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Original article

Environmental assessment of heavy metals in soils around Al-Janabeen Dam, southwest Saudi Arabia

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ABSTRACT

Thirty surface soil samples were collected from soils around Al-Janabeen Dam, southwest Saudi Arabia to assess the contamination and environmental risk of heavy metals (HMs) using various pollution measurements, sediment quality guidelines (SQGs), and statistical methods. The average concentrations of HMs (μg/g) were listed in the following decreasing order: Fe (5487.73) > Mn (323.54) > Cr (37.52) > Cu (30.25) > Zn (24.55) > Ni (17.48) > Co (9.51) > Pb (7.50) > Cd (0.81). The investigated soils were very severely enriched, moderate severe enriched with Cu and Pb, and moderate enriched with Co, Cr, Ni and Zn. The reported values of Cd, Zn, Pb, and Co were lower than the ISQG-Low values, while few samples reported levels of Ni, Cr, and Cu between the ISQG-Low and ISQG-High values, implying a low risk of exposure to these HMs. Statistical analysis indicated natural sources for Cr, Mn, Fe, Co, and Ni; and anthropogenic effects for Cu, Zn, Cd, and Pb.

1. Introduction

Water and air pollution, and desertification are the major environmental challenges in Saudi Arabia, and the government is working on a number of remedies to mitigate their effects (Elimam, 2022). The lack of rain, high temperature and droughts, increased activities of the population, logging and overgrazing, and improper agricultural practice were the most causes for deterioration of agricultural lands and desertification (Amin, 2004). Heavy metals are important environmental pollutants and their presence with higher concentrations in plants, atmosphere, soil and water can cause serious problems to all organisms (Al-Hammad and Abd El-Salam, 2016; Al-Kahtany et al., 2018). Heavy metals are not easily biodegradable and can consequently be transferred into the human food chain via many pathways and accumulated in important human organs causing significant health problems, particularly for children (Farooq et al., 2008; Antoniadis et al., 2019; Rinklebe et al., 2019; Alharbi and El-Sorogy 2021).

Al-Baha region is located in the southwest of Saudi Arabia between the Hijaz Mountains and the Tihama Plain, with an area of 10,362 Km^2. Al-Janabeen Dam in Baljurashi governorate is one of the strategic dams which stores floodwaters collected in Al-Janabeenn Valley and secure a drinking water for the Al-Balshahem village. Geologically, the study area is composed of two major Precambrian assemblages (Greenwood, 1975; Al-Shanti, 2009): 1) Baish and Baha groups of metamorphosed basalt, graywacke, and chert, and 2) Jiddah and Ablah groups of *meta*-andesitic and coarse clastic assemblage. The Baish, Baha, and Jiddah Groups are folded, metamorphosed to greenschist facies, and intruded by gabbroic to quartz dioritic plutons about 960 My ago during the Aqiq orogeny. Rocks of the Ablah Group were deposited unconformably on older dioritic and layered rocks.

In their study on hydrochemical characterization of groundwater of Al-Baha, Al-Barakah et al. (2020) recorded contamination by E. coli and nitrate near urban area, while the soluble ions, dissolved salts, and trace elements were found to be within acceptable limits for irrigation and drinking. The saturation index of the Al-Baha groundwaters were undersaturated for gypsum, halite, and anhydrite. Soil can affect human health in many points of view. It enters the body through ingestion, inhalation and through wounds, and elements in the soil pass through the food chain and can cause illness for humans, especially if the concentration of elements is

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either toxic or deficient. Moreover, some soils emit radioactive elements, such ar radon, which is a carcinogen element (Oliver, 1997). Accordingly, we estimate the extent of HM contamination in the soils around Al-Janabeen Dam and determine the significantly enriched HMs contaminating the studied soils. Moreover, we examine potential sources of HMs in the study area using various contamination metrics and multivariate analytical methods.

