Emirati Journal of Civil Engineering and Applications
Vol 2 Issue 1 (2024)
Pages (78- 84)

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Assessment of Heavy Metal Contamination in the Sediments and Soils in the City of Dubai based on the Geoaccumulation Index

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ARTICLE INFO

Published on 7th of June 2024
Doi: 10.54878/fk289z29

KEYWORDS

Soil contamination, heavy metal pollution, geoaccumulation, earth crust, Dubai soil quality assessment, soil pollution, environmental pollution

HOW TO CITE

Assessment of Heavy Metal Contamination in the Sediments and Soils in the City of Dubai based on the Geoaccumulation Index. (2024). *Emirati Journal of Civil Engineering and Applications*, *2*(1), 78-84. https://doi.org/10.54878/fk289z29

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ABSTRACT

This research assesses heavy metal contamination in surface sediments and soils in Dubai using the geoaccumulation index model. Soil and sediment samples were collected from 19 sites across Dubai, with sampling conducted twice to detect variations in heavy metal concentrations. Eight heavy metals—Silver (Ag), Cadmium (Cd), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Lead (Pb), and Zinc (Zn)—were analyzed for their environmental impact and abundance.Results showed that the soil was highly polluted with Silver (Ag). Nickel (Ni) concentrations ranged from Unpolluted to Moderately Polluted. Chromium (Cr) levels indicated Unpolluted to Moderately Polluted status, except in Al-Marmoum Heritage Village, Jumeirah Lakes, Al-Mamzar Open Beach, and Remram, which showed higher contamination. Cadmium (Cd) levels varied, with some sites Unpolluted and others Unpolluted to Moderately Polluted. Copper (Cu), Manganese (Mn), Lead (Pb), and Zinc (Zn) levels indicated unpolluted status.Area-wise, Jumeirah Lakes, excluding silver contamination, was generally Unpolluted. Dubai Creek exhibited the highest geoaccumulation index for several metals, including Silver, Cadmium, Chromium, Nickel, and Zinc.

1. Introduction

Soil distribution and quality are crucial for urban planning, aiding decision-makers in land use for agriculture, residential, industrial, and commercial purposes. It is fundamental in managing, protecting, and conserving natural resources (Gray et al., 2009). Despite the growing demand for soil information due to heightened environmental awareness and food security concerns, a more comprehensive global soil database is still needed (McBratney et al., 2003).

Soil quality plays a vital role in the sustainability of land use, resulting in the productivity of the agro-business of the nation and the long-term protection of ecological systems. Heavy metal-contaminated soil has raised concerns for researchers to provide a database on soil quality, environmental protection, heavy metal impact, and sustainable solutions. Such a database will help researchers understand any short or long-term impacts on the soil overall on planet Earth and its negative or positive impacts on public health.

The coastal city of Dubai is a fast-growing, multicultural community that attracts investors, tourists, scientists, job seekers, and medical tourists. The population and residential and commercial areas are rapidly increasing. This growth necessitates intelligent and innovative urban planning aligned with the city's current needs and vision. Additionally, it is crucial to identify and analyze the city's soil table and its components. Sediments may be contaminated with heavy metals due to continuous exposure to various pollution sources, including vehicle emissions, power plants, industries, and potentially contaminated sewage effluent used for irrigation. The particle size of soils and sediments contributes to the presence of heavy metals, which tend to co-precipitate and form complex ions on surface particles (Krishna & Mohan, 2013).

Heavy metals are well known for their negative impacts on humans and the environment due to their toxicity and accumulation in soil, sediments, plants, and water bodies (Ahmadipour et al., 2014). Agricultural soil contamination with heavy metals is often due to the continuous application of poorly treated wastewater effluent, which can result from the illegal discharge of industrial influents into sewage or irrigation networks. Additionally, the use of chemical fertilizers and pesticides in agriculture contributes to heavy metal contamination of the soil (Mingorance et al., 2007).

In addition to their negative impacts on ecological systems, heavy metals also pose a significant risk to public health. Accumulation of heavy metals in the human body can lead to adverse health conditions, including kidney damage, tumors, and cancers (Rahman et al., 2012).

