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Evaluation of Trace Metal Pollution and Ecological Risk in the Soils of Koy Sanjaq, Northeastern Iraq

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Abstract

Heavy metal pollution in the soil has garnered increasing concern due to rapid urbanization and intensified industrial and agricultural activities. This study investigates the ecological risk associated with heavy metals in 60 samples of surface soil (0–20 cm depth) from the Koy Sanjaq District, Northeastern Iraq. These samples were analyzed for heavy metals, including As, Cd, Co, Cr, Ni, Cu, Pb, Mn, Zn, and V, major elements (Ca, Al, Fe), and pH. Contamination was evaluated using multiple indices: enrichment factor, contamination degree, geoaccumulation index, contamination factor, modified contamination degree, pollution load index, ecological risk, and risk index. Results indicate elevated concentrations of As, Cu, Pb, V, Zn, and Cd compared to Upper Continental Crust background values. enrichment factor analysis shows moderate enrichment for Zn, Cu, and Pb in some samples and very high enrichment for Cd in approximately 50% of the samples. Contamination factor values suggest moderate contamination for V, Zn, As, Cu, and Pb; and very high contamination for Cd across all samples. The order of average enrichment factor and contamination factor values is: Cd > Pb > Cu > As > Zn > V > Mn > Co > Ni > Cr. While modified contamination degree values indicate moderate contamination overall, contamination degree values indicate very high contamination. Despite moderate overall contamination indicated by modified contamination degree, contamination degree points to very high contamination; Igeo labels all metals except Cd as uncontaminated (Cd: heavily to extremely contaminated); 27% of western samples are strongly to extremely polluted per pollution load index; only Cd poses very high ecological risk rank: Cd > As > Pb > Cu > Co > V > Ni > Zn > Cr > Mn); overall RI indicates high to severe risk, especially in the north. Factor analysis attributes Co, Cr, Cu, Ni, and V to geogenic sources; Mn, Pb, Zn, and Cd to anthropogenic activities; and Fe, Na, and pH to soil alkalinity.

Keywords: Koy Sanjaq soil; Soil contamination evaluation; Heavy metals; Factor analysis; Ecological risk

1. Introduction

Soil is a complex and dynamic system composed of multiple distinct layers, or horizons, each exhibiting unique physical, chemical, mineralogical, and biological properties. These horizons are shaped by influences such as climate and the activities of living organisms (Sousa et al., 2008). Soil pollution, driven by rapid urbanization and intensive industrial and agricultural activities, has emerged as a significant environmental concern that has attracted considerable academic and public attention over the past few decades (Seleiman et al., 2020). Soil functions as a major sink for pollutants and serves

as a pathway for their transfer into the atmosphere, hydrosphere, and biosphere (Kabata-Pendias, 2010; Alloway, 2012). Soil is the habitat of numerous organisms, the skeleton of the terrestrial ecosystem, and the most threatening factor in our environment due to the likely influence of various pollutants from human actions, such as agriculture, industry, etc. (Morton-Bermea et al., 2002). Pollution by heavy metals is derived from anthropogenic activity, mainly associated with industrial processes and natural sources, such as volcanic eruptions (Aras et al., 2012). Heavy metal concentrations in soils and sediments have grown globally over the past century as a result of fast population growth mixed with increasing human activity, such as agricultural, industrial, and many other activities. Consequently, soil pollution is increasingly recognized as a critical challenge with profound implications for both environmental integrity and human health (Lourenco and Landim, 2005).

All heavy metals exhibit toxic effects on soil when their concentrations exceed natural background levels (Ogunkunle and Fatoba, 2013). Koy Sanjaq is situated approximately 73 km east of Erbil and lies roughly 20 km north of the Little Zab River, a tributary of the Tigris. Although Haibat Sultan Mountain surrounded the area from the north, northeast to the east, which denotes a southeastern limb of the Safeen anticline. According to Iraqi statistics of 2023, the Koy Sanjaq population is approximately 45 thousands people and represents 0.1 % of the total population of Iraq. Geographical coordinates of latitude and longitude are 35° 50′- 36° 18′ N and 44° 18′- 44° 59′ E, with an area of around more than 1000 Km^2 (Fig. 1). The area situated within the Low Folded Zone (Jassim and Goff, 2006) characterized by a semi-arid climate (dry hot summer, and wet cold winter). Geographically, Koy Sanjaq District lies within the Erbil Governorate in northeastern Iraq. The northern part is mountainous, characterized by uplifted terrain, whereas the southern and southwestern sections gently slope into a fertile alluvial plain extending to the border with Kirkuk part of the historic Tigris River floodplain. Intensive cultivation of wheat and barley is distributed in the plains covering from Erbil to the south of Koy Sanjaq. Correspondingly, the average soil depth increases steadily from north to south, reaching up to 1.3 meters (Kahraman and Layla, 2004).

