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Heavy Metals Distribution and Pollution in the Sediments of the Wadi Gaza Mouth, Eastern Mediterranean Coast, Palestine

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Resumen: *DISTRIBUCIÓN DE METALES PESADOS Y CONTAMINACIÓN EN LOS SEDIMENTOS DEL WADI GAZA BOCA, COSTA MEDITERRÁNEA ORIENTAL, PALESTINA.* El Wadi de Gaza es el humedal más importante de la Franja de Gaza. Debido a las dificultades económicas, la ocupación Israelí y la carencia de recursos, el Wadi de Gaza se ha transformado en un repositorio de residuos líquidos que provienen de las áreas circundantes. El objetivo de este trabajo es evaluar los metales pesados en los sedimentos del Wadi de Gaza, al Norte y al Sur río abajo a lo largo de la playa de la franja de Gaza. Esto se ha logrado a través del muestreo de sedimento a lo largo de la corriente descendente del Wadi de Gaza, al norte y al sur de las arenas de playa, habiendo realizado los análisis geoquímicos en los laboratorios del Ministerio de Salud. Las concentraciones en los sedimentos de Mn, Zn, Ni, Cd, Cu, y Pb fueron determinadas usando un espectrofotómetro de absorción atómica. Las concentraciones promedio de metales pesados (Mn, Zn, Ni, Cd, Cu, y Pb) en los sedimentos de la boca del Wadi de Gaza fueron 16.04, 49.33, 3.38, 1.72, 3.83, y 0.79 mg/kg, respectivamente. El área de la corriente abajo del Wadi de Gaza fue la que mayor concentración de metales pesados presentó, en contraste con otras zonas, excepto para el Cd, que denota altos niveles en las arenas de playa en el norte y el sur del área de estudio, con un promedio de 2.08 mg/kg, mientras que su concentración media en los sedimentos del wadi corriente abajo fueron de alrededor de 1.02 mg/kg. Los niveles de concentración de los metales pesados (Mn, Cd, Cu, and Pb) en los sedimentos del área de estudio estuvieron debajo de lo estándar para sedimentos, pero Ni y Zn fueron contaminantes moderados en comparación a las normas de Ontario y US EPA para calidades de sedimentos. Los patrones de distribución para Zn y Ni claramente indican que la contaminación es debida a factores antropogénicos, y puede volverse alarmante si las medidas de mitigación no son consideradas. El estudio recomienda detener el flujo de aguas residuales en el entorno marino, que es la principal fuente de contaminación en el área de estudio. El método de descarga de efluentes debe ser reconsiderado. Además fortalecer los esfuerzos de investigación científica para mejorar los programas de monitoreo del Wadi de Gaza y, en consecuencia, la calidad de los humedales.

Abstract: Wadi Gaza is the most important wetland in Gaza Strip. Due to the difficult economic conditions, the Israeli occupation and lack of the resources, Wadi Gaza became a place for solid and liquid waste disposal from surrounding provinces. The aim of this study is to assess the heavy metals in the sediments of the Wadi Gaza, North, and South of downstream along the beach of Gaza Strip. This was achieved through sediment sampling along the course of the Wadi downstream; north and south of the beach sands, and the geochemical analysis was done in the Ministry of Health Laboratories. The concentrations of Mn, Zn, Ni, Cd, Cu, and Pb were determined in the sediments, using atomic absorption spectrophotometer.

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The mean concentrations of the heavy metals (Mn, Zn, Ni, Cd, Cu, and Pb) in the sediments of the mouth of the Wadi Gaza were 16.04, 49.33, 3.38, 1.72, 3.83, and 0.79 mg/kg, respectively. The area of Wadi Gaza downstream was the most higher concentration of the heavy metals than other locations, except the Cd, it shows high-level in beach sands in the north and south of the study area with mean about 2.08 mg/kg, while its mean concentration in the wadi downstream sediments was about 1.02 mg/kg. The concentration levels of the heavy metals (Mn, Cd, Cu, and Pb) in the sediments of the study area were below the limits of standard for sediments, but Ni and Zn were moderate pollutant compared with Ontario and US EPA of the sediment quality guidelines. The distribution patterns for Zn, and Ni clearly indicate that sediment contamination is due to anthropogenic factors, and may become alarming if mitigation measures are not considered. The study recommends to stop the flow of sewage into the marine environment, which is the main source of pollution in study area. The effluent discharge method should be reconsidered. Strengthening the scientific research efforts to improve Wadi Gaza monitoring programs and consequently wetland quality.

Key words: Palestine, Gaza Strip, Wadi Gaza, Mediterranean Coast, Heavy Metal Distributions, Sediments Investigation, Pollution.

Palabras clave: Palestina, Franja de Gaza, Wadi de Gaza, Costa del Mediterráneo, Distribución de Metales Pesados, Investigación de Sedimentos, Polución.

Introduction

The Gaza Strip is located at the southwestern part of Palestine, at the southeastern coastal plain of the Mediterranean Sea (Figure 1A, B), between longitude 34° 20\` and 34° 25\` East and latitude 31° 16\` and 31° 45\` North. Gaza Strip is bordered by Egypt from the south, Negev desert from the east and the green line from the north. Its area is about 365 km^2, it has a length of about 45 km along the coastline from Beit Hanoun in the north to Rafah in the south, and its width ranges from 6 km in the north to a maximum of 12 km in the south (GEP, 1994; Ubeid, 2011a; 2016 and Al-Agha, 2016). The southern Mediterranean coast has been shaped by the sediment transport from the Nile river upward via the north coast of Sinai to Gaza Strip (Ubeid, 2011a).

The Gaza Strip is considered one of the denser places in the world. The total population of the Gaza Strip at 2016 was about 2 million inhabitants.

The aims of this study are to estimate the level of heavy metals (Ni, Zn, Pb, Cd, Cu, and Mn) in the downstream sediments of Wadi Gaza, and to examine the pollution in the marine sands to north and south of the Gaza beach with respect to the wadi downstream.

The Gaza Strip Coast and Its Geology

Palestine's coastline is broadly concave, trending generally NNE-to-SSW (Figure 1B). It lies between two parallel lineaments; the eastern, or onshore, lineament is an escarpment that is locally steeper than 45 degrees and rises as high as 50 m above mean sea level (MSL) (Neev *et al.*, 1987). A sequence of Late Pleistocene to Holocene sediments crops out along the cliff. The top of this sequence extends eastward to form Palestine's now-elevated alluvial coastal plain. The western, or offshore, lineament is a low submarine escarpment. It forms the western limit of a patchy abraded terrace that is a few hundred meters wide.

The coastal plain adjoins the coastline on the land and the continental shelf beneath the ocean. Both areas contain broadly curved subparallel sand ridges that are similar to each other. River valleys and ridge bifurcations provide smaller interruptions. The ridges necessarily are farther apart at the southwest and converge toward the north because the combined coastal plain and shelf narrows to the north, yet has relatively smooth slopes toward an approximately uniform 130 m shelf break, and because the base of each ridge has approximately the same eleva-

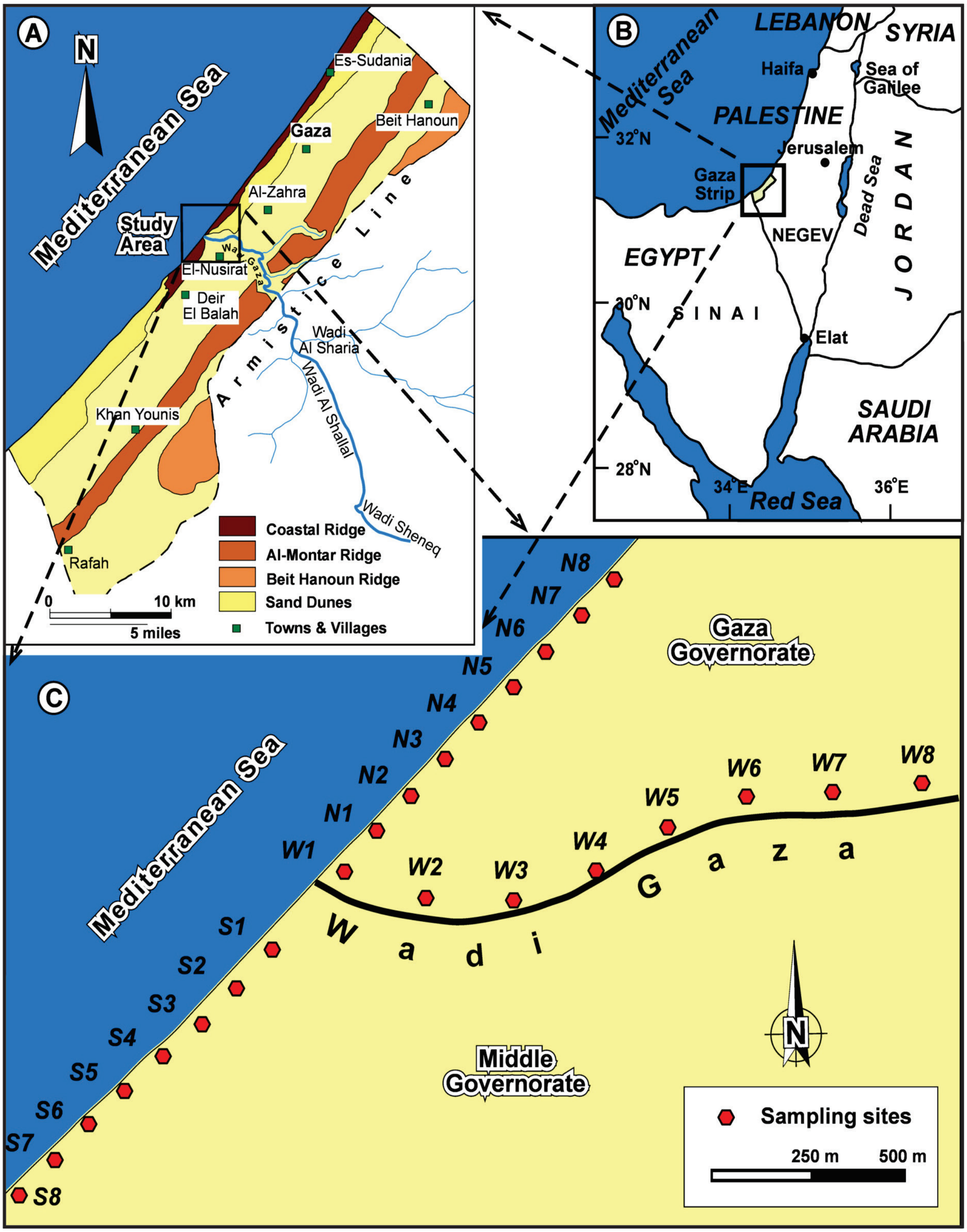

Figure 1. Location Map of the study area. / **Figura 1.** *Mapa de ubicación del área de estudio.*

tion along its entire length. These characteristics are to be expected for the deposition of coastal sand ridges, but they are unusual for purely tectonic features. Local people have mapped three accessible ridges on land and refer to them as kurkar ridges. People have used these ridges' hard sandstone, also called kurkar, extensively for construction since ancient times (Neev *et al.*, 1987).

The Gaza Strip which is situated in the

south-western part of Palestine on the Mediterranean Sea's southeast coastal plain (Figure 1A, B). The three kurkar ridges define its topography. The Coastal ridge is up to 50 m above MSL and extends up to the current coastline in the west. The Al-Montar and Beit Hanoun ridges run along its middle and the eastern parts (Figure 1A). Stratigraphically, these ridges belong to the Pliocene-Pleistocene Kurkar Group. They consist of marine and continental calcareous sandstone (Bartov *et al*., 1981; Frechen *et al*., 2004; Al-Agha and El-Nakhal, 2004; Galili *et al*., 2007; Ubeid, 2010), intercalated with red, sandy loam soils, called locally hamra, which is the Arabic word for red (Yaalon and Ganor, 1973; Ubeid, 2010, 2011b). Deep depressions separate the ridges 20 to 40 m above MSL with alluvial deposits.

The coastal zone is a band of water and land along the marine shoreline in which different activities interact. It includes sand dunes in the south and north, coastal kurkar cliffs in the middle to the north, non-urban areas, and part of Gaza valley, which is also called Wadi Gaza. The coastal zone covers approximately 74 km^2, of which 2.7 km^2 are beaches (Al-Agha, 2000). The coastline has a straight and sandy shore. The near-coast continental shelf slopes down with a gradient of 1:100. The irregular and rocky seabed of the coastal shelf to the depth of 100 m is 28 km wide in the south and 14 km wide in the north. The seabed drops quickly beyond the depth of 100 m. Its sediments consist mainly of sand 25 m deep, with muddy places near the Wadi Gaza.

Sea Water Pollution of Gaza Strip

The sandy coast of the Gaza Strip is one of the most beautiful. However, several spots along the coast are used as waste disposal and landfills. According to the municipal sources in Gaza, some million cubic meters of wastewater are disposed in the Mediterranean Sea annually. About 110,000 m^3 per day of untreated or partially treated wastewater is discharged into the Mediterranean Sea, which mostly coming from around eight sewage stations and Wadi Gaza, which are pumping sewage into the seawater (Figure 2). The sewage is either disposed near the seashore or few meters inside the seawater (Abualtayef *et al*., 2014; Al-Agha, 1993; 1999; 2000; Ubeid and Al-Agha, 2016). The pollution presents a major health risk for swimmers and marine life; there are also indications that the quality of fish is influenced by coastal pollution (Muzyed, 2011; Moqat, 2014).

This pollution can be prevented by the introduction of wastewater recycling and reuse in the Gaza Strip. The introduction of these industries will require considerable financial, technical, and managerial efforts, but will contribute greatly to solving the water pollution and related economic problems in the area (Al-Agha, 1997).

The Wadi Gaza

Wadi Gaza is located in the center of the Gaza Strip, and it crosses the Strip from east to west (Figure 1A). The last 9 km of it is located in Gaza Strip, where it extends from the armistice line in the east to the Mediterranean coast in the west. The general elevation of the topography on both sides of the wadi ranges from 20 to 40 m above sea level, the Wadi floor descends from 30 m above sea level at its eastern limits its downstream. The width and depth of Wadi Gaza vary a lot, being 40–60 m wide in its eastern and middle ranges, it becomes more than 400 m wide at its downstream in the west. The depth varies from 5 to 10 m in the east to 3-4 m in the west at the downstream. Its watershed is estimated to cover around 3600 km^2 in Gaza Strip and neighbor areas (the northern Negev Desert and Hebron Mountains) beyond the armistice border (Rabou *et al*., 2008; Ubeid, 2016). The

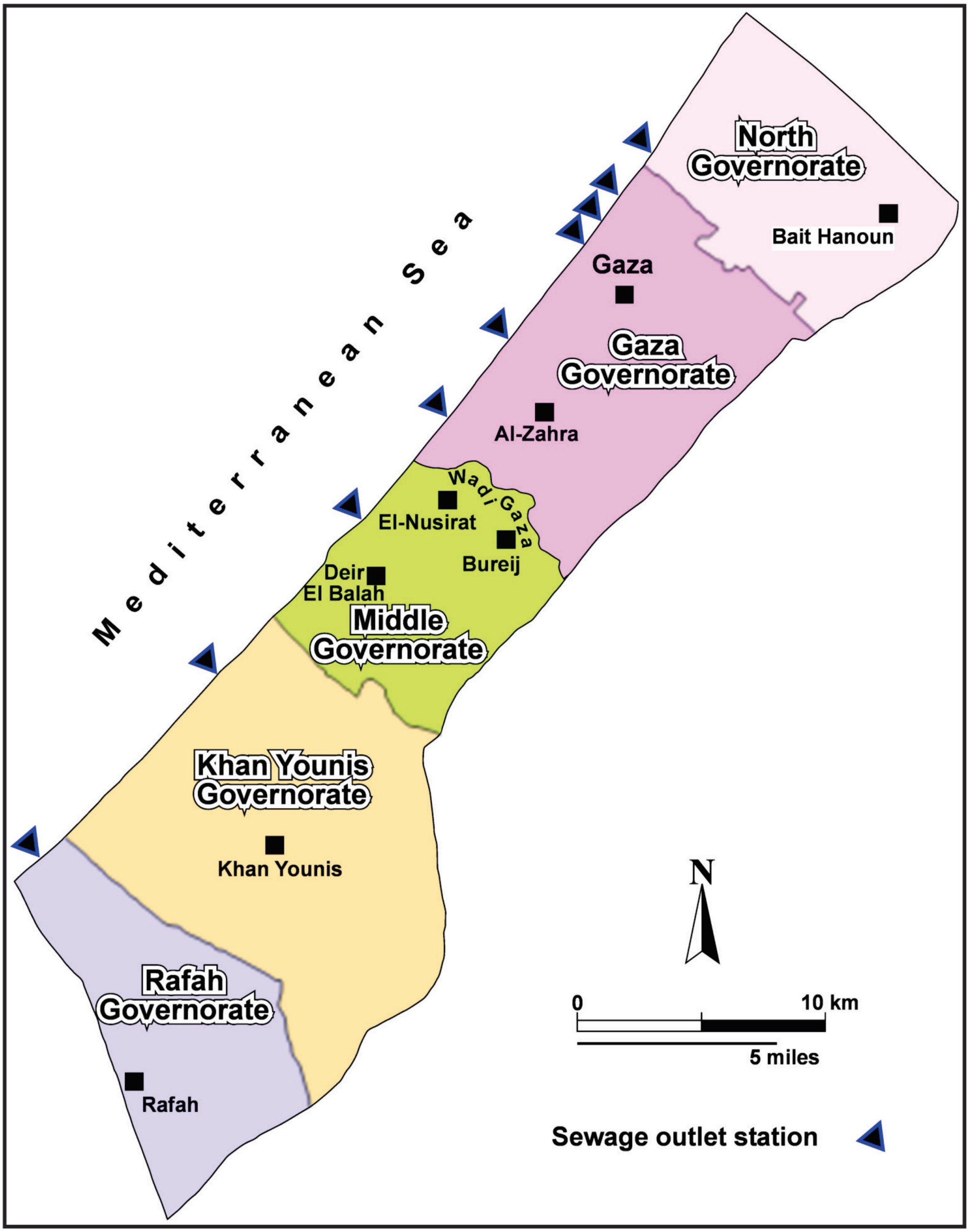

Figure 2. Sewage outlet stations along the beach of the Gaza Strip. / **Figura 2.** *Estaciones de salida de aguas residuales a lo largo de la playa de la Franja de Gaza.*

light-brown palaeosols of the Pleistocene–Holocene cover the most of the wadi's area. The sandy and gravelly deposits crop out in few locations because of excavation of gravels for construction purposes (MedWetCoast, 2001; Ubeid, 2011b; 2013; 2016).

Materials and Methods

Sediments Sampling

Sediment samples were collected from three locations in the study areas: Wadi Gaza downstream, the north and south of the wadi downstream along the beach of Gaza Strip. Twenty four samples were collected from upper 20 cm sediments depth (Figure 1C). The distribution of samples were: eight sediment samples from the area of wadi downstream, the distance separation between the each sampling sites were about 200 m; eight samples from the beach sands to north of the wadi (Gaza beach); and another eight from the south were collected, the distance separation between the sampling sites were about 120 m. Sediment samples were placed in polyethylene bags, tightly closed, and transported to the laboratory.

The sediment sampling sites selected for these investigations were diverse in terms of depositional environment. They were located by Global Positioning System (GPS) devices (Table 1).

Sample No.	Coordinates	
	E	N
(A)		
1-W	34.37575909	31.46417742
2-W	34.37771922	31.46356843
3-W	34.37979736	31.46349546
4-W	34.38174716	31.46416433
5-W	34.38348863	31.46517784
6-W	34.38531988	31.46587871
7-W	34.38743251	31.46597425
8-W	34.38952708	31.46618102
(B)		
1-N	34.37652052	31.46509649
2-N	34.37735372	31.46589817
3-N	34.37814691	31.46674187
4-N	34.37895929	31.46755848
5-N	34.37978286	31.46837135
6-N	34.38055936	31.46921826
7-N	34.38140704	31.47001457
8-N	34.38219321	31.47085314
(C)		
1-S	34.37318053	31.46153691
2-S	34.37238388	31.46068433
3-S	34.37142364	31.45997365
4-S	34.37059472	31.4591533
5-S	34.36981206	31.45829794
6-S	34.36981206	31.45829794
7-S	34.36897031	31.45748274
8-S	34.36810890	31.45668961

Table 1. Shows the coordinates of the observation sites. **A)** For wadi downstream sites; **B)** For north beach sites; **C)** For south beach sites. / **Tabla 1.** *Muestra las coordenadas de los sitios de observación.* **A)** *Para sitios aguas abajo de wadi;* **B)** *Para sitios de playa norte;* **C)** *Para sitios de la playa sur.*

Laboratory and Statistical Analysis

Mechanical and chemical analysis

To assess contamination in an environmental monitoring perspective, in the laboratory, the coarse particles or large materials were removed by sieving. Samples were dried in an oven at 105 °C for 24 hours. Samples were sieved to pass < 90 µm, where metals are most often associated with fine grains. After completion of the drying and sieving of samples, weight about four grams were taken for analyzing.

Reagents used in this study were of the highest available quality, acids (Nitric (HNO_3) and Hydrochloric (HCl) were of highest quality from Merck, Germany.

The four grams of dried sediment sample were added to 3 ml concentrated nitric acid and 9 ml of hydrochloric acid (Aqua regia) in prewashed beaker by distilled water and digested at room temperature. The sediment samples were then evaporated almost to dryness at moderate temperature 65-70°C on the hot plate under the clean air-fuming hood. Finally, the samples were diluted up to 50 ml with 2% nitric acid. Heavy metals (Ni, Zn, Pb, Cd, Cu, and Mn) in the sediment samples were analyzed by Flame Atomic Absorption Spectrophotometer (FAAS). The results were expressed as mg/kg dry weight for sediment samples.

Statistical analysis

This study used the Statistical Package for the Social Science (SPSS) for manipulating and analyzing the data. The software SPSS uses to describe statistics such as mean; standard deviation; coefficient of variation; minimum; and maximum values. Also it used to determine the following statistic items: (1) Pearson correlation coefficients for measuring the correlation between two paired of metals. (2) 1-sample K-S to test the normality of the data. (3) One way ANOVA test for the difference between the means of the metals due to area of the Wadi (wadi downstream; North; and South). (3) Friedman Test for testing the difference in means of metals in different area of the Wadi. (4) Matrix Scatter plots for correlation between two paired of metals. (5) Clustered bar charts to compare between the means of metals in each area of the Wadi.

Results and Discussion

Heavy metal concentrations in the sediments

The concentrations of the studied elements Mn, Zn, Ni, Cd, Cu, and Pb in the sediments of the Wadi Gaza downstream, and along the beach to the north and south of the wadi downstream are presented in table 2; and table 3 which summarizes the statistical results of the element concentrations in the sediment samples of the study area.

For Mn, its values in the study area range from 2.78 to 48.33 mg/kg, with mean value about 16.04 mg/kg. The values in the wadi downstream sediments range from 11.15 to 48.33 mg/kg, with mean value about 28.09 mg/kg. The high level areas are mainly found in the downstream at the observation sites W2; W3; W4 and W8. The Mn contents at these sites are 40.42; 41.74; 38.63; and 48.33 mg/kg (Figure 3A).

Whereas, the Mn values in the beach sands to north of the wadi downstream range from 2.78 to 17.5 mg/kg with mean value about 10.36 mg/kg, in the opposite direction at the south of the wadi downstream, the values of the Mn range from 4.03 to 16.77 mg/kg, with mean value about 9.68 mg/kg (Table 2 and 3).

Overall, the highest Mn values where observed around the pool accumulation of the sewage, at the observation sites W2; W3; W4, and solidwaste dump site at observation site W8.

The Zn values in the study area range from 7.23 to 190.73 mg/kg, with mean value about 49.33 mg/kg. The values in sediment samples of the wadi downstream in the study area range from 27.84 to 190.73 mg/kg, with mean value about 101.6 mg/kg. The high-level of the Zn, were mainly found at observation sites W2; W3; W4; and W5, while the low-level were found at observation site W8. The highest-level of Zn values where observed around the pool accumulation of the sewage, around the observation sites W2; W3; W4; and W5 (Figure 3B).

In the sand samples of the beach at the north direction of the wadi downstream the Zn high-level was about 25.23 mg/kg at observation site N1 which is very

Sample No.	Mn	Zn	Ni	Cd	Cu	Pb
(A)						
W1	12.67	27.84	2.19	0.19	1.23	0.24
W2	40.42	190.73	50.53	1.14	9.88	2.55
W3	41.74	111.94	88.54	1.04	12.78	0.67
W4	38.63	118.66	36.5	1.29	9.24	0.41
W5	19.5	126.82	61.35	1.1	8.09	0.62
W6	12.29	107.1	81.52	1.29	10.46	1.92
W7	11.15	81.04	48.14	0.83	4.43	0.43
W8	48.33	48.67	45.48	1.28	5.14	0.52
(B)						
N1	13.6	25.23	3.76	2.19	1.12	0.62
N2	10.62	12.85	22.91	1.69	2.31	0.54
N3	9.71	13.26	20.75	2.19	1.29	0.65
N4	5.88	11.68	8.96	1.44	0.74	0.2
N5	2.78	7.82	16.72	2.34	0.6	0.41
N6	6.39	7.23	29.42	2.41	0.9	1.25
N7	16.4	18.49	32.6	2.27	0.56	0.68
N8	17.5	15.35	40.21	2.08	0.69	0.96
(C)						
S1	13.94	26.26	1.26	2.24	7.47	0.93
S2	8.37	71.94	25.48	1.89	3.76	0.94
S3	5.12	51.8	15.39	1.69	4.43	0.21
S4	7.25	36.31	10.52	2.35	1.91	0.65
S5	4.03	23.38	18.22	2.23	1.17	0.47
S6	6.21	16.28	30.97	2.3	2.47	1.19
S7	16.77	17.1	28.37	1.39	0.47	0.55
S8	15.74	16.22	33.21	2.53	0.89	0.69

Table 2. Heavy metal concentrations (mg/kg) in the sediment samples of the study area. **A)** For wadi downstream sediment samples; **B)** For north sand beach samples; **C)** For south sand beach samples. / **Tabla 2.** *Concentraciones de metales pesados (mg / kg) en las muestras de sedimentos del área de estudio.* **A)** *Para muestras de sedimentos aguas abajo de wadi;* **B)** *Para muestras de playa de arena norte;* **C)** *Para muestras de playa de arena del sur.*

closed to value at observation sites S1 and W1 (about 26.26 and 27.84 mg/kg respectively), where these three observation sites considered the contact between the wadi downstream and the sea. These values are low compared with those in observation sites W2 to W5, this could be refer to wave current which dispersive the concentration of the element. In the south direction the high level was found at observation site S4 with about 36.31 mg/kg.

The mean value of the Ni contents

Metal	Min.	Max.	Mean	Co. V.*	Std. Dv.**
(A)					
Mn	11.15	48.33	28.09	55.6	15.62
Zn	27.84	190.73	101.6	49.5	50.25
Ni	2.19	88.54	51.78	52	26.92
Cd	0.19	1.29	1.02	36.3	0.37
Cu	1.23	12.78	7.66	49.3	3.78
Pb	0.24	2.55	0.92	91.3	0.84
(B)					
Mn	2.78	17.5	10.36	50.5	5.23
Zn	7.23	25.23	13.99	41.8	5.85
Ni	3.76	40.21	21.92	55.4	12.14
Cd	1.44	2.41	2.08	16.3	0.34
Cu	0.56	2.31	1.03	56.3	0.58
Pb	0.2	1.25	0.66	48.5	0.32
(C)					
Mn	4.03	16.77	9.68	52.1	5.04
Zn	16.22	71.94	32.41	62	20.11
Ni	1.26	33.21	20.43	54.2	11.08
Cd	1.39	2.53	2.08	18.3	0.38
Cu	0.47	7.47	2.82	82.6	2.33
Pb	0.21	1.19	0.7	44.3	0.31
(D)					
Mn	2.78	48.33	16.04	80.4	12.89
Zn	7.23	190.73	49.33	99	48.85
Ni	1.26	88.54	31.38	72.7	22.81
Cd	0.19	2.53	1.72	36	0.62
Cu	0.47	12.78	3.83	98.7	3.78
Pb	0.2	2.55	0.76	71.1	0.54

* Co. V.= Coefficient of Variation; ** Std. Dv.= Standard Deviation

Table 3. Descriptive of statistics analysis of heavy metal concentrations in the sediment samples of the study area. **A)** Wadi downstream; **B)** North beach; **C)** South beach; **D)** Total study area. / **Tabla 3.** *Descriptivo del análisis estadístico de las concentraciones de metales pesados en las muestras de sedimentos del área de estudio.* **A)** *Wadi aguas abajo;* **B)** *Playa norte;* **C)** *South Beach;* **D)** *Área total de estudio.*

in the sediments of the study area was 31.38 mg/kg, the values range from 1.26 to 88.54 mg/kg. At the wadi downstream the mean value was 51.78 mg/kg, while they were 21.92 and 20.43 mg/kg in the north and south of the beach sands respectively.

The high-level of the Ni in the sediments were found at observation sites W3 and W6 in the wadi downstream, with values about 88.54 and 81.52 mg/kg respectively. Where, they located close to the sewage accumulation in the wadi (Figure 1 and 3C). In the beach sands, the high-level contents of the Ni were 40.21 and 33.21 mg/kg at N8 in the north and S8 in the south of the study area.

The mean value of the Cd concentrations in the sediments of the study area was 1.72 mg/kg, the values range from 0.19 to 2.53 mg/kg. The high-level of the Cd concentrations in the sediments of the study area were found in the beach sands, with average about 2.08 mg/kg in the north and south of the study area. The value of the Cd concentrations in the sands of the observation sites along the beach of the study area were closed to each others, except the observation sites N4 and S7 were recorded the lowest values, they were 1.44 and 1.39 mg/kg respectively (Figure 1 and 3D). Whereas, the average value of the Cd concentration in the sediments of the wadi downstream was 1.02 mg/kg. The values of the Cd contents at the observation sites in the wadi downstream were close to each other where they range from 1.04 to 1.29 mg/kg, except observation sites W1 and W7, they were recorded the lowest level, with values about 0.19 and 0.83 mg/kg respectively.

The mean value of the Cu concentrations in the sediments of the study area was 3.83 mg/kg, the values range from 0.47 to 12.78 mg/kg. The high-level of Cu contents in the sediments was observed in the wadi downstream, with mean value 7.66 mg/kg. The observation sites from W2 to W6 were recorded the highest values, which range from 8.09 to 12.78 mg/kg. These observation sites were closed to sewage accumulation. The beach sands have low values of Cu contents with average 1.03 mg/kg in the north and 2.82 mg/kg in the south of the study area (Figure 1 and 3E).

The mean value of the Pb concentrations in the sediments of the study area was 0.76 mg/kg, the values range from 0.2 to 2.55 mg/kg. The high-level concentrations of the Pb in the sediments were found in the wadi downstream with average value about 0.92 mg/kg. The observation sites W2 and W6 were recorded the high-level of Pb contents with value about 2.55 and 1.92 mg/kg respectively, which are located close to sewage accumulation. Whereas, the Pb concentrations in the beach sands varied between low-to intermediate-levels, with average values about 0.66 mg/kg in the north and 0.7 mg/kg in the south of the study area (Figure 1 and 3F).

Assessment of heavy metals pollution by sediment quality guidelines

The extent of metals pollution was assessed by comparing of the mean value metal concentrations in study area to the sediment quality guidelines (SQGs) developed by US EPA (Pekey *et al.*, 2004), and the Ministry of Environment and Energy, Ontario, Canada (MOE, 1993) (Table 4).

The results show that the Mn concentrations in the Wadi Gaza downstream sediments, north and south of the Wadi Gaza downstream in beach sands were below the lowest effect level with respect to the Ontario guidelines (Table 2 and 4).

The Zn concentrations in the sediments of the wadi downstream and beach sands in north and south of the study area were below the lowest effect level, except at two observation sites in wadi downstream W3 and W5 they fall within category severe effect level with respect to the Ontario guidelines (Table 2 and 4). Whereas, the Zn concentrations were moderate polluted in sediments of the wadi downstream (from W1

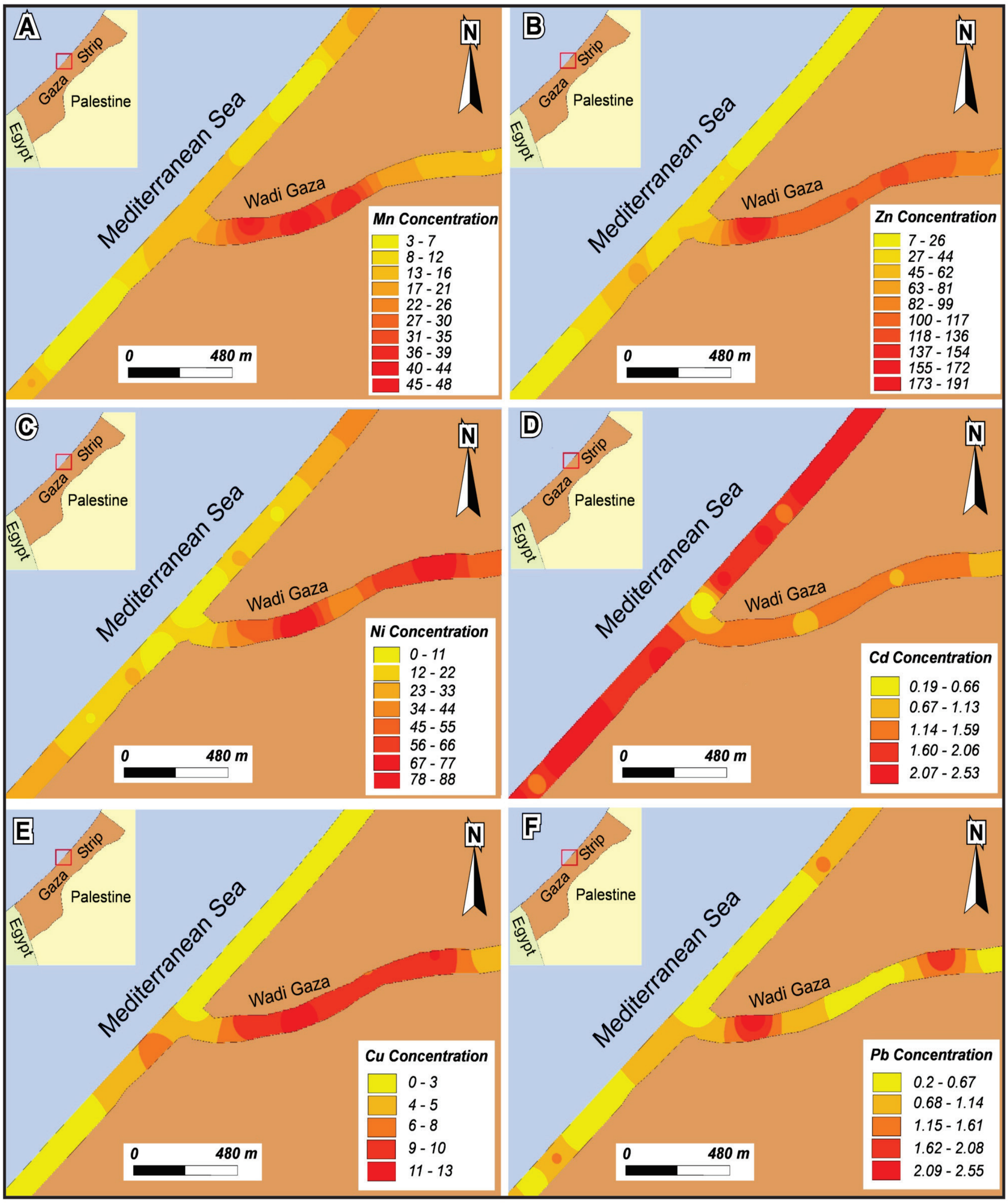

Figure 3. Spatial distribution maps of the selected heavy metal concentrations (mg/kg) in the sediments of the study area. **A)** Mn concentration ; **B)** Zn concentration; **C)** Ni concentration; **D)** Cd concentration; **E)** Cu concentration; and **F)** Pb concentration. / **Figura 3.** *Mapas de distribución espacial de las concentraciones de metales pesados seleccionados (mg / kg) en los sedimentos del área de estudio.* **A)** *concentración de Mn;* **B)** *concentración de Zn;* **C)** *concentración de Ni;* **D)** *concentración de Cd;* **E)** *concentración de Cu; y* **F)** *concentración de Pb.*

to W6 which are around pool sewage, see figure 1), and nonpoluted in beach sands to the North and South directions of the study area with respect to the US EPA guidelines.

For the Ni and Cd concentration levels in the sediments, the Ontario guidelines indicate that Ni concentration in the wadi downstream sediments, and in the beach sands in the north and south of the study area exceeded the lowest effect level. Except two observation sites in the wadi downstream (W3 and W6), in which the Ni concentrations exceeded the sever effect level. The US EPA guidelines, on the other hand, indicate that the Ni concentration in the wadi downstream sediments was moderate polluted, except the observation sites W3 and W6, they were heavy polluted. Whereas, the beach sands of the north and south of the study area were non- to moderate polluted. The Cd concentration levels in the sediments of the study area were non-polluted according to US EPA guidelines

The Ontario guidelines indicate that Cu and Pb concentration levels in the Wadi Gaza downstream sediments and beach sands in north and south of the study area were the lowest effect level. On the other hand, the US EPA guidelines indicate that their concentration levels in the sediments of the study area were non-polluted.

Overall, the relatively high-level contents of the heavy metals (Mn; Zn; Ni; Cu; and Pb) in the sediments of the study area were found in the wadi downstream at observation sites W1 to W6 and W7. The high-level concentrations of these heavy metals were attributed to raw sewage from the Nussirate, Bureij, Maghazi, Deir Al-Balah and Al-Zahra-City localities discharged without treatment into Wadi Gaza at a rate of more than 15,000 cubic meters per day (UNEP, 2009) (Figure 2). Sewage pollutes the land adjacent wetlands, groundwater and beaches near the downstream of Wadi Gaza (Figure 1 and 4A-D). The municipal solidwaste dumped (Figure 4E) in the Wadi Gaza. Waste were disposed to the tested soils for long periods before they were transferred to the central dumping site. During the period of accumulation of the solidwastes, leachates may have percolated through soil, increasing the levels of trace metals (Shomar *et al.*, 2005). The fine grained-size and high contents of the organic matters of soils (Ubeid, 2011b; 2016), and the use of fertilizer in formulations which were carried by the runoff to the wadi, from which the samples were collected help to adsorb these heavy in the sediments of the downstream of the wadi. In addition to that, the geomorphology of the wadi could had effect in the accumulation of the heavy metals, where the higher concentration observed in the wadi bends (Figure 3). Where at the bends low water speed and high deposition rated of sediments.

On the other hand, the results show that the Cd relatively high-level concentration was in the beach sands in the north and south of the study area. The distribution of Cd in beach sands was less affected by fine grained-size (silt and clay) (Liu *et al.*, 2015), where the grain size distribution along the Gaza beach is mainly composed of medium- to coarse sand (Gan *et al.*, 2003; Wang *et al.*, 2007; Ubeid, 2011a; Wei *et al.*, 2012). Presumably, it is mainly affected by fishing; ports of fishermen; marine parks; and solidwaste of material buildings dumped in the beach.

Generally, in the total study area which includes three parts the sediments were nonpolluted by the heavy metals (Mn, Zn, Cu, and Pb), where their average concentration values (16.04, 49.33, 3.83, and 0.76 mg/kg respectively) were below the limits of standard for sediments. While, the sediments polluted by heavy metals (Ni and Cd), where their average concentration values (31.38 and 1.72 mg/kg respectively) were above the limits of standard for sediments (Table 3D and 4).

Correlation Analysis

In order to establish relationships among metals and determine the common source of metals in the study area, a correlation matrix was calculated for the heavy metals in the sediments. Table 5 and figure 5 show the relationships of the heavy metals pollution in the sediments of the study area

(Wadi Gaza downstream; North and South of the downstream). There were significant positive relationships between the following elements since the P-Value for each paired less than 0.05 as follows:

- The Pearson Correlation between (Ni and Zn) is with 0.654 with P-value 0.001.
- The Pearson Correlation between (Pb and Ni) is with 0.433 with P-value 0.035.
- The Pearson Correlation between

Figure 4. Shows the fieldphotogrphs of the sewage and solidwaste through the downstream of Wadi Gaza at observation sites W2; W3; W4 and W8 (for location of observation sites see figure 1). / **Figura 4.** *Muestra los fotos de campo de las aguas residuales y los desechos sólidos a través de Wadi Gaza en los sitios de observación W2; W3; W4 y W8 (para la ubicación de los sitios de observación ver figura 1).*

(Cu and Zn) is with 0.699 with P-value 0.000.

- The Pearson Correlation between (Cu and Ni) is with 0.856 with P-value 0.000.

- The Pearson Correlation between (Cu and Pb) is with 0.422 with P-value 0.017.

- The Pearson Correlation between (Ni and Mn) is with 0.699 with P-value 0.006.

- The Pearson Correlation between (Zn and Mn) is with 0.616 with P-value 0.001.

- The Pearson Correlation between (Cu and Mn) is with 0.636 with P-value 0.001.

On the other hand, there were significant negative relationships between the following elements since the P-Value for each paired less than 0.05 as follows:

- The Pearson Correlation between (Cd and Zn) is - 0.560 with P-value 0.004.

- The Pearson Correlation between (Cd and Cu) is - 0.482 with P-value 0.017.

- The Pearson Correlation between (Cd and Mn) is - 0.447 with P-value 0.028.

There were no relationships between the remainder metals since the P-value for each paired is greater than 0.05.

Overall, the Mn shows moderate- to strong positive correlation with Ni (0.699), Zn (0.616) and Cu (0.636), but it shows a negative correlation with Cd (-0.447). The Zn shows a positive correlation with Ni (0.654), Cu (0.699) and Mn (0.616). On the other hand, Zn shows negative correlation with Cd (-0.560). The Cu correlated positively with Ni (0.856), Zn (0.699) and Mn (0.636), it correlated negatively with Cd (-0.482). The correlation matrix shows a positive correlation between Ni (0.433) and Cu (0.422). The correlation matrix shows a positive correlation between Ni and Zn (0.654), Pb (0.433), Cu (0.856) and Mn (0.616). The correlation coefficient of the studied sediments indicates that Cd has a negative correlation with Zn (-0.560), Cu (-0.482) and Mn (-0.447)

Positive correlation between the heavy metals suggests that the metals could be have common sources, mutual dependence and identical behavior during transport (Liu *et al.*, 2010; Liu *et al.*, 2013; 2015). Negative correlations between heavy metals suggest that it does not share above specifically metal traits with others.

Moreover, plotting of the heavy metals (Ni, Zn, Cd, Cu, and Pb) as bivariate scatter plot was used in order to reveal the relationship between their environmental deposition. Figure 6, discriminates two groups of the heavy metal concentrations in the sediments of the study area. The first group includes the heavy metal concentrations in the beach sands, and the second group includes the heavy metal concentrations in the wadi downstream sediments. The two groups are separated as in the relationships between the Ni versus Cd, and Zn

		Mn	Zn	Ni	Cd	Cu	Pb
Ontario Guidelines	LEL*	460	120	16	0.6	6	31
	SEl*	1100	820	75	10	110	250
SQGs of US EPA	Nonpolluted	-	90	20	-	25	40
	Moderate polluted	-	90-200	20-50	-	25-50	40-60
	Heavily polluted	-	200	50	6	50	60

Table 4. Sediment quality guidelines (mg/kg) in different countries (LEL = Lowest Effect Level; SEL = Severe Effect Level; SQGs = Sediment Quality Guidelines). / **Tabla 4.** *Directrices de calidad del sedimento (mg / kg) en diferentes países (LEL = nivel de efecto más bajo; SEL = nivel de efecto severo; SQG = pautas de calidad del sedimento).*

Metal	Statistics	Ni	Zn	Pb	Cd	Cu	Mn
Ni	Pearson Correlation	1.0					
	P-Value						
Zn	Pearson Correlation	0.654**	1.0				
	P-Value	0.001					
Pb	Pearson Correlation	0.433*	0.512*	1.0			
	P-Value	0.035	0.011				
Cd	Pearson Correlation	-0.373	-0.560**	0.043	1.0		
	P-Value	0.073	0.004	0.840			
Cu	Pearson Correlation	0.699**	0.856**	0.422*	-0.482*	1.0	
	P-Value	0.000	0.000	0.040	0.017		
Mn	Pearson Correlation	0.547**	0.616**	0.230	-0.447*	0.636**	1.0
	P-Value	0.006	0.001	0.279	0.028	0.001	

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).
* No of sample (24).

Table 5. Correlation between each paired of the heavy metal concentrations in the sediments of the study area. / **Tabla 5.** *Correlación entre cada emparejamiento de las concentraciones de metales pesados en los sedimentos del área de estudio.*

versus Cd (figure 6 A, B), and they are overlapped-to tangency as in the relationships between the Pb versus Cd, and Zn versus Cu (Figure 6 C, D).

Conclusion

Generally, the heavy metals (Mn, Zn, Ni, Cd, Cu, and Pb) concentrations were found in different sampling sites. However, the higher contents of these heavy metals were identified in wetlands due to long-term domestic sewage and agrochemicals discharge. The mean concentrations of the heavy metals (Mn, Zn, Ni, Cd, Cu, and Pb) in the sediments of the mouse of Wadi Gaza were 16.04, 49.33, 3.38, 1.72, 3.83, and 0.79 mg/kg, respectively. The area of Wadi Gaza downstream was the higher concentration of the heavy metals than the other locations, except the Cd, it shows high-level in beach sands in the north and south of the study area with mean value about 2.08 mg/kg, while its mean concentration in the wadi downstream sediments was about 1.02 mg/kg.

The concentration levels of the heavy metals (Mn, Cd, Cu, Pb) in the sediments of the three locations of the study area were below the lowest effect level, except the concentration levels of Ni and Zn were exceeded the lowest effect level according to the Ontario guidelines.

Whereas, the concentration levels of the Cu, Pb, and Cd in the sediments of the three locations of the study area were non-polluted due to the US EPA guidelines. The Zn and Ni concentrations in the sediments of the wadi downstream were moderately polluted, while non-polluted- to moderately polluted.

The main source of the heavy metals pollution comes from sewage and solidwaste dumped in the wadi downstream.