2. Materials and methods

2.1. Analytical and assessment procedures

Thirty soil samples were collected from the study area, between latitudes 19.9023171–19.911044 N and longitudes 41.7103489–41.7119024 E (Fig. 1). The samples were collected at a depth of < 30 cm from the soil surface using a plastic hand trowel and placed in plastic sample bags, and stored in an ice box. Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb were analyzed using inductively coupled plasma-mass spectrometry (ICP-MS) in laboratories of the College of Science, King Saud University, according to USEPA 3050B (USEPA, 1992). Soil samples were air-dried and sieved before chemical analysis. Approximately 200 mg of samples were accurately weighed into a dry and clean Teflon beaker, and then 2 ml of HNO_3, 6 ml of HCl, and 2 ml of HF were added (Trabzuni et al., 2014). Samples were digested on a hot plate with sand at gentle heat 60–120℃ for approximately 40 min. The resulting digest was filtered and transferred to 25 ml plastic tubes. A blank digest was conducted in the same way. ICP-MS calibration was conducted via external calibration. The coordination of the sampling sites, and the concentrations of the analyzed HMs (μg/g) are listed in Supplementary Table 1.

Herein, the enrichment factor (EF), contamination factor (CF), and pollution load index (PLI) were calculated to estimate the HM contamination in soil samples (El-Sorogy et al., 2016; Kowalska et al., 2018). The PLI was used to determine the integrated pollution status of the associated hazardous groups at the sampling sites, and the potential ecological risk index (RI) was employed to measure the level of risk of metal accumulation in the soil to community health (Hakanson, 1980; Bhuiyana et al., 2010). Furthermore, the sediment quality guideline (SQG) procedure was used to estimate the detrimental effects of polluted soils on microorganisms (Long et al., 1995; Crane and MacDonald, 2003). The aforementioned indices are classified in Supplementary Table 2.

The last mentioned pollution indices were calculated based on the following equations:

$$EF = (M/X)_{sample}/(M/X)_{background},$$

$$I_{geo} = \mathrm{Log2}\,(Cm_{sample}/1.5 \times Cm_{background}),$$

$$CF = C_o/C_b,$$

$$PLI = (CF_1 \times CF_2 \times CF_3 \times CF_4 \ldots\ldots \times CF_n)^{1/n},$$

$$Eri = Tri \times Cf^{i},$$

$$RI = (Tr^{i} \times Cf^{i}),$$

where M represents the analyzed metal and X denotes the level of the normalizing element. Fe was selected as the normalizing element in this study, Cm_{sample} represents the analyzed metal within the sample and $Cm_{background}$ denotes the level of the normalizing element, C_o represents the HM concentration in the sediment and C_b represents the normal background value of the HM, CF_n denotes the CF for metal n, Eri denotes the potential ecological RI for each individual HM; its biological toxic response factor and CF are represented by Tri and Cfi, respectively.

Multivariate statistical techniques, namely hierarchical cluster analysis (HCA), Pearson's correlation coefficient, and principal component analysis (PCA)were used to determine the likely sources of HMs in the soil.

3. Results

3.1. Spatial distribution of heavy metals

The average HM levels are listed in decreasing order: Fe (5487.73) > Mn (323.54) > Cr (37.52) > Cu (30.25) > Zn (24.55) > Ni (17.48) > Co (9.51) > Pb (7.50) > Cd (0.81). Fig. 2 presented the distribution of HMs up on the studied sites. Sample 3 reported the highest concentrations of Cu, Cd, and Pb (41.6, 1.1, and 9.5 μg/g, respectively). Samples 5, 18, and 20 reported the highest concentrations of Zn, Mn, and Ni (32, 4733.6, and

