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Heavy Metal Content, Occurrence and Distribution in Soil of Al-Qilt Catchment, Palestine

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Abstract

Heavy metal pollution in Palestine soils has been ignored for decades; anthropogenic pollution of soils has a negative effect on the environment and on human life. Determination of the elemental background and identifying the anthropogenic pollution in Palestine soils will help in screening the anthropogenic metal-based pollution and lead to the setting of water and soil quality management techniques. Several soil sediment samples were collected from Al-Qilt catchment, in addition to samples from pristine areas along the main wadi of Al-Qilt. All samples were analyzed for heavy and trace metals using inductively coupled plasma (ICP-MS) and after sequential fractional extraction based on Bureau Communautaire de Reference (BCR). Data was analyzed by computing the correlation coefficient of heavy and trace metals versus Al and Fe as reference elements. Fe was chosen as elemental normalizer, based on the higher values of correlation factor (R²) as compared to Al. Enrichment Factor (EF) was determined for all elements to account for the contribution of anthropogenic sources. Metals Ti, V, Mn, Co, Rb, Ag, Li, B and Be were found to occur as anthropogenic pollutants at most of the Al-Qilt sites. The EF calculation showed that Pb had the highest value of trace metals in most of the studied locations. The heavy metals measured in this study show a high degree of contamination. This should be investigated using other environmental factors. This can be seen as hints for high risk of pollution by these trace metals.

Keywords: *Heavy metals, Sediments, Anthropogenic pollutants, Groundwater, Enrichment factor, Soil*

Introduction

Groundwater is considered to be the main freshwater resource in Palestine. Due to the rapid increase of population which can be referred to natural growth and the increasing number of Israeli settlements, the demand for potable water in West Bank for domestic uses has increased in the last two decades[1].

Environmental pollution continues to grow at an alarming rate due to human activities such as urbanization, technological progress, unsafe agricultural practices and

rapid industrialization, which degrades the environment. Toxic metals released into the environment are persistent and pose a serious threat to organisms exposed to high levels of such pollutants[1,2].

The studies of heavy metal pollution in sediments and soils have increased in recent years[3-8]. Heavy metals are considered as serious pollutants of aquatic ecosystems, due to their environmental persistence[9], toxicity, and ability to combine with food chains[10].

Toxic metal pollution in Palestine soils was ignored for decades; anthropogenic pollution of soil has a negative effect on the environment and human life[11]. Determination of elemental background for anthropogenic pollution in Palestine soils will help in screening the anthropogenic metal-based pollution[12]. Soil samples from pristine areas of Al-Qilt catchments were analyzed for the assessment of heavy and trace metals mainly those considered as anthropogenic sources for pollution in the area. Sources and impact of anthropogenic pollution in Al-Qilt catchment soils are also discussed. Samples along Al-Qilt catchment were collected on a monthly bases.

An environmental survey reveals that there are 363 disposal sites discharging raw waste-water into the environment in the West Bank[13]. Eight of these are at Al-Qilt catchment which starts from Al-Bireh wastewater treatment plant (5000 m³/d).

This treated wastewater is discharged at Wadi Al-Ein, then mixed downstream with untreated wastewater that is discharged from Qalandiah Camp and Al-Ram (1500 and 1300 m³/d) respectively. Furthermore, there are Israeli colonies and other Palestinian communities discharging their wastewater into the wadi (Figure 1). Moreover, the problem increases when people evacuate their septic tanks by tanker trucks into Al-Qilt wadi at arbitrary places. All these sources are mixed with the urban runoff and dumping site leachates in the winter season.

In general, soil pollution in urban regions may occur from other pollutants such as non-soil origin pollutants. However, the main soil pollutants are radionuclides, chloro organic compounds, and toxic metals. There are different pollutants sources such as road infrastructures, vehicular traffic, and manufacturing activities[15].

For a long time, the water from the Al-Qilt catchment was used for drinking purposes, irrigation, and washing. Today, more than 65,000 people from Palestinian communities[16] and six Israeli colonies totaling about 15,000 people[14] live in the Al-Qilt catchment. From the wastewater which discharges to the catchment, less than 10 percent is treated efficiently in the West Bank, whereas most of it is discharged untreated into the open environment near the wadis[17].

In our study, the criteria used to define toxic metals have included density, atomic number, atomic weight, or periodic table position[22]. Density criteria range from above 3.5 g/cm³ to above 7 g/cm³. The Periodic Table refers to toxic metals as "all the metals in groups 3 to 16 and in periods 4 and greater[23]. There is no widely agreed definition of heavy metal.

The main goal of this research was to study the anthropogenic pollution in Al-Qilt catchment soil and determine the soil elemental background of heavy metals in Al-Qilt catchment. This can be achieved by screening heavy and trace metal content of the Al-Qilt soil as either naturally occurring or resulting from anthropogenic activities using the elemental background for the toxic metals in the pristine area of Al-Qilt soil catchment and studying the occurrence of toxic metals in the pristine area soils of Al-Qilt catchment.

Materials and Methods

Study area
Al-Qilt catchment is located in the West Bank on the western side of the Jordan Valley and covers an area of

about 173 km² (Fig.1). It is characterized by a steep relief with elevations in the range of 700 m.a.s.l in the western part to the range of -250 m.b.s.l in the eastern part by the Jordan Valley. At Al-Qilt, there are about 96,935 inhabitants from Palestinian communities and Israeli colonies, and they discharge about 14,000 m³/d of wastewater. Only about 30% of this wastewater is being treated and then mixed again with raw wastewater. The mean annual rainfall in the Al-Qilt basin is estimated to be about 600 mm in the higher Western part and about 150 mm in the lower Eastern part. The average annual rainfall over the catchment is about 400 mm. The long-term observations of flow mainly for Al-Qilt springs range from 3.0 to 12.0 Mcm/yr, and the continuous base flow for the Ras Al-Qilt spring of around 300 L/s[20].

An environmental survey revealed that there are 363 disposal sites discharging raw wastewater into the environment in the West Bank[19]. Eight of these are in the Al-Qilt catchment which starts from the Al-Bireh wastewater treatment plant (5000 m³/d). The treated wastewater from Al-Bireh is discharged to Wadi Al-Ein and mixed downstream with untreated wastewater that is discharged from Qalandiya Camp and Al-Ram, 1500 and 1300 m³/d respectively. Furthermore, there are Israeli colonies and other Palestinian communities discharging their wastewater into the wadi (Fig. 1). Moreover, the problem is exacerbated when people arbitrarily empty the septic tanks of tanker trucks into Al-Qilt wadi at different places. All these sources are mixed with the urban runoff in addition to leachates from dumping sites during the wet winter season[21].
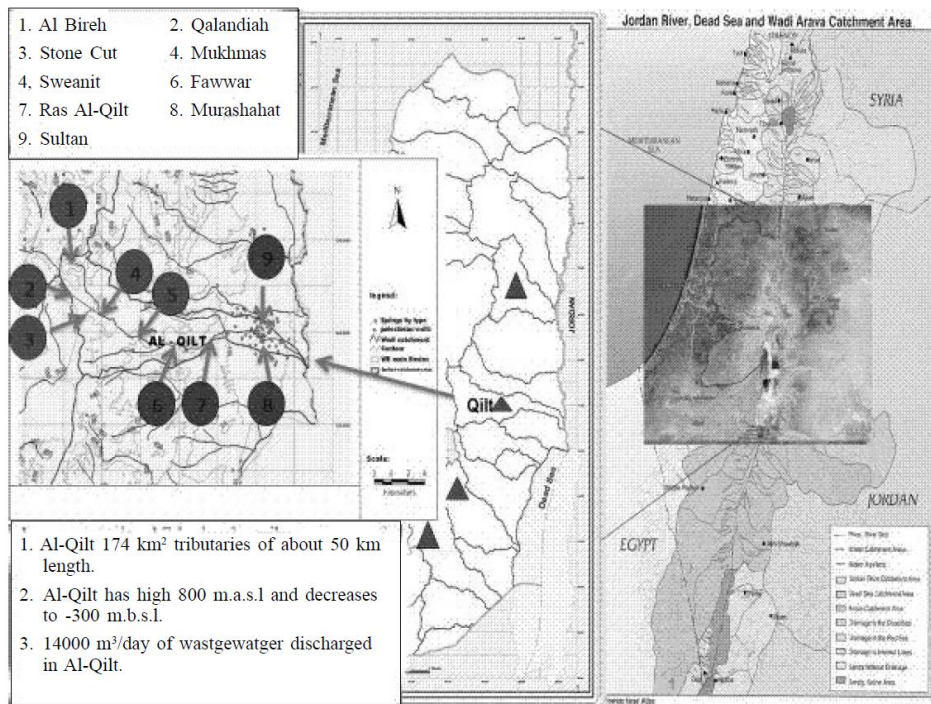

Fig. 1. Location of Al-Qilt catchment

Sampling

Soil sampling can be classified into three major categories: random, systematic and stratified sampling methods. The random sampling is the easiest and can be used for a pilot study with disadvantage is that soil samples may not represent the whole study site. The major objective of random sampling is to determine whether heavy metal concentrations of the soils are above background and/or legislative standards. In heterogeneous sites, stratified and systematic sampling strategies are needed, because they need a more detailed and accurate description of a given site with respect to the spatial and vertical distribution of heavy metals in the soil. In systematic sampling, soil samples are usually collected in a systematic manner, such as at a regular distance from one another across the study area, and at some of the fixed sampling grids., The systematic sampling strategy is often employed in the geochemical mapping of heavy metals, since it enables detailed characterization of the spatial distribution of heavy metals in a large region.

There are several factors that can affect soil sampling include sampling density, sampling depth and the use of composite soil samples. In an ideal situation, the larger the number of soil samples collected, the better the sample population can reflect the conditions of the site.

Like other kinds of environmental assessment, it is important to understand the specific purposes of the investigation. Therefore, at the initiation of the investigation, its primary objectives must be clearly defined and stated, since the objectives will be used as guidelines according to which all subsequent sampling and analytical procedures will be developed. For instance, if the goal of the investigation is to determine whether the soils are contaminated with heavy metals, analysis of the heavy metal concentrations of the soils will be adequate, and sampling of the soils will be relatively simple. However, if knowledge of the spatial distribution of heavy metals in soils is also sought, a systematic sampling approach

will be required. In the preparatory stage, site information, such as soil type, parent materials, topography, and surrounding human activities, should also be collected. This information will assist the planning of the sampling strategy and interpretation of analytical results.

Ten soil samples were collected in December 2012 along the Al-Qilt catchment, and from nine locations as shown in Fig. 2: Ramallah, Al Bireh, Mukhmas, Qalandiah, Stone-cut zone, Sweanit, Fawwar, Ras Al-Qilt, Murashahat and Sultan. About 500 g of composite samples were taken below the top surface of the soil by polyvinylchloride-shovel and then placed in 250 mL polyethylene bottles. All samples were refrigerated at 3^0C for further analysis. Samples were analyzed according to the Water and Wastewater Standard Methods[22].

In addition, four samples were taken from Sweanit, Fawwar, Ras Al-Qilt and Murashahat, from a location far away from any human activity and considered as pristine samples.

Sample preparation and analysis

The water samples were collected during December 2012 in one-liter high-density polyethylene bottles (pre-cleaned with 10% nitric acid followed by repeated rinsing with twice distilled water), stabilized with a few drops of ultrapure nitric acid (0.5% HNO3) that were added to prevent additional microbial growth. All water samples were then preserved in a refrigerator at 4^0C and transported to Germany for examination and laboratory analysis purposes.

ICP-MS (Agilent Technologies 7500 Series, Agilent, Santa Clara, CA, USA) was used for analysis of the selected heavy and trace metals.

The analytical technique and operating conditions of ICP-MS were as follows:

Nebulizer gas (argon) flow rate, 0.9 L/min; auxiliary gas (argon) flow rate, 0.3 L/min; plasma (argon) gas flow rate, 15 L/min; reaction gas flow (helium) rate,
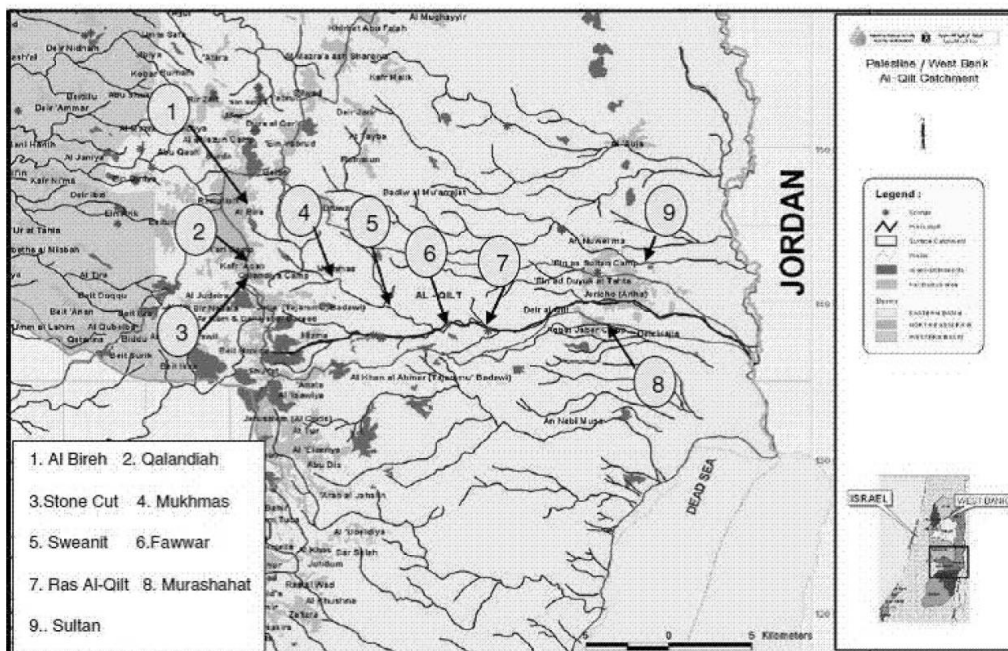
Fig. 2. Sampling location through Al-Qilt catchment

4 mL/min; lens voltage, 7.25 V; and ICP RF power, 1100W.

In terms of quality assurance concepts, an internal standard (Er) and a multi-standard calibration method (29 metal standards with a concentration of matrix 5% HNO3) were used to obtain an accurate quantitative determination for each of the selected toxic metals in water samples. Water samples were prepared by dilution of 1.0 mL of the water samples to 10.0 mL with 0.3% ultrapure nitric acid and they were analyzed by ICP-MS (Agilent, Santa Clara, CA, USA). The descriptive analytical approach has been used to analyze data, as well as to describe the obtained results. For the soil samples:

– About 200-250g of each sample was taken, dried and sieved to <63μm using "Fritsch D-55743" sieving analyzer.

– About 0.25g of each sample and Buffalo Reference Material (8704) as reference standard were weighed accurately in 100 ml Teflon digestion tube for Aqua Regia digestion and then mixed with 6mL of HNO_3 (65%) and 3ml of HCl (37%).

– The samples were digested for two hours using "Microwave MARS 5" digester and then the samples were kept at room temperature

– Samples were centrifuged, and the supernatant transferred to 50mL tube for analysis by doing the proper dilution[21].

Trace metal concentrations of Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Sr, Mo, Ag, Cd, Sn, Sb, Ba,

Pb, Bi, U, B, Li, and Be were measured by an Inductive Coupled Plasma Mass Spectrometer (ICP-MS) (Agilent 7500).

For BCR fractionation analysis, about one gram of the samples was weighed. All soil samples analyses were conducted in the water research Centre of the Helmholtz-Centre for Environmental Research (UFZ), Magdeburg, Germany.

Bureau Communautaire de Reference (BCR)

BCR sequential fractionation extraction was used as a recommended standard procedure for the characterization of heavy and traces metals in sediment and soil[21]. The BCR method compresses four steps classified in terms of reagents used. 'This method is recommended by the Measurements and Testing Program of the European Commission. The fractions of each method are grouped into four "equivalents" (acid soluble, reducible, oxidable, and residual).

Data Analysis

Statistical analysis

Toxic metals were graphed against Al and Fe as reference elements to facilitate the comparison between Al-Qilt sites. Samples were divided into groups based on comparison with the concentrations of the pristine samples (equal or less than), whereas for Al and Fe concentration was around 17217.5 mg/kg and 15896.25 mg/kg, respectively. Analysis of variance was performed using statistical software package SPSS® to identify the variation among heavy metals in the samples.

Normalization of toxic metals

The normalization was based on the supposition that metal concentrations are very consistent with the concentration of reference elements unless the metals were of anthropogenic origin. Normalization is a way to compensate for the natural variability of trace metals in soils, so that any anthropogenic metal contributed may

be detected and quantified by reducing the natural effect of grain size. This assumption allows us to identify the trace metal as a man-made pollutant[23].

The normalization method was based on the following assumptions:
(1) The concentration of metals was regular with respect to the reference elements unless the metals were of anthropogenic origin.
(2) The normalization method is a way to compensate for the natural variability for toxic metals in soil and sediments.
(3) Any anthropogenic metal contribution may be detected and quantified by reducing the natural effect of grain size.

These assumptions allow us to identify the trace metal as a man-made pollutant since many researchers have used Al and Fe as elemental normalizer.

Enrichment Factor (EF)

The first step in the calculation of EF is finding the relation between a metal and a normalizer, and then using this factor to identify anomalous metal concentrations that may have an anthropogenic source. The enriched site can then be specified. The selected normalizer can be divided by the same ratio of anthropogenic to un-impacted geological material (background). This permits the definition of Enrichment Factor (EF) parameters such as (Me/N) sample/(Me/N) background, where (Me/N) sample is metal to normalizer ratio in the soil sample and (Me/N) background is the metal to normalizer ratio in anthropogenic un-impacted geological material[24, 25].

$$EF = (Me/N) \text{ sample}/(Me/N) \text{ background} \qquad (1)$$

Me/N sample is the metal or element to normalizer ratio.

Me/N background is the natural background value of the metal to normalizer ratio.

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Enrichment Factor shows the status of environmental contamination where the EF values were interpreted by Acevedo-Figueroa et. al.,[26], where EF < 1 indicates no enrichment; 1-3 is minor; 3-5 is moderate; 5-10 is moderately severe; 10-25 is severe; 25-50 is very severe and Ã 50 is extremely severe.

Elemental background for soil (EBS)
Trace and heavy metal concentrations indicate anthropogenic pollution if they are compared with the elemental background. Samples from the pristine area (places with no known human activities) in Al-Qilt catchment were analyzed to make the elemental background. Average of the four samples from the pristine areas were calculated and used for the calculation of the above EF.

Quality control and assurance
During sampling and lab analysis, care must be taken when storing the samples in bottles and using lab equipment to avoid contamination from the glassware and bottles. Even the chemicals which will be involved should be of analytical grade and of high purity. All metallic devices and containers of metals should be avoided to prevent contamination or leaching of some metals to soil samples. In such cases, stainless steel devices and plastic containers should be used eq. polystyrene plastic bags. Samples should be stored at 4^0C before analysis.

All glass and plastic containers should be rinsed with dilute acid (10% (v/v) nitric acid) and rinsed thoroughly with distilled and deionized water before use, to ensure that there is no contamination from the laboratory accessories.

In order to provide accurate and producible data, a quality control system must be used throughout the analytical process. The quality control is a set of procedures and practices which result in an increase in precision and a decrease in bias. The use of duplicate analysis, spiked samples, standard reference materials, and QC check samples are all mechanisms used to demonstrate the control of quality. In general, to detect contamination and evaluate the reproducibility and effectiveness of the analytical procedures, procedural blanks, duplicates and certified standard reference materials, such as those offered by the National Institute of Standards & Technology (NIST), should be included in the analytical program.

Results and Discussion

The correlation coefficient (R^2)
Toxic concentrations of collected samples from Al-Qilt were graphed as metal vs. reference element such as Al and Fe and the correlation coefficient were calculated.

The correlation factor between the concentration of all measured metals against Fe were higher than Al. Al and Fe were found to be good normalizers due to their high R^2 values. (Table. 1)

Significant variation (α <0.05) were found among the metals V, Mn, Co, Sr and U for normalization with Al. While for normalization with Fe, significant variation (α < 0.05) were found among the metals V, Mn, Co, Rb, Sr, U, and Li. Complete statistical analysis was done for supplementary materials.

Me/Al, Me/Fe normalization for anthropogenic para-meters: Normalization procedures were adopted by dividing the concentration of any metal by the concentration of the reference element. In this study, we use the normalization procedure to recover the natural variability of trace metal in soil. In this way, the anthropogenic metal contribution could be detected and quantified. The normalization of metal per Al and Fe were calculated and then the normalization results were visualized as numerical numbers and not fractions; the highest value is considered as an indication of anthropogenic pollutants.

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The toxic metals concentrations were graphed as metal vs. reference element and then the correlation coefficients were calculated as shown in Figures 3 to 5.

Table 1. Correlation coefficient values (R²) for metals with Al, Fe, and EBS. along Al-Qilt catchment

| Me	Metal/Al	Metal/Fe	Metal/EBS. *
Ti	0.0469	0.2087	0.8456
V	0.5503	0.7179	0.1000
Cr	0.3837	0.3331	0.8514
Mn	0.4211	0.4222	0.4153
Co	0.6711	0.7253	0.3590
Ni	0.3362	0.3155	0.0939
Cu	0.3602	0.1895	0.4960
Zn	0.3803	0.2362	0.0319
As	0.3942	0.2902	
Rb	0.6297	0.4987	0.0421
Sr	0.5678	0.6026	0.6554
Mo	0.1027	0.1393	0.3333
Ag	0.0068	0.0341	0.3086
Cd		0.0005	0.2727
Sn	0.0762	0.0365	0.1341
Sb	0.2772	0.1698	
Ba	0.1715	0.0194	0.6618
Pb	0.3577	0.2677	0.0884
Bi	0.0003	0.0795	
B	0.0982	0.1277	
Be	0.0727	0.2483	
Li	0.6862	0.7364	
U	0.4127	0.3041	0.0526
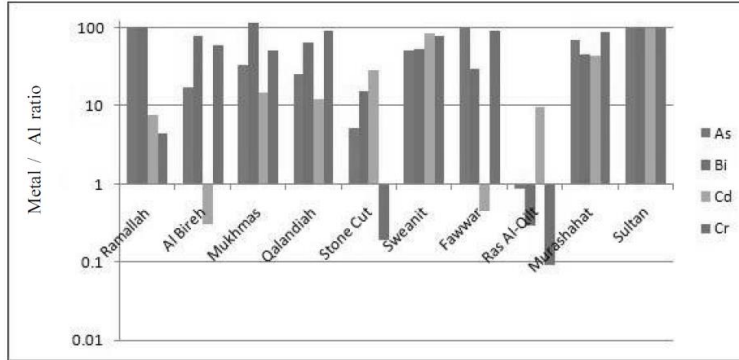
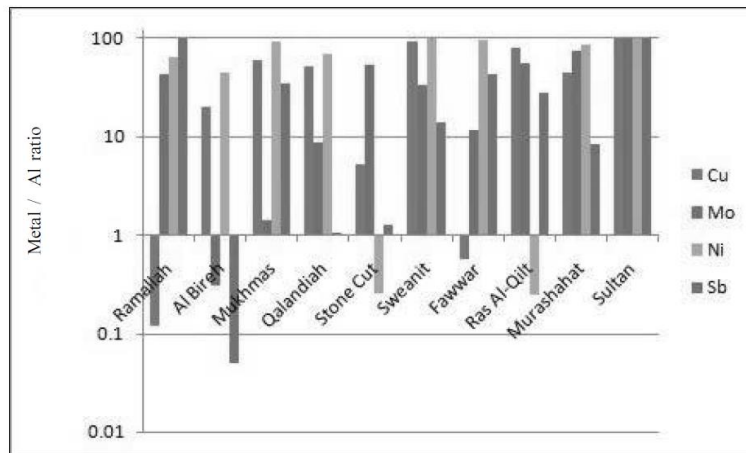**Fig. 3: Metal/Al ratio less than 1 for As, Bi, Cd, and Cr.**

Fig. 4: Metal/Al ratio less than 1 for Cu, Mo, Ni, and Sb.

The results showed that metal/Al was less than 1 for Cr, Ni, Zn, Cu, Sr, Cd, Sb, U, Bi, As and Mo. This indicates that these values of the mentioned parameters are to be considered as background or natural effects. Values of metal/Al greater than one are shown in Figs 6 -8, which indicates anthropogenic pollution.
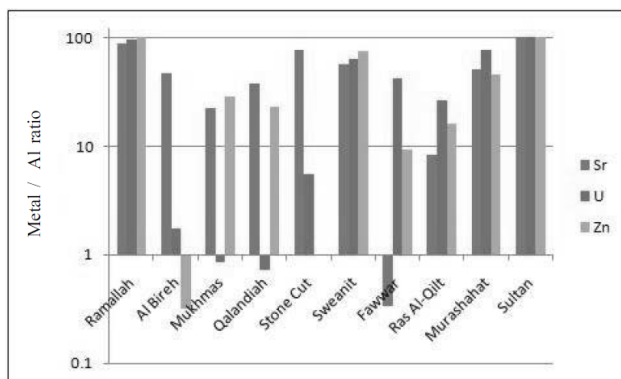
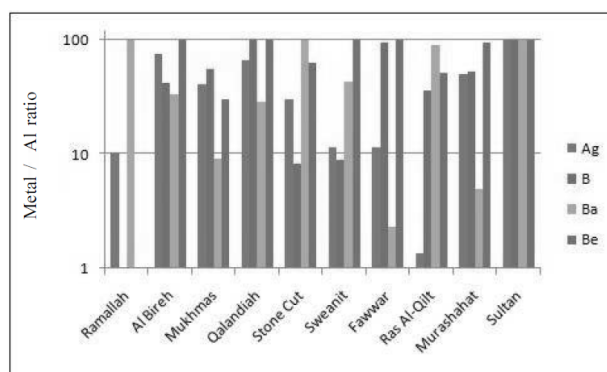**Fig. 5: Metal/Al ratio less than 1 for Sr, U, and Zn.**

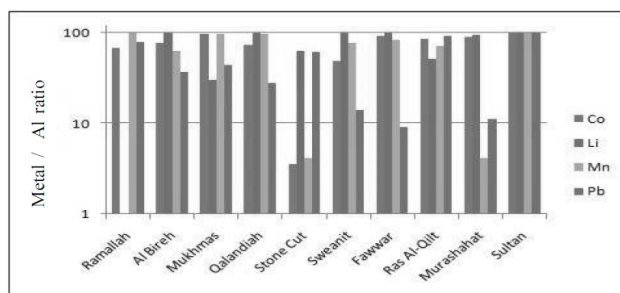**Fig. 6: Metal/Al ratio more than 1 for Ag, B, Ba and Be**

Fig. 7: Metal/Al ratio more 1 for Co, Li, Mn and Pb.

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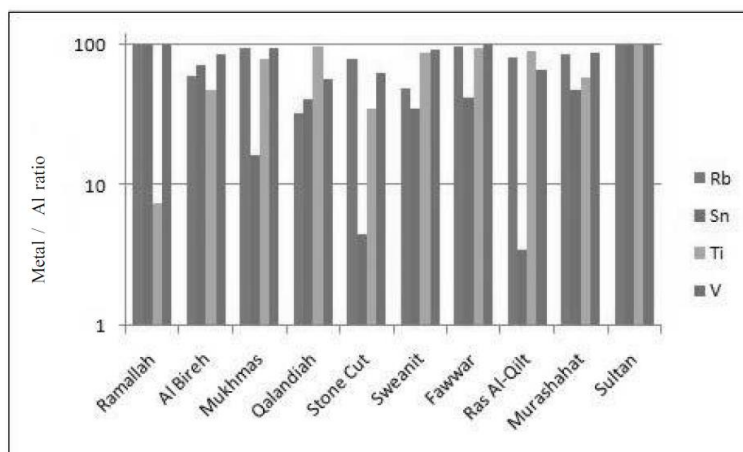

Fig. 8: Metal/Al ratio more 1for Rb, Sn, Ti, and V.

Furthermore, the results showed that metal/Fe ratios for Ni, Zn, Sr, Cd, Sn, Ba, Pb, Bi, and U were less than one, and so these toxic metals are not considered as anthropogenic pollutants at Al-Qilt sampling site as shown in Figs. 9-10.
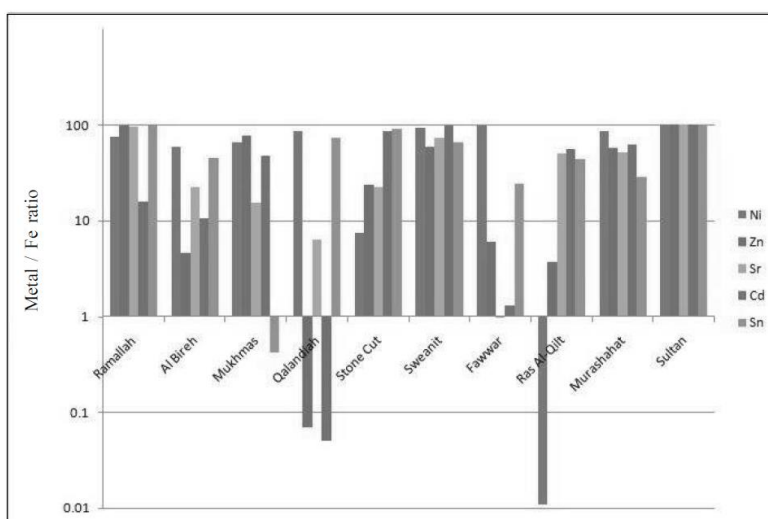

Fig. 9: Metal/Fe ratio less than 1for Ni, Zn, Sr, Cd, and Sn.