However, no research has been conducted to assess the impacts of the oil wells on the composition of their neighboring soils in the Koy Sanjaq District (Shewashok oil field southwest of Koya city). There is a noteworthy lack of geochemical analyses addressing soil contamination and trace element concentrations in the selected study area. To address this gap, the present study is essential, as it offers critical knowledge to support stakeholders and decision-makers in implementing effective environmental management strategies for the region.

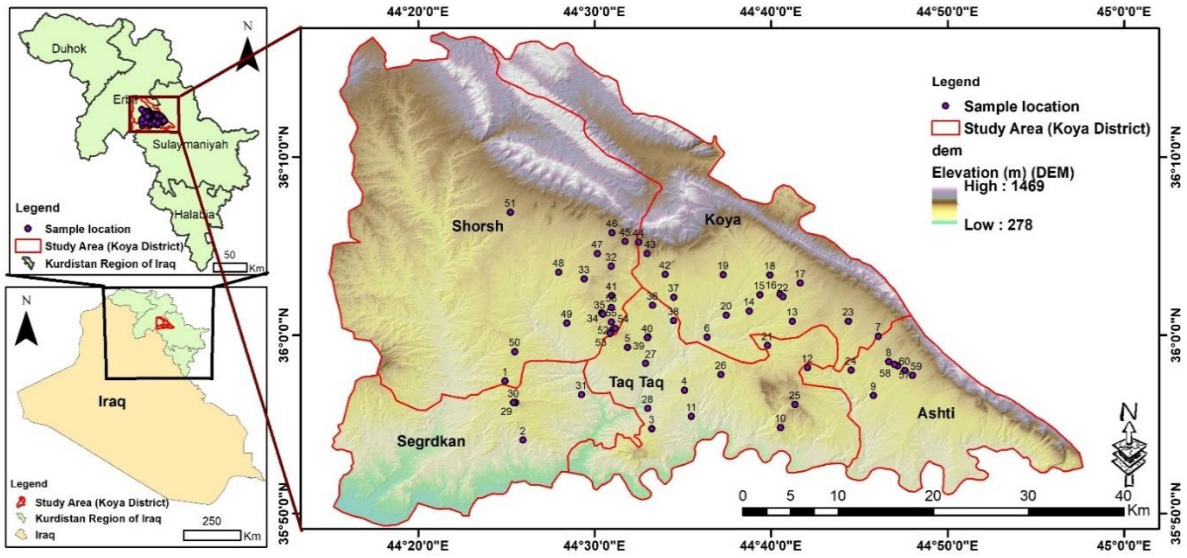


Fig. 1. Location map of the study soil samples, Koy Sanjaq (Koya) District

2. Geological Setting

From a tectonic perspective, the study area lies within the Mountain Front Flexure, which represents the transitional boundary between the High-Folded and Low-Folded zones of the Chemchemal–Butmah Subzone. The exposed structural features in the area generally trend northwest-southeast, consistent with the general trend of Zagros (Jassim and Goff, 2006). Within the study area, five distinct geological formations are exposed, spanning in age from the Middle Eocene to the Pleistocene, in addition to superficial Quaternary sediments. The oldest unit is the Pila Spi Formation, which belongs to the Middle–Late Eocene (Bellen et al., 1959). Fatha Formation, dating to the Middle Miocene, this formation comprises of cyclic deposits of mudstone interbedded with thin layers of limestone and gypsum. Injana Formation: Of Upper Miocene age, the formation consists of fine-grained molasse sediments, including sandstone, red or grey siltstone and claystone. The Mukdadiya Formation, dated to the Late Miocene–Pliocene, consists primarily of gray pebbly sandstone interbedded with siltstone and claystone (Bellen et al., 1959; Jassim and Goff, 2006). The Bai Hassan Formation, dated to the Pliocene–Pleistocene (Bellen et al., 1959), is distinguished by extensive sequences of conglomerates alternating with red claystone and gray sandstone layers. The depositional environment is continental, freshwater molasses. Quaternary sediments: Primarily of alluvial origin and varying from Pleistocene to Holocene in age, these sediments are heterogeneous and comprise alternating layers of gravel, sand, silt, and clay (Bellen et al., 1959; Jassim and Goff, 2006).