A study by Rao et al. (1998) identified 26 soil series in Dubai and 13 in the Dubai-Hatta sector. These soils were predominantly sandy, extremely undeveloped, coarse, and poor in organic matter. The coastal area soils were found to be highly saline, while the desert soils were saline or sodic. The concentrations of heavy metals in the upper earth continental crust (Bn), as reported by Wedepohl (1995), are listed in Table 1.

No	Element	Upper Crust concertation (B_n) (mg/kg)
1	Manganese (Mn)	527
2	Nickel (Ni)	18.6
3	Copper (Cu)	14.3
4	Cadmium (Cd)	0.102
5	Chromium (Cr)	35
6	Lead (Pb)	17
7	Zinc (Zn)	52
8	Silver (Ag)	0.055

Table 1 Concentration of heavy metals in the upper earth crust (Bn)

2. Research Methodology

This research was conducted in the city of Dubai. The selection of soil sampling sites was based on the status of the soil and sediments in populated areas of Dubai and recent human activities. These activities include community development, industrial waste generation, and using treated wastewater effluent to irrigate large areas across the city.

2.1. Sampling & Analytical Procedure

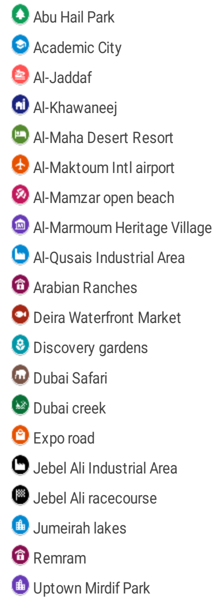
Each sample was numbered and tagged with GPS coordinates and the corresponding nearest landmark. Table 2 details the sampling sites and their Global Positioning System (GPS) coordinates.

Sampling Site	**Google Coordinates**
Abu Hail Park	25.2809442, 55.3447504
Academic City	25.1022485, 55.3880971
Al-Jaddaf	25.2169945, 55.3299242
Al-Khawaneej	25.2425117, 55.4999915
Al-Maha Desert Resort	24.8234404, 55.6626374
AL-Maktoum Intl Airport	24.8955522, 55.1387664
Al-Mamzar Open Beach	25.3283955, 55.349299
Al-Marmoum Heritage Village	24.9680805, 55.4857245
Al-Qusais Industrial Area	25.3002779, 55.386286
Arabian Ranches	25.0517526, 55.2630967
Deira Waterfront	25.292245, 55.3244827
Discovery Gardens	25.0412716, 55.1420602
Dubai Safari	25.1801315, 55.4516368
Dubai Creek	25.2447057, 55.3430322
Expo Road	24.9700858, 55.1598737
Jebel Ali Industrial Area	25.0011981, 55.1209262
Jebel Ali Racecourse	25.0854851, 55.1866575
Jumeirah Lakes	25.0699529, 55.1412496
Remram	25.0009084, 55.2493045
Uptown Mirdif Park	25.2230036, 55.4259454

Table 2 Sampling sites and corresponding GPS Coordinates

To better demonstrate the sampled areas, Google Maps from the public domain were used to generate the sampling site location map, as shown in Figure 1. Each site is marked with a uniquely colored location icon for easy identification.

Figure 1: Soil Sampling Location Map



Soil samples were collected twice from each location in two different rounds, with a two-month gap between each round, to ensure the accuracy of the overall sampling and analysis procedures as part of quality control. The soil samples were collected from the surface layer, 15 to 50 centimeters deep, using a stainless-steel Ekman Grab Sampler. The processing and analysis of heavy metals in the soil samples were performed according to the standard techniques and methods detailed in Table 3.

Parameter	**Unit**	**Reference standard / standard method**	**Method**	**Remarks**
Ag	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes of microwave digester and USEPA 3015 & 3051 guide
Cd	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes of microwave digester and USEPA 3015 & 3051 guide
Cr	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes of microwave digester and USEPA 3015 & 3051 guide
Cu	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes

				of microwave digester and USEPA 3015 & 3051 guide
Mn	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes of microwave digester and USEPA 3015 & 3051 guide
Ni	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes of microwave digester and USEPA 3015 & 3051 guide
Pb	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes of microwave digester and USEPA 3015 & 3051 guide
Zn	mg/Kg	APHA 3120 B	Thermo-Fischer Application Note	USEPA SW-846 supplemental guide; sample preparation using manufacturer application notes of microwave digester and USEPA 3015 & 3051 guide

Table 3 heavy metal standard analytical procedure of samples

2.2. Geoaccumulation Index

Defining and assessing potential heavy metal contamination in soil requires a mathematical model to elaborate on the variations from baseline standard concentrations of heavy metals in soils and sediments worldwide. One such geological-based mathematical model is the geoaccumulation index (Igeo), which introduces the relationship between current and natural, historical baseline concentrations of heavy metals. The geoaccumulation index (Igeo) was first introduced by G. Muller in 1969, using the following formula. Equation 1 demonstrates the mathematical model of Igeo.

$I_{geo} = \log_2 \left(\frac{C_n}{1.5B_n}\right)$ which also can be rewritten as a 3.22 log $\left(\frac{C_n}{1.5B_n}\right)$ Equation (1)

Where:

C_n: the concentration of heavy metal in the soil sample (mg/kg)

B_n: the concentration of heavy metal in the background (mg/kg)

1.5: A factor introduced to make up for the unexpected variation in the background values of the heavy metals caused by the lithological changes.

According to the American Geological Institute (AGI, 2019), lithological variations describe the visible physical characteristics of a rock outcrop, including grain size, composition, color, and texture properties, whether at a macro or microscopic level. The background values of heavy metal concentrations are mostly referred to as the Earth's crust content, as they are used to measure the minerals.

One of the most reliable references related to the geochemistry of the Earth's crust was established in 1961 by German geochemist Karl Hans Wedepohl (1925-2016) and Karl K. Turekian. The Wedepohl Earth's crust geodata reference is used to calculate soil heavy metal contamination and assess heavy metal enrichment in soils and sediments.

According to Wedepohl (1995), sampling and investigating the upper continental crust is more representative and accessible than the lower crust due to its higher exposure and visibility.

Muller (1981) classified the geoaccumulation index values to express the contamination status of heavy metals in soil and sediment. Table 4 presents the categories and classification of the geoaccumulation index.

I_{geo} value	Class	Classification
I_{geo}<0	0	Unpolluted
0>I_{geo}> 1	1	Unpolluted to moderately polluted
1>I_{geo}> 2	2	Moderately polluted
2>I_{geo}> 3	3	Moderately polluted to strongly polluted
3>I_{geo}> 4	4	Strongly polluted
4>I_{geo}> 5	5	Strongly polluted to extremely polluted
I_{geo}> 5	6	Extremely polluted

Table 1: Classifications of Igeo

3. Results & Discussion

Lab results from both rounds of samples are tabulated in Table 5, showing the average concentration of heavy metals measured in the soil samples at each location.

Soil sampling site ID	Ag	Cd	Cr	Cu	Mn	Ni	Pb	Zn
Abu Hail Park	21.01	0.083	52.53	9.555	267.4	37.82	2.961	39.23
Academic City	14.49	0.184	74.65	8.288	268.5	43.68	1.71	40.4
Al-Jaddaf	12.95	0.211	84.86	10.35	256.6	43.56	5.25	52
Al-Khawaneej	15.41	0.209	84.26	8.044	252.3	39.9	1.689	22.73
Al-Maha Desert Resort	12.41	0.141	101.7	7.44	239.9	45.19	2.943	51.94
Al-Maktoum Intl airport	14.86	0.205	65.44	6.725	244.4	30.39	1.36	18.77
Al-Mamzar open beach	21.73	0.171	48.71	8.182	237.5	40.07	5.591	35.77
Al-Marmoum Heritage Village	14.82	0.21	49.92	8.506	251.5	33.79	2.329	56.12
Al-Qusais Industrial Area	21.6	0.138	65.31	7.154	243.7	39.17	2.071	18.94
Arabian Ranches	13.81	0.195	56.2	7.976	219.7	33.62	1.583	43.03
Deira Waterfront Market	21.8	0.144	53.21	11.58	241.6	46.74	6.617	36.39
Discovery gardens	14.69	0.146	78.6	6.56	230.1	35.54	1.801	27.82
Dubai Safari	15.7	0.201	74.22	7.905	234.7	35.82	1.753	16.05
Dubai creek	17.43	0.29	72.25	20.19	229.9	44.36	11.37	105.6
Expo road	15.93	0.193	80.04	6.336	238.8	29.81	1.305	18.8
Jebel Ali Industrial Area	15.76	0.199	72.61	6.787	251.6	37.43	1.395	44.99
Jebel Ali racecourse	14.15	0.118	65.64	23.09	217.2	56.41	3.954	58.29
Jumeirah lakes	14.7	0.111	44.86	5.832	251.2	27.26	1.614	19.32
Remram	15.46	0.186	44.8	6.075	237.4	28.72	1.245	19.98
Uptown Mirdif Park	21.31	0.185	75.46	10.85	265.5	49.06	9.77	39.39

Table 5: the average concentration of the heavy metals measured in the soil samples vs. their location

Table 6 presents the values of the geoaccumulation index (Igeo). A color code is used to classify the categories of Igeo according to their values.

Soil sampling site ID	Ag	Cd	Cr	Cu	Mn	Ni	Pb	Zn
Abu Hail Park	7.23	0.26	0.49	-1.33	-1.51	0.63	-3.90	-0.92
Academic City	7.26	0.44	-0.07	-1.29	-1.60	0.27	-3.47	-0.46
Al-Jaddaf	7.07	0.45	0.67	-1.02	-1.57	0.62	-2.34	-0.57
Al-Khawaneej	7.49	0.89	0.45	-0.08	-1.73	0.65	-1.25	0.42
Al-Maha Desert Resort	7.16	0.34	0.10	-1.38	-1.79	0.26	-4.01	-0.83
Al-Maktoum Intl airport	7.01	-0.11	0.92	-1.48	-1.67	0.67	-3.15	-0.57
Al-Mamzar open beach	7.25	-0.07	0.56	-1.66	-1.73	0.34	-3.83	-1.44
Al-Marmoum Heritage Village	7.25	-0.45	-0.22	-1.82	-1.60	-0.03	-3.99	-1.95
Al-Qusais Industrial Area	7.19	-0.36	0.31	0.10	-1.81	0.98	-2.73	-0.41
Arabian Ranches	7.77	0.27	0.51	-0.95	-1.53	0.79	-1.47	-0.96
Deira Waterfront Market	7.79	-0.14	0.31	-1.54	-1.65	0.47	-3.64	-1.98
Discovery gardens	7.79	0.16	-0.10	-1.35	-1.68	0.51	-2.25	-1.09
Dubai Safari	7.75	-0.86	0.00	-1.13	-1.52	0.43	-3.14	-0.96
Dubai creek	7.80	-0.08	0.02	-0.86	-1.66	0.72	-2.01	-1.07
Expo road	7.34	0.38	0.48	-1.40	-1.70	0.35	-3.87	-2.21
Jebel Ali Industrial Area	7.31	0.44	0.66	-1.37	-1.60	0.50	-3.92	-1.72
Jebel Ali racecourse	7.32	0.27	-0.22	-1.76	-1.68	0.04	-4.35	-1.90
Jumeirah lakes	7.36	0.32	0.59	-1.71	-1.67	0.09	-4.28	-1.99
Remram	7.35	0.37	0.45	-1.61	-1.60	0.41	-4.19	-0.77
Uptown Mirdif Park	7.26	0.41	0.31	-1.62	-1.64	0.12	-4.22	-1.99

	Igeo < 0		Igeo > 0		Igeo > 5

Table 6: Average concentration of the heavy metals measured in the soil samples vs. their locations

The Igeo values provide a reasonable descriptive investigation of soil contamination status, the distribution profile of heavy metals, and the correlation between soil texture and heavy metal accumulation.

Silver has the highest Igeo values in all the soil sampling sites, indicating extreme pollution. Its background concentration in the Earth's crust is the lowest among the tested heavy metals. The measured concentrations suggest that the accumulation of silver in Dubai soils might have an unexplained natural history. The consistent range of silver concentrations across soil samples could help in determining the history of this heavy metal.

Nickel geoaccumulation is classified as moderately polluted in all sites except Jumeirah Lakes (S8), which is classified as unpolluted (Igeo < 0). Nickel is naturally abundant and has been studied in the context of contamination from mining industries. Understanding the distribution of nickel in Dubai's soil adds value when making decisions about land development.

Cadmium is a common soil and sediment contaminant, with particles found in dust, soil, sediment, and water. These particles can deposit on plants, soils, and water bodies, entering the food chain of animals and humans. Cadmium has been classified as a B1 (probable) carcinogen by the International Association for Research on Cancer (IARC, 2008). The geoaccumulation index values of cadmium range from unpolluted to moderately polluted, with the highest value found in Dubai Creek. Despite its low background concentration in the Earth's crust, cadmium negatively impacts soil, plants, and public health. Adverse health effects include severe organ damage, such as to the kidneys, and the development of tumors.

In Al-Marmoum Heritage Village, Jumeirah Lakes, Al-Mamzar Open Beach, and Remram, the Chromium (hexavalent) geoaccumulation index values were classified as unpolluted. In contrast, it was classified as moderately polluted at the other sites, with the highest value found at Al-Maha Desert Resort. Hexavalent chromium is a probable human carcinogen, as reported by IARC (2008). It can migrate from soil to water and plants. Oral exposure to chromium can cause unexpected adverse health issues in the digestive system, leading to various types of cancer.

The geoaccumulation index of copper in the sampling sites is classified as unpolluted (Igeo < 0), except for the Jebel Ali Racecourse site, which is classified as unpolluted to moderately polluted (0 < Igeo < 1).

Manganese and lead are classified as unpolluted, with geoaccumulation index values of (Igeo < 0) across all sampling sites.

For zinc, only the Dubai Creek site has a geoaccumulation index value greater than 0. The other sites are classified as unpolluted.

If we eliminate silver from the matrix, Jumeirah Lakes is the only soil sampling site with unpolluted geoaccumulation for all selected heavy metals.

Dubai Creek (S4) has the highest geoaccumulation index values for the heavy metals Ag, Cd, Ni, Cr, and Zn.

4. Conclusion

This study is the first step in a more extensive descriptive investigation of heavy metal contamination in Dubai's soil and sediments. It is crucial to assess the figures obtained from the heavy metal concentrations in the soil samples and the geoaccumulation index. Future studies can incorporate additional elements for a more comprehensive analysis.

The results reveal that cadmium, chromium, and nickel are the highest geoaccumulating heavy metals in all of Dubai's soil sites where samples were collected in this study. This finding prompts further investigation into the historical use of the sampled locations and any activities that may have resulted in heavy metal contamination. Additionally, it is essential to correlate these findings with the current use of these areas, which may pose concerns for public health and the environment. Corrective measures can be implemented by identifying the possible sources of heavy metals, conducting a comprehensive audit of heavy metal pollution sources, and proposing effective, innovative solutions.

Silver is a strongly geoaccumulating heavy metal in Dubai's soil sampling sites. Industrial wastewater containing silver may be illegally discharged into the sewer network, contaminating the treated wastewater effluent, which is used for irrigation in public areas, farms, gardens, and parks.

Dubai Creek is geoaccumulated with heavy metals such as cadmium, chromium, nickel, and zinc. This heavy metal accumulation could be linked to sediment contamination that has occurred over the years, leading to the buildup of these metals in the sand and soils. This area was historically used to maintain light ships and dhows, which may have contributed to the contamination.

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