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Geo-Environmental Assessment of Hazardous Effects of Disposal Wastewater, Jeddah, Red Sea Coast, Saudi Arabia

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Abstract:
Nowadays, the coastal region of Jeddah City must be protected against heavy metal contamination of the marine environment by using advanced treatment techniques of before discharging of wastewater to coastal areas. The surface soil layers are composed mainly of poorly graded sand and specific gravity values vary from 2.6 to 2.8 (gm/cm3). The hydraulic conductivity values of these soils nearly direct proportional with their sand content. The concentration heavy metals in surface polluted soil samples in the studied area are directly controlled by the sand fraction content especially Ni, Co and Mn species. The wastewater contaminations are higher than Saudi, WHO and FAO Standards.

Key words: *Wastewater, Heavy metals, Jeddah, Saudi Arabia*

1. Introduction

The coastal areas are considered as one of the most important dynamic and productive ecosystems in the world in which numerous beneficial ecosystem services create to humans and shallow marine-living benthic and plankton (UNEP 1992). These planktons play a vital rule in support of marine environment biodiversity. Also, the shallow marine organisms (e.g. living-corals) build reefs more or less parallel to the coastal areas and might protect these coasts against tidal wave erosion. These corals will decay and migrate if the wastewater contaminated the shallow marine coastal water with toxic substances like heavy metals. Heavy metals contamination is considered as a complex issue of nowadays contamination problems. Widespread uses of metals, the legacies of past contamination, and new technologies continue to pose important ecological risks for aquatic environments across the earth (Luoma and Rainbow 2008). Beaches and sandy shores also provide ecological services and are being altered worldwide. Sandy shores have undergone massive alteration due to coastal development, pollution, erosion, storms, alteration to freshwater hydrology, sand mining, groundwater use, and harvesting of organisms (Brown and McLachlan 2002). Human health effects are also caused by pollution of near shore waters, whereby humans eat fish or other marine products that contain heavy metals and other toxins that have bio-accumulated in the food chain (Verlaan 1997).

Traces of heavy metal ions are ubiquitous in the modern industrialized environment (Davis, and Cornwel, 1991). Countries usually regulate and set up limits on levels of trace metals in the environment that should be at a safe level (Soylak, et al., 2000). Thus, heavy metal pollution in urban environment represents an important issue and has attracted large number of researchers during past decades (e.g. Dean, et al., 1972; Narin, et al., 1997; Soylak, and Turkoglu, 1999; Ghaedi, et al., 2007 and 2008).

The introduction of pollutants by human activities in many parts of the world has seriously degraded the environment (Soylak, and Turkoglu, 1999). Domestic and industrial activities in all over the world, especially the developed countries generate large volumes of by-products wastes. These by-products must be properly disposed in order to avoid threats to both the environment and public health (Meegoda et al. 2003). These human activities lead to chemical compounds being discharged into the environment. While some metal compounds are essential to animal and humans. Others are known to be toxic and the environmental impact of many of them remains to be elucidated. Nevertheless, these contaminants together represent a threat both to the aquatic and soil ecosystem and eventually to animal and human health (European Communities, 2001). In Jeddah, some of the wastewater sewages directly into Red Sea (Fig. 1), this method of wastewater disposal is quite common in such coastal regions. Economically, Jeddah is focusing on further developing capital investment in scientific and engineering leadership within Saudi Arabia, and the Middle East. Jeddah was independently ranked 4th in the Africa-Mid-East region in terms of modernization in 2009 in the Innovation Cities Index, so that its economic strength was increasing rapidly especially during the last 30-years (IBI, 2007). Jeddah has witnessed a dramatic increase in population primarily due to out-migration from villages into the city as individuals search for jobs and better standards of living owing to its strategic location.

The treated wastewater is usually discharged to surface waters (rivers, lakes, or ocean), where water quality problems can still occur (Keller, 2011). The quality of wastewater treatment must be put into consideration before sewage processes to protect the ecosystem, waterfront inhabitants, swimmers and fishermen of these coastal regions against the environmental damages. Epidemiological studies which had been done on some coastal areas in which wastewater sewages directly to coastal environments revealed that the children are more susceptible to parasitic infections (Chandrasekhar and Nagesha, 2003; Fatima-Zahra and Assobhei, 2005). Urban environmental pollution by chemicals from wastewater has become of public interest particularly in developing countries. Industrial development, modern civilization, poor planning and rapid population growth that utilize large range of chemicals have led to the introduction of uncontrolled and unknown contaminants into wastewater, many of them are not removed completely in conventional wastewater treatment plants (Ouyang, 2005; Battaglin et al., 2007).

The main objective of the present study is to throw highlight on environmental indicator that should indicate toxicity and risks of wastewater in the coastal marine environment for both humans and biological ecosystem in Jeddah City, Saudi Arabia

2. Geological Setting

Jeddah is located in the western region of Saudi Arabia along Red Sea Coast (latitude: 21° 29' N and longitude: 39° 13' 9'' E, Fig. 2) and it is considered as the second largest city in Saudi Arabia. Jeddah city lies in the Tihamah region, which is characterized by a mountainous high land to the east and a variable coastal plain to the west. The coastal plain of Jeddah varies in width from 5 to 10 km, thus limited from east by a number of mountain chains with average altitude of about 200 m. (Al Saud, 2010). As well as Jeddah locates on a flat lying narrow coastal plain nearly oriented more or less north south, along the Red Sea to the west and a chain of Precambrian hills to the east. The coastal plain is approximately 10 km wide and 80 km in length in this district between Jebel At Tawilah in the south and Al Kura in the north. The old city of Jeddah was built on relatively higher grounds that rise 7 to 13 m above sea level (Alqahtani, 1999). This natural setting protected it locally against floods hazards as well as groundwater rising in the past. The hills and mountains east of Jeddah consist of metamorphosed layered rocks and intrusive batholiths of the Arabian Shield while the coastal plains consist of alluvial sand, sabkha and coralline reef rocks (Moore and Al-Rehaili, 1989).

3. Site Investigation and Experimental Methodology

Twelve samples were selected from the soil layer covering the coastal plain in a good pattern consisting four rows. On the other hand, the wastewater samples were taken from the disposal sites before sewage into the coastal marine environment. The coordinates of investigated sites were determined by using GPS. All collected samples were put in special plastics bottles and sacs and labeled for further testing in the Faculty of Earth Sciences, King Abdul-Aziz University. The grain size analysis (gradation) of soil samples was done according to ASTM C136 (2004). The initial moisture water content was determined by heating to 110ºC for 24h according to ASTM D 2216 (2005). The total organic matters (TOM) were calculated by using ignition methods according to ASTM D 2974 (2000). Specific gravity of soil samples was measured according to ASTM C127 (1999). Similarly, falling head permeability test (k) was done according to ASTM D 2434 (2006). The heavy metal contents were determined by using inductively coupled plasma (ICP) model: ICP Optima 4300 DV in wastewater (ppm units) and surface soil samples (g/g units).

Figure 1: Site photographs show disposal of wastewater into the Red Sea (a and b) and Green algae resulted from pollution along Jeddah Red Sea Coast (c)

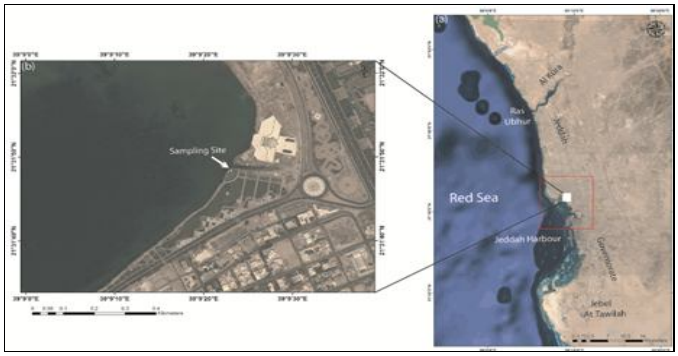

Figure 2: Satellite images showing location of the study area (a) and sampling site (b)

Site No.	Coordinates	Site No.	Coordinates
1	**N** 21° 31' 47"2 / E 039° 09' 22"1	7	**N** 21° 31' 47"5 / E 039° 09' 22"3
2	**N** 21° 31' 47"6 / E 039° 09' 22"3	8	**N** 21° 31' 46"4 / E 039° 09' 23"7
3	**N** 21° 31' 48"1 / E 039° 09' 22"4	9	**N** 21° 31' 46"6 / E 039° 09' 24"2
4	**N** 21° 31' 48"8 / E 039° 09' 23"1	10	**N** 21° 31' 47"0 / E 039° 09' 24"2
5	**N** 21° 31' 48"6 / E 039° 09' 23"8	11	**N** 21° 31' 47"8 / E 039° 09' 22"5
6	**N** 21° 31' 47"6 / E 039° 09' 23"4	12	**N** 21° 31' 48"3 / E 039° 09' 22"7

Table 1: Sites of sampling and their coordinates

4. Results and Discussion

The followings are the descriptions and interpretations of the most important geo-environmental physical and chemical properties of the studied samples.

4.1. Grain Size Distribution

The grain size distribution of surface soil samples plays a vital factor affecting the downward infiltration rate of wastewater within the surface soil layers and amount of heavy metal concentration within these soil samples. The studied soil samples were nearly classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS) (Table 2 and Fig. 3). Gravel percents range between 6% and 40.5%, sands fluctuate from 52% to 86%. Fine components (silts and clays) in the studied samples vary from 3.5% to 8% with an average 4.2%. It was indicated that these samples are dominated by poorly graded and well rounded sand grains. The physical investigation of the sand grains reveals their well rounded grains. The poorly graded characters (well-sorted) rounded sand grains are well common in coastal environments (Alicia et. al., (2008). These characters of sand grains were led to enlarge both of pores between the sand grains and the rate of infiltration downward within these sandy soil layers.

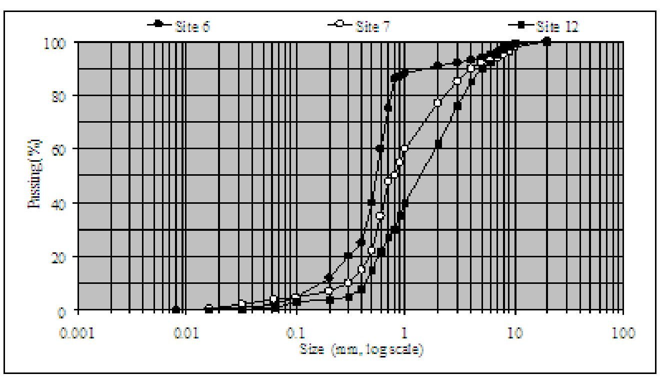

Figure 3: Grain size distribution curves for the studied soil samples at sites 6, 7 and 12

4.2. Specific gravity (G_S)

Specific gravity of coarse soil gives essential information about its gradation and porosity. Very low specific gravity frequently indicates soil that is poorly graded and porous (Langer 1993). The specific gravity values of the studied soil samples vary from 2.6 to 2.8 (gm/cm^3, Table 2). The narrow variation in specific gravity values of the studied soil samples means that, these soil samples have limited variation in grain size and porosity. It was observed that, the specific gravity values of the studied soil samples have a direct relationship with the sand fraction percentages (Fig. 4a) with strong relation (Fig. 4b, R-Value = 0.64)

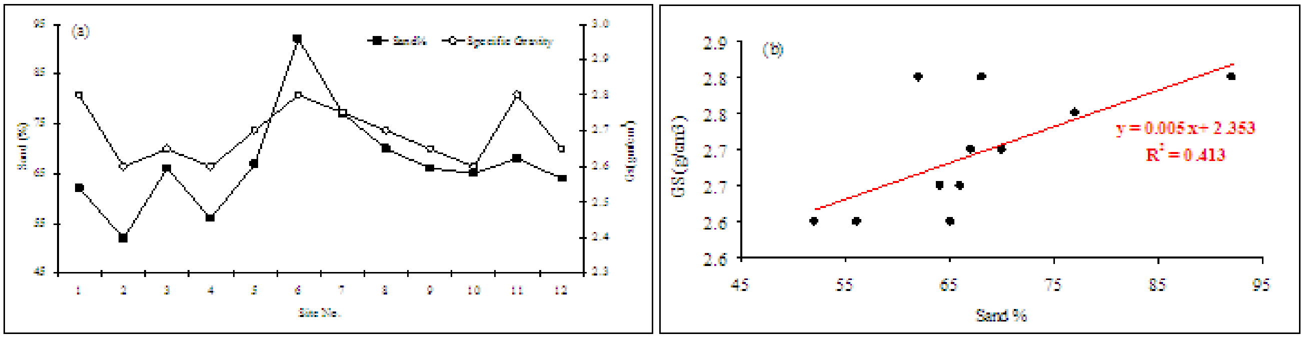

Figure 4: Mutual relationship between specific gravity values and sand percentages of the studied soil samples

4.3. Permeability (k)

The permeability of soils is due to occurrence of interconnected voids through which water can flow from points of higher hydraulic energy to ones of low hydraulic energy within soil layers. Hydraulic conductivity (k) depends on several factors: fluid viscosity: pore-size distribution, grain-size distribution, void ratio, textural characteristics of soil particles and level of soil saturation. The value of hydraulic conductivity (k) varies widely for different soil types Chapuis et al., 1989). The grain size, sorting and surface texture characteristics are effectively controlled the hydraulic conductivity of coarse-grained soil. The hydraulic conductivity of the studied soil samples vary from 0.75 cm/min (very rapid permeability) to 30.58 cm/min (very rapid permeability) (Table 2). Figure 5a shows a strong direct proportional relationship between hydraulic conductivity and sand content of the studied soil samples (R-value=0.81.).

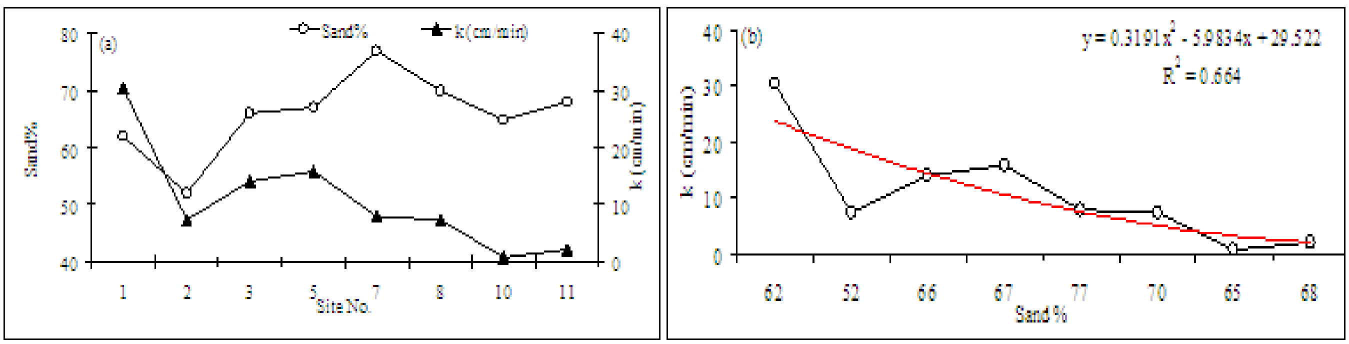

Figure 5: Mutual relationship between hydraulic conductivity and sand content of the studied soil samples

Site No.	Gravels (%)	Sands (%)	Fines (%)	Organic Matter (%)	Moisture water (%)	Specific Gravity (G_S)	Soil Type	Permeability K (cm/min)
1	37.5	59	3.5	3.7	19.3	2.8	SP	30.58
2	45	52	3	3.1	22.1	2.6	SP	7.407
3	31	65	4	4.2	39.92	2.7	SW/SM	14.3
4	40.5	56	3.5	3.5	21.33	2.6	SW	
5	29	67	4	4.1	23.8	2.7	SP/SM	7.84
6	6	86	8	8.2	41.7	2.8	SP	18.3
7	21	75	4	4.2	20.2	2.8	SP	
8	25	70	5	5.1	24.8	2.7	SP	15.92
9	29	68	3	3.1	10.5	2.7	SP	7.31
10	31	65	4	2.3	7.76	2.6	SP	
11	28	67	5	5.2	13.49	2.8	SP	
12	32	64	4	4.3	8.9	2.7	SP	11.3
Av.	32.9	62.9	4.2	4.25	21.22	2.71	SP	14.12

Table 2: Physical properties of the studied soil samples

4.4. Organic Matter

Organic matter in soils and sediments is widely distributed over the earth surface occurring in almost all terrestrial and aquatic environments (Schnitzer, 1978). The result showed that, the level of organic matter content of the studied soil samples is varying from 0.21% to 0.73. The low value of organic matter content of the studied samples was owing to sandy nature of these sediments and low content of fines (silts and clays) within these soil samples. The highest value was occurred at the site No. 6 that had the lowest gravel content and the highest fines content (silts and clays) (Table 2 and Fig 6a). Figure 6b shows a strong direct proportional relationship between fines percents and organic matter content of the studied soil samples (R-value=0.89).

4.5. Moisture water

The moisture water content varies from 41.7% to 9.8% with an average value of 2.22% (Table 2). Figure 7a shows that, the level moisture water content of the studied soil samples is clearly affected by fine materials (silts and clays). Also, both of them had a mutual moderately strong direct relationship (R-value = 0.64, Fig. 7b). That owing to low permeability of fine materials

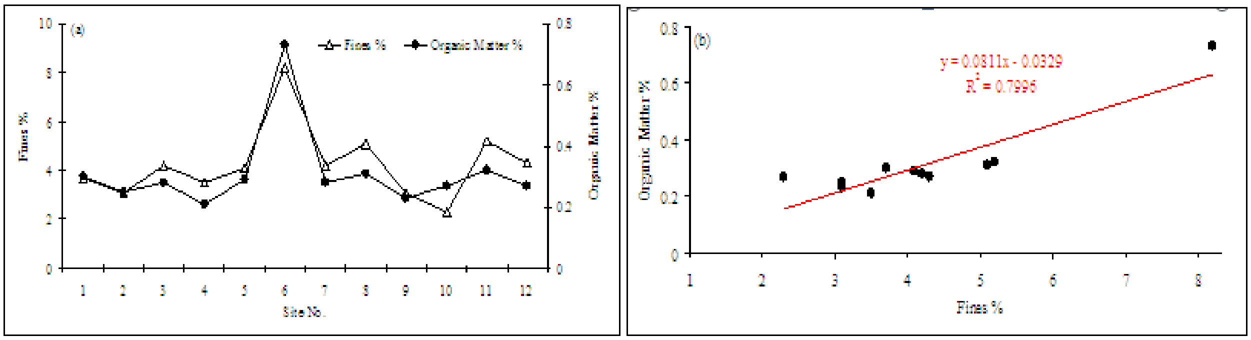

Figure 6: Mutual relationship between fines % sand organic matter % of the studied soil samples

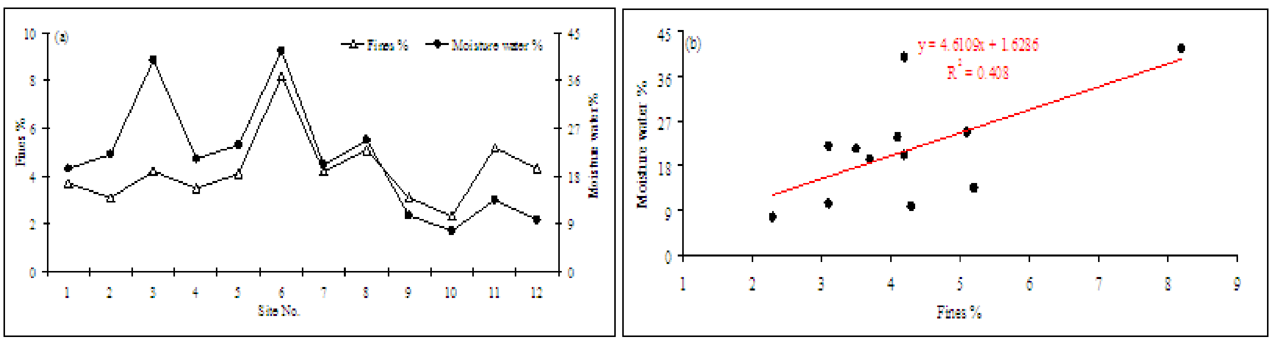

Figure 7: Mutual relationship between moisture water % and fines content of the studied soil samples

4.5. Chemical properties

In this section, the results of heavy metals analysis for both polluted soil and wastewater samples are evaluated and compared with WHO (World Health Organization) and Saudi Standards.

4.4.1 Heavy metals concentrations in soil samples

Heavy metals such as Cu, Cd, Pb and Zn cause the greatest environmental concern from sources including sewage water which has been reclaimed (Al-Musharafi et. al., 2012). The heavy metals are inheritably persistent in bio-accumulating throughout the ecosystem and can be found at high levels, eventually reaching the food chain (Han et. al., 2003). The toxicity of heavy metals in organisms is largely due to its ability to bind to bio-molecules. Many of the heavy metals are well known to be a mutagen causing cancer (He, et. al., 2005).

Arsenic, (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni) and zinc (Zn) concentrations (□g/g units) of the studied soil samples were determined (Table 2 and Fig. 8). The results show a lateral variation in the concentration of heavy metals. The highest percentages of cobalt, manganese and nickel were recorded in site No. 6 (Fig. 8). It is also observed that the concentrations of some heavy metal species (e.g. Ni, Co and Mn) are correlated with both fine fraction and organic matter percents of the studied soil samples (Figs. 9a and 9b). Also, it was noticed that, the concentrations of Co, Mn and Ni are strongly correlated (Fig. 10). Results indicate that, the distribution of heavy metals concentrations in the studied soil samples are greatly controlled by grain size, and organic matter. (Aprile and Bouvy, 2008; Aloupi and Angelidis, 2001; Liaghati et al., 2003)

Station No	Mg	Pb	As	Zn	Ni	Cu	Mn	Cr	Co	Cd
1	10075	14.77	29.57	86.63	2.84	2.635	65.68	10.8	1.02	0.55
2	10070	13.47	44.05	81.54	3.99	3.793	62.6	7.08	0.7	1.03
3	12291	37.57	2.438	1343	17.1	392.3	372.2	61.5	9.98	1.459
4	11492	66.41	1.159	1037	5.28	254.72	217.5	37.4	5.5	2.471
5	146441	38.81	2.918	273.6	23.5	105.5	390.4	66.2	11	1.511
6	13155	1.598	1.75	503.1	121	137.06	1549	88.2	45.8	0.25
7	10054	13.8	7.23	120.8	6.07	14.505	112.8	12.3	1.02	0.055
8	7505.3	1.29	6.66	114.4	4.69	13.02	48.26	22.6	2.59	0.083
9	21.7	6.016	8.569	6.204	0.65	0.303	0.063	0.2	0.1	4.53
10	34.38	3.287	6.44	0.152	0.34	0.055	0.049	0.07	0.02	0.753
11	10037	29.86	29.15	115.7	10.3	17.2	62.78	7.7	0.7	0.731
12	9862.1	62.58	32.49	180.1	9.66	10.777	69.74	7.45	0.73	0.627
Average	20087	24.12	14.37	321.8	17.11	79.32	245.94	26.78	6.59	1.17