3. Materials and Methods

3.1. Soil Sampling

Sixty topsoil samples were collected, which were obtained seasonally from October 2021 to March 2023 in residential areas of the study area. The geographic coordinates of sampling points were measured using a Global Positioning System (GPS) with ±5 m accuracy. The distance between the samples collected randomly depends on the activity in the study area. Soil samples were taken systematically in the first (0-20) cm of soil using a hand auger within the A-horizon below the organic layer. The surface layers, including leaves, grasses, stems, roots of partially decomposed vegetation, and pebbles, were first removed. A quartering procedure was then performed at each sampling point to ensure the collection of representative soil samples. The obtained samples were subsequently stored in labelled polyethylene bags. Initially, the samples were air-dried under sunlight, ground into a fine powder, and finally sieved through a 200-mesh stainless steel wire. Generally, the soils are reddish-brown in colour and comprise only a sparse fraction of gravel.

3.2. Physicochemical Analysis

The samples were analyzed for Al, Ca, and Fe contents using the ICP-AES technique, code ME-ICP06; and for heavy metals (As, Cd, Cu, Co, Mn, Zn, Ni, Pb, and V) using the ICP-MS technique, code ME-MS81; however, Co and Ni were tested according to the code ME-4ACD81. All laboratory analyses were conducted at the ALS Laboratory Group facility in Seville, Spain. The precision of the analysis was examined by duplicating some samples and was less than ±5, whereas the accuracy was better than ±4 for the analyzed elements using international reference materials (MRGeo08 and AMIS0304). In addition, the soils were analyzed for their pH values by Hanna Instruments.

3.3. Data Analysis

The correlation coefficient analysis has been performed on the geochemical data using the IBM SPSS Statistics 26 program, and principal component analysis (PCA) was applied to determine and examine the correlation among the elements. Selecting background values as a key factor in

geochemical data interpretation. Many scholars have employed the average shale values (Mohiuddin et al., 2011; Salam et al., 2021; Tnoumi et al., 2022; Al-Dahar et al., 2023) or the upper continental crust (UCC) data (Xuefeng et al., 2016; Tang et al., 2019; Dytłow and Górka-Kostrubiec, 2021; Hamid et al., 2022) as reference baselines. The estimated concentrations of the elements were compared with the geochemical background values of the UCC given by Rudnick and Gao (2003). Soil pollution was evaluated using individual pollution indices, including the enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF), degree of contamination (Cdeg), modified contamination degree (mCdeg), pollution load index (PLI), and the potential ecological risk index (RI). These indices are computed from heavy metal content in soils and can be used to classify soils into numerous categories based on pollution level (Weissmannová and Pavlovský, 2017).

3.4. Spatial Analysis

The study area was mapped utilizing the ALOS PALSAR-DEM within the ArcGIS 10.8 environment. Accurate sampling locations were recorded using a handheld GPS and subsequently integrated with trace element concentration data. This integrated dataset was applied to the GIS platform for comprehensive spatial analysis.

Spatial distribution maps of selected trace elements, along with various contamination indices, have been created using the spatial analysis extension in ArcGIS 10.8. In this study, maps were constructed through the IDW interpolation method, where the values of unsampled locations are estimated according to their spatial relationship with nearby measured points (Fatah et al., 2025). In this approach, weights are allocated in inverse relation to the distance separating sampled from unsampled sites, so that nearby points have a stronger effect on the estimated values.

To facilitate interpretation, international classification standards were used for evaluating trace element concentrations and contamination indices.

3.5. Evaluation of Soil Pollution

3.5.1. Enrichment factor (EF)

The Enrichment Factor (EF) was first introduced as a tool to trace the origins of elements in atmospheric deposition, seawater, and air. The EF method is extensively applied to soils, lake sediments, peat, and various environmental media to differentiate natural contributions from anthropogenic element inputs (Reimann and de Caritat, 2005; Bourennane et al., 2010). It has been widely employed to identify the anthropogenic source of metal elements (Wang et al., 2021; Zhang et al., 2022). Following Chester and Stoner (1973) and Zoller et al. (1974), the enrichment factor (EF) is calculated using the general form of Equation (1).

$$EF = \frac{\left(\frac{C_m}{C_{Fe}}\right)_{sample}}{\left(\frac{B_m}{B_{fe}}\right)_{Background}}, \quad (1)$$

The C_m/C_{Fe} denotes the ratio of heavy metal concentration to Fe in the sample, while Bm/BFe refers to the corresponding background ratio in the upper continental crust (UCC). In this work, Fe has been selected as the reference element because it is the most common reference element and several authors have successfully used Fe as a reference, it is one of the most significant parts of soil, and iron is difficult to change by other human activities (Martínez et al., 2007; Bourennane et al., 2010; Malsiu, et al., 2020; Al-Dahar, et al., 2023). The interpretation of the EF was conducted according to Chester and Stoner (1973) into five categories (Table 1).

