

Seasonal variations of chemical composition of water and bottom sediments in the wetland of Wadi Gaza, Gaza Strip

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Abstract

Water and sediment samples were collected from 18 sampling stations in Wadi Gaza for two successive years in order to: (1) Establish a baseline condition of the geochemistry of surface water and sediments; (2) assess the impact of seasonal variation on distribution of heavy metals and major ions; and (3) identify possible natural and anthropogenic sources of pollution. The heavy metal concentrations in the sediments of the lake (downstream) were higher than those of the eastern eight stations (upstream) where the water was shallower. Shallower areas showed greater temporal variation than deeper areas. Several elements (P, Fe, Mn and As) showed the greatest temporal variability. For example, in the winter rainy season these elements decreased 2–10 times compared to their values in summer. Moreover, Ca, Na, Cl, PO₄, and NO₃ decreased 3, 3, 5, 2, 4 times, respectively. Some of the trace metals were more abundant in these waters compared to the domestic wastewaters of the study area. The averages of Cd and Co were 6 and 43 µg/l, respectively and they were 50 times higher than the domestic wastewater results. The discharge of olive oil mill wastewater was recorded in the Ca, Na, Mg, K and P concentrations in sediments of one of the sampling stations.

Introduction

The Gaza Strip is one of the most densely populated areas in the world (2638 people/km²; PCBS 2000). With limited and deteriorated resources, it has already started to suffer the outcomes of environmental quality deterioration. The shortage and pollution of resources, coupled with high population growth and insufficient job opportunities have created many environmental hazards. The shortage of water and the deterioration of water quality constitute a limiting factor in the economic development of Palestine (MEnA 1999). Because of these problems, the Wadi Gaza is un-

der threat (MEnA 2000). Moreover, the Wadi is closed from both upper (inlet) and lower (outlet) streams. There is urgent need to obtain background geochemical data for this site, as no data are currently available.

The capacity of sediment to accumulate contaminants makes them one of the most important tools to assess environmental impact on aquatic ecosystems (Silva and Rezende 2002). In fact, lake sediments can serve as an information archive of environmental changes through time (Haworth and Lund 1984). Chemical speciation studies have shown that heavy metals display different degrees of affinity for either organic or inorganic compounds

and that this is an important factor influencing metal distribution (Lu et al. 1983). In aquatic ecosystems research, the role of sediments in the cycling of chemical elements has often been underestimated, and the exchange of elements (especially nutrients) between sediment and water is a crucial topic (Alloway and Ayres 1997; Kelderman et al. 2000). Seasonal variation may also affect the exchange process directly and indirectly. Anaerobic conditions in summer period were shown to cause a rapid phosphorus release from the sediment to the hypolimnion of the water body. This mechanism is still one of the key examples of sediment–water interaction (Kelderman 1985). Many factors affect the sediment–water exchange of nutrients such as sediment type and grain size, aerobic and anaerobic conditions, temperature and pH (Rippey 1977; Holdren and Armstrong 1980; Nixon et al. 1980; Kelderman 1996).

The main goal of this paper was to establish a baseline study of water and sediment quality of the Wadi Gaza. A secondary objective was to identify the extent to which the relevant water and sediment quality parameters vary seasonally.

Materials and methods

The study area

Wadi Gaza* is the only major watercourse in the Gaza Strip (Figure 1). Its catchment covers 3500 km² most of which is in the Israeli territory, with only the last 7 km of its course in the Gaza Strip (MEnA 2002). The Gaza section, which lies some 7–8 km south of Gaza City, is a sandy valley 20–50 m wide, with steep cliffs 6–8 m high. The river flow has eroded the Wadi banks, expanding to a permanent, brackish, water body several 100 m wide (forming a lake) shortly before it reaches the Mediterranean Sea. No data are available on flood-flow frequency, height or volume; yet it is evident that occasional or regular flash floods sweep down the Wadi bed, although their frequency may be reduced by the suspected presence of small dams, or diversion schemes, in the catchment. The study area is a part of the coastal zone of the Gaza Strip and the hydroge-

ology of the coastal aquifer consists of one sedimentary basin, the post-Eocene marine clay (Saqiya), which fills the bottom of the aquifer. Wadi Gaza as well as the whole Gaza Strip area is located in the transitional zone between the temperate Mediterranean climate to the East and North and the arid desert climate of the Negav and Sinai deserts to the East and South. As a result, the Wadi Gaza area has a characteristically semi-arid climate. There are two well defined seasons: the wet season starting in October and extending into April, and the dry season from May to September.

The average daily mean temperature ranges from 25 °C in summer to 13 °C in winter, with the average daily maximum temperature ranges from 29 to 17 °C, and the minimum temperature range from 21 to 9 °C in the summer and winter, respectively. The daily relative humidity fluctuates between 65% in the daytime and 85% at night in the summer and between 60 and 80%, respectively, in the winter. The mean annual solar radiation is 2200 J/cm²/day. There is a significant variation in the wind speed during the daytime, and the average maximum wind speed velocity is about 3.9 m/s. Moreover, storms have been observed in winter with a maximum wind speed of about 18 m/s. Peak months of rainfall are December and January; the average annual rainfall is 335 mm/y (26-year average). There is a constant flow of untreated domestic sewage water and agricultural runoff into the Wadi from the Refugee-Middle Camps with the main outlet at the southern bank of the Wadi under Salahedden Bridge (Figure 1). This maintains a trickle of water in the Wadi bed, and feeds the permanent stagnant pool that covers several hectares at the mouth of Wadi Gaza, hence maintaining an extensive water body during the dry season (CAMP 2000). Fish are known to occur in this pool, although it is dominated by dense algal growth in summer season. No surface water quality data are available, but several wells around the Wadi appear to have unacceptable levels of bacterial contamination, indicating that the pollution is extending to the groundwater in this area (MEnA 2002). Three bridges cross the Wadi (two roads and one rail) and numerous dry season tracks criss-cross the Wadi bed where it widens near the refugee camps. At the southern side of the Wadi there is a three stage olive mill which disposes the wastewater and the marc directly to the Wadi. On either side of the Wadi, farmland

*The part of the Wadi located in the Gaza Strip.

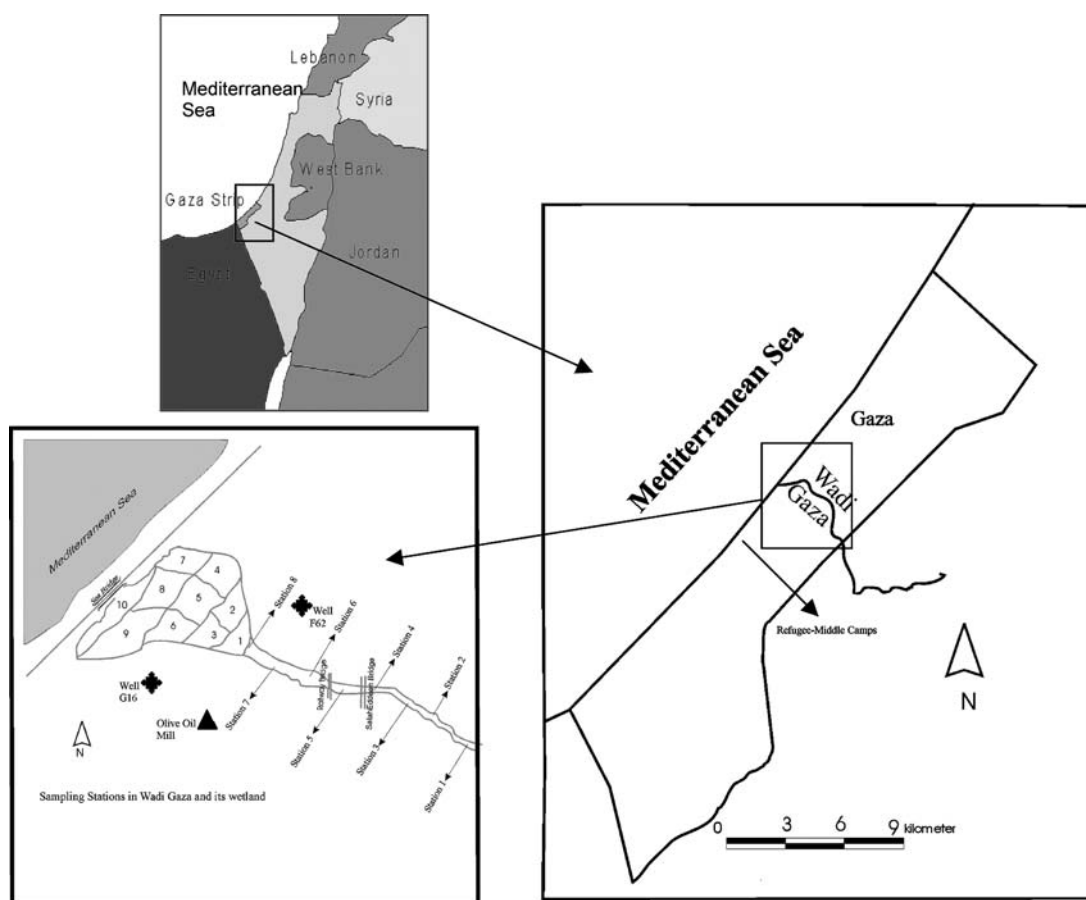


Figure 1. Location of the Wadi Gaza and schematic illustration of the sampling stations.

extends with olives, vines, fruits and vegetables, some of which are probably flooded during major storm events. At the eastern road bridge, farmers dam the river in summer using earth, and pump the water for irrigation; this water is affected by algal blooms and has a bright green color. The vegetation in the Wadi is dominated by *Tamarix* growing on the dunes and sand deposits in and around the Wadi bed. The wetter areas have stands of *Typha* which also fringe the water body near the outlet to the sea (Issac et al. 1997). Around 125 ha of saltmarshes recorded in the Gaza Environmental Profile of 1994 have disappeared following construction of the new bridge at the Wadi Gaza outflow in 1996. This has disrupted the outlet, affected windblown sand deposition, improved access to the public and generally modified the ecology and geomorphology of Wadi Gaza estuary. Local staff reports indicated that the

foundations of the bridge have also blocked the river course and therefore raised the level of the pond. While this may be the case, it is evident that sand accumulation, either brought down by the Wadi Gaza in recent floods, or deposited during sea storm events is another proximate cause of the blockage (MEnA 2002). During westerly storms, seawater may be pushed over the sand barrier into the Wadi, maintaining brackish conditions in the downstream part of the system.

The sampling and analysis

The study area (Figure 1) is divided into nine parts, each about 1-km long, numbered from east to west (K1–K7). The eighth part (En 8) represents the entrance of the Wadi to the lake and the ninth is the lake. The lake is divided into 10 areas

(W1–W10). During the sampling period, the water depth varied between 0.4 and 1.5 m due to change in the total wastewater discharged to the Wadi; the topographic depression of wetland has an average depth of 1.8 m. The two sampling campaigns were conducted at the end of summer dry season 2001 and at the end of winter rainy season 2002.

Water samples

A total of 17 composite water samples were collected in late summer (November, 2001) and 18 in late winter (April, 2002). Water samples were collected from the six eastern parts (Stations 2–7); the first Station was dry in summer, and another sample from Station 8 which represents the entrance of the Wadi to the lake. Ten water samples were collected from the lake. One-liter samples were collected, then divided into two subsamples, the first (500 ml) was filtered in acid-washed filter holder and through 0.45 μm pore size membrane filters, the first few milliliters were used to rinse then they were discarded, and the filtrate was transferred to clean acid-washed polyethylene bottles and acidified by concentrated nitric acid (Ultrapur, Merck, v/v), and stored at 4 °C until analyses of total metal contents by ICP/MS (Perkin Elmer-Sciex, Elan 6000) were performed; the other part of water was filtered with no additives and stored at 4 °C for anion analyses by Ion Chromatography (IC). Several parameters were measured in the water samples during the field-work: temperature, turbidity, electric conductivity and pH, other parameters were measured in the lab. As excessive fluoride concentrations are known to be problematic in this area, fluorides were measured also, using Ion Selective Electrode (ISE) according to the American standard methods (APHA 1995). One wastewater composite sample was collected from the open canal directly before entering the Wadi and two groundwater samples were collected from the wells F62 and G16 which are located 50–100 m away from the Wadi.

Sediment samples

Thirty six sediment samples were collected from the same stations in the two sampling campaigns. They were collected using a stainless steel dredge; approximately 0.5 kg was put in polyethylene cups and stored at 4 °C during its transport to laboratories. Sediments were sieved through a 20- μm sieve with deionized water, and then were dried in

an oven at 50 °C until constant weight. Samples were ground in an agate mortar. Approximately 1–2 g of the homogenized sample were dissolved with 10.5 ml of concentrated hydrochloric acid (37% p.a.) and 3.5 ml of concentrated nitric acid (65% p.a.) in 50 ml retorts. The samples were allowed to degas (12 h). Then all samples were heated to 160 °C on a sand bath until complete extraction (3 h). After cooling, the solutions were diluted with distilled water in 50 ml volumetric flasks and kept in 100 ml polyethylene bottles for analysis. Trace metals were analyzed using a Flame Atomic Absorption (AAS vario 6-Analytik Jena). The distribution of phosphorus as (P_2O_5) was measured for all sampling stations (APHA 1995). Mercury concentrations were determined using atomic absorption spectroscopy after thermal combustion of freeze dried samples (50–100 mg) and Hg pre-concentration on a single gold trap by means of an AMA 254 solid phase Hg-Analyzer (LECO). Total carbon and sulfur were determined directly in dried samples by using a Carbon-Sulfur Determinator (Leco CS-225). Carbonates were measured directly by a carbonate bomb (Müller and Gastner 1971).

Quality control

For quality control, analytical blanks and two samples with known concentrations of heavy metals were prepared and analyzed using the same procedures and reagents (Avila-Perez et al. 1999). For the surface water, groundwater and wastewater analyses, Standard Reference Materials 1643c and 1643d were used for the determination of trace elements (National Institute of Standards and Technology NIST, Gaithersburg 1991 and 1994) and SPS-WW2, Wastewater Level 2 (SPS 2002).

Precision was estimated evaluating the reproducibility between the duplicates and a coefficient variation of lower than 5% was found. The accuracy was evaluated by two River Sediment Standard Reference Materials-RS1 and RS3-Deutsche Industrie Norm (DIN 1997, 1989). As an independent check on the trace element measurements of the sediments, these were also measured in solid samples using the Energy-dispersive Miniprobe Multielement Analyzer EMMA-X-Ray Fluorescence Spectrometry (Cheburkin 1996).

The EMMA was calibrated and standardized for trace elements in sediments using a variety of

certified, standard reference materials. These materials were used in the AAS measurements. A rigorous quality control program was implemented to check the results obtained from the two methods (AAS and EMMA). From the statistical point of view, a simple comparison (in percentage) was calculated between the results for the same parameter of the two methods.

Results and discussion

Many parameters were not detected in any of the water samples, while other parameters (Hg and Cd) in the sediments were found to be less than the background. Consequently data from these elements are not presented in Figures 2 and 4.

Water quality

Table 1 shows the results of all water samples from all stations in summer and winter and Figure 2 indicates the trend of each parameter along the Wadi.

Temperature, pH, electric conductivity and dissolved oxygen

Both Table 1 and Figure 2 show the seasonal variation of water temperature, pH, DO and EC. The latter has the same trend of Cl. The rainy winter season reduced EC and Cl by diluting the waters of the Wadi.

Major ions

The average total dissolved solids (TDS) in groundwater, wastewater and Wadi's water was 1800 mg/l and major ions of Cl, F, NO₃, SO₄, CO₃, PO₄, Na, Ca, Mg, K were higher than their concentrations in several surface water bodies in the world (Song and Müller 1999). The western stations of the wetland are exposed to the sea waves especially in summer and this resulted in the high concentrations of Cl, Na, Ca, Mg, SO₄ in area 10 of the lake. In the winter, the concentrations of these ions were influenced by rainwater and wastewater; while in summer their concentrations were influenced only by wastewater. In the winter, rainwater inputs decreased NO₃ concentrations; moreover the lake was eutrophic in summer and not in winter. Groundwater concen-

Table 1. Water quality of Wadi Gaza.

	Summer, November 2001				Winter, April 2002				Fresh-water ^a	Domestic wastewater ^b	LD ^c (µg/l)
	Max	Min	Mean	σ	Max	Min	Mean	σ			
Temp. (°C)	24	21	23	0.8	17	15	16.15	0.71		25.5	
PH	9	6.5	7.6	0.5	8.6	8	8.39	0.214		7.5	
DO (mgO ₂ /l)	7	3.9	5.3	0.86	9.6	4.3	8.4	1.3			
EC (mS/cm)	4.85	2.9	4.2	0.8	2.8	1.76	2.18	0.33		3	
Cl (mg/l)	1142	450	924	296	700	320	478	107.7		650	
NO ₃ (mg/l)	21	2	8	5.3	31	17	22.70	4.2	0.225		
SO ₄ (mg/l)	2536	14	236	614	305	80	184.8	82.09	11.1		
F (mg/l)	31	1	4.4	7.9	3.2	0.89	1.81	0.68	0.1	1.2	
PO ₄ (mg/l)	85	5	49	19.2	42	12	24.79	11.44	0.06	25	
Na (mg/l)	8233	19	678	2015	160	102	124	15.9	6	380	
Mg (mg/l)	303	53	89	60.4	95	42	65.7	15.9	4	36	
Ca (mg/l)	348	68	136	62.8	124	67	102.9	16.8	15	43	
Fe (µg/l)	776	192	382	174.1	6600	223	909.8	1666	500	200	15
Zn (µg/l)	206	1	82	45.1	1560	13.65	148.5	408.2	15	100	10
Cu (µg/l)	10	1	4	2.9	123	5.55	16.49	30.9	3	6	1
Mn (µg/l)	580	320	423	64.9	385	38.35	266.9	85.5	8	300	1
As (µg/l)	9.4	0.5	1.7	2.1	27.6	7.65	12.7	4.6	0.5	0.4	5
Pb (µg/l)	30	1	12	10	135.5	5.1	40.8	63.4	3	2	2.5
Cr (µg/l)	139	3	65	38.3	130.5	4.66	20.6	34.2	1	7	2.5
Cd (µg/l)	12	1	6	3.4	3.495	0.5	1.6	1.33	0.1	0.5	0.5
Co (µg/l)	70	15	43	19.6	8.05	1.19	2.3	1.78	0.2	0.3	0.3

^aElemental composition of freshwater (Bowen 1979).

^bElemental composition of domestic wastewater discharged to the Wadi.

^cLD: Limit of detection by the ICP/MS in (µg/l).

trations of sulfate averaged between 240 and 190 mg/l in summer and winter, respectively and SO₄ contents were not affected by seasonal variation (Figure 2c). Although it was assumed that fluoride is a natural constitute of the groundwater of the Gaza Strip (Shomar et al. 2003), F decreased to the half in winter. The results of fluoride analysis using IC were consistent with the results of the ISE and only few samples showed a difference of around 5%. Phosphates in the same figure fluctuated along the Wadi due to the different factors affecting the existence of phosphate in the river. Phosphate contents in the groundwater of the area were very low, while they were much higher in domestic wastewater (25 mgPO₄/l).

Fe and Mn

Water of Wadi Gaza was oxygenated and the Fe and Mn were in the oxidized soluble forms. The measurement of DO of water samples collected from Wadi Gaza showed an average of 9.6 mgO₂/

l, keeping in mind that the sampling program was carried out under windy conditions in winter. Groundwater wells in the same area had lower Fe and Mn contents than the Wadi Gaza samples. Figure 2e shows stability of Mn concentrations in the eastern stations of the Wadi, while there was a gradual increase of Mn in the lake from east to west. Fe, on the other hand, decreased from east to west, remained constant in eight stations of the wetland, and only Station 6 had higher Fe compared with other stations.

Trace elements (Zn, As, Pb, Cr, Co, Cd, and Cu)

These elements come to the Wadi from the wastewater and generally were high in summer and low in winter. Groundwater samples of wells F62 and G16 have considerable amounts of these elements (Figure 3). The impact of seasonal variation was recorded for As and Cd and they showed opposite behavior, while Pb, Co, and Cu were not significantly affected.

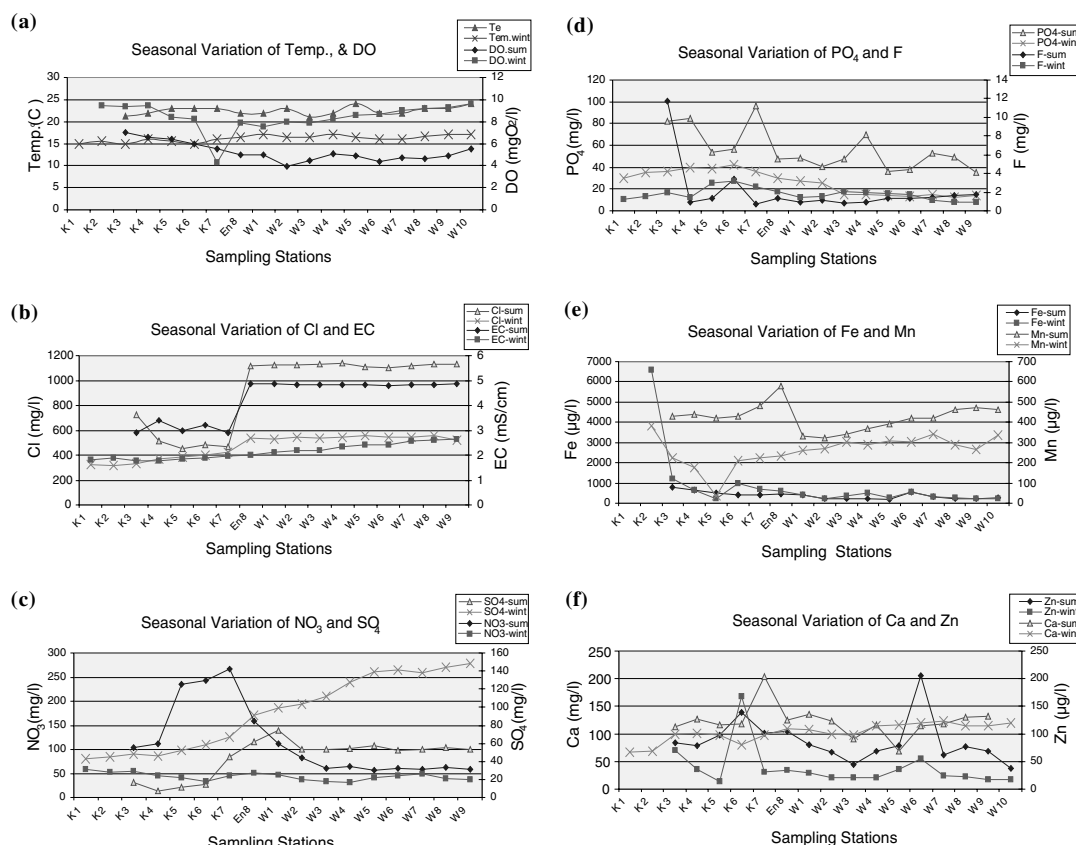


Figure 2. (a) Temperature and DO, (b) Cl and EC, (c) NO₃ and SO₄, (d) PO₄ and F, (e) Fe and Mn, (f) Ca and Zn in water samples of the Wadi Gaza.

Human inputs in the Wadi Gaza

Figure 3 shows the comparison between wastewater, water of sampling stations 7 and area 3 of the lake and groundwater of the two wells nearby. Untreated wastewater is directly discharged to the Wadi and has high amounts of microorganisms, which during summer increase the biodegradation activity, reduce DO and pH, and affect the redox processes of Fe, Mn, As and P. In summer, wastewaters also expressed an increase in NO_3 , SO_4 , F, Cu, Al, Ni, Zn, Pb, Cr and Cd concentrations in Wadi Gaza. Some industrial wastes of detergents and fertilizers increase P contents, while metallic wastes and construction materials in the area increase Ca, Na, Mg, Fe and Mn concentrations. The three stage olive oil extraction mill

generates oil and two by-products: wastewater and marc (solid waste formed by olive stone and pulp wastes). The amount of waste generated ranges between 0.5 and 1.4 l/kg of processed olive. The wastes of the olive oil mill reduced the pH of surface water in summer and increased the Na, Mg, Ca and P concentrations in station 7. The groundwater in the area showed high amounts of Cl and NO_3 , especially in summer. Well F62 had 989 mg Cl/l and 117 mg NO_3 /l and well G16 had 890 and 110 mg/l of the same anions.

Sediment metal concentration

The coefficient of variation for two independently prepared aliquots of the same sample was less than

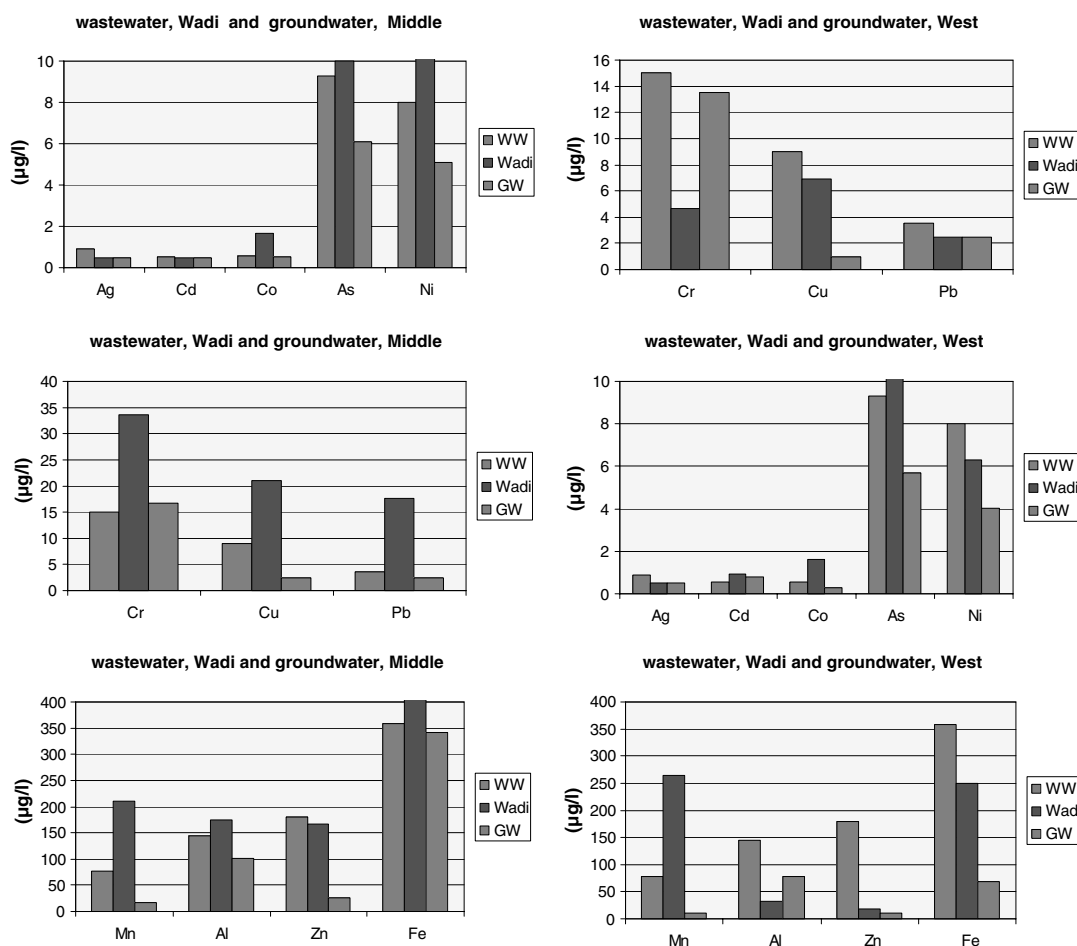


Figure 3. Comparison between trace metals in domestic wastewater (WW) discharged to Wadi Gaza, water of Wadi (W) in two sampling stations and groundwater (GW) of two wells in the middle (F62) and the western (G16) areas of Wadi Gaza.

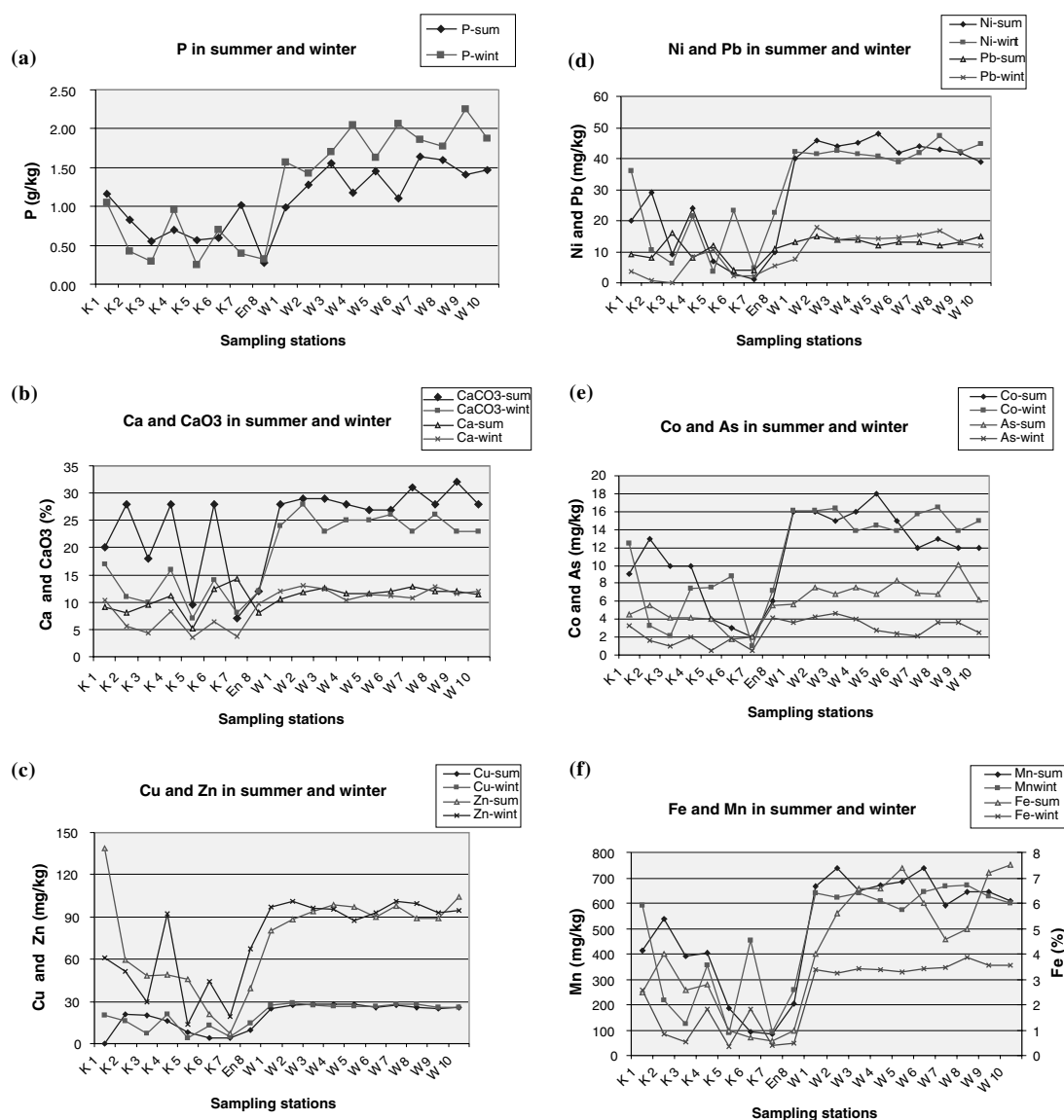


Figure 4. (a) P, (b) Ca and CaCO₃, (c) Cu and Zn, (d) Ni and Pb, (e) Co and As, (f) Fe and Mn in the sediment samples of Wadi Gaza.

2% for all parameters. Only Cd had a coefficient of variation of more than 6%. The agreement between the certified and experimentally established concentrations in Standard Reference Materials was less than 2% for all parameters except for Cd which was more than 6%. The difference between the Standard Reference Materials (RS1 and RS3) supplied by DIN was used to estimate the accuracy of the method analyzed. The difference rates (%) were: CaCO₃ = 0.9, Mg = 0.44, Ca = 1.05, Cu = 0.7, Zn = 0.72, Ni = 0.77, Pb = 0.65, Mn = 0.73, Fe = 0.67, Cr = 1.26, Cd = 6.7 and As = 0.66.

Phosphorus

Phosphorus in sediment followed an opposite trend to P in water; P in sediment was high in winter and low in summer. Figure 4a shows the trend of P along the Wadi. The eastern stations were shallow and the P content in the lake was higher than its values in these stations. Moreover, the water flow in summer was very slow, eutrophication phenomena appeared in the western lake, and limited algal blooms appeared in the eastern stations. The major source of phosphorus in the area is wastewater, containing detergents and fertilizers applied in the surrounding agricultural areas. The

Table 2. Chemical characteristics of sediments by flame AAS.

Parameter	Summer, November 2001				Winter, April 2002				^a Background
	Max	Min	Mean	σ	Max	Min	Mean	σ	
P (g/kg)	1.6	0.3	1.0	0.4	2.3	0.2	1.3	0.7	
C (%)	9.7	0.6	4.0	2.4	5.1	1.2	3.56	1.3	
S (%)	1.2	0.0	0.5	0.4	1.92	0.0	0.78	0.6	
CaCO ₃ (%)	32.0	7.0	24.6	7.8	28	7	19.3	7.0	
Mg (%)	2.1	0.2	1.4	0.7	2.0	0.3	1.34	0.6	
Ca (%)	12.9	3.0	10.1	2.8	13.1	3.4	9.40	3.4	
Na (mg/kg)	28714	196	6586	7302	43072	81	11762	13814	
K (mg/kg)	10964	624	7370	3597	9207	655	5336	3348	
Cu (mg/kg)	28.0	4.0	20.5	8.7	28.6	3.8	20.88	8.7	45
Zn (mg/kg)	104.0	7.0	70.4	30.2	101.1	13.9	74.77	31.0	95
Ni (mg/kg)	48.0	1.0	30.4	17.3	47.4	3.5	31.14	15.8	68
Pb (mg/kg)	16.0	4.0	11.6	3.6	17.7	0.1	10.91	5.8	20
Mn (mg/kg)	739	85	502	228	671.0	88.2	483.74	217.2	850
Fe (%)	7.5	0.6	4.3	2.5	3.9	0.4	2.53	1.3	4.7
Cr (mg/kg)	59.0	6.0	35.8	17.8	62.5	5.1	37.28	20.6	90
Co (mg/kg)	18.0	2.0	11.4	4.9	16.5	0.9	11.43	5.3	19
Cd (mg/kg)	0.4	0.0	0.2	0.1	0.4	0.0	0.21	0.1	0.3
As (mg/kg)	10.1	1.8	5.9	2.2	4.6	0.5	2.62	1.3	
Hg (mg/kg)	0.9	0.0	0.1	0.2	0.1	0.004	0.05	0.03	0.4

^aTurekian and Wedepohl (1961).

relationship between P and Fe is discussed under the results of Fe in water and sediments. Table 2 and Figure 4a show the variation of P in summer and winter. Generally P increased by a factor of 2 in winter compared with summer in the western lake. The decay of water plants in winter may have increased the P in sediment and decreased

the P in water. Moreover, the sediments release P to water in summer and sorb it in winter (Kelderman 1996).

Carbon and sulfur

The field survey indicated that the sources of carbon in the Wadi Gaza include not only natural

Table 3. Chemical characteristics of sediments by EMMA.

Parameter	Summer, November 2001				Winter, April 2002			
	Max	Min	Mean	σ	Max	Min	Mean	σ
K (%)	2.4	0.6	1.8	0.6	2.6	0.9	2.0	0.6
Ca (%)	12.0	4.4	10.2	1.8	12.9	5.8	10.3	2.1
Ti (%)	0.6	0.4	0.5	0.1	0.8	0.3	0.5	0.1
Cr (mg/kg)	117.1	32.3	76.1	25.4	117.2	32.1	85.8	26.6
Mn (mg/kg)	672.8	122.9	475.1	171.3	597.7	145.5	465.1	147.4
Fe (%)	4.1	0.8	3.0	1.1	4.2	1.0	3.1	1.2
Ni (mg/kg)	59.9	4.5	35.5	17.2	52.0	7.7	34.1	14.2
Cu (mg/kg)	566.1	4.7	50.9	128.8	34.3	6.7	24.2	9.0
Zn (mg/kg)	140.4	14.7	81.0	30.4	118.5	18.0	86.5	34.0
Ga (mg/kg)	13.9	2.3	10.0	3.7	15.4	2.1	10.8	4.6
As (mg/kg)	7.6	0.0	3.8	2.6	6.1	0.0	3.7	2.0
Se (mg/kg)	0.9	0.0	0.1	0.3	0.0	0.0	0.0	0.0
Br (mg/kg)	84.1	2.4	23.2	22.3	168.3	1.6	36.7	43.7
Rb (mg/kg)	45.6	11.0	34.4	12.9	46.2	10.3	34.4	13.6
Sr (mg/kg)	385.3	140.6	284.6	64.9	455.6	106.0	285.4	93.2
Y (mg/kg)	26.4	8.0	20.3	7.0	25.9	5.6	19.0	7.2
Zr (mg/kg)	511.3	144.6	246.9	130.0	330.9	103.3	175.1	67.5
Pb (mg/kg)	193.3	2.5	21.1	43.1	18.8	3.8	12.5	3.8
Th (mg/kg)	8.1	0.0	4.2	2.2	6.3	0.0	3.9	2.4

sources but also different construction materials dumped to the Wadi. There was no significant difference in the contents of C and S in summer and winter and only two sampling stations showed sudden increases in C summer samples.

CaCO₃, Ca, Mg and Na

Figure 4b shows the trend of CaCO₃ and Ca in the summer and winter. Sampling station 6 has a sudden increase in the Ca contents in the summer presumably from the accumulated wastewater produced from the olive oil mill opposite to this station. The wastewater was very rich in Ca and may have percolated to the sediment of that area. The CaCO₃ showed the same trend as Ca. Generally, seasonal variation affected the contents of CaCO₃ and it was higher in summer than winter. The results of Mg and Na in summer and winter were similar, especially in the eastern sampling stations, and the reason of the fluctuation of Na in three stations within the lake was not clear. The lake showed higher Na in winter than summer, while the Mg remained the same in all stations.

Cu, Zn, Cr, Ni, Pb, Co, As, Hg and Cd

The analysis of Cu and Zn in sediments of the Wadi Gaza showed similar values in summer and winter with no major difference. The two metals displayed the same trend in summer and winter and also in all sampling stations (Figure 4c). Cu started low in the east and increased gradually in the west. The concentration of each metal remained the same within the lake's 10 areas. Chromium had the same trend in summer and winter; it started in the eastern sampling stations then increased in the lake. As shown in Figure 4d, the concentrations of Ni and Pb were the same in summer and winter. Only sampling Station 6 showed an increase in Ni in winter while the others remained the same. Cobalt fluctuated in summer and winter but both results had the same range (Figure 4e). As, on the other hand, was two times higher in summer than in winter especially in the lake where the water depth was about 1.8 m; the eastern stations showed less difference as the water was shallow (30–60 cm depth).

During the summer sampling, some medical wastes were found in the area, as a result of the disposal activities by local clinics. The recent observations agreed with the findings of Zoarob (1997) who identified Wadi Gaza as a disposal site

of medical wastes. This is probably the main source of Hg in the area. Mercury values were not affected by seasonal variation. They remained low and two anomalous readings only appeared in Station 1 and area 5 (W5) of the lake in summer sediments. Hg levels were still below the German and the European standards for sediments (Oka-Elbe Project 2000). Cadmium was low but fluctuated in all sediment samples with no significant differences along the Wadi.

Fe and Mn

Fe and Mn represented the major metals in sediment samples of Wadi Gaza. Fe and Mn in the sediments were also much higher than the Fe and Mn contents in the soils of the other areas in the Gaza Strip. As mentioned before, most of the metallic solid wastes dumped into Wadi had high amounts of Fe. The results showed that both Fe and Mn followed similar trends (Figure 4f). The summer season had many impacts on water and sediment and the sediment–water exchange of P was much dependent on the season. In the summer the sediment released P whereas in the winter, a P accumulation took place. In the summer season this phosphorus was used as a main source of nutrients needed for water plants covering the Wadi. Higher temperatures could lead to anoxic conditions in sediment resulting in Fe and P release. In winter the sediments are oxygen-rich, and Fe is in the Fe(III) form, which forms an insoluble bond with phosphate. Under anaerobic conditions of summer (to be more specific, at redox potentials below 150 mV), the Fe(III) was reduced to Fe(II). Since Fe(II)-phosphates are 100 times more soluble than Fe(III)-phosphates, this gave rise to a P release from Fe–P bondings.

AAS and EMMA

Tables 2 and 3 and Figure 5 show the results obtained from the flame AAS and the EMMA. The agreement between the two methods was generally good and was compatible with the findings of Cheburkin and Shotykh (1996). The shared parameters between the two methods were Ca, Fe, Mn, Cu, Zn, Ni, Pb, Cr, As and K. The flame AAS showed levels 5 and 10% higher than the EMMA for Ca and As, respectively and 6–8% higher than the Mn concentrations. Both systems have a difference of 5% for Cu, Zn and Pb. They showed <2% difference for Fe. The Cr and Ni were 40

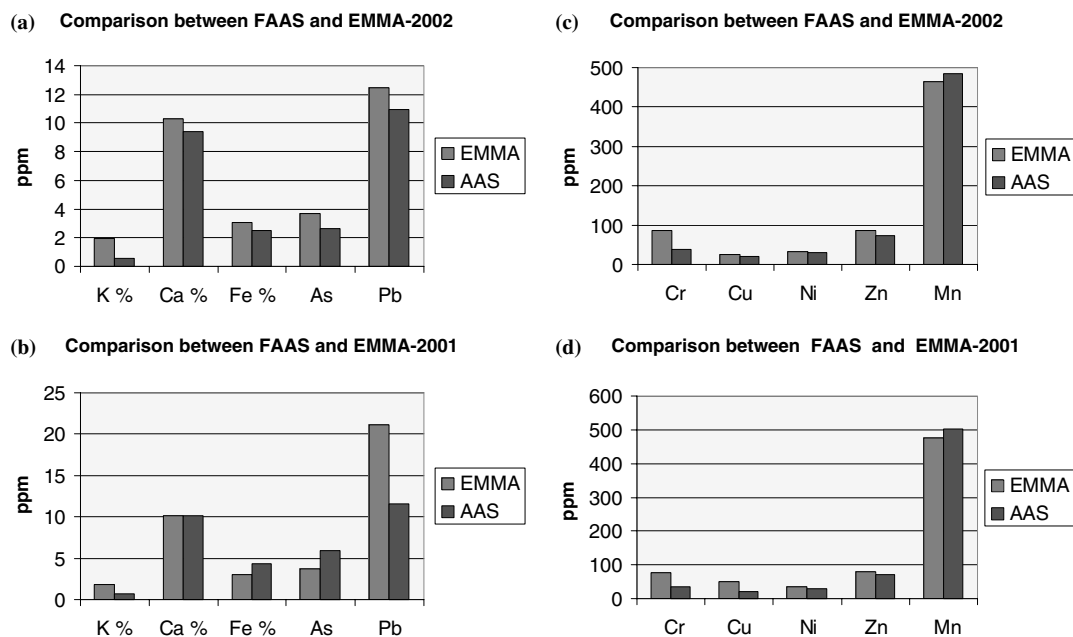


Figure 5. Comparison between the results of AAS and EMMA for sediment samples of Wadi Gaza for two successive years.

and 20% higher in the EMMA to the AAS results, respectively, probably because of an incomplete dissolution of the soil samples during the digestion process by acids. Additional metals were measured by the EMMA and Table 3 showed the contents of these metals (Ti, Ga, Se, Br, Rb, Sr, Y, Zr and Th) in summer and winter.

Conclusions

- (1) The results obtained served to increase our knowledge of the geochemistry of water and sediment of the Wadi Gaza. In spite of this, the study has highlighted the need for further research, by increasing sampling density and regularity to better characterize the geochemical conditions of the Wadi.
- (2) Excluding Station 7, no major contamination of Fe, Zn, Cu, Mn, As, Pb, Cr, Cd, and Co was found in water at most of the stations. Sediments in only two stations had high Hg, Cd, Fe and Zn compared to background values of Turekian and Wedepohl (1961). Heavy metal contents in sediment samples were low in the eastern stations and higher in the lake.
- (3) The various anthropogenic inputs may lead to the enrichment of many metals in the sedi-

ments of Wadi Gaza. Pollution of several sites was found to be considerably high for Hg, Cd, Fe and Zn and to a somewhat lesser extent for As, Pb, Ni, Cu and Co, whereas anthropogenic input of Ga, Se and Th seems to be less important.

- (4) The chemical composition of water and sediments exhibited seasonal variation. The human inputs affect the concentrations of the tested parameters in summer; while the precipitation inputs in winter diluted pollutants to minimum levels.

Recommendations and management strategies

Wadi Gaza is the only wetland in the Gaza Strip and its unique habitat and species warrant careful management. The opportunity exists to apply measures which can bring both ecological and socio-economic benefits. Measures to clean up and restore the wetland would bring ecological, landscape and visual improvements. This may improve the health and the environmental conditions for local people, bring new opportunities in education, recreation, tourism and research, as well as maintain a range of cultural, social and historical heritage values.

The main pressures should be reduced in short, medium and long term measures. These pressures include overgrazing, pollution from the untreated wastewater, discharge of oils and pesticides, cutting and burning of natural vegetation, building roads, agricultural encroachment, hunting and poaching. By reduction of these pressures, the ecosystem functions and productivity will be restored. Examples of short term measures would be to open the mouth of the Wadi to the Mediterranean Sea and to stop the use of oil and pesticides for combating mosquitoes. Examples of medium and long term measures would be to stop the discharge of raw wastewater to the Wadi and to cooperate with the upstream regions in management of the Wadi water resources. Because the Wadi is subject to many jurisdictions, local, governmental, and non-governmental institutions should all play a role in protecting and conserving the Wadi. The efforts should aim to support the conservation of the wetland by implementing activities such as: (1) cleaning campaigns, (2) removal of construction debris, (3) development of recreational areas, (4) building of bridges of culverts, hiking trails, observation towers, and water retention structures and (5) planting of trees in the site.

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