FACTORS INFLUENCING DEVELOPMENT OF MANAGEMENT STRATEGIES FOR THE ABOU ALI RIVER IN LEBANON I: SPATIAL VARIATION AND LAND USE

May A. Massoud[1, 2], Mutasem El-Fadel[3], Mark D. Scrimshaw[1] and John N. Lester[1*]

[1] *Environmental Processes and Water Technology Research Group, Department of Environmental Science and Technology, Faculty of Life Sciences, Imperial College London, London SW7 2AZ, UK*
[2] *Department of Environmental Health, Faculty of Health Sciences, American University of Beirut, PO Box 11-0236, Bliss Street, Beirut, Lebanon*
[3] *Department of Civil and Environmental Engineering, American University of Beirut, PO Box 11-0236, Bliss Street, Beirut, Lebanon*

Abstract

Surface water bodies are progressively subject to increasing stress as a result of environmentally degrading processes primarily related to anthropogenic activities. This study assesses and examines the impact of land use and anthropogenic activities on the spatial variation in water quality of the Abou Ali River in North Lebanon. It is the first detailed study of its kind in Lebanon and adds to the existing Knowledge by shedding light on a relatively small Mediterranean river in a developing country where there is a paucity of such studies. The assessment was conducted at the end of the dry season in 2002 and 2003 and the end of the wet season in 2003 and 2004. The study has demonstrated the importance of anthropogenic influences on the water quality of the Abou Ali River Basin, as concentrations of most contaminants were higher at locations with greatest human activity. The most adversely affected area was the section of the river that flows through an entirely urbanized and highly populated region, the Tripoli conurbation. Upstream rural sites were enriched by contaminants primarily from non-point sources such as agricultural runoff and poultry litter whereas contaminant concentrations at the urban sites were enriched by a combination of sewage discharge and flow of contaminants from upstream. If the Abou Ali River is to be utilized as a managed water resource and its water quality sustained, point source discharges will require treatment and land use management must be planned to minimize the impact of diffuse source pollution on the river. A high priority should be given to the implementation and enforcement of the precautionary and polluter pays principles. Moreover, an effective legal, economic and institutional framework is required to encourage investment in waste reduction and control and to introduce environmentally sound practices.

Keywords: Water quality, spatial variation, land use, management, Abou Ali River, Lebanon.

* Corresponding Author: Environmental Processes and Water Technology Research Group, Department of Environmental Science and Technology, Faculty of Life Sciences, Imperial College London, London SW7 2AZ, UK. Tel.: +44-207-594-6015; Fax: +44-207-594-6464; E-mail: j.lester@ic.ac.uk.

1. Introduction

The quality of surface water at any point reflects the combined effects of several processes along its pathways (Peters and Meybeck, 2000). Most watersheds encompass various land uses and each has an impact on water quality (Albek, 2003; Meador and Goldstein, 2003). Anthropogenic activities in a watershed result in inputs via point and non-point sources which may degrade surface waters and impair their use for potable supply, industrial, agricultural, recreation or other purposes (Simeonova et al., 2003; Kepner et al., 2004). Deteriorating fresh water quality thus limiting its use, exacerbated by a continuous increase in population and socio-economic development will typically result in water scarcity. Worldwide, contaminant loads delivered to surface water bodies are becoming so intense that aquatic ecosystems are seriously degraded (Massoud et al., 2005). Freshwater ecosystems and coastal areas are increasingly at risk from pollution impacts on a global scale with land-based discharges being the preponderant source (Greiner et al., 2000; Storelli et al., 2001; Wells et al., 2002; Massoud et al., 2003). Developed and developing countries alike have been affected by the impacts of human activities on water resources (Da Silva and Sacomani, 2001) and the lack of waste treatment facilities in areas of high-population in developing countries has aggravated the situation (Peters and Meybeck, 2000). The Middle East region in particular is characterised by scarce water resources and rapid population growth. Accordingly water is the most important and binding constraint for any future development in this region (Haddad and Mizyed, 1996).

Numerous studies on the impacts of land use and anthropogenic activities on water quality have been carried out in the last three decades (Hanratty and Stefan, 1998; Meissner et al., 1999; Bellos et al., 2004), mainly focusing on heavily polluted rivers in industrialized countries as well as major rivers in other less developed countries. In contrast, 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 changes (Dassenakis et al., 1998). 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). In contrast, developing countries are still faced with issues such as fecal contamination and impacts on public health. Moreover, developing countries suffer from a lack in human and financial resources coupled with ineffective and outdated institutional frameworks (Massoud et al., 2003). As water drains from the land surface, it carries a significant load of contaminants from both natural and anthropogenic sources. It is therefore reasonable to expect a strong relationship between land use and the quality of water (Gburek and Folmar, 1999). Accordingly, the main objective of this study was to assess and examine the spatial relationships between land use, anthropogenic activities and water quality of the Abou Ali River in North Lebanon. This is intended to provide information to advise and inform policy makers and environmental managers who will increasingly be required to deal with these types of catchments in developing countries which as yet have not been the subject of scientific investigation and evaluation.