3.5.2. Geoaccumulation index (I_{geo})

The geoaccumulation index (I_{geo}) proposed by Müller (1969) is calculated to estimate the degree of soil contamination, highlighting contamination that is mainly associated with anthropogenic activities (Chabukdhara and Nema, 2012; Liu et al., 2020) and stream sediments (Chung and Chon, 2014; Kinimo et al., 2018). This empirical index compares an assumed concentration to a normalized geochemical background using the following formula:

$$I_{geo} = \log_2 \left[\frac{C_m}{(1.5 \times B_m)} \right], \quad (2)$$

Here, Cm represents the concentration of a specific metal within soil and stream sediment samples. B_m represents the local geochemical background value, and 1.5 is an exaggeration factor applied to account for possible lithological variations within the study area. The interpretation of the I_{geo} will be accomplished based on seven classes of contamination (Table 1) assumed by Müller (1969). The I_{geo} was computed for the enriched chemical elements.

3.5.3. Contamination Factor (CF)

CF is applied to determine the level of metal contamination in sediment, which is computed as:

$$CF = \frac{C_{m_{Sample}}}{B_{m_{Background}}}, \quad (3)$$

where: C_m= concentration of the metal m, B_m= background value, which is equivalent to UCC in the studied sediments (Rudnick and Gao, 2003), which was widely used. The degree of contamination (C_{deg}) is the summation of all contamination factors of all the considered metals in the sample. Ahdy and Khaled (2009) classified C_{deg} in terms of four categories (Table 1), and due to the limitation of the C_{deg} equation, Abrahim (2005) proposed the modified CF (mC_{deg}) used to assess the quality of the soil, which can be calculated from the following equations:

$$C_{deg} = \sum CF, \quad (4)$$

$$mC_{deg} = \sum \frac{CF}{n}, \quad (5)$$

where *n* is the number of elements evaluated, CF is the contamination factor for each element individually, and mC_{deg} is the modified contamination factors are classified into six categories (Liu et al., 2016; Da Silva Junior et al., 2022) as shown in Table 1.

3.5.4. Pollution load index (PLI)

The PLI evaluates the level of pollution of potentially toxic metals in the study area (Hamid et al., 2022). PLI can be calculated by employing the following equation (Lu et al., 2009):

$$\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \times \cdots \times \mathrm{CF}_n)^{1/n}, \quad (6)$$

where CF is the contamination factor, and n is the number of parameters.

The Pollution Load Index (PLI) is calculated as the *n*th root of the product of the contamination factors (*n*CF). Based on Tomlinson et al. (1980), PLI values are categorized into four levels (Table 1).

3.5.5. Potential ecological risk index (RI)

Håkanson (1980) developed this index to assess the toxicity of heavy metals in sediments, and it has been widely used in soils (Cao et al., 2009; Sun et al., 2010). The formula for the potential ecological risk index of individual heavy metal pollution accounts not only for the toxicity of a single element but also for the cumulative effects when multiple metals are present.

$$Er = T_m \times CF = T_m \times (C_m / B_m), \quad (7)$$

$$RI = \Sigma Er = \Sigma T_m \times CF, \quad (8)$$

Here, T_m represents the toxic response factor of an individual heavy metal. The values assigned are 30, 10, 2, 5, 5, 5, 1, 5, 2, and 1 for Cd, As, Cr, Co, Cu, Pb, Mn, Ni, V, and Zn, respectively (Zhang et al. 2012; Liu and Zhang, 2014). Here, ecological risk (Er) denotes the ecological risk factor of a given metal (m), CF represents its contamination factor, and Cm is the concentration of the metal in the analyzed soil sample from the study area. The overall risk index (RI) is given as the summation of the ecological risk factors for the metals in the samples. The Risk Index (RI) is employed to assess the overall level of metal pollution in soil, taking into account the toxicity of each metal (Håkanson, 1980; Yang et al., 2009). The ecological risk index is divided into five distinct categories, as presented in Table 1.