Table 3: Heavy metal concentration (□g/g) of the studied soil samples

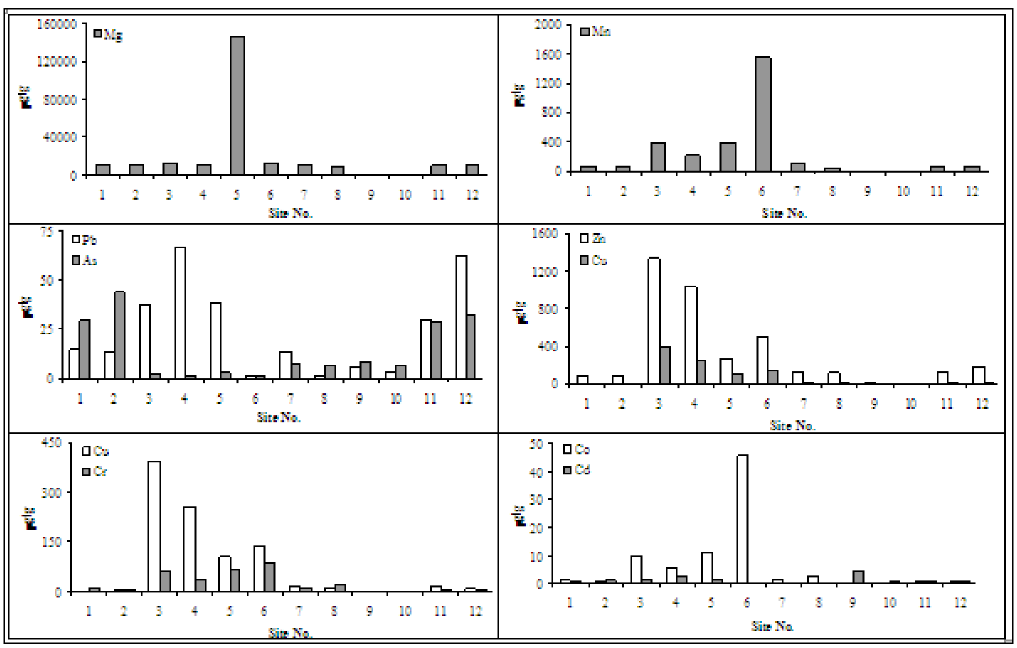

Figure 8: Heavy metal species concentration at different sites of the studied soil samples

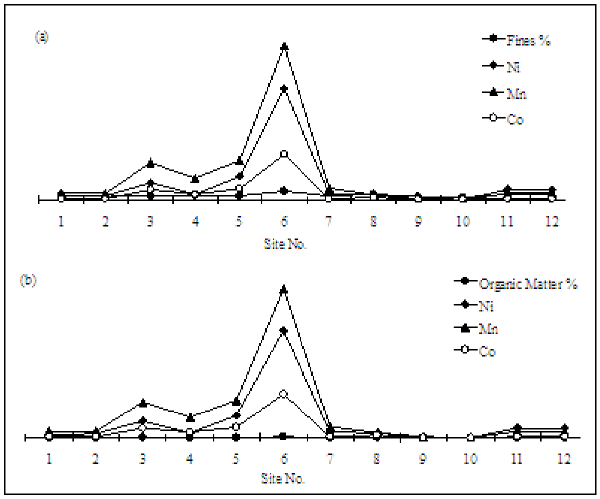

Figure 9: Mutual relationship between heavy metal species with both fines content (a) and organic matter content (b) of the studied soil samples

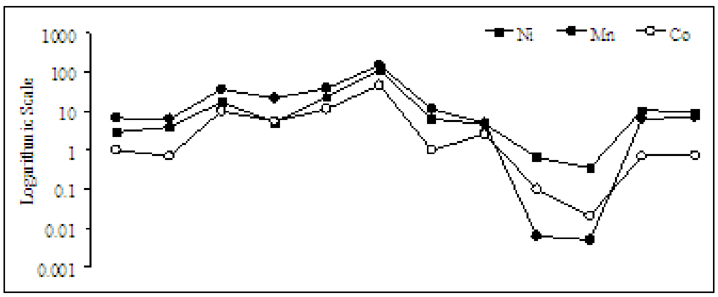

Figure 10: Lateral smooth correlation among cobalt, manganese and nickel concentrations of the studied soil samples

4.4.1 Heavy metals concentration in wastewater samples

The concentration of some heavy metals: cadmium (Cd), chromium (Cr). Copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni) and zinc (Zn) of the studied wastewater samples were determined. It was clearly indicated that, the highest concentrations of both (Ni and Cr) and (Cd and Cu) and (Fe and Mn) were recorded in sites No. 5, 3 and 2, respectively. Whereas, pb was mostly concentrated in site No. 4 (Table 3 and Figs. 11a, 11b and 11c).

The obtained heavy metal concentration of the studied wastewater samples were compared among Saudi (MWE, 2006), WHO (2006) and FAO (1985) Standards (Table 4 and Fig. 12). It was clearly noted that the concentration of Cu, Fe, Mn, Ni, Pb in the studied wastewater samples were higher than in Saudi, WHO and FAO Standards. Whereas, others Cd, Cr and Zn concentrations are higher than in Saudi Standards.

Site No.	Fe	Ni	Mn	Cr	Zn	Cd	Pb	Cu
1	19.64	5.36	1	0.52	1.44	0.84	3.2	0.52
2	53.68	4.36	1.88	0.72	1.4	1.4	10	2.24
3	19.44	1.6	1.84	1	1.44	1.92	5.2	2.4
4	48.96	3.28	0.88	0.92	2	0.8	12.8	1.32
5	39.63	9	0.52	1.24	1.68	1.04	4.8	1.4
Average	36.27	4.72	1.224	0.88	1.59	1.2	7.2	1.58
Saudi Standard (MWE, (2006)	5	0.2	0.2	0.1	2	0.01	0.1	0.4
WHO Standard (2006)	10	1	1	1	5	0.1	0.1	1
FAO Standard (1985)	0.2	0.2	0.1		0.01	5	0.2	0.2

Table 4: Heavy metal concentration (ppm) of the studied wastewater samples

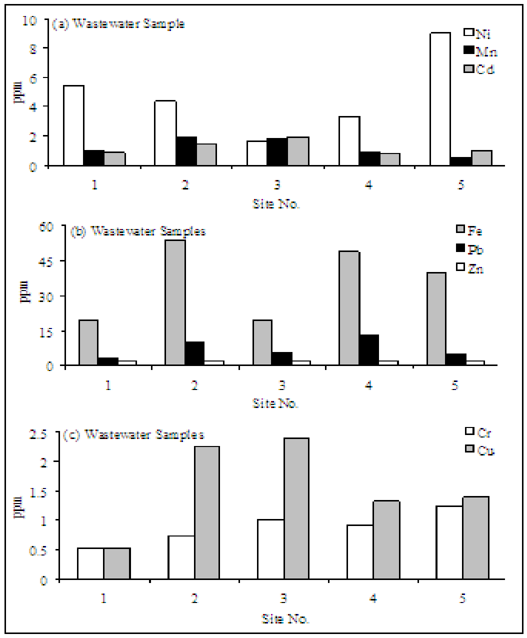

Figure 11: Heavy metals concentration at different sites of the studied wastewater samples

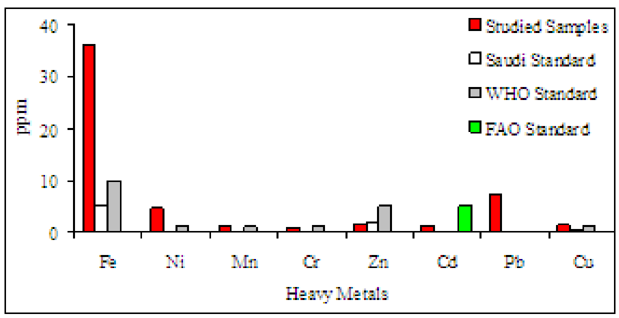

Figure 12: Comparison among WHO, FAO and Saudi standards of Heavy metal concentration (ppm) of the studied wastewater samples

5. Conclusion and Recommendations

The planned framework, in combination with such an inclusive data base on the obtained results of geo-environmental information and heavy metals concentrations of both soil and wastewater in the present study on Jeddah Coast, Red Sea, Saudi Arabia, it is able to formulate the following conclusions;

- The studied soil samples characterized by poorly graded sand, well rounded and moderately higher porosity. Also, these soil layers have moderately hydraulic conductivity.
- It is also observed that the concentrations of some heavy metal species were correlated with the sand fraction percents of the studied soil samples.
- The concentration of Cu, Fe, Mn, Ni, Pb in the studied wastewater samples are higher than Saudi, WHO and FAO Standards.
- The wastewater of the studied area in Jeddah Coast must be subjected to advanced treatment to reduce the concentration of heavy metals to correlate with the acceptable standards.

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