2. Description of the Study Area

2.1. Characteristics of the Abou Ali River

Around 600,000 inhabitants live in the Abou Ali River catchment whose basin area is estimated at 484 Km^2 of which 97 percent is mountainous. The average annual discharge rate is 262 million m^3 (SOER, 2001). The river is 44.5 km-long and its basin encompasses nearly 236 towns and villages distributed among several administrative districts. The basin's major urban complex is Tripoli, the second largest Lebanese city, with approximately 350,000 inhabitants. Historically, the region has been almost exclusively agricultural, but during the last three decades there has been a rapid increase in urban development at the expense of agriculture. The river crosses the coastal mountains in a narrow valley with steep profiles. The source is at an elevation of 1,850 m and the river falls to nearly sea level passing through Tripoli on the flat coastal plain. The funnel shape of the basin makes it prone to flooding in its lower portion, with significant floods 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 to reduce the risk of flooding and an artificial, near rectangular concrete channel was constructed with vertical lateral retaining walls (≈5 m high). The channel has a total length of approximately 3 km and its width varies between 24 and 29 m. The channel capacity was designed for flows of 1,500 m^3s^{-1}, which allows for the safe routing of a 1,000 year flood event in combination with the upstream retention basin (CES, 1998).

2.2. Climate, Geology and Hydrology

The river basin and its coastal area are characterized by a Mediterranean climate with moderately warm dry summer and autumn, and moderately cold, windy, and wet winter with almost 80 to 90 percent of total precipitation occurring between November and March. Scattered rainfall events begin to occur in October and end in May. Mean annual rainfall is approximately 1,600 mm for the headwaters of the basin, decreasing to about 700 mm at the river mouth. The basin was formed by carboniferous deposits during the Tertiary, Jurassic and Cretaceous periods. Two calcareous formations of the Jurassic and Cenomanian age form the two major aquifer systems although Eocene, Miocene, and Quaternary layer aquifers of local importance also exist. 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. The average flow rate of the river for the months of October (dry season) and March (wet season) are approximately 0.8 m^3s^{-1} and 17.2 m^3s^{-1}, respectively.

Several complex systems of mountain ranges, with intervening valleys and plains lie within the basin. It is a complex catchment with many side streams in addition to small and large tributaries that join the main channel. It has been divided for the purposes of this study into four distinct sub-catchments estimated from topographic and hydrologic Geographic Information System (GIS) maps. Sub-catchment I is predominantly rural agricultural with both pasture and arable cultivation and an estimated drainage area of 144.2 km^2. Sub-catchment II is largely a mountainous rural region at the upper reaches, with some urban influence at the lower reaches and an estimated drainage area of 258.3 km^2. Sub-catchment III is entirely urbanized predominantly residential with an estimated drainage area of 40.8 km^2. Sub-catchment IV (40.7 km^2) was almost dry in summer and therefore was excluded in this analysis.

2.3. Land Use Patterns and Water Use

The Abou Ali River Basin has a rich and diverse landscape with areas of scenic beauty characterized by mountain ranges, plateaus, and river valleys. Arable land, forest, settlements and recreational spaces constitute the main land use categories. Most agricultural land in the basin is located in the hinterland at more than 400m above sea level. Agricultural 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.). The use of nitrogenous fertilizers and chlorinated pesticides is a common practice. Industries comprise small facilities scattered throughout the study area including car repair workshops, food processing establishments, furniture manufacturing and woodcrafts, restaurants, and various shops (CES 1998). Moreover, solid waste dumping sites are scattered throughout the area with little or no consideration given to environmental impacts. Almost all municipalities practice co-disposal of industrial waste in conjunction with municipal solid waste. In Tripoli, the average rate of generation of solid waste is approximately 0.65 kg/capita/day, resulting in a total of 382 tons/day. This has been dumped (25 years) in an open area (65,000 m^2) at the mouth of the Abou Ali River encroaching more than 150 m into the sea (CES, 2001). There is also quarrying for the extraction of construction materials and two nature reserves. 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 units (JICA and CDR, 2001).

At present, there are no wastewater treatment plants within the catchment area of the Abou Ali River. There are no sewerage networks in any of the settlements except in Tripoli where wastewater is discharged directly without treatment to the sea through short outfalls (5 sea outfalls in the City of Tripoli) or indirectly via coastal streams (SOER, 2001). Groundwater is the major source of domestic water to the community within the basin. There are a large number of private wells, for individual or joint use. Major water uses of the Abou Ali River include domestic water supply, hydropower generation, irrigation, tourism and recreation. Two water treatment plants with a capacity of 40,000 and 16,000 m^3d^{-1} abstract water from the river these along with groundwater springs on the slopes of the surrounding mountain ranges supply the Tripoli and Koura regions. There are three hydroelectric plants along the river with a combined nominal capacity of 12.1 MW (SOER, 2001).

3. Research Methodology

3.1. Study Design

Firstly, an assessment of information sources was conducted to review existing data pertaining to the study area and to identify community perceived problems or issues of interest. A field-based assessment of land use patterns and their implications for water quality was then conducted and supplemented, where possible, with secondary sources such as catchment study reports, environmental assessment studies, GIS coverage, together with oral evidence. Following a reconnaissance survey to identify the catchment priority areas or hot spots and the potential point and non-point sources of pollution, a two-year sampling program was initiated. The assessment was conducted at the end of the dry season in October 2002 and 2003 and the end of the wet season in March 2003 and 2004. Due to the size of the study area, water samples were collected over a period of 2 to 3 days on each full sampling round.

3.2. Sampling Strategy

The sampling strategy was designed to incorporate the widest range of indictors to define the water quality of the river system and account for inputs from tributaries that could have important impacts upon downstream water quality. Samples were collected from upper, mid and downstream sites. The two-year sampling program was a spatial survey encompassing the collection of 19 water samples labeled S1 to S19 distributed throughout the basin and along the main stream of the Abou Ali River, as well as on major and minor tributaries (Fig. 1). The samples were distributed among the three sub-catchments of the Abou Ali River Basin as follows: eight samples in Sub-catchment I (S1-S5 inclusive, S7, S8, S10), six samples in Sub-catchment II (S6, S9, S11-S14 inclusive) and five samples in Sub-catchment III (S15-S19 inclusive). A summary of the general conditions encountered at each location as they are schematically divided among the sub-catchments is illustrated in Fig. 2. Sampling sites were selected to achieve the best possible compromise between representativeness and operational feasibility, as access to the river over much of its length is rendered impossible or unsafe due to the topography and terrain. Several segments of the river that were safely crossed in summer became extremely difficult to access in winter. In many locations, it was difficult to collect samples particularly, the section of the river that flows through Tripoli due to the flood protection channel. The width and depth of water differ at each sampling location, which in turn introduces great variability in flow rates.

Insert Fig. 1

Insert Fig. 2

3.2.1. Sub-catchment I

This sub-catchment is predominantly rural and agricultural with both pasture and arable cultivation. Sampling locations in the upland areas (S1, S2) consisted of steep-sided valleys with a high gradient. The mid (S3-S5) and lower reaches (S7, S8, S10) have shallower sloping valley sides and a lower river gradient. Sites S1 and S2 where the adjoining area is sparsely populated and dominated by arable land, represent the headwaters and background levels. Site S3 is located on a minor tributary upstream of site S4 that itself was located on the mainstream of the river, with site S5 approximately 0.8 km downstream. The main anthropogenic activities at these sites are primarily agricultural. In addition, there is a hydroelectric plant with a nominal capacity of 7.4 MW and an old church which is a popular picnic site in the vicinity of site S4. Sites S7, S8 and S10 are located along the mainstream of the river and are in either agricultural areas or residential areas. Site S7 is located upstream of a hydroelectric plant and S8 is located downstream of it. Site S10 is located downstream of a pig farm in a residential area dominated by olive trees.

3.2.2. Sub-catchment II

Sampling site S6 at the headwaters is considered the background reference site in sub-catchment II. The adjacent area is used mainly for recreation with several restaurants located downstream of site S6. it should be noted that sites S9 and S11 are located on two distinct tributaries while the remaining three sites are located on a third different tributary having site S12 downstream of sites S13 and S14. Thus, it is less likely for water quality at these sites to be influenced by the headwaters. Site S9 is mainly a residential and agricultural area dominated by olive trees. Upstream of this site there are two chicken slaughterhouses and an olive oil press. Site S11 is primarily a residential area with higher population density and some urban and development influence. The surrounding locality of sites S12 to S14 is a mixture of residential (sub-urban), agricultural and recreational areas with several restaurants located along the river banks where raw domestic wastewater is discharged. In addition, family picnics are common at these sites, thus resulting in rubbish deposited on the riverbanks as well as in the water.

3.2.3. Sub-catchment III

This section of the river carries the confluence of sub-catchments I and II and crosses the City of Tripoli, a highly populated urban area. As previously mentioned, the downstream river course was straightened and an artificial near rectangular concrete flood protection channel was constructed for flood control. Populations along the river bank and in adjacent streets use the flood channel for wastewater discharge and trash disposal resulting in the accumulation of refuse on both sides of the channel. While sites S15, S16 and S17 are located along the canalised mainstream of the river mainly at the beginning, mid and end of the channel, sites S18 and S19 are located at the river's mouth and estuary where the adjoining area consists of an uncontrolled solid waste disposal site.

3.3. Analytical Procedures

All sampling equipment and containers 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 (1%) nitric acid solution and deionized water. Glass collection bottles were also washed in low phosphate detergent and tap water, followed by deionized water, and dried. Except during processing, all samples were kept chilled (4 ºC) from the time of collection until analysis. Physico-chemical analyses were conducted at the American University of Beirut following standard and recommended methods (APHA-AWWA-WEF, 1998). Water temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured on site using a Hach Model 44600 Conductivity/TDS Meter. In addition, the dissolved oxygen (DO) was also measured on site using a membrane electrode.

Water samples were analysed for total and fecal coliform bacteria, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrate-nitrogen (NO_3^-_N), ammonia-nitrogen (NH_3_N), orthophosphate ($O\text{-}PO_4^{3-}$), chlorides (Cl^-), sulfates (SO_4^{2-}), alkalinity, total and calcium hardness, metals and organochlorine pesticides. A titration procedure was used for alkalinity (0.02 N H_2SO4; Standard Methods 2320-B), Cl^- (0.0141 N mercuric nitrate; Standard Methods 4500-Cl^- B), Ca and total hardness (0.01 M EDTA; Standard Methods 3500 Ca D, Mg E). A spectrophotometer was used for NH_3_N (Direct Nesslerization, Standard Methods 4500 NH_3 C), NO_3^-_N (Cadmium reduction; Standard Methods 4500-NO_3^- E), SO_4^{2-} (Turbidimetry; Standard Methods 4500-SO_4^{2-}E) and $O\text{-}PO_4^{3-}$ (Ascorbic acid; Standard Methods 4500-P E). The BOD was based on 5 days incubation at 20ºC and the COD was determined by Closed Reflux/Colorimetry (Standard Methods 5220 D). The bacteriological analyses were determined by the membrane filtration technique (Millipore) (APHA-AWWA-WEF, 1998).

Where possible, samples were collected from the middle of the river at approximately mid-water. Since concentrations of nearly all metals and pesticides determined during the first year of sampling were below the detection limits, metal and pesticide analysis was discontinued thereafter. Industries that can be a potential source for heavy metals, are practically absent in the catchment of the Abou Ali River. In order to estimate variability in sampling and laboratory techniques, quality control samples were submitted for analysis. The field quality assurance/quality control (QA/QC) component consisted of field blanks, equipment blanks and duplicates. The QA/QC component of the analytical methods consisted of procedural blanks, lab duplicates, surrogate standard recoveries and reference samples (laboratory spikes and reference materials). The results from duplicate analyses were averaged for use in this study.

3.4. Data Management and Analysis

As there is minimal water quality data available for the Abou Ali River, the objective of the analyses was the establishment of a water quality database. The results were then analyzed in spatial context to assess stream responses to land use change and anthropogenic activities. Digitized maps were obtained from the Lebanese Ministry of Environment and other local authorities primarily at a scale of 1:20,000. The data were transformed into a common digital format, projected onto a common coordinate system (Local Lebanese Lambert System) and analyzed using ArcGIS 8.3. A variety of catchment characteristics including land use patterns, surface geology, and elevation were incorporated into the GIS to assess spatial variation and anthropogenic impacts. Water quality data were analyzed by a variety of graphical and statistical methods. The Statistical Package for Social Sciences (SPSS) and Microsoft Excel were used for statistical analyses and graphical display.

4. Results

The headwater sites of the Abou Ali River namely S1 and S2 in sub-catchment I and S6 in sub-catchment II exhibited the lowest contaminant values. This was consistent for all sampling occasions. The concentrations of most indicators at almost all the other sites exhibited values higher than background levels confirming the influence of human activities on the water quality of the Abou Ali River. The values of pH and temperature were recorded at all sites for all sampling occasions, yet no marked significant variation was observed. Likewise, COD levels exhibited very slight variation among the different sites due to the lack of industries in the study area. Total and Ca hardness as well as alkalinity were all higher than background levels with no clear increasing or decreasing trend among the sites. In the sections that follow the parameter which exhibited marked variation between the different sites are described.

4.1. Impacts of Agricultural Practices on Water Quality

Sites S3, S4 and S5 which are located in the middle of sub-catchment I exhibited levels of TDS that were higher than background levels which may be attributed to agricultural runoff and soil erosion. The highest value recorded is 261 mgl^{-1} at site S5 at the end of the wet season in 2003. Agricultural activities at these sites had also a noticeable effect on the DO levels causing a reduction of approximately 15 percent at the end of the dry season. There was also a concomitant increase in the BOD_5 values by over 50 percent as compared to background levels. This may be attributed to animal (cattle, swine and poultry) waste manure which is primarily organic in nature and may cause dissolved oxygen depletion. Higher BOD_5 values were detected at site S4 (Table 1) which may be attributed to recreational activities in the form of restaurants that are located along the banks of the river as well as family picnic areas in addition to agricultural runoff. The levels of fecal and total coliform bacteria were also very high with average values of 71,000 and 94,000 MPN/100ml, respectively. The concentrations of Cl^- exhibited the highest values at site S4 which may also be attributed to domestic wastewater. Although no extreme values of Cl^- were recorded at site S5, relatively high values were observed which may be a result of the upstream effect of site S4.

Insert Table 1

The values of NO_3^-_N were all higher than background levels with the highest values detected at site S4 (3.5 mgl^{-1}). Likewise, the levels of NH_3_N exhibited an increase as compared to background levels with over 2 and 4-fold increases at the end of the wet and dry seasons, respectively. This originates from runoff from fields where crops are irrigated and the use of inorganic fertilisers (usually as ammonium nitrate) and animal manure is substantial. Thus, the qualitative and quantitative improvement of agriculture productivity resulting from agrochemical use is counter-balanced by the detrimental consequences on human health, environment, and hydrologic systems. Contamination may also be enhanced by decomposition of nitrogen containing organic compounds such as proteins and urea occurring in municipal wastewater discharges occurring in the vicinity. The levels of O-PO_4^{3-} and SO_4^{2-} exhibited a substantial increase over background levels with over 4 times for O-PO_4^{3-} and up to 14 times for SO_4^{2-} concentrations at the end of the dry season. This may be the result of a combination of factors including soil erosion and manure and fertilizer runoff resulting from improper application as well as wastewater discharge.

Water quality in the lower reaches of sub-catchment I namely sites S7, S8 and S10 manifested a clear relation with land use and human activities with the concentrations of almost all indicators above natural background levels. The levels of TDS were fluctuating among the sites with the highest values recorded at site S7 probably a result of the higher flow rate as compared to the other sites. Total (3,500-540,000 MPN/100ml) and fecal (1,700-150,000 MPN/100ml) coliform bacteria were detected at almost all sites indicating animal and/or human waste contamination. The values of DO were all lower than background levels. The values of BOD_5 exhibited a distinct peak at site S10 (25.2 mgl^{-1}) at the end of the dry season in 2002. This almost inevitably attributable to a pig farm where the manure is disposed directly into the river. The farm stocks between 500 to 5000 animals depending on time. These pigs feed on expired domestic food products such as flour and potatoes in addition to food waste. This data was only obtained with great difficulty none the less is severely limited as there is a very high level of secrecy and skepticism amongst farmers and their workers, indicative of the type of problems inherent in a project such as this in a developing country. Fig. 3 depicts the elevated levels of BOD_5 at this site as compared to the other sites in sub-catchment I using GIS spatial analysis. A Buffer zone parallel to the stream channel was generated so that only land use directly adjacent to the stream is related to the water quality. The values of Cl^- did not exhibit a consistent increasing or decreasing trends with levels ranging between 15 and 25 mgl^{-1}. Likewise, NO_3^-_N did not exhibit an obvious increasing or decreasing trend with values oscillating among sites. The levels of NH_3_N were close to those detected at the mid reaches of sub-catchment I with a similar increase of more than 4-fold compared to background levels. The levels of O-PO_4^{3-} and SO_4^{2-} were also higher than background levels with over 3 and 4 times increase, respectively which may to be attributed to runoff.

Insert Fig. 3

The most marked and consistent influence of anthropogenic activities resulting in higher concentrations of most indicators as compared to background levels occurred along the stretch of the river at site S9 in sub-catchment II. This is attributed to the two chicken slaughterhouses which discharge their liquid and solid waste directly into the river without prior treatment in addition to agricultural activities and an olive oil pressing plant. During the field visits it was noticed that there is a very low level of environmental consciousness among the workers. They were not aware about the adverse impacts of their activities on the water quality of the Abou Ali River. Moreover, when this was explained to them they do not care. The flow at site S9 is relatively low (0.8 m^3s^{-1}) which may exacerbate the problem due to insufficient dilution and increasing residence time. The TDS values exhibited a fourfold increase compared to the values observed at site S6. The values of DO exhibited lower values with a decrease of approximately 25 percent as compared to background levels. The levels of fecal and total coliform bacteria were notably high which can be attributed to the slaughterhouse waste with more than 500 chickens slaughtered per day. Elevated levels of BOD_5 and Cl^- were also observed with an approximate increase of 40 percent as compared to values detected at site S6 (headwaters). Concentrations of both NO_3^-_N and NH_3_N exhibited elevated levels compared to the background site with more than 2 and 6 times increase, respectively. Fig. 4 depicts the high level of NH_3_N detected at the end of the dry season in 2002. Similarly, the values of O-PO_4^{3-} and SO_4^{2-} were all higher than background levels with over 10 and 4 percent increase, respectively.

Insert Fig. 4

4.2. Influence of Urban Development on Water Quality

Site S11 exhibited contaminant values that are higher than background levels but lower than those detected at site S9, which may be due to differences in land use and anthropogenic activities at these sites. While site S9 is mainly an agricultural area in the vicinity of a chicken slaughterhouse and olive oil press, site S11 is primarily a residential area with some urban and development. Additionally, the flow rate at site S11 (6.2 m^3s^{-1}) was higher than that at site S9 (0.8 m^3s^{-1}) which may enhance dilution and dispersion of contaminants as well as DO. The levels of TDS were about 2 times higher than background levels. The DO values were generally high with levels ranging between 6.4 and 10 mgl^{-1} (Table 2). High levels of BOD_5 were also observed with about 2 times greater values than background levels. The concentrations of the remaining indicators including Cl^-, NO_3^-_N, NH_3_N, O-PO_4^{3-}, and SO_4^{2-} were all higher than background levels indicating human influence on water quality.

Insert Table 2

Similarly, lower water quality conditions as compared to background levels were observed at the remaining sites located on the third tributary of Sub-catchment II. Relatively lower values of contaminants were detected at site S12, as compared to sites S14 and S13, suggesting that the water partially recovered downstream probably as a result of dilution, indicated by the flow rate at site S12 (3.5 m^3s^{-1}) being higher than that at sites S14 and S13 (0.8 m^3s^{-1}) where the water was almost stagnant. Flow rate may enhance turbulence, hence aeration and self purification capacity. The levels of TDS were approximately twice background levels with the highest values detected at site S13. The DO levels exhibited values ranging between 5.9 (S14) and 10.1 mgl^{-1} (S12, S13). Elevated levels of fecal and total coliform bacteria as well as BOD_5 were observed as compared to background levels which may be attributed to recreational activities, primarily restaurants in the vicinity. The fact that there is no sewerage network at these localities, resulted in the discharge of raw domestic wastewater generated at the restaurants directly into the river. Moreover, recreational activities at these sites may have caused the increase in Cl^- concentrations with distinct peaks observed at the end of the dry season in 2002 at sites S12 (48 mgl^{-1}) and S13 (50 mgl^{-1}). The levels of NO_3^-_N were all higher than those detected at site S6 with about 2 times increase at site S14 and 1.5 times increase at sites S13 and S12. Similarly, levels of NH_3_N exhibited higher values than background levels with about 2 times greater at sites S14 and S13 and 4 times greater at site S12. A slight increase in the levels of O-PO_4^{3-} was observed at the three sites as compared to the values measured at site S6 due primarily to the nearby restaurants that are discharging their raw domestic wastewater directly into the river.

Sub-catchment III which is the section of the river that crosses the City of Tripoli, a highly populated residential area, was characterized by the most elevated levels of contaminants as compared to the two other sub-catchments which may also be attributed to the influence of anthropogenic activities dominated by the discharge of raw sewage. As a result of lower flows, particularly during summer (0.8 m^3s^{-1}), and higher temperature values, the conditions for bacterial growth were stimulated and the dilution and the self-purification capacity were reduced. The levels of DO were the lowest at site S19 with more than a 30 percent decrease as compared to the remaining sites which are attributed to raw sewage discharge at the time of sampling in addition to solid waste and litter disposal. Compared to site S15, the levels of BOD_5 doubled at site S16 with a distinct peak (25.6 mgl^{-1}) recorded at the end of the dry season in 2002. The levels then decreased gradually at sites S17 and S18 to increase again at site S19 by about 60 percent with a distinct peak (20 mgl^{-1}) observed at the end of the dry season in 2002. Fecal and total coliform bacteria were significantly high at all sites with ranges of 1,700-650,000 MPN/100ml and 3,500-880,000 MPN/100ml, respectively. The flood control channel has permanently altered the nature of the river in this section, and the main consideration with respect to water quality in this area is associated with its potential impact on the coastal zone where the river discharges.

The levels of Cl^- decreased slightly at sites S16 and S17 as compared to S15 then increased gradually and reach the highest values at site S19 with a distinct peak (145 mgl^{-1}) at the end of the dry season in 2003 which may be attributed to mixing with seawater at the estuary. The values of NO_3^-_N varied among the sampling sites with the highest levels detected at site S15. The values of NH_3_N exhibited a slight decrease at site S16 as compared to S15 to increase again at site S17 by about 4 times and then slightly decrease at site S18 to reach the highest values at site S19 by over 4 to 5 times increase. Distinct peaks were observed at site S17 (5.68 mgl^{-1}) at the end of the dry season in 2002 and site S19 (11.3 mgl^{-1}) at the end of the dry season in 2003, inevitably the consequence of pollution by untreated sewage. The values of O-PO_4^{3-} exhibited an increasing trend along the section of the river that crosses the City of Tripoli to reach the highest values at sites S18 and S19 with a 6 fold increase as compared to site S15 which may be attributed to direct discharge of raw sewage. The levels of SO_4^{2-} increased slightly at sites S16 and S17 and then decreased to increase again at site S19 with the highest value of 36 mgl^{-1} observed at the end of the dry season in 2003 possibly due to mixing with saline water.

5. Discussion

The results from this study demonstrated that concentrations of most parameters at almost all sites were above natural background levels indicating human influence. In particular, fecal and total coliform bacteria were detected at almost all sites indicating animal and/or human waste contamination. Apart from the headwaters, the river is largely influenced by domestic sewage discharge followed by agricultural activities and wastes from slaughterhouses, pig farms, and olive oil presses and to a lesser extent recreational activities. In addition to anthropogenic perturbations, the difference in topography among the sampling locations, actual volume of water in the stream and flow rate are important factors introducing changes to water quality. This may explain the generally higher levels of DO observed at the upstream tributaries. The shallow, rapidly flowing and rocky nature of the Abou Ali River enhances aeration and hence saturation of water with DO. Besides, higher levels of DO upstream correlated with the lowest temperatures as solubility of oxygen in water decreases with increasing temperature (Boorman, 2003).

The lack of turbulent flow at certain sites such as the section of the river that crosses the City of Tripoli and higher temperatures renders the aeration process more difficult and may explain the observed reduction in DO levels. Historically, this section used to be rich in fish; however the construction of the flood protection channel altered the river flow. The impact of low water regimes and increased water temperature was more obvious at sub-catchment III as compared to sub-catchments I and II. The EC Freshwater Fish Directive (78/659/EEC) specifies guideline and imperative (mandatory) values for the protection of designated salmonid (sensitive) fisheries and designated cyprinid (less sensitive) fisheries of >9 and >8 mg 0_2/l, respectively. The majority of the sites particularly in sub-catchment III exhibited values lower than the EC guidelines. This assessment was adopted as the Lebanese Ministry of Environment (MOE) Standards for surface waters, does not include all of the parameters reported here, therefore values for the UK Environmental Quality Standards (EQS) or EC values were used in addition.

Agriculturally impacted sites, mainly in the central areas of sub-catchments I and II correlated predominantly with elevated levels of NO_3^-_N as compared to background levels consistent with trends reported (Ekholm et al., 2000; Jones et al., 2001; Magner et al., 2004; Parr and Mason, 2004; Yaun, 2004). This is may be attributed to agricultural runoff and the improper use of fertilisers and animal manure. However, compared to the Lebanese Ministry of Environment standards for surface waters with a guideline value of 25 mgl^{-1} and maximum allowable value of 50 mgl^{-1}, the measured NO_3^-_N concentrations were all within these values. Similarly, the high levels of NH_3_N may be attributed to agricultural runoff in addition to raw sewage discharges. Moreover, NH_3_N peaks are generally associated with nutrient influx in streams with little to no flow and low DO content (Ryan et al., 2002). This was demonstrated at site S9 (9.04 mgl^{-1}) in Sub-catchment II which is prone to low flow (0.8 m^3s^{-1}) and DO (2.2 mgl^{-1}) conditions. Almost all sites exhibited NH_3_N values higher than the UK Environmental Water quality Standards (EQS). In general, elevated levels of NH_3_N and Cl^- were concomitant suggesting the same source. The increase in fertilizer usage also resulted in increased concentrations of O-PO_4^{3-}, but the effects are generally more limited than for NO_3^-_N as O-PO_4^{3-} is strongly absorbed in the soil and in calcareous aquifers (Neal et al., 2003). Leakage of O-PO_4^{3-} to river courses from such fertilizer sources is therefore sometimes linked to soil erosion and sediment movement.

Continuous sewage discharge has resulted in elevated levels of BOD_5, Cl^-, NH_3_N and O-PO_4^{3-} as a consequence of inadequate dilution. As such, the river did not recover downstream primarily due to reduced assimilation capacity for contaminants. High levels of O-PO_4^{3-} are frequently attributed to municipal wastewater discharges since it is an important component of detergents (Perona et al., 1999). Since sediments may act as a sink for nutrients such as phosphorus (Parr and Mason, 2004), the lack of sediments in the Abou Ali River may explain the high O-PO_4^{3-} levels. Due to the subsurface calcareous nature (limestone) of the watershed and the steep slopes, there are no significant quantities of sediments, particularly the section of the river that crosses the City of Tripoli due to the concrete flood protection channel. The growth of algae has also been noted to have an effect on phosphate concentrations. Vegetation decay results in organically bound phosphorus becoming available from decaying plant tissue (Parr and Mason, 2004). Fig. 5 depicts the increase in the levels of Cl^- and O-PO_4^{3-} along sub-catchment III as compared to the other two sub-catchments. Though the Mediterranean is characterized by very weak tides with tidal amplitudes that are very small by world standards (Miller, 1983), the high level of Cl^- and SO_4^{2-} detected at site S19 may be attributed to saline water intrusion. However, the elevated levels of O-PO_4^{3-} are primarily attributed to land based sources dominated by sewage discharge (Karafistan et al., 2002).

Insert Fig. 5

Association of point source discharges with increased phosphorus concentrations, especially in relation to urban areas is consistent with many other studies (Younga et al., 1999; Neal and Whitehead, 2003).

Phosphorus availability is generally believed to be a critical factor in eutrophication of water bodies, thus causing a further increase in concentration of organic matter and consequently in oxygen demand. Based on the UK Environmental Agency (EA) Nutrient General Quality Assessment scheme (GQA) which assigns a grade from 1 (very low) to 6 (excessively high) for the levels of NO_3^-_N and O-PO_4^{3-}, it is evident that the river is enriched with O-PO_4^{3-}. Sub-catchments I and II exhibited O-PO_4^{3-} values ranging between moderate to high with exception of the higher elevation reaches that exhibited low values. High to very high values characterized the section of the river that flows through Tripoli (Sub-catchment III), which may be attributed to raw sewage discharge. While concentrations of O-PO_4^{3-} were generally high at the three sub-catchments of the Abou Ali River Basin, NO_3^-_N concentrations were very low at almost all sites (Fig. 6). The levels of SO_4^{2-} were all above background levels indicating anthropogenic influence and reflecting a large number of potential sources, including sewage discharge, agricultural fertilizers and naturally occurring deposits of sodium sulfate or magnesium sulfate. Determinants whose distribution is not directly related to anthropogenic activity include total and Ca hardness, which are subject to geological controls, particularly the distribution of carbonate minerals within the bedrock (Oguchi et al., 2000).

Insert Fig. 6

As is the case with most developing countries, the optimal management of Lebanese rivers is limited by a scarcity of data and the difficulties of obtaining information. Although the Abou Ali River is contaminated with organic matter that is causing oxygen depletion, nutrients and microbiological contamination, it is very difficult to identify the source and the pathway of pollution from suspected sources. Given the huge differences between developed and developing countries in political structures, national priorities, socio-economic conditions, cultural traits, and financial resources, adoption of developed country's strategies for river basin management is neither appropriate nor viable for developing countries. Environmental planners and resource managers need appropriate legislation to support and facilitate the development of successful river basin management plans for developing countries. Moreover, the institutional framework must allow adaptation of the plan to meet changing national, regional, and local priorities. To ensure public interest, the planning, development and management of the water resource must be a government responsibility. Considering the limitations of external and domestic financial resources in developing countries, it will be necessary to develop new innovative financial schemes which could include public-private partnership in financing such as concessions. Furthermore, environmental education as well as public awareness and participation primarily of resource users should be given high priority to achieve sustainability.

A high priority should also be given to preventive actions which are less expensive, such as the reduction of waste through cleaner technologies and processes, than to curative actions. The precautionary and polluter pays principles should be implemented, thus creating an environment in which it will become possible to put responsibility on industry to resolve its problem through best practice and waste minimization. Given the financial constraints, emphasis should be placed on meeting expenditure requirements from revenues generated at the project level. The introduction of the Mogden Formula (or simplified version) for industrial waste discharges even if the charges initially are insignificant would assist in developing an awareness of waste discharge impacts by industries (Lester and Brikett, 1999). Although this could mean significant impact on industries, it ultimately helps to achieve sustainable development. Moreover, from a public policy perspective, it allows polluters to be charged in proportion to the amount of pollution they generate, thus giving them the incentive to pollute less. Likewise, environmentally sound national agricultural policies should be introduced in addition to controlled and optimal use of fertilizers and pesticides. Practical methods such as buffer zones and barriers can be planted to intercept and contain contaminants that are being carried from agricultural lands to ensure that risks to the environment are minimized without sacrificing economic productivity.

In line with available resources, phased expansion of sewerage and municipal waste water treatment capacity based on known and proven technology and cost-benefit analysis is essential. Local conditions largely determine the best strategy for wastewater treatment. In many locations sewage networks already exist, thus facilitating the adoption of wastewater treatment plants. Other locations still lack these services and the adoption of on site (anaerobic) treatment of sewage such as septic tanks could be more appropriate, thus leading to cost reductions in the construction and maintenance of the sewage network. Several factors should be considered for the determination of the best wastewater management strategy including but are not limited to: availability of sewage network, population densities, groundwater or surface water pollution, institutional manageability, and financial sustainability.

6. Conclusion

- Sites impacted by arable farming mainly in the central areas of sub-catchments I and II were characterized by elevated levels of NO_3^-_N.

- In the tributary watersheds where poultry and livestock production predominated, higher levels of BOD_5, Cl^-, and NH_3_N, were recorded.
- The impact of recreational activities in the form of restaurants that are located along the banks of the river as well as family picnic areas resulted in elevated levels of several water quality indicators including BOD_5, Cl^-, NO_3^-_N, and NH_3_N as the result of the discharge of untreated domestic wastewater.
- Continuous sewage discharge in the entirely urbanized sub-catchment III resulted in elevated levels of BOD_5, Cl^-, NH_3_N and O-PO_4^{3-}.
- A river basin management plan that reduces negative impacts of activities in the Abou Ali River basin and adjacent coastal zone and improves the availability and quality of water is required.
- A high priority should be given to the enforcement of the precautionary and polluter pays principles and the possibility of implementing the Mogden formula.
- An effective legal, economic and institutional framework is needed to encourage investment in waste reduction and control and to introduce environmentally sound practices.
- Control of run-off from agricultural enterprises and livestock operations as well as municipal wastewater treatment are critical elements in the short and longer term water strategy to restore the balance of the Abou Ali River basin.

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