Table 1. Criteria for soil classification using pollution indices

Index, values	Equation, class	References
Enrichment factor (EF)	$EF= [(C_m/ C_{Fe})_{samnle}]/[(B_m / B_{Fe})_{background}]$	Chester and Stoner, 1973; Zoller et al., 1974
EF≤2	Minimal enrichment	
2<EF≤5	Moderate enrichment	
5<EF≤20	Significant enrichment	
20<EF≤40	Very high enrichment	
EF>40	Extremely enrichment	
Geoaccumulation index	$I_{geo}= Log2[(C_m)/ 1.5(B_m)]$	Müller, 1969
Igeo≤0	Uncontaminated	
0<Igeo≤1	Uncontaminated to moderately contaminated	
1<Igeo≤2	Moderately contaminated	
2<Igeo≤3	Moderately to heavily contaminated	
3<Igeo≤4	Heavily contaminated	
4<Igeo≤5	Heavily to extremely contaminated	
5<Igeo	Extremely contaminated	
Contamination Factor	$CF = C_{m_sample} / B_{m_background}$	Håkanson, 1980
CF<1	Low contamination	
1≤CF<3	Moderate contamination	
3≤CF<6	Considerable contamination	
CF>6	Very high contamination	
Contamination Degree	$C_{deg}= \Sigma CF$	Ahdy and Khaled, 2009
C_{deg}<6	Low contamination	
6≤ C_{deg} <12	Moderate contamination	
12≤ C_{deg} <24	Considerable contamination	
C_{deg} >24	Very high contamination	
Modified	$mC_{deg} = \Sigma CF/n$	Abrahim and Parker, 2008
mC_{deg} <1.5	Very low contamination	
1.5≤ mC_{deg} <2	Low contamination	
2≤ mC_{deg} <4	Moderate contamination	
4≤ mC_{deg} <8	High contamination	
8≤ mC_{deg} <16	Very high contamination	
16≤ mC_{deg} <32	Extremely contamination	
Pollution load index	$PLI= (CF1 \times CF2 \times CF3 \times \cdots \times CFn)^{1/n}$	Tomlinson et al., 1980
PLI<1	Unpolluted	
1<PLI<2	Moderately polluted	
2<PLI<10	Strongly polluted	
PLI>10	Extremely polluted	
Risk factor (Er)	$Er = Tm \times CF = Tm \times (Cm/Bm)$	Håkanson, 1980
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	Very high ecological risk	
Risk index (RI)	$RI = \Sigma Er = \Sigma T_m \times CF$	Håkanson, 1980
RI<150	Low ecological index	
150<RI<300	Moderate ecological index	
300<RI<600	High ecological index	
600<RI<1200	Moderately severe index	
RI>1200	Severe ecological index	

4. Results

4.1. Estimation of Elements in the Soil of Koy Sinjaq

Table 2 presents the results of the chemical analysis of major and heavy metals in soil samples collected from the Koy Sanjaq , Erbil . The pH results of the analyzed soils ranged from 7.0 to 8.1 with an average of 7.5. Additionally, the studied soils are enriched in Fe (55252 ppm) and depleted in Al compared with the UCC. The highest contents of heavy metals including V (119.8ppm), Zn (92.9ppm), Cu (43.9ppm), Pb (30.4ppm), As (6.9ppm), and Cd (3.1ppm), were recorded for the samples from 30 to 38 (SE Shorsh area); However, the presence of Pb, Zn, and Cd were detected in samples 31–33 and 39–43 (Table 2). The average concentrations of heavy metals in the samples were ranked in the following order: Mn > V > Cd > Cu > Cr > Pb > Co > As > Zn. Heavy metals originating from natural (geogenic) sources typically exhibit low coefficients of variation (CV%), while those impacted by human activity show higher variability (Baran et al., 2017). The high concentrations of heavy metals may still reflect natural (geogenic) origins, as soils derived from basaltic, ultramafic, shale, or other metalliferous rocks inherit the metal-rich composition of their parent bedrock. Weathering of these lithologies can naturally release elements such as V, Cr, Ni, and Mn into the soil without substantial human influence. Fei et al. (2019) and Su et al. (2023) found elevated CVs% of heavy metals were >50% indicate that the existence of influence of anthropogenic pollution. Similarly, a recent study noted that higher CVs often correlate with increased anthropogenic activity . In our analysis, As, Co, Mn, Ni, V, and Zn displayed CVs below 50%, suggesting minimal human impact. Conversely, Pb (153), Cr (71.2), Cu (59.7), and Cd (56.2) exhibited CVs above 50%, implying the coexistence of anthropogenic and geogenic sources affecting their distribution in the soil (Table 2).

4.2. Evaluation of Heavy Metals and Contamination Level

EF, *Igeo*, and CF values were calculated using the data obtained in this study and are given in Figs. 2, 3, 4, and 5. The highest EF value was detected at site 39 (66.7) for Cd, which indicated extremely high enrichment. The lowest enrichment factor (EF) for Cr, indicating minimal enrichment, was observed at sites 6 and 54–60, with a value of 0.1. Pb exhibited the second-highