Preprints.org

Article

Not peer-reviewed version

GIS and Contamination Indices for Environmental Risk Assessment of Landfill Disposal Sites in Central Saudi Arabia

Talal Alharbi * , Abdelbaset S. El-Sorogy * , Naji A. Rikan , Yousef Salem

Posted Date: 9 October 2024

doi: 10.20944/preprints202410.0641.v1

Keywords: Landfill; Contamination factor; GIS; Arsenic; Cobalt

Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024
doi:10.20944/preprints202410.0641.v1

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

GIS and Contamination Indices for Environmental Risk Assessment of Landfill Disposal Sites in Central Saudi Arabia

Talal Alharbi *, Abdelbaset S. El-Sorogy *, Naji Rikan and Yousef Salem

Geology and Geophysics Department, College of Science, King Saud University, Riyadh 11451, Saudi Arabia
* Correspondence: asmohamed@ksu.edu.sa; tgalharbi@ksu.edu.sa

Abstract: Landfills pollute air, soil, surface and groundwater worldwide. Present work aims to assessment environmental Risks three landfills in southern Riyadh using GIS, soil quality guidelines, and contamination indices. GIS tools indicated an increase in the area of the landfill sites with time. The concentration of heavy metals (HMs) in the investigated landfills had the following descending order: Fe (11532 mg/kg) > Al (5405 mg/kg) > Pb (561.7 mg/kg) > Zn (356.8 mg/kg) > Mn (165 mg/kg) > Cr (74.8 mg/kg) > Cu (42.7 mg/kg) > Ni (22.4 mg/kg) > V (21.8 mg/kg) > As (5.16 mg/kg) > Co (4.08 mg/kg). The highest values of Al, As, Co, Ni, Pb, V, and Zn were recorded in Riyadh landfill 3, at the third industrial city. However, average values of all HMs decrease those from most worldwide soils and background, except Zn, Cu, Cr, and Pb. Results of enrichment factor and statistical analysis indicated deficiency to minimal enrichment and geogenic sources for Al, Co, Mn, and V, while those of As, Cr, Pb, Zn, and Ni showed EF > 2 implied anthropogenic activities, especially in in Riyadh landfill 3. Additionally, very high contamination and high effects range-median were reported in individual samples, especially for Pb, As, and Zn, indicated frequent adverse effects for these HMs. The difference in contamination for the HMs in the studied landfill sites might be attributed to the difference in the magnitude of input for each metal into the landfill site and/or the difference in the removal rate of each metal from it.

Keywords: landfill; contamination factor; GIS; Arsenic; Cobalt

1. Introduction

There is a growing annual increase in the quantity of waste produced. Landfilling is the primary technique of waste disposal in the majority of countries due to its cost-effectiveness. Landfills present a significant environmental challenge due to the production of several hazards, such as gas and leachate, during landfill operations [1,2]. The content of leachate varies significantly from one dump to another, depending on the specific characteristics of each site. Heavy metals are among the most dangerous substances found in leachate. There is an increasing apprehension about the accumulation of heavy metals in soil and groundwater. Various types of garbage contribute to the prevalence of heavy metals in landfills. According to [3], the presence of heavy metals in landfills is heightened by sources such as electronic trash, painting waste, and spent batteries.

Landfills and open dumpsites were commonly used worldwide for the disposal of municipal solid waste (MSW). In the United States, 52.6% of MSW was discarded in landfills (Sun et al., 2019), while in Brazil the figure was 59.1% (Costa et al., 2019). In the Kingdom of Saudi Arabia (KSA), the percentage was 85% [4], in Malaysia it was 94.5% [5], and in China it was 79% [6]. In Venezuela, sanitary landfills accounted for 32%, controlled disposal for 43%, and non-controlled disposals or open dumps for 24% [7]. In Mexico, sanitary landfills accounted for 65%, while uncontrolled and open dumps accounted for 30% [8]. Lastly, in Thailand, the percentage was 27% [9,10]. The primary sources of emissions from landfill sites include the waste materials upon arrival, emissions from transportation, waste dispersed by wind, dust formed from the landfill surface, landfill gas production, and leachate generation.

© 2024 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

The primary distinction between a dump and a landfill is in the absence of any effort to segregate the garbage from the underlying soil or rock layers in a dump. Additionally, in cases when the hole extends below the groundwater level, waste is directly deposited into the groundwater [11]. On the other hand, a sanitary landfill is a man-made construction that includes bottom liners, systems for collecting and removing leachate, and final covers (Figure 2). Landfills are specifically engineered to serve as storage facilities for waste materials, as well as to undergo treatment processes. The significant risk associated with MSW landfill arises mostly from the movement of polluted leachate and landfill gas. Consequently, the environmental consequences of the numerous landfills present worldwide must not be disregarded. Significant emissions, including as leachates and biogas, are released from biological activities that occur within them. If municipal solid waste (MSW) is deposited in a landfill without any pre-treatment, emissions are generated during the operation of the landfill. These emissions continue to be produced even after the landfill has been closed [10,12–14].

The soil in the Kingdom of Saudi Arabia is diverse due to its large area and the variation in climate across different regions of the Kingdom (eastern, western, northern, southern, and central). In general, in recent years, a number of studies have emerged focusing on evaluating the quality of the Kingdom's soil (e.g. [15–22]). The field investigations revealed that landfills in Riyadh receive a wide variety of waste, representing the diverse municipal solid waste of the city, including food scraps, packaging materials, paper, cardboard, plastics, glass, textiles, grass clippings, leaves, branches, old furniture, mattresses, and appliances. Additionally, industrial waste such as scrap metals, plastics, chemicals, concrete, bricks, wood, chemicals, paints, and solvents, as well as electronic waste like computers, mobile phones, televisions, and other electronic devices, are also disposed of in these landfills. E-waste refers to electronic waste, while medical waste includes used syringes, bandages, gloves, and expired or unused medications. Agricultural waste consists of animal manure, crop residues, and other organic materials from agricultural activities in Riyadh, as well as pesticide containers, plastic sheeting, and other materials used in modern agriculture. Special waste encompasses used and discarded tires, batteries, and sludge. The present aimed to assess the environmental risks of three landfill disposal sites in southern Riyadh, central Saudi Arabia using GIS tools, soil quality guidelines and several contamination indices.

2. Materials and Methods

Three landfills were selected for this study in southern Riyadh (Figure 1). The Riyadh landfill site 1 (RL1), is located in the northeast of a Noor - Sulay industrial district, at latitudes 24.6340 - 24.6485 N and longitudes 46.8046 - 46.8213 E. The Riyadh landfill site 2 (RL2) is situated in Al Birriyyah district in northeast of the second industrial city, at 24.5687 - 24.5456 N, and 46.9095 - 46.9329 E, while the Riyadh landfill site 3 (RL3) is located in Al Kharj Road in the southeast of the third industrial city, at 24.4948 - 24.4620 N and 46.9349 - 46.9571 E. This extensive study used satellite imagery to examine how three landfill sites in Riyadh changed over time. The images were obtained from Esri's World Imagery, which provides global satellite images dating back to February 20, 2014. Each version in the archive shows the state of the World Imagery map on the date it was published. This service is beneficial for temporal analyses, allowing users to access and compare past imagery that may have been updated or replaced in the current dataset.

In order to obtain the necessary images, the Wayback service through the ArcGIS Online platform were accessed. The historical layers for 2014, 2018, 2022, and 2024 were identified and retrieved. These layers are organized in a timeline and a list format within the Wayback interface, making it easy to select specific dates. It is worth noting that versions resulting in local changes are highlighted, which helps identify relevant imagery updates for the study area. Utilizing this archive ensured consistent data sourcing for each time point under investigation. Access to previous imagery allowed for a detailed assessment of the landfill sites' expansion, contraction, and other changes over the selected years.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

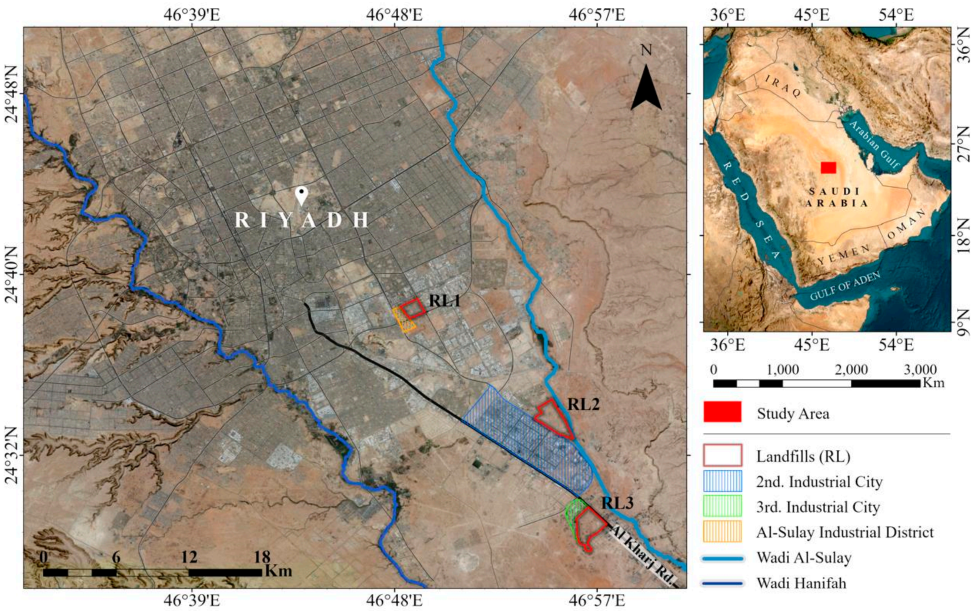


Figure 1. Location map of the three studied landfills in Riyadh.

Various single and integrated contamination indices, including the enrichment factor (EF), geoaccumulation index (Igeo), contamination factor (CF), potential ecological risk index (RI), and pollution load index (PLI), were used in this study to evaluate the contamination levels and ecological risks of PTEs. Equations (1)−(6) and Table 1 present the calculation procedures and classification of these contamination indices and the parameters utilized in this work [23–25].

$$EF = (M/X)\text{ sample } /(M/X)\text{ background} \quad (1)$$

$$\text{I-geo} = \text{Log2 } (Cn/ (1.5 \times Bn)) \quad (2)$$

$$CF = Co /Cb \quad (3)$$

$$PLI = (CF1 \times CF2 \times CF3 \times CF4\ldots \times CFn)1/n \quad (4)$$

$$Eri = Tri \times Cfi \quad (5)$$

$$RI = \Sigma\ (Tri \times Cfi) \quad (6)$$

M and Co represent the concentrations of the analyzed metal, while X and Cb signify the levels of a normalizer element (Fe). Cn is the measured concentration of metal (n) in the soils, Bn is the geochemical background concentration of the metal (n) in shale, and 1.5 is introduced to minimize the effects of possible variations in the background values. Eri indicates the potential ecological risk factor of an individual element, Tri represents the biological toxic response factor of an individual element, and Cfi denotes the contamination factor for each single element. The toxic response factor for metals follows this order: Zn = Co = Mn = 1, Cr = 2, Ni = 6, Cu = Pb = Ni = 5, As = 10. Table 1 provides the classification of the contamination indices applied in this study [25].

Table 1. Classification of the contamination indices.

	EF < 2	Deficiency to minimal enrichment
	EF= 2–5	Moderate enrichment
EF	EF= 5–20	Significant enrichment

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

	EF= 20–40	Very high enrichment
	EF > 40	Extremely high enrichment
CF	Cf < 1	Low contamination factor
	1 ≤ Cf <3	Moderate contamination factor
	3 ≤ Cf < 6	Considerable contamination factor
	Cf ≥ 6	Very high contamination factor
Igeo	Igeo < 0	Uncontaminated
	0 < Igeo < 1	Unpolluted to moderately contaminated
	1 < Igeo < 2	Moderately contaminated
	2 < Igeo < 3	Moderately to strongly contaminated
	3 < Igeo > 4	Strongly contaminated
	4 < Igeo < 5	Strongly to extremely contaminated
	Igeo > 5	Extremely high contaminated
RI	Er < 40	Low ecological risk
	40 < Er ≤ 80	Moderate ecological risk
	80 < Er ≤ 160	Considerable ecological risk
	160 < Er ≤ 320	High ecological risk
	Er > 320	Serious ecological risk
	RI < 150	Low ecological risk
	150 < RI < 300	Moderate ecological risk
	300 < RI < 600	High potential ecological risk
	RI ≥ 600	Significantly high ecological risk

3. Results and Discussion

3.1. Landfill Variation through Time

3.1.1. Riyadh Landfill 1 (RL1)

RL1 in a Noor – Sulay district is characterized diverse municipal solid wastes, including packaging materials, paper, cardboard, plastics, textiles, old furniture, scrap metals, plastics, chemicals, concrete, bricks, and wood. Moreover, discarded tires, batteries, and sludge. In 2014, the site appears to be a warehouse or a car maintenance workshop complex, and it has been in this state since around April 2005. Before this date, it was an open space with small, scattered landfills around its edges. The site was surveyed in August 2015, and it began being used as a landfill in March 2016. In December 2018, the use of the northern part of the site expanded to an area of approximately 418,066 m^2, which is about 25.5% of the total area of the square. In December 2020, all parts of the site were used as a landfill, with the utilized areas expanding to reach about 1 km^2, representing 59.3% of the square's area (Figure 2). By August 2024, the site's use as a landfill had increased to about 78.1%, with the utilized area expanding to approximately 1.3 km^2.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

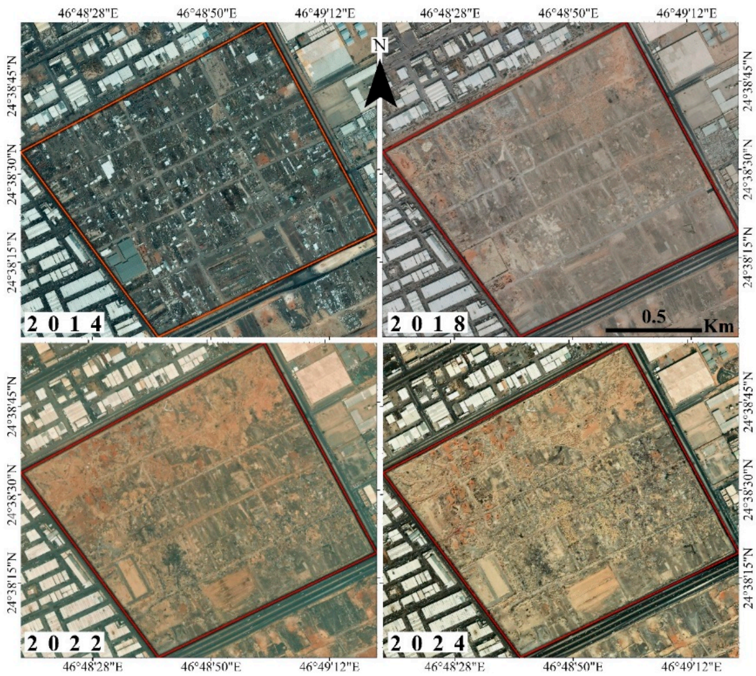


Figure 2. Change in surface area of RL1 from 1014 to 2024.

3.1.2. Riyadh Landfill 2 (RL2)

RL2 in Al Birriyyah district showed diverse municipal solid wastes of packaging materials, paper, wood, plastics, glass, textiles, old furniture, scrap metals, chemicals, concrete, bricks, chemicals, paints, and solvents. In December 2014, the total utilized area reached approximately 736,980 m², representing 17.9% of the total site area, which has been the same since around 2004, as no images are available prior to 2004. In December 2018, the site's use as a landfill reached approximately 39.7%, with the utilized areas expanding to about 1.64 km². In December 2022, the site's use as a landfill reached approximately 44.9%, with the utilized areas expanding to about 1.85 km² (Figure 2). By August 2024, the site's use as a landfill reached approximately 46.8%, with the utilized area expanding to about 1.93 km².

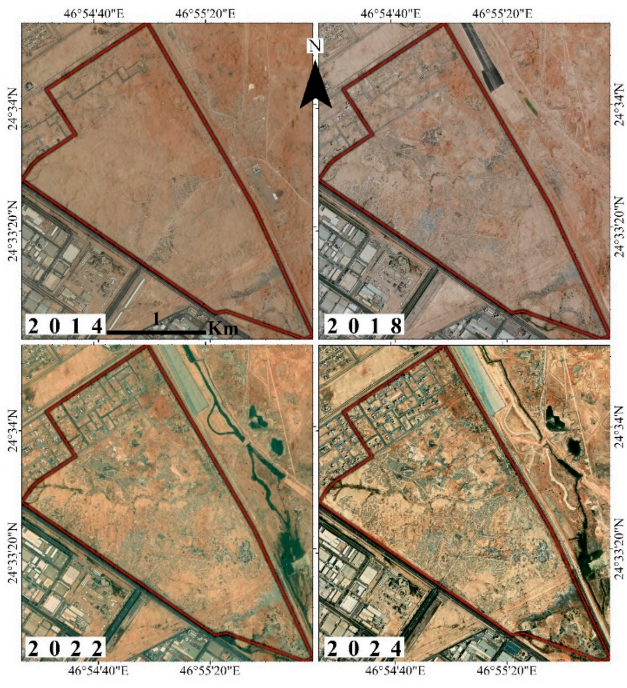


Figure 3. Change in RL2 area from 1014 to 2024.

3.1.3. Riyadh Landfill 3 (RL3)

RL3 in Al Kharj Road is characterized by diverse solid and liquid wastes including cardboard, old furniture, used tires and car oils, concrete, bricks, wood, chemicals, paints, and solvents, as well as electronic and medical wastes. In December 2014, the total utilized area at that time was approximately 521,962 m², representing 12.3% of the total site surface area, which had remained the same since around 2004, as no images are available before 2004. In December 2018, the site's use as a landfill reached approximately 17.7%, with the utilized areas expanding to about 0.75 km². In December 2022, the site's use as a landfill reached approximately 51.5%, with the utilized areas expanding to about 2.18 km² (Figure 4). By August 2024, the site's use as a landfill reached approximately 52.3%, with the utilized area expanding to about 2.21 km².

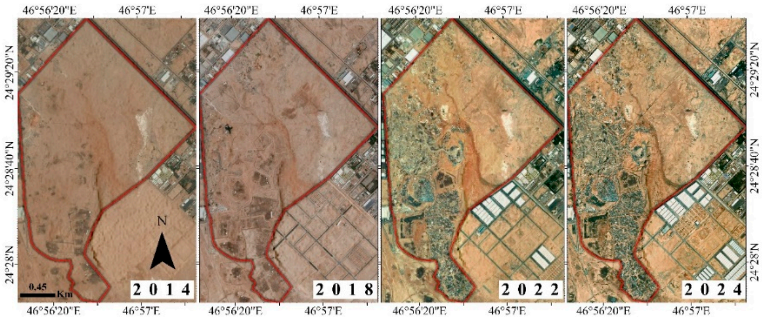
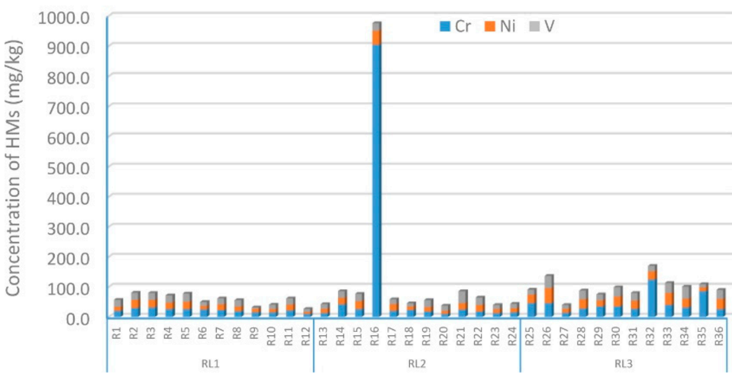


Figure 4. Change in RL3 surface area from 1014 to 2024.

3.2. Concentration and Distribution of HMs

The concentration of HMs (mg/kg, dry weight) in the investigated landfills is shown in Table S.1. The HMs average values had the following descending order: Fe (11532) > Al (5405) > Pb (561.7) > Zn (356.8) > Mn (165) > Cr (74.8) > Cu (42.7) > Ni (22.4) > V (21.8) > As (5.16) > Co (4.08). Our average values of Ni, Al, V, As, Co, Fe, and Mn decrease those from worldwide soils [26], Earth's crust [27], continental crust [28], and the recommended levels of HMs [29]. However, Zn and Pb average values exceed the averages of the last mentioned worldwide soils. Moreover, Cu and Cr average values decrease those of the worldwide soils except that of [26] and the recommended levels of HMs [29]. Figure 5 and Table S.1 implied that most of the highest values of the HMs were recorded in RL3, at the third industrial city, for instant Al (10400 mg/kg), As (41.0 mg/kg), Co (10.0 mg/kg), Ni (50.0 mg/kg), Pb (8960 mg/kg), V (41.0 mg/kg), and Zn (2230 mg/kg). The highest values of Cr and Cu were recorded in RL2 (904 and 302 mg/kg, respectively), at the second industrial city. Fe and Mn highest values were recorded in RL1 at Al Sulay industrial district (29000 and 346 mg/kg). However, the lowest HMs were recorded in RL2, Al, As, and V in sample R9; Co, Fe, Mn, Ni in sample R12; Cr, Cu, Pb, and Zn in sample R20 (Figure 5, Table S.1).



Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

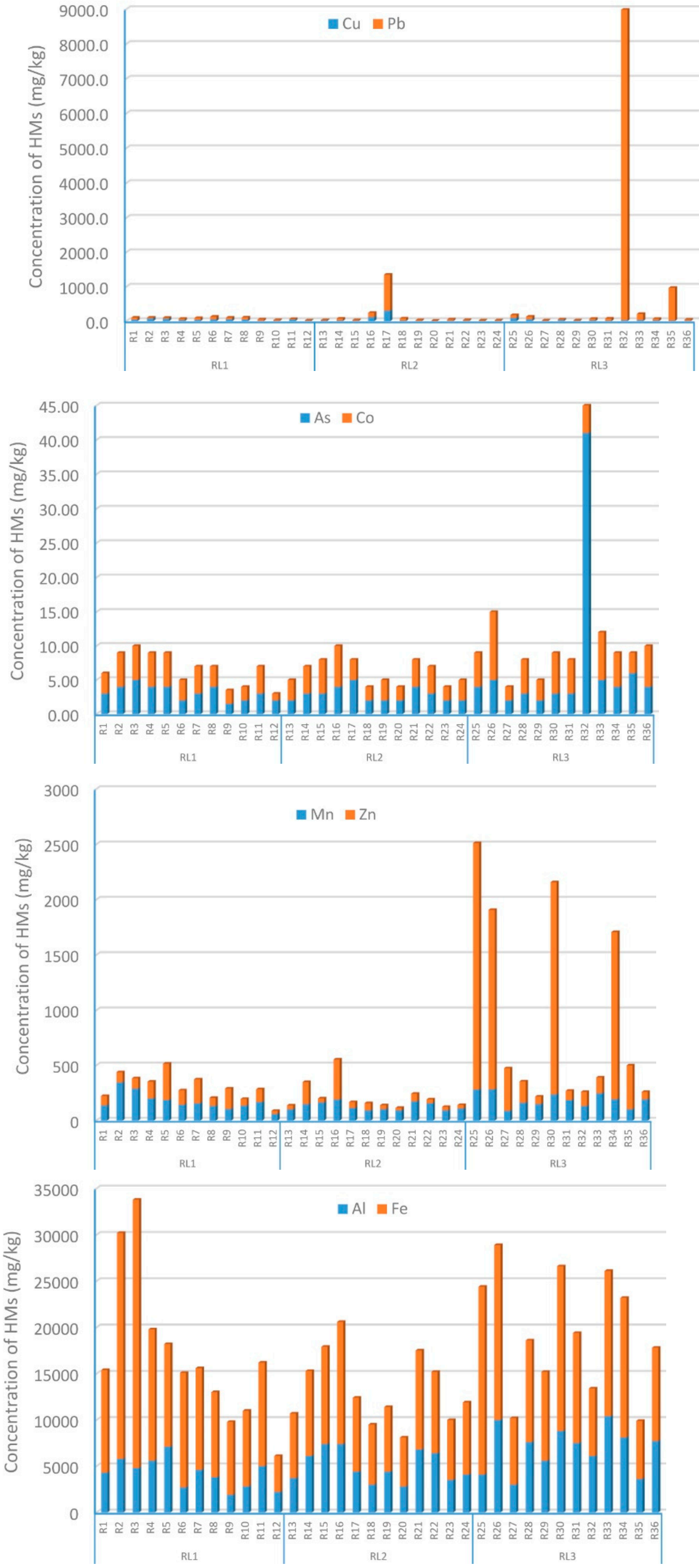


Figure 5. Distribution of HMs per sample locations in the three investigated landfills.

3.3. Risk Assessment and Potential Sources of HMs

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

The anthropogenic contribution of the selected HMs in landfill disposal sites can be estimated from the metal enrichment relative to unpolluted reference materials or widely accepted background (pre-industrial) levels. For calculation of pollutant indicators of toxic metal pollution in in Riyadh landfill disposal sites, the following factors were taken into consideration.

3.3.1. Enrichment Factor (EF)

This method is proposed by Sinex and Helz (1981) to estimates the anthropogenic impact of HMs using a normalization element (Fe) to to normalize the data as normalization factor. The EF is a good tool to differentiate between the anthropogenic and natural sources of metals in environmental samples [29–34]. The Minimum, maximum and average EF values for the HMs are presented in Table S.2. Results of EF indicated the following descending averages: Pb (177.65) > Zn (12.35) > Cu (4.41) > Cr (3.36) > As (2.14) > Ni (1.43) > Co (0.92) > Mn (0.82) > V (0.76) > Al (0.30). All samples collected from the landfill disposal sites showed EF < 2 for Al, Co, Mn, and V, indicating deficiency to minimal enrichment for these HMs and were entirely originate from the crustal materials or natural processes, while those As, Cr, Pb, Zn, and Ni with EF > 2 are most likely the product of anthropogenic activities [35].

Additionally, four samples (R25, R26, R30, R34) showed EF > 40 for Zn, three samples (R17, R32, R35) showed EF > 40 for Pb, implying extremely high enrichment with these two HMs. However, a significant enrichment was reported in 19 samples for Pb, 10 samples for Zn, 2 samples for Cr and Cu (Table 2). Generally, the difference in EF values for the different HMs in the studied landfill disposal sites may be attributed to the difference in the magnitude of input for each metal into the disposal site and/or the difference in the removal rate of each metal from the disposal site [36,37].

Table 2. Class distribution (sample %) of contamination indices for HMs examined in the studied landfills.

Indices	Classes	Al	As	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe
EF	Deficiency to minimal enrichment	36	33	36	33	17	36	32	0	36	4	-
	Moderate enrichment	0	2	0	0	16	0	4	11	0	16	-
	Significant enrichment	0	0	0	2	2	0	0	19	0	10	-
	Very high enrichment	0	1	0	0	1	0	0	3	0	2	-
	Extremely high enrichment	0	0	0	1	0	0	0	3	0	4	-
CF	Low contamination factor	36	35	36	34	28	36	36	10	36	19	36
	Moderate contamination factor	0	0	0	1	7	0	0	14	0	9	0
	Considerable contamination factor	0	1	0	0	0	0	0	7	0	4	0
	Very high contamination factor	0	0	0	1	1	0	0	5	0	4	0
Igeo	Uncontaminated	36	35	36	33	36	31	36	7	36	13	36
	Unpolluted to moderately contaminated	0	0	0	2	0	4	0	12	0	12	0
	Moderately contaminated	0	1	0	1	0	1	0	12	0	7	0
	Moderately to strongly contaminated	0	0	0	0	0	0	0	2	0	0	0
	Strongly contaminated	0	0	0	0	0	0	0	0	0	4	0
	Strongly to extremely contaminated	0	0	0	0	0	0	0	2	0	0	0
	Extremely high contaminated	0	0	0	0	0	0	0	1	0	0	0
	Low ecological risk	-	36	36	36	36	36	36	32	36	36	-

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

Er^i	Moderate ecological risk	-	0	0	0	0	0	0	1	0	0	-
	Considerable ecological risk	-	0	0	0	0	0	0	0	0	0	-
	High ecological risk	-	0	0	0	0	0	0	2	0	0	-
	Serious ecological risk	-	0	0	0	0	0	0	1	0	0	-

3.3.2. Contamination Factor (CF)

The contamination factor was also used to assess the level of contamination and the possible anthropogenic impact of contaminants in sediments [23,38–40]. Results of CF in Table S.3 indicated the following descending averages: Pb (28.09) > Zn (3.76) > Cu (0.95) > Cr (0.83) > As (0.40) > Ni (0.33) > Fe (0.24) > Mn (0.19) > V (0.17) > Co (0.09) > Al (0.07). The 36 investigated samples were low contaminated with Co, Fe, Al, Mn, Ni, and V. A very high contamination was recorded in 5 samples of the landfill disposal sites (R16, R17, R32, R33, R35) for Pb, 4 samples (R25, R26, R30, R34) for Zn, one sample (R16, R17 for Cu and Cr, respectively. However, a considerable contamination was reported in 7 samples for Pb, 4 samples for Zn and one sample for As (Table 2).

3.3.3. Geoaccumulation Index (Igeo)

The geoaccumulation index (Igeo) is a common criterion used for evaluating the HM pollution in soil [25], where HM contamination was determined by comparing their current concentration levels with those from preindustrial times. Results of Igeo in Table S.4 indicated the following descending averages: Pb (1.19) > Zn (0.60) > Cr (-0.84) > Ni (-0.94) > Cu (-1.58) > As (-2.52) > Fe (-2.78) > Mn (-3.08) > V (-3.31) > Co (-4.23) > Al (-4.62). All studied samples were uncontaminated with Al, Co, Cu, Ni, V, and Fe (Igeo < 0). However, moderately to strongly contamination, strongly to extremely contamination, and extremely high contaminated for Pb were reported in 2 samples (R16, R33), 2 samples (R17, R35), and one sample (R32), respectively (Table 2).

3.3.4. Potential Risk Index (RI)

Potential ecological risk was introduced by [23] for the assessment of the degree of ecological risk caused by HM concentrations in the water, air, as well as the soil. This index covers a various environmental effects, such as toxicology, environmental chemistry, and ecology, and can evaluate ecological risks caused by heavy metals [25,41,42]. The RI is calculated on the basis of 3 indices: single index of ecological risk factor (E^i_r), the pollution coefficient of a single element (C^i_f), and toxic response factor of individual metals (T^i_r). All samples collected from the landfill sites showed $Er^i < 40$ for As, Co, Cr, Cu, Mn, Ni, Pb, V, and Zn, indicating low ecological risk for these HMs. However, Pb showed serious ecological risk in sample R32, high ecological risk in samples R17 and R 35, and moderate ecological risk in sample R33 (Table 2 and Table S.5). The average RI values varied from 5.35 in sample R20 to 2281 in sample R32, with an average of 154.95. This finding indicates that moderate ecological risk due to presence of HMs in the landfill soils. However, few individual samples showed high potential and significant high ecological risks (Table S.5).

3.3.5. Soil Quality Guidelines

Chemical concentrations of metals corresponding to the 10th and 50th percentiles of adverse biological effects were called the effects range-low (ERL) and effects range-median (ERM). There are three ranges in chemical concentrations, where adverse effects rarely (< ERL), occasionally (≥ ERL and < ERM), and frequently occur (≥ ERM) [43,44]. Table 3 illustrates the range of ERL and ERM values for samples quality guidelines (SQG) of [45] in Cu, Ni, Zn, As, Cr, and Pb along with the percentages of samples falling within these SQG ranges. 35 samples (97.22%) were <ERL and one sample >ERL and <ERM for As measurements, indicating that the samples under study do not pose a risk due to the presence of As except sample 32, which may cause some potential risk. However, Zn in 4 samples, Pb in two samples, Cu in one sample, and Cr in one sample indicated frequent adverse effects (>ERM). Additionally, Ni in 19 samples, Zn in 19 samples, Pb in 13 samples, Cu in 11 samples, As in one sample, and Cr in one sample revealed occasional adverse effects for these HMs (Table 3).

Table 3. Distribution of samples in the ranges established by the SQG according to the HMs levels (mg/kg).

HMs	Mean concentration	Sediment quality guideline*		% of samples within ranges of the sediment quality guideline		
		ERL	ERM	<ERL	>ERL and <ERM	>ERM
Cu	42.7	34	270	66.67 (24)	30.55 (11)	(1) 2.78
Ni	22.4	20.9	51.6	47.22 (17)	52.78 (19)	0
Zn	356.8	150	410	36.11 (13)	52.78 (19)	11.11 (4)
As	5.16	8.2	70	97.22 (35)	2.78 (1)	0
Cr	74.8	81	370	94.44 (34)	2.78 (1)	2.78 (1)
Pb	561.7	46.7	218	58.33 (21)	36.11 (13)	5.56 (2)

Results of Pearson's correlation (Table 4) showed strongly positive correlations between some of the HM pairs, such as Al - Co (r = .886), Al – Mn (r = .620), Al - Ni (r = .887), Al - V (r = .877), As - Pb (r = 988), Co - Fe (r = .657), Co - Mn (r = .794), Co - Ni (r = .937), Co - V (r = .786), implying similar sources for these pairs [46]. Occurrence of Fe, Al, and Mn in such correlations indicated natural sources for these HMs, particularly Al, Co, Mn, and V showed average EF values less than 2 [40,47]. Differently, the strong positive correlation between As and Pb indicated anthropogenic sources related to agricultural and industrial wastes [48]. This suggestion is supported by results of the contamination indices for these two HMs.

Table 4. Correlation matrix of the investigated HMs.

	Al	As	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Al	1										
As	0.149	1									
Co	**.886****	0.112	1								
Cr	0.197	0.114	0.236	1							
Cu	0.023	0.044	0.142	0.265	1						
Fe	.444**	-0.031	**.657****	0.079	0.237	1					
Mn	**.620****	0.024	**.794****	0.102	0.198	**.939****	1				
Ni	**.887****	0.186	**.937****	.460**	0.269	**.574****	**.717****	1			
Pb	0.045	**.988****	-0.009	0.092	0.058	-0.146	-0.101	0.079	1		
V	**.877****	0.013	**.786****	0.076	-0.019	.471**	**.602****	**.738****	-0.104	1	
Zn	.350*	-0.005	.499**	0.049	0.098	.462**	.483**	.458**	-0.057	.358*	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Results of Pearson's correlation is supported for a great extent by principal component analysis (PCA) which extracted three PCs, accounting 47.78%, 20.73%, and 12.56% of the total variance, respectively (Table 5, Figure 6). The PC1 showed high loading for Al, Co, Fe, Mn, Ni, V, and Zn, which were entirely originate from the crustal materials or natural processes. The PC2 showed high loading for Pb and As, while the PC3 presented high loading for Cr and Cu, revealing different sources of anthropogenic factors.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

Table 5. Principal component loadings and variance percentage for the extracted three components.

	Component		
	PC1	PC2	PC3
Al	**0.893**	0.06	-0.258
As	0.123	**0.967**	-0.138
Co	**0.96**	-0.002	-0.082
Cr	0.297	0.243	**0.606**
Cu	0.22	0.113	**0.805**
Fe	**0.754**	-0.21	0.139
Mn	**0.868**	-0.154	0.043
Ni	**0.947**	0.128	0.102
Pb	-0.005	**0.983**	-0.105
V	**0.830**	-0.111	-0.326
Zn	**0.572**	-.115	-0.001
% of Variance	47.78	20.73	12.56
Cumulative %	47.78	68.5	81.07

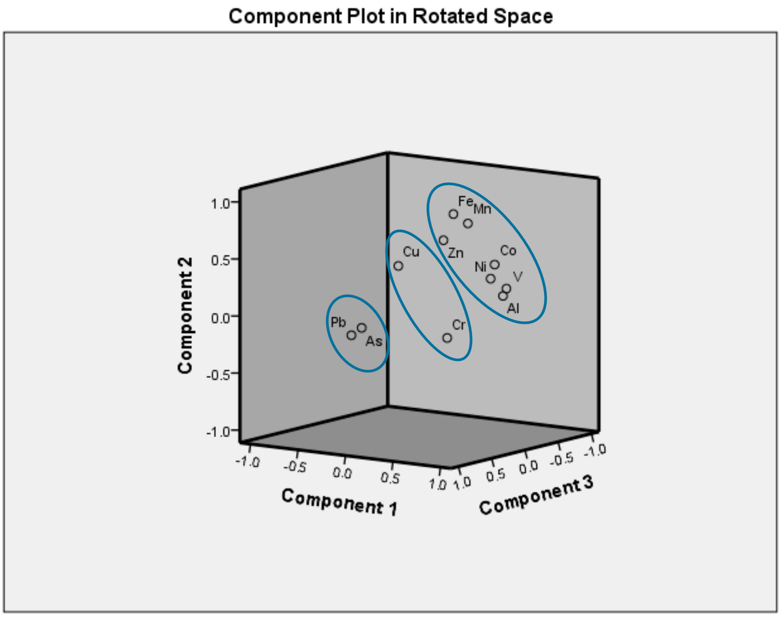


Figure 6. Three component plots using the varimax method with the kaiser normalization.

4. Conclusions

The current study highlighted the environmental risks associated with the presence of three landfills in the central Saudi Arabia. The study's findings can be summarized as follows: GIS tools have demonstrated a significant increase in the area of these landfills over time. Due to the horizontal expansion of Riyadh, some of these landfills have become situated within urban areas, which might be pose an environmental risk. The locations of the landfills along valleys cause the leaching of contaminated liquids, which either flow along the valleys or seep into the ground layers, polluting groundwater reservoirs. Pollution indices and soil quality guidelines have proven that the soil in these landfills is contaminated with certain HMs such as Pb, As, Cu, and Cr, which were mostly caused by the diverse wastes in these landfills. Finally, the study recommends relocating these landfills to mountainous areas far from urban regions and future horizontal urban expansion. It also suggests that the landfills be developed using modern, investment-oriented methods, where plastic and metal materials are recycled, and methane gas is produced from the decomposition of organic materials in these landfills.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Table S1: The concentration of HMs (mg/kg) from three landfills in Riyadh; Table S2: The enrichment factor for HMs from three landfills in Riyadh; Table S3: The contamination factor for HMs from three landfills in Riyadh; Table S4: The geoaccumulation index for HMs from three landfills in Riyadh; Table S5: The ecological risk factor and potential risk index for HMs from three landfills in Riyadh.

Author Contributions: Conceptualization, T.A. and A.S.E; methodology, Y. S. and N.R.; software, Y. S. and N.R.; validation, T.A., A.S.E, Y. S. and N.R.; writing—original draft preparation, T.A., A.S.E, Y. S. and N.R.; writing—review and editing, T.A., A.S.E, Y. S. and N.R.; project administration, T.A.; funding acquisition, T.A. All authors have read and agreed to the published version of the manuscript.

Funding: Researchers Supporting Project number (RSPD2024R791), King Saud University, Riyadh, Saudi Arabia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated or analyzed during this study are included in this published article and its Supplementary Information Files.

Acknowledgments: The authors extend their appreciation to Researchers Supporting Project number (RSPD2024R791), King Saud University, Riyadh, Saudi Arabia. Moreover, the authors thank the anonymous reviewers for their valuable suggestions and constructive comments.

Conflicts of Interest: The authors have no relevant financial or non-financial interests to disclose.

References

1. Modin, H., 2012. Modern landfill leachates – quality and treatment, Ph.D. dissertation, Lund university.
2. Al Raisi, S.A., Sulaiman, H., Suliman, F.E., Abdallah, O., 2014. Assessment of Heavy Metals in Leachate of an Unlined Landfill in the Sultanate of Oman. International Journal of Environmental Science and Development, 5, 1, 60-63.
3. Adeolu, A. O., Ada, O. V., Gbenga, A. A., Adebayo, O. A., 2011. Assessment of groundwater contamination by leachate near a municipal solid waste landfill, African Journal of Environmental Science and Technology, 5, 1, 933-940.
4. Ouda, O.K.M.; Raza, S.A.; Nizami, A.S.; Rehan, M.; Al-Waked, R.; Korres, N.E.Waste to energy potential: A case study of Saudi Arabia. Renew. Sustain. Energy Rev. 2016, 61, 328–340.
5. Tan, S.T.; Lee, C.T.; Hashim, H.; Ho, W.S.; Lim, J.S. 2014. Optimal process network for municipal solid waste management in Iskandar Malaysia. J. Clean. Prod. 71, 48–58.
6. Havukainen, J.; Zhan, M.; Dong, J.; Liikanen, M.; Deviatkin, I.; Li, X.; Horttanainen, M. 2017. Environmental impact assessment of municipal solid waste management incorporating mechanical treatment of waste and incineration in Hangzhou, China. J. Clean. Prod. 141, 453–461.
7. Balda, M.C.; Furubayashi, T.; Nakata, T. 2016. Integration of WTE technologies into the electrical system for low-carbon growth in Venezuela. Renew. Energy 86, 1247–1255.
8. Güereca, L.P.; Torres, N.; Juárez-López, C.R., 2015. The co-processing of municipal waste in a cement kiln in Mexico. A life-cycle assessment approach. J. Clean. Prod107, 741–748.
9. Wichai-utcha, N.; Chavalparit, O. 2019. 3Rs Policy and plastic waste management in Thailand. J. Mater. Cycles Waste Manag. 21, 10–22.
10. Vaverková, M.D., 2019. Landfill Impacts on the Environment-Review. Geosciences 9, 431; doi:10.3390/geosciences9100431.
11. Vallero, D.A.; Blight, G., 2019. The Municipal Landfill. In Waste, 2nd ed.; Academic Press: Cambridge, MA, USA.
12. Laner, D.; Crest, M.; Schar, H.; Morris, J.W.F.; Barlaz, M.A. 2012. A review of approaches for the long-term management of municipal solid waste landfills. Waste Manag. 32, 498–512.
13. Ziyang, L.; Luochun,W.; Nanwen, Y.; Youcai, Z., 2015. Martial recycling from renewable landfill and associated risks: A review. Chemosphere 131, 91–103.
14. Shen, S.; Chen, Y.; Zhan, L.; Xie, H.; Bouazza, A.; He, F.; Zuo, X., 2018. Methane hotspot localization and visualization at a large-scale Xi'an landfill in China: E_ective tool for landfill gas management. J. Environ. Manag. 225, 232–241.
15. Alarifi, S.S., El-Sorogy, A.S., Al-kahtany, Kh., Hazaea, S.A., 2023. Contamination and health risk assessment of potentially toxic elements in Al-Ammariah agricultural soil, Saudi Arabia. Journal of King Saud University – Science 35, 102826.
16. Alarifi, S.S.; El-Sorogy, A.S.; Al-Kahtany, K.; Alotaibi, M. (2022) Contamination and Environmental Risk Assessment of Potentially Toxic Elements in Soils of Palm Farms in Northwest Riyadh, Saudi Arabia. Sustainability 14, 15402. https://doi.org/10.3390/su142215402

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

17. Alharbi, T., El-Sorogy, A.S., 2021. Spatial distribution and risk assessment of heavy metals pollution in soils of marine origin in central Saudi Arabia. Marine Pollution Bulletin 170 (2021) 112605.
18. Alharbi, T.; El-Sorogy, A.S. (2023) Risk Assessment of Potentially Toxic Elements in Agricultural Soils of Al-Ahsa Oasis, Saudi Arabia. Sustainability 15, 659. https://doi.org/10.3390/su15010659
19. Alzahrani, Y., Alshehri, F., El-Sorogy, A.S., Alzahrani, H. (2023) Environmental assessment of heavy metals in soils around Al-Janabeen Dam, southwest Saudi Arabia. Journal of King Saud University – Science 35, 102503. https://doi.org/10.1016/j.jksus.2022.102503
20. El-Sorogy, A.S., Al Khathlan, M.H., 2024. Assessment of potentially toxic elements and health risks of agricultural soil in Southwest Riyadh, Saudi Arabia. Open Chemistry 22: 20240017. https://doi.org/10.1515/chem-2024-0017
21. Alharbi, T., El-Sorogy, A.S., Al-Kahtany, Kh., 2024. Contamination and health risk assessment of potentially toxic elements in agricultural soil of the Al-Ahsa Oasis, Saudi Arabia using health indices and GIS. Arabian Journal of Chemistry. 17 105592. https://doi.org/10.1016/j.arabjc.2023.105592.
22. Alzahrani, H.; El-Sorogy, A.S.; Okok, A.; Shokr, M.S. 2024. GIS- and Multivariate-Based Approaches for Assessing Potential Environmental Hazards in Some Areas of Southwestern Saudi Arabia. Toxics 12, 569. https://doi.org/10.3390/toxics12080569.
23. Hakanson, L. (1980). An ecological risk index for aquatic pollution control: A sedimentological approach. Water Research, 14(8), 975–1001.
24. Reimann, C., de Caritat, P. (2005). Distinguishing between natural and anthropogenic sources for elements in the environment: Regional geochemical surveys versus enrichment factors. Science of The Total Environment, 337(1–3), 91–107.
25. Weissmannová, H.D., Pavlovský, J. (2017). Indices of soil contamination by heavy metals—methodology of calculation for pollution assessment (minireview). Environmental Monitoring and Assessment, 189(12), 616. https://doi.org/10.1007/s10661-017-6340-5
26. Kabata-Pendias, A., 2011. Trace Elements of Soils and Plants, fourth ed. CRC Press, Taylor & Francis Group, LLC, USA, p. 505.
27. Turekian, K.K., Wedepohl, K.H., 1961. Distribution of the elements in some major units of the Earth's crust. Geol. Soc. Am. Bull. 72, 175–192.
28. Taylor, S.R., 1964. Abundance of chemical elements in the continental crust: a new table. Geoch. Cosmoch. Acta 28, 1273–1285. https://doi.org/10.1016/0016-7037(64)90129-2.
29. DOE International Affairs. National Norms and Standards for the Remediation of Contaminated Land and Soil Quality in the Republic of South Africa; Department of Environmental Affairs (DEA), National Environmental Management: Pretoria, South Africa, 2013.
30. Selvaraj, K., Ram Mohan, V., & Szefer, P. (2004). Evaluation of metal contamination in coastal sediments of the Bay of Bengal, India: Geochemical and statistical approaches. Marine Pollution Bulletin, 49(3), 174-185. doi:10.1016/j.marpolbul.2004.01.006
31. Adamo, P., Giordano, S., Naimo, D., & Bargagli, R. (2005). Trace element accumulation by moss and lichen exposed in bags in urban areas: Factors affecting bioconcentration. Environmental Pollution, 136(3), 431-442. doi:10.1016/j.envpol.2004.12.013
32. Fang, T.H., & Chen, J.F. (2010). Accumulation and pollution of heavy metals in sediments from the southern East China Sea. Environmental Earth Sciences, 60(7), 1587-1596. doi:10.1007/s12665-009-0293-7
33. Youssef, M., Al Otaibi, S., El-Sorogy, A.S. 2024. Distribution, Source, and Contamination of Heavy Metals in Coastal Sediments of Jeddah, Red Sea, Saudi Arabia. Bulletin of Environmental Contamination and Toxicology (2024) 113:12. https://doi.org/10.1007/s00128-024-03923-9
34. El-Sorogy, A.S. Tawfik, M., Almadani, S., Zumlot, T. 2024. Evaluation of sediment quality for heavy metal(loid)s contamination and health risk assessment in the Gulf of Suez, Egypt. Marine Pollution Bulletin 203, 116496. https://doi.org/10.1016/j.marpolbul.2024.116496
35. Zhang, J., Li, H., Zhou, Y. et al., 2018. Bioavailability and soil-to-crop transfer of heavy metals in farmland soils: a case study in the Pearl River Delta, South China. Environ. Pollut. 235, 710–719. https:// doi. org/ 10. 1016/j.envpol. 2017. 12. 106.
36. Calmano, W., Hong, J., & Förstner, U. (1990). Binding and mobilization of heavy metals in contaminated sediments affected by pH and redox potential. Water Science and Technology, 22(5), 243-254. doi:10.2166/wst.1990.0032
37. Al-Kahtany, Kh., El-Sorogy, A.S. (2023) Contamination and health risk assessment of surface sediments along Ras Abu Ali Island, Saudi Arabia. Journal of King Saud University – Science 35, 102509. https://doi.org/10.1016/j.jksus.2022.102509
38. Cevik, F., Göksu, M.Z.L., Derici, O.B., & Fındık, Ö. (2009). An assessment of metal pollution in surface sediments of Seyhan Dam by using enrichment factor, geoaccumulation index and statistical analyses. Environmental Monitoring and Assessment, 152(1-4), 309-317. doi:10.1007/s10661-008-0317-3

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2024 doi:10.20944/preprints202410.0641.v1

39. Al-Kahtany, Kh, Al-Hashim, M.H., El-Sorogy, A.S. 2024. Heavy metal(loid)s contamination and ecological-health risk assessment of coastal sediment from Salwa Bay, Saudi Arabia. Arabian Journal of Chemistry 17, 105868. https://doi.org/10.1016/j.arabjc.2024.105868
40. Alzahrani, H., El-Sorogy, A.S., Qaysi, S., 2023. Assessment of human health risks of toxic elements in coastal area between Al-Khafji and Al-Jubail, Saudi Arabia. Marine Pollution Bulletin 196, 115622. https://doi.org/10.1016/j.marpolbul.2023.115622
41. Lim, H. S., Lee, J. S., Chon, H. T., Sager, M. (2008). Heavy metal contamination and health risk assessment in the vicinity of the abandoned Songcheon Au–Ag mine in Korea. Journal of Geochemical Exploration, 96(2–3), 223–230. doi:https://doi.org/10.1016/j.gexplo.2007.04.008.
42. Ke, X., Gui, S., Huang, H., Zhang, H., Wang, C., & Guo, W. (2017). Ecological risk assessment and source identification for heavy metals in surface sediment from the Liaohe River protected area, China. Chemosphere, 175(Supplement C), 473 – 481. https://doi.org/10.1016/j.chemosphere.2017.02.029.
43. McCready, S., Birch, G.F., & Long, E.R. (2006). Metallic and organic contaminants in sediments of Sydney Harbour, Australia, and vicinity—a chemical dataset for evaluating sediment quality guidelines. Environmental International, 32(4), 455-465. doi:10.1016/j.envint.2005.10.006
44. Christophoridis, C., Dedepsidis, D., & Fytianos, K. (2009). Occurrence and distribution of selected heavy metals in the surface sediments of Thermaikos Gulf, N. Greece. Assessment using pollution indicators. Journal of Hazardous Materials, 168(2-3), 1082-1091. doi:10.1016/j.jhazmat.2009.02.154
45. Long, E., MacDonald, D., Smith, S., Calder, F., 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ. Manage. 19, 81–97.
46. Alharbi, T.; El-Sorogy, A.S.; Al-Kahtany, K. Distribution and Comprehensive Risk Evaluation of Cr, Cd, Fe, Zn, and Pb from Al Lith Coastal Seawater, Saudi Arabia. Water 2024, 16, 1923. https://doi.org/10.3390/w16131923
47. Youssef, M., El-Sorogy, A.S., M., Al-Kahtany, KH., Al-Otaibi, N., 2015. Environmental assessment of coastal surface sediments at Tarut Island, Arabian Gulf (Saudi Arabia). Marine Pollution Bulletin 96: 424–433.
48. Kahal, A.Y., El-Sorogy, A.S., Qaysi, S.I., Al-Hashim, M.H., Al-Dossari, A., 2023. Environmental Risk Assessment and Sources of Potentially Toxic Elements in Seawater of Jazan Coastal Area, Saudi Arabia. Water 15, 3174.https://doi.org/10.3390/w15183174.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.