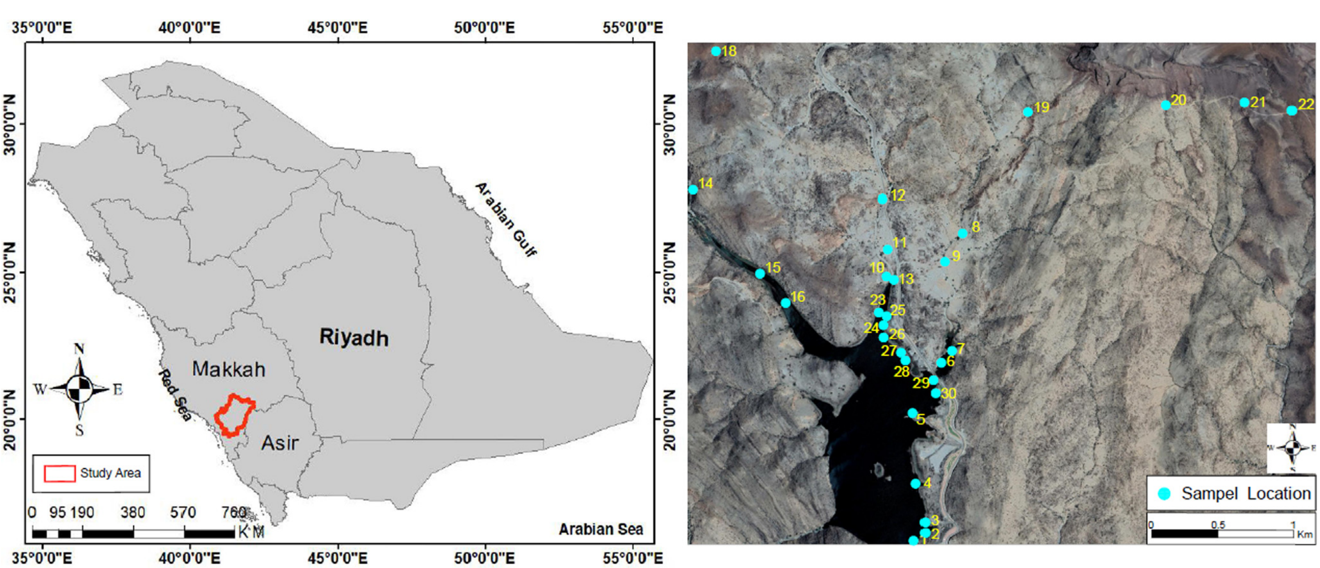

Fig. 1. Location map of the study area and sampling sites.

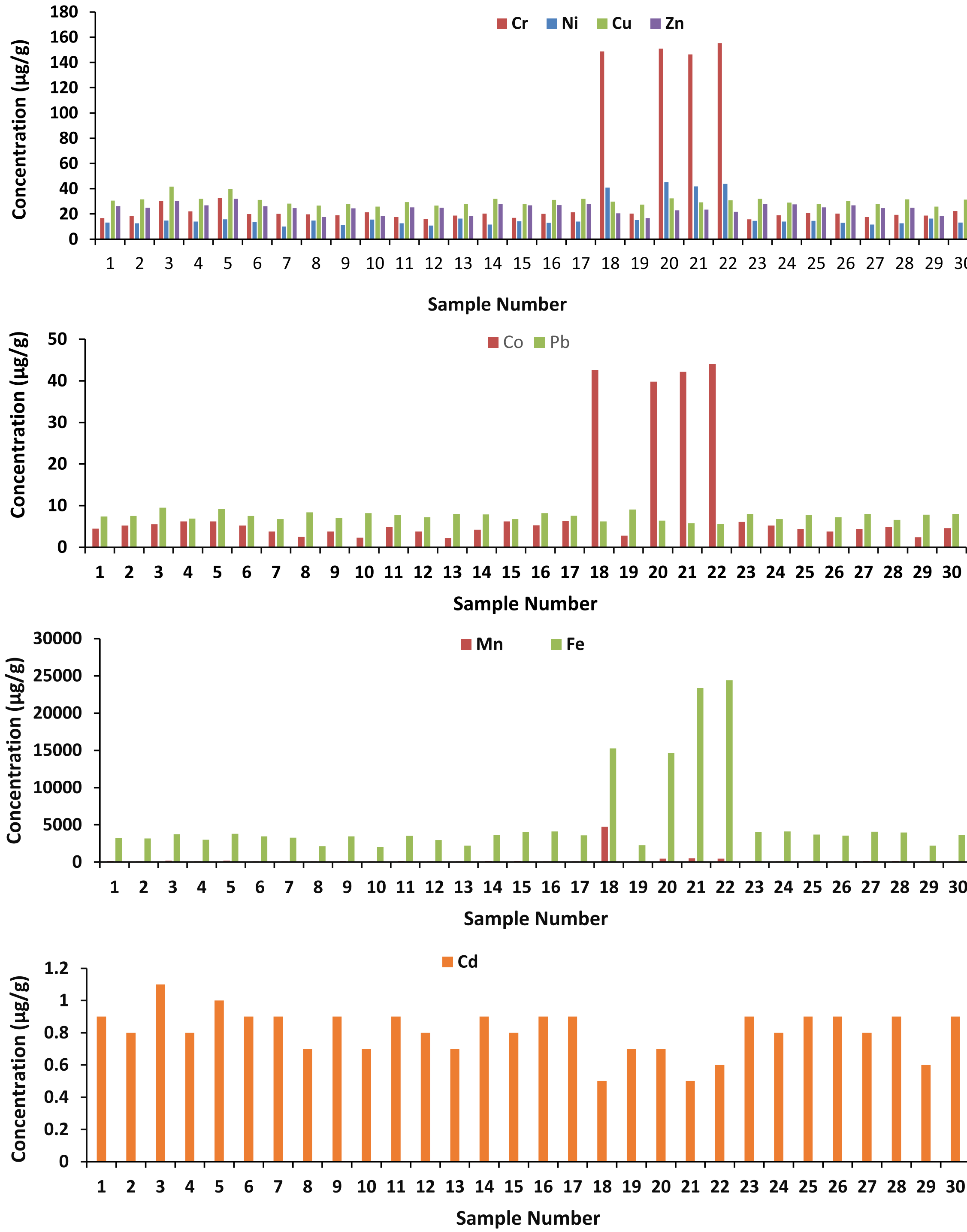

Fig. 2. Distribution of HMs up on the studied sites.

45.2 μg/g, respectively). Sample 22 reported the highest concentrations of Cr, Fe, and Co (155.2, 24400, and 44.1 μg/g, respectively). On the other hand Samples 7, 10, 13, 19, 21, and 23 reported the lowest HM concentrations. Results of the Q-mode HCA supported for a great extent the last mentioned distribution of HMs in the studied soil. It clustered the soil samples into two clusters (Fig. 3A). The first cluster comprised samples 18, 20, 21, and 22, which located in the northern part of the study area and reported mostly the highest values of the investigated HMs, while the second cluster accounted the remaining samples.

The average values for the HMs in the soil samples are listed in Table 1, along with their comparison to diverse soils in Saudi Arabia, worldwide background references, and SQGs. The average values of Ni, Zn, and Pb were less than those reported in soils worldwide (Kabata-Pendias, 2011), earth's crust (Turekian and Wedepohl, 1961; Yaroshevsky, 2006), and continental crust (Taylor, 1964; Rudnick and Gao, 2003), as well as the SOGs and other Saudi examples (Al-Boghdady and Hassanein, 2019; Alharbi and El-Sorogy, 2021). Alternatively, average values of Cu, Cd, Cr, and Co were greater than those reported in Al Uyaynah soil, Saudi Arabia (Alharbi and El-Sorogy, 2021), moreover, average Cd value

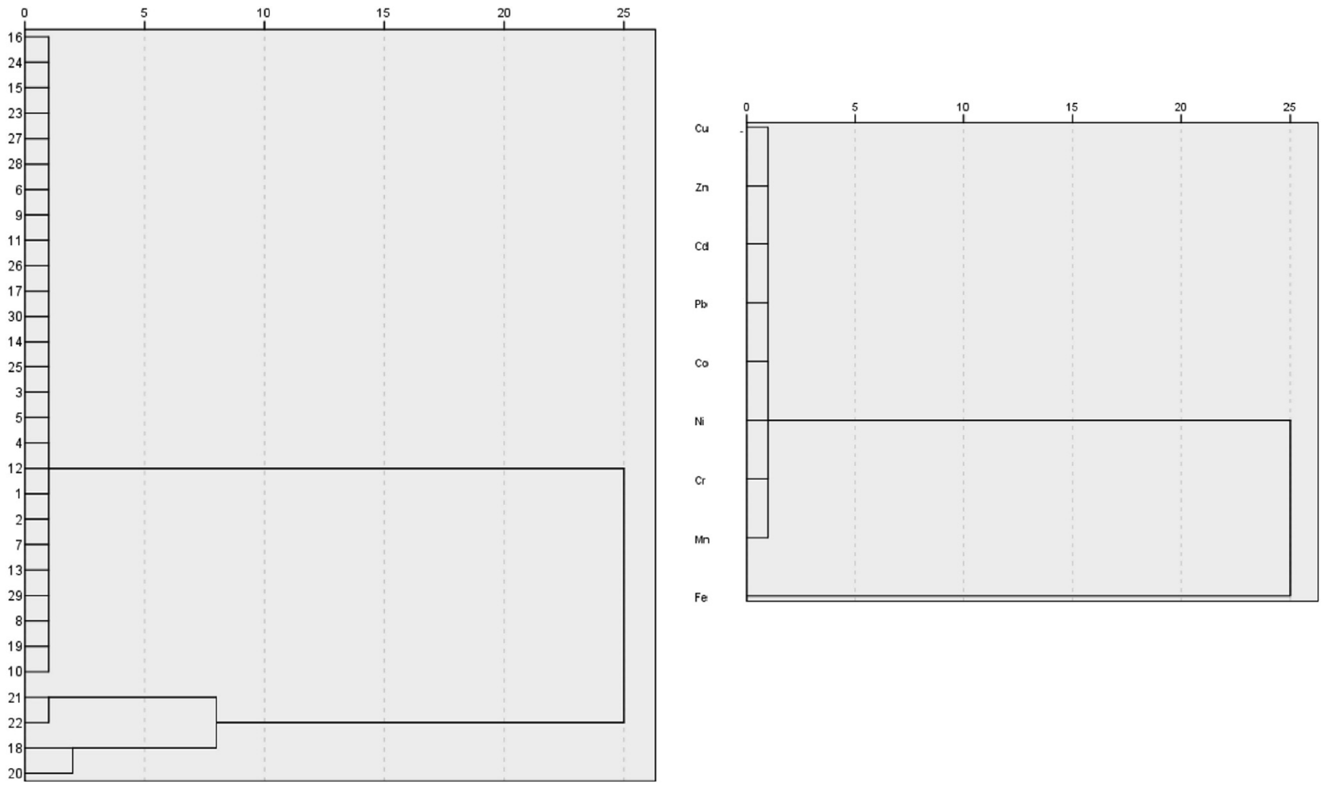

Fig. 3. A. Q mode-HCA of soil samples; B. R mode-HCA of HMs.

Table 1
Minimum, maximum, and average (μg/g) of HMs in the study area and the average levels in other Saudi and worldwide soils, and sediment quality guidelines.

Location and references		Ni	Zn	Cu	Fe	Mn	Cd	Pb	Cr	Co
Al-Baha, southwest Saudi Arabia (present study)	Minimum	10	16.8	25.8	2025	108.8	0.5	5.6	15.8	2.2
	Maximum	45.2	32	41.6	24,400	4733.6	1.1	9.5	155.2	44.1
	Average	17.48	24.55	30.25	5487.73	323.54	0.81	7.50	37.52	9.51
Al Uyaynah soil, Saudi Arabia (Alharbi and El-Sorogy 2021)		19.25	64.33	10.56	35,667		0.38	28.48	30.18	2.45
Wadi Jazan, Saudi Arabia (Al-Boghdady and Hassanein 2019)		48.66	75.80	72.85	23,811	583.58	20.97	19.41	77.22	7722
Worldwide soils (Kabata-Pendias 2011)		29	70	38.9	35,000	488	0.41	27	59.5	11.3
Earth's crust (Yaroshevsky 2006)		58	83	47	46,500	1000	0.13	16	83	18
Continental crust (Rudnick and Gao 2003)		47	67	28			0.09	17	92	17.3
Earth's crust (Turekian and Wedepohl 1961)		68	95	45	47,200	850	0.3	20	90	19
Continental crust (Taylor 1964)		75	70	55	56,300	950	0.2	12.5	100	25
Maximum allowable concentrations (Kabata-Pendias 2011)		60	300	150	50,000		5	300	200	50
National sediment quality guidelines of (Crane and MacDonald, 2003;	ISQG Low	21	200	34			1.5	50	80	
Simpson et al. 2013)	ISQG high	52	410	270			10	220	370	

exceeded those reported from reported in soils worldwide and continental crust which may be attributed to extensive fertilizer usage and other agricultural activities.

3.2. Risk assessment of heavy metals

Results of the EF (Table 2) indicated that the soils around Al-Janabeen Dam are significantly very severe enriched with Cd (average EF = 35.58), moderately severe enriched with Cu and Pb (average EF = 8.64 and 5.10, respectively), moderately enriched with Co, Cr, Ni and Zn (average EF = 3.89, 3.75, 3.33, and 3.29, respectively), and minor enriched Mn (average EF = 2.65). Cadmium is one of the most dangerous of soil pollutants and easily transfers from soil to plants through root absorption (Oliver, 1997). Chronic exposure to cadmium can affect the nervous system, liver, cardiovascular system and may lead to renal failure and death in mammals and humans (Semerjian, 2010). Some individual samples exhibited high enrichment, such as sample 10 showed very high Cd and Cu enrichment (EF = 54.39 and 13.36, respectively), and sample 18 with significant Mn enrichment (EF = 14.64).

Results of the I_{geo} indicated that the investigated soil is moderately polluted with Cd (average I_{geo} = 1.26) and unpolluted with the remaining HMs (Average $I_{geo} < 0$). Moreover, CF results indicated a moderate contamination of Cd (average CF = 2.70), and low contamination of the other HMs (average CF < 1). However, samples 18 and 22 yielded CF values of 4.73 and 3.39 for Mn and Co, respectively, suggesting considerable contamination of the two HMs. The PLI was used to assess HM contamination at a particular site (Rabee et al., 2011; Hossain et al., 2021). The average PLI values (Supplementary Table 1) indicated that the study area was unpolluted with HMs (PLI < 1).

The average values of the ecological RIs suggested a moderate risk of Cd (Eri = 80.94) and no to low risk of the other HMs (Eri < 40). The potential ecological RI ranged from 68.08 (sample

Table 2
Minimum, maximum and average values of the EF, I-geo, CF, and Eri.

	EF			I_{geo}			CF			Er^i		
	Min.	Max.	Avg.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.
Pb	0.54	9.56	5.10	−0.99	−0.46	−0.70	0.28	0.48	0.38	1.40	2.38	1.88
Cd	3.37	54.39	35.58	0.80	1.59	1.26	1.67	3.67	2.70	50.00	110.00	80.94
Zn	0.44	4.56	3.29	−1.44	−0.80	−1.08	0.18	0.34	0.26	0.18	0.34	0.26
Ni	1.46	6.27	3.33	−1.47	0.04	−1.00	0.17	0.78	0.31	1.03	4.68	1.87
Cu	1.31	13.36	8.64	−1.39	−0.70	−1.16	0.57	0.92	0.68	2.87	4.62	3.39
Co	2.61	7.32	3.89	−3.15	1.18	−1.70	0.17	3.39	0.80	0.85	16.96	3.99
Cr	2.22	5.95	3.75	−1.37	0.91	−0.83	0.19	1.87	0.49	0.38	3.74	0.98
Fe				−5.13	−1.54	−4.05	0.04	0.52	0.13			
Mn	0.92	14.64	2.65	−3.79	1.66	−3.00	0.11	4.73	0.45			

29) and 121.70 (sample 3), with an average of 92.99 (Supplementary Table 1), indicating a considerable risk. Cd, Zn, Pb, and Co exhibited values less than the interim sediment quality guideline lower values (ISQG-Low) (Crane and MacDonald, 2003; Simon et al., 2013), indicating a low risk of these HMs in the soil. However, 5 samples of Ni, 4 samples of Cr, and 3 samples of Cu were reported values between the ISQG-Low and the interim sediment quality guideline upper values (ISQG-High), indicating a low risk of exposure to these three HMs with some anthropogenic effects.

4. Discussion

The positive correlations between the members of the two elemental groups: "Cr, Mn, Fe, Co, Ni" and "Cu, Zn, Cd, Pb" indicated similar sources for each group (Table 3). The HMs of the first group indicated natural sources due to the presence of Mn and Fe, mainly originated from the weathering of tonalite, diorite, and alluvial deposits in the study area (Al-Kahtany et al., 2015; El-Sorogy et al., 2020). Alternatively, members of the second groups implied anthropogenic sources, mainly from agricultural activities (Kahal et al., 2020). R-mode HCA classified the HMs into two clusters (Fig. 3B). Fe is included in the one cluster, which represent the most significant element implying natural sources from the Earth's crust (Kahal et al., 2018), while the remaining HMs are accounted in the second cluster, which suggests anthropogenic origins, but presence of Mn implies that a natural source, at least to a certain extent.

PCA enables researchers to summarize large datasets with many variables into fewer principal components that can be easily visualized and analyzed. This method contributes to our understanding of the main processes involved in soil contamination and its possible sources (Jolliffe and Cadima, 2016). Herein, PCA supported the Pearson's correlation coefficient and revealed two principal components that cumulatively explained 81.95 % of the total data variance (Table 4, Fig. 4). The first component explained 59.39 % and showed a strong association of Cr, Mn, Fe, Co, and Ni, indicating natural (Alharbi et al., 2017; El-Sorogy et al., 2018). The presence of Fe and Mn indicated a natural process, but the average EF values of Cr, Co, and Ni were slightly greater than 2 (Table 2), implying minor anthropogenic effects (Javed et al., 2018; Kahal et al., 2020). The second component represented 22.55 % and was highly associated with Zn, Cd, and Cu, which showed higher EF values, indicating anthropogenic processes, may be related to different agricultural chemicals and P fertilizers (Weissmannová and Pavlovský, 2017; Alharbi and El-Sorogy, 2019).

Table 4
Loading matrix of PCs and the total variance explained by each PC.

	Component	
	1	2
Cr	**0.959**	0.240
Mn	**0.627**	0.058
Fe	**0.924**	0.254
Co	**0.962**	0.257
Ni	**0.957**	0.181
Cu	-0.155	**0.926**
Zn	-0.405	**0.820**
Cd	-0.801	**0.524**
Pb	-0.713	0.038
% of Variance	59.39	22.55
Cumulative %	59.39	81.95

5. Conclusions

The present work highlighted the hazardous HMs in the soil around Al-Janabeen Dam using several pollution indices and SQGs. Results of assessment indicated very severe enriched and moderate risk with Cd, moderate severe enriched with Cu and Pb, and moderate enriched with Co, Cr, Ni and Zn. Cd, Zn, Pb, and Co reported values lower than the ISQG-Low values and few samples reported levels of Ni, Cr, and Cu between the ISQG-Low and ISQG-High values, indicating a low risk of exposure to these HMs with some anthropogenic effects. Multivariate statistical methods indicated

Table 3
Correlation matrix for HMs of soil samples.

	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
Cr	1								
Mn	**0.573****	1							
Fe	**0.952****	0.431*	1						
Co	**0.994****	**0.584****	**0.964****	1					
Ni	**0.988****	**0.536****	**0.932****	**0.978****	1				
Cu	0.093	-0.001	0.064	0.086	0.056	1			
Zn	-0.233	-0.214	-0.153	-0.188	-0.296	**0.704****	1		
Cd	-0.638**	-0.471**	-0.604**	-0.630**	-0.682**	**0.560****	**0.759****	1	
Pb	-0.610**	-0.333	-0.668**	-0.657**	-0.578**	0.312	0.113	**0.510****	1

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

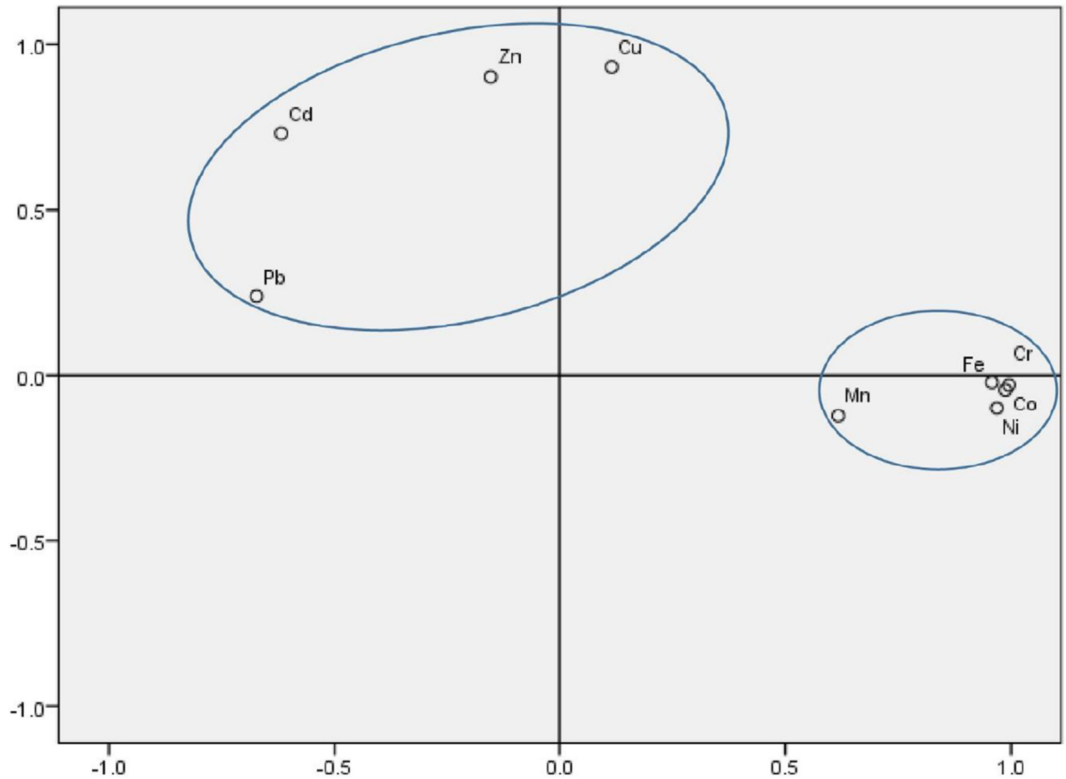

Fig. 4. Factor analysis and distribution of HMs in two component plots.

natural sources for Cr, Mn, Fe, Co, and Ni, primarily originating from the weathering of earth materials and atmospheric deposition; and anthropogenic sources for Cu, Zn, Cd, and Pb, which might be originated from sewage and agricultural activities. The concentrations of HMs in the soil around Al-Janabeen Dam must be monitored periodically to control and prevent increased HM levels, particularly those of Cu, Zn, Cd, and Pb. Moreover, farmers should use biofertilizers and manure and reduce their dependency on chemical fertilizers and pesticides.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jksus.2022.102503.

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