 10, 16, and 19 primarily related to land use. The pig farm at site 10 could have contributed to the high BOD levels exacerbated by raw sewage discharge that is also the main contributor to elevated BOD levels at sites 16 and 19. Note that concentrations of most indicators at almost all sites were above natural background levels indicating human influence. Moreover, total (3500-880000 MPN/100ml) and fecal (1700-650000 MPN/100ml) coliform bacteria were detected at almost all sites indicating animal and/or human waste contamination.

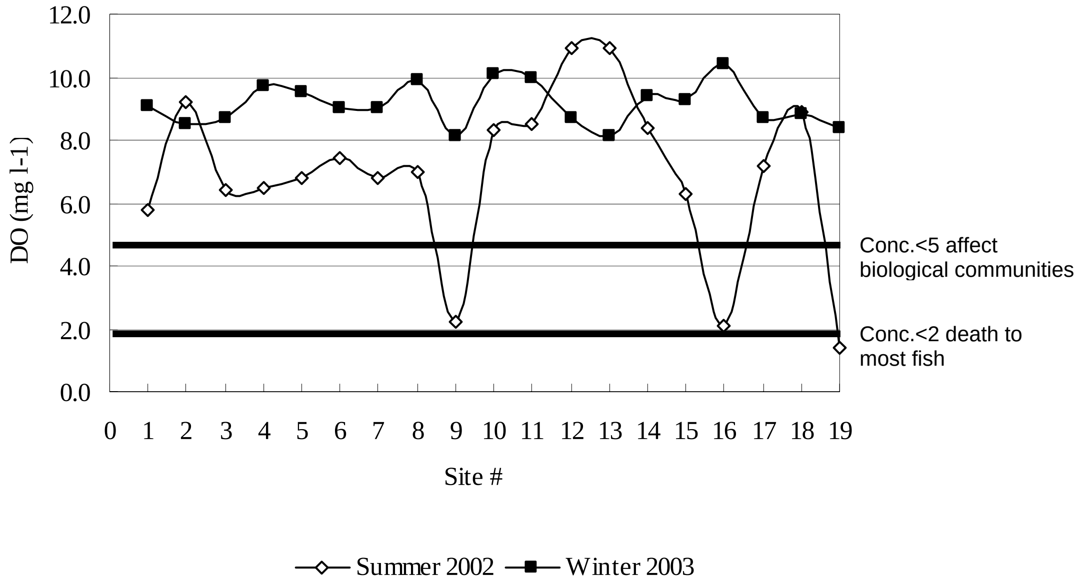


Figure 6. DO levels along Abou Ali River

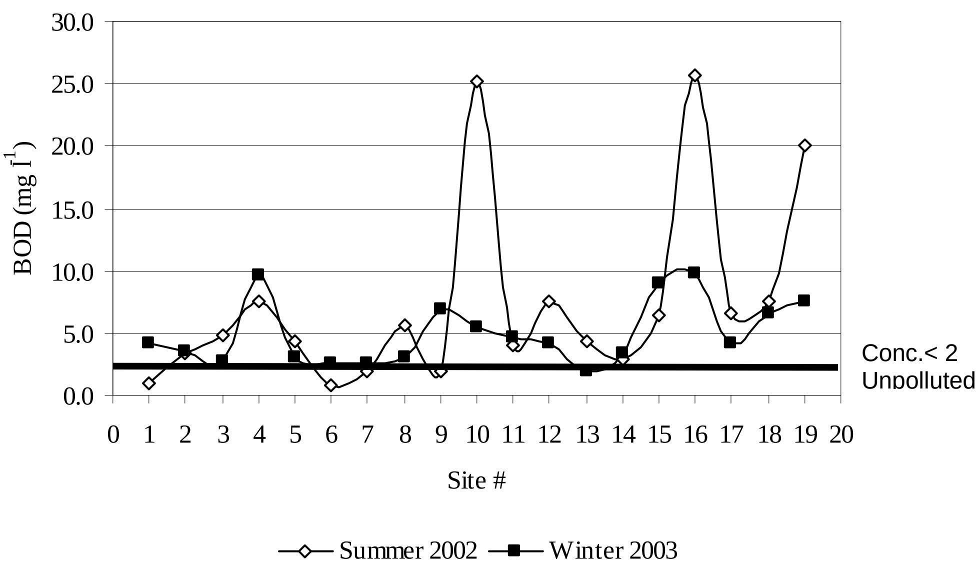


Figure 7. BOD levels along Abou Ali River

Anthropogenic activities influence the level of nitrates in surface waters leading to nitrate concentrations up to 5 mgl^{-1} NO_3-N, but often less than 1 mgl^{-1} NO_3-N (Chapman, 1996). Concentrations above 5 mgl^{-1} usually indicate pollution by human or animal waste. In cases of extreme pollution, concentrations may reach 200 mgl^{-1} NO_3-N. Concentrations above 5 mgl^{-1} NO_3-N were not detected in samples collected from the Abou Ali river with the exception of sites 17 and 18 at the end of the river in Tripoli (Figure 8). Ammonia occurs naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic compounds in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro-organisms and from gas exchange with the atmosphere. Total ammonia concentrations measured in surface waters are typically less than 0.2 mgl^{-1} but may reach 2-3 mgl^{-1} (Chapman, 1996). Higher concentrations could be an indication of organic pollution such as from domestic sewage, industrial waste and fertilizer runoff. Ammonia concentration did not exceed 2 mgl^{-1} along Abou Ali river with the exception of sites 9 and 17 (Figure 9) which is expected due to pollution by animal and human waste. Phosphorous is rarely found in high levels in freshwaters and typically ranges from 0.005 to 0.02 mgl^{-1}. Elevated concentrations of phosphates can indicate the presence of pollution and are responsible for eutropic conditions. Similar to ammonia, phosphorus was relatively high at site 9 and 16. Since phosphorus is an important component of detergents, the higher concentrations detected can be attributed to direct sewage discharge.

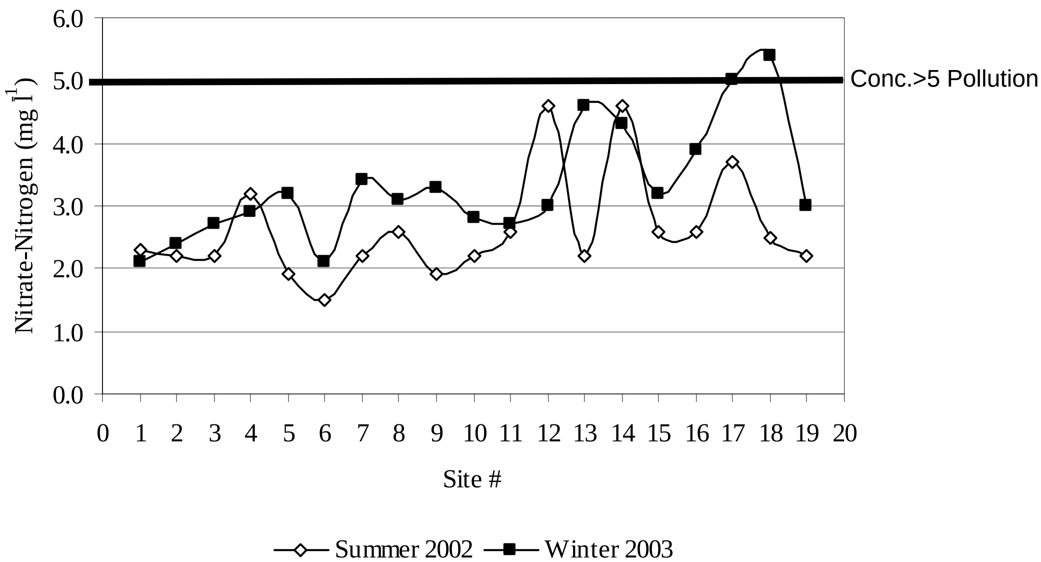


Figure 8. Nitrates concentrations along Abou Ali River

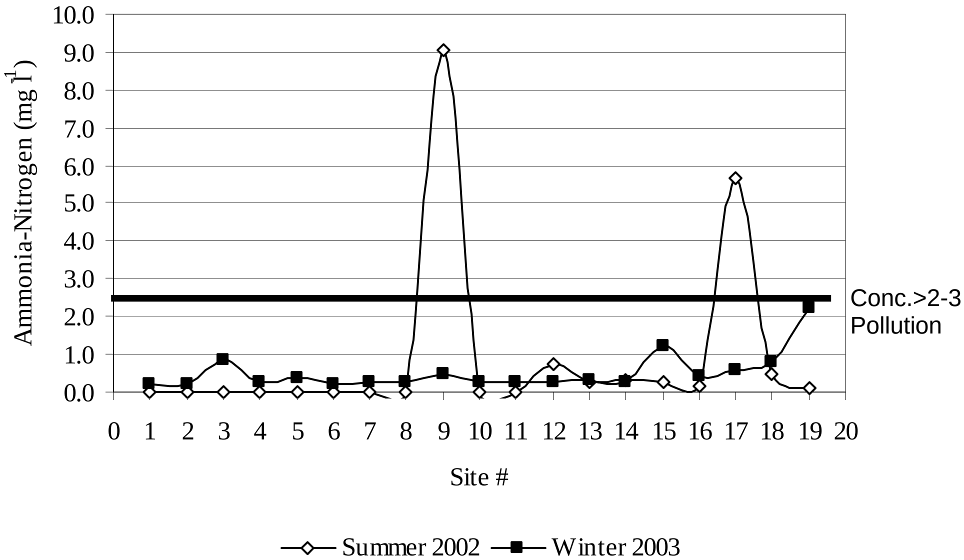


Figure 9. Ammonia Nitrogen concentrations along Abou Ali River

Considering that most of Abou Ali river is base-saturated calcareous soil mainly limestone, high concentrations of calcium ranging from 29.4 to 128.7 mgl^{-1} were detected. Magnesium is also common in natural waters and contributes to water hardness along with calcium. Natural concentrations of magnesium are also often incorporated into assessments as an indication of possible sewage contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies. In this study magnesium concentrations ranged form 7.35 to 19.8 mgl^{-1} with most sites exhibiting concentrations greater than the background level thus indicating human sources of pollution.

7. Conclusion

Although, it is not significantly evident from the chemical analysis results, it is still envisaged that the most polluted and endangered area is the river mouth and estuary. The pollution loads transferred by the river have been compounded by local pollution. The fact that Abou Ali River drops from 1,850m from its origin to where it joins the sea results in flushing contaminants towards the estuary and eventually ending in the sea. Considering the intrinsic link through the physical and ecological structure as well as related physical and biological processes, any modification in a river basin will ultimately affect the coastal zone. Despite the fact that the levels of most water chemistry parameters were fairly low and initial expectations that certain parameters would be correlated with land use or at least show some relationship, the trends witnessed so far, if continued in the future could result in further deterioration of the freshwater and marine ecosystems. Activities in upper parts of Abou Ali river basin may have a cumulative effect throughout the system the results of which may only become apparent over long periods. Very extensive, concentrated and continuous inputs of pollutants from point and non-point sources may overcome the inherent ability of the river to assimilate pollution. Future work requires the development of the approach that assists in evaluating current and future environmental conditions at a river/estuary/sea interface within a rigorous framework. Hence, integrated assessment of environmental conditions of Abou Ali River basin and its associated coastal zone linking land use, water quality measurements, environmental modeling and GIS is essential.

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