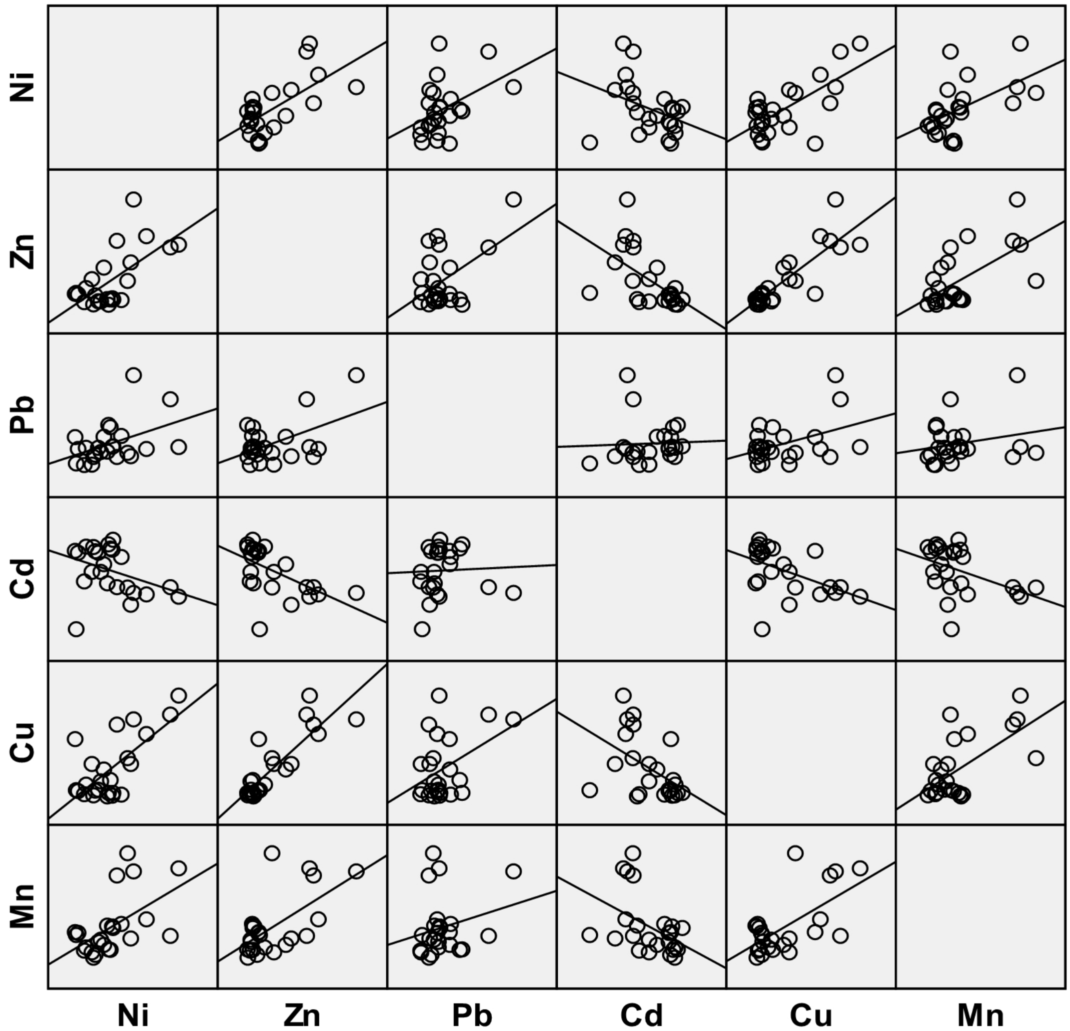

Figure 5. Scatter plot shows the relationships between the heavy metal concentrations in the sediments of the study area. / **Figura 5.** *El diagrama de dispersión muestra las relaciones entre las concentraciones de metales pesados en los sedimentos del área de estudio.*

The fine grained-size and high contents attributed to the organic matters of soils, and the use of fertilizer help to adsorb these heavy metals in the sediments of the downstream of the wadi.

The correlations between the heavy metals in the study area show positive correlations, these suggest that they come from the same sources, e.g. sewage, solidwastes and fertilizers, where the negative correlations with Cd, suggesting it possibly comes from fishing activities, ports of fishermen, marine parks, and solidwaste of material buildings dumped on the beach.

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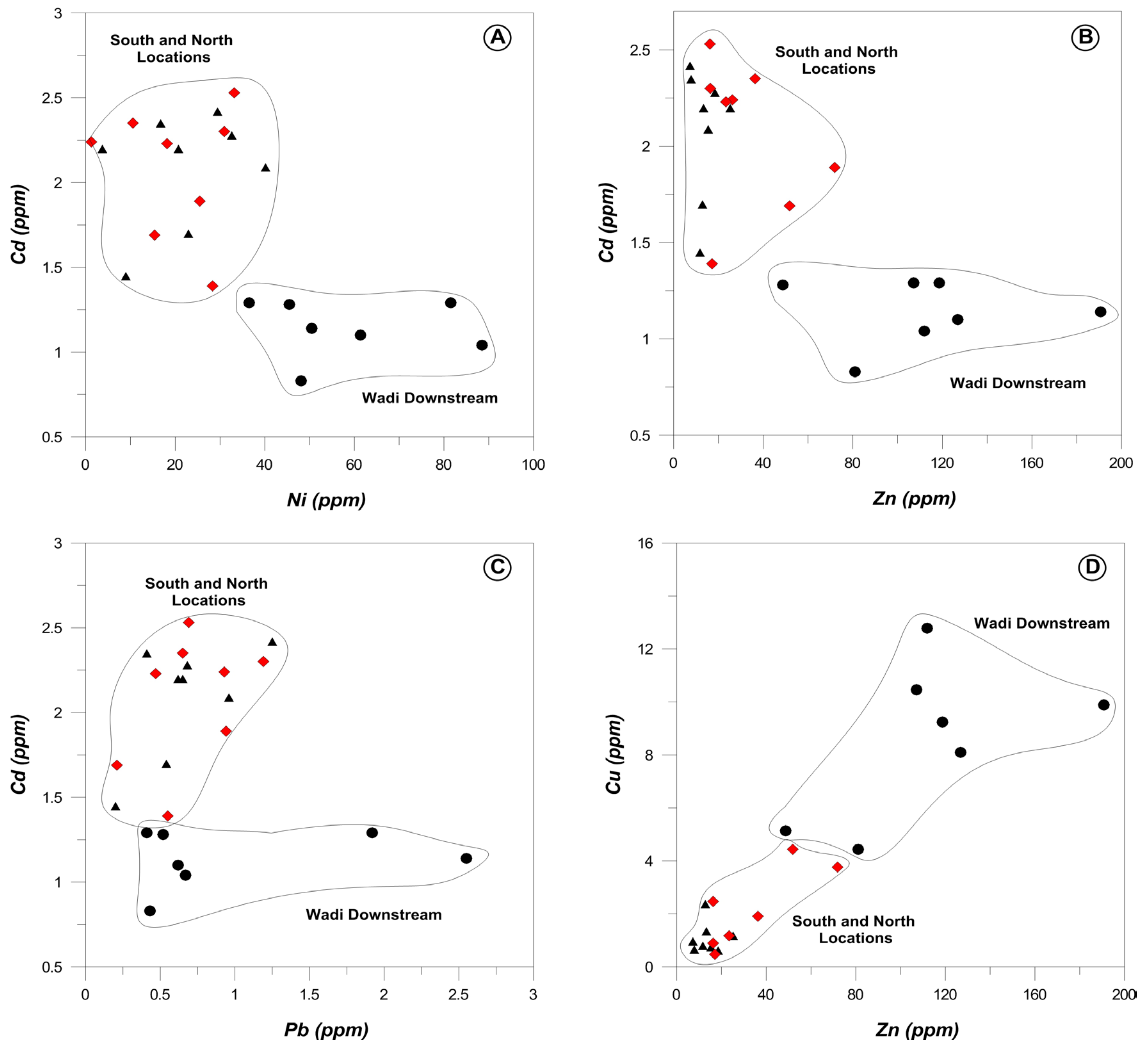

Figure 6. Shows the relationship among the heavy metals contents (Ni, Zn, Cd, Cu, and Pb) in the sediments of different locations of the study area. / **Figura 6.** *Muestra la relación entre los contenidos de metales pesados (Ni, Zn, Cd, Cu y Pb) en los sedimentos de diferentes ubicaciones del área de estudio.*

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