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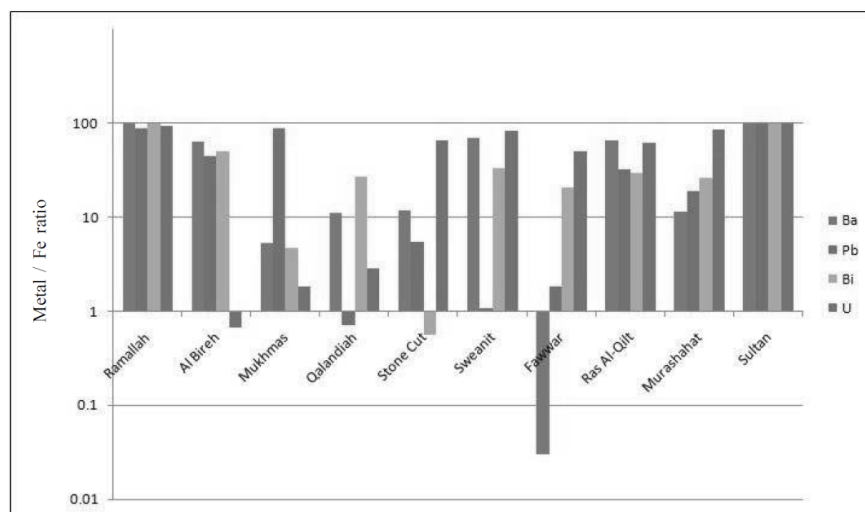
Fig. 10: Metal/Fe ratio less than 1 for Ba, Pb, Bi, and U.

On the other hand, the ratios greater than one, are considered as an anthropogenic indication of pollution and shown in Figs. 11-14.

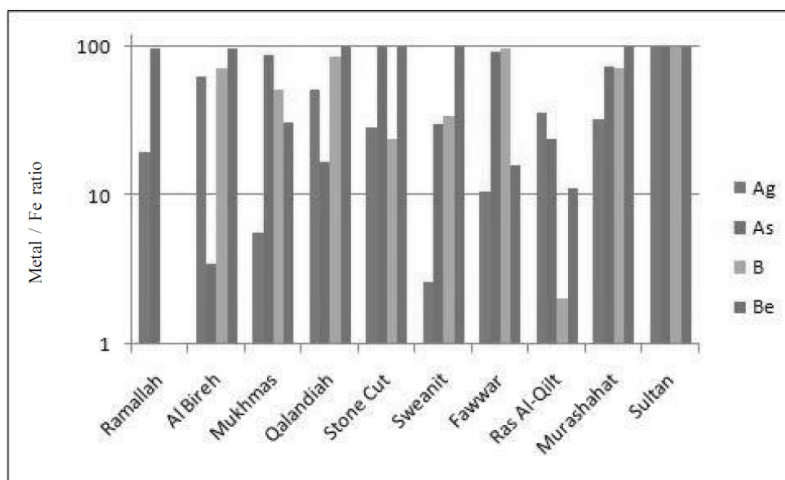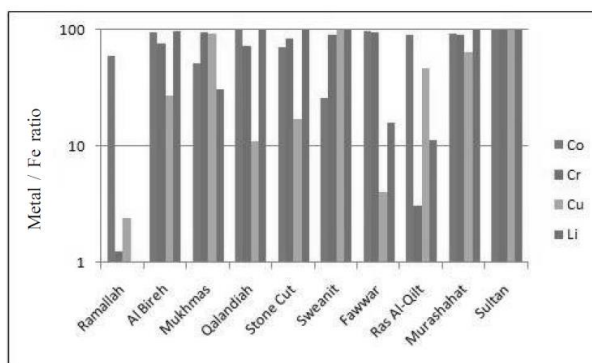**Fig. 11: Metal/Fe ratio more than 1 for Ag, As, B and Be.**

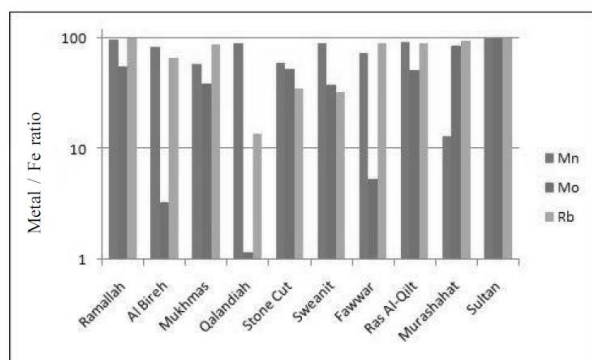**Fig. 12: Metal/Fe ratio more than 1 for Co, Cr, Cu, and Li.**

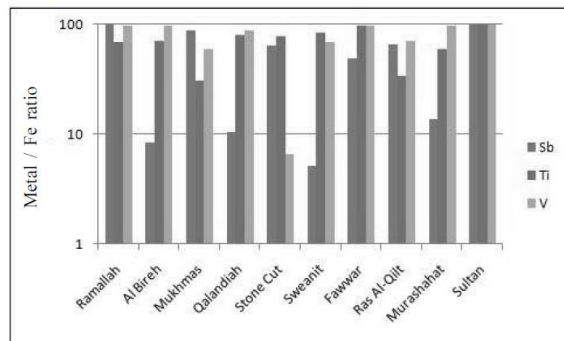**Fig. 13: Metal/Fe ratio more than 1for Mn, Mo, and Rb.**

Fig. 14: Metal/Fe ratio more than 1 for Sb, Ti, and V.

The metal/Al and metal/Fe normalization values for Ti, V, Mn, Co, Rb, Ag, Li, B and Be indicated that these metals are anthropogenic pollutants in most of the Al-Qilt sites.

Furthermore, Fe was more suitable for normalization compared to Al for trace and heavy metals, since it has the highest R^2 values compared to Al as shown in Table 1.

According to the normalization method, we can assign them as anthropogenic pollutants. Thus, we can use the results of Fe as background values for the samples to calculate the Enrichment Factor (EF).

Enrichment Factor (EF)
Table 2 summarizes the results of enrichment factors at Al-Qilt catchment for trace metals tested at each site. If the EF values are between 0.5 and 1.5, the metal must be entirely from crustal materials or natural weathering processes. EF value greater than 1.5 suggests that a significant portion of the metal has originated from non-crustal or anthropogenic processes.

Table 2. Enrichment factor along Al-Qilt. For EF<1: no enrichment, EF=1-3: minor, EF=3-5: moderate, EF=5-10: moderately enriched.

Sampling Location	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Rb	Sr
Ramallah	0.15	0.51	0.41	0.52	0.61	0.38	1.05	1.21	1.33	2.18	0.07
Al Bireh	0.66	0.69	0.36	0.74	0.80	0.49	0.41	0.45	0.52	0.98	0.08
Mukhmas	0.96	0.77	0.41	0.80	0.84	0.54	0.47	0.49	0.58	0.90	0.14
Qalandiah	0.94	0.70	0.34	0.79	0.80	0.47	0.48	0.50	0.47	0.93	0.06
Stone Cut	0.84	0.75	0.65	0.75	0.85	0.57	0.71	0.80	0.64	1.00	0.11
Sweanit	0.92	0.96	0.50	0.58	1.14	0.96	0.82	1.40	1.31	1.31	0.57
Fawwar	0.93	0.90	0.74	1.44	1.09	1.01	1.21	0.92	0.87	0.87	0.93
Ras Al-Qilt	1.06	1.21	0.90	0.86	0.85	1.17	0.83	1.04	0.97	0.85	1.46
Murashahat	1.05	0.91	0.66	0.99	0.93	0.83	1.04	0.75	0.93	1.04	0.92
Sultan	2.16	0.90	0.38	0.20	0.98	0.54	0.41	0.32	0.55	0.80	0.13
	Mo	Ag	Cd	Sn	Sb	Ba	Pb	Bi	U	B	Li
Ramallah	0.33	0.00	0.64	0.31	1.87	0.63	5.71	0.50	0.21		
Al Bireh	0.25	0.60	0.21	0.12	0.37	0.40	0.81	0.50	0.16	0.55	1.00
Mukhmas	0.42	1.16	0.27	0.40	0.48	0.46	1.10	0.64	0.42	0.46	0.50
Qalandiah	0.22	0.00	0.19	0.22	0.34	0.37	0.93	0.45	0.15	0.29	0.93
Stone Cut	0.44	1.93	0.45	0.36	1.20	0.44	4.09	1.07	0.17	0.45	0.95
Sweanit	1.16	2.10	0.75	3.83	1.31	2.23	1.35	1.75	0.58	0.91	1.12
Fawwar	0.77	0.69	0.49	0.51	0.87	1.24	0.89	1.16	0.77	0.68	0.91
Ras Al-Qilt	1.30	0.78	1.67	0.24	0.97	1.08	1.00	1.30	1.73	1.01	1.02
Murashahat	0.82	0.74	1.06	0.23	0.93	0.65	0.85	0.00	0.82	1.37	0.97
Sultan	0.20	4.07	0.26	0.53	0.46	0.32	0.58	1.85	0.41	0.52	1.10

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The EF for heavy and trace metals in soil at Al-Qilt varied with years. From the table we can see that Pb is moderately severe in Ramallah while Pb, Sn and Ag are moderate in stone cut areas (Sweanit and Sultan) respectively.

Values of FE in Table 2 show that there is mostly no enrichment for most of the studied heavy and trace metals. Pb, Sn, and Ag have moderate EFvalues. Pb has the highest value and sometimes showed moderate values like in Ramallah. This value may be due to war and military activities in that region and originates from urban activities such as vehicles, road, and urban runoff prior to phasing out of leaded gasoline.

Conclusions

In this research, Al-Qilt area was found to be with reduced contamination levels in its sediments for heavy and trace metals contents. Such a result is currently a positive factor for the water quality in the region, though, a continuation of discharging untreated wastewater to the main course of Al-Qilt may cause an increase in the contamination levels. When applying the calculation of CF to single steps of the BCR sequential extraction scheme, a more realistic view on the potential impact of the trace metals to the environment is gained. Considering the first two steps of the BCR scheme (exchangeable, reducible) which are the most relevant fractions from which the metals can be released to the environment, Cu, Pb, Zn, Ag, Sb, and Bi exhibit CF values greater than six. The pollution caused by the discharge of wastewater, dumping site leachate, urban runoff, plastic material, and batteries have led to these results. These reveal that there is severe contamination by Ag, Bi, Cd, Zn and Hg at most of the sites. The heavy metals measured in this study show a high degree of contamination and should be investigated. This can be seen as hints for high risk of pollution by these trace metals. For future research, Iron levels are recommended as elemental normalizer. Levels of Pb contamination in Al-Qilt

sediments were found to be moderately enriched, and such contamination might decrease with time due to phasing out of leaded gasoline in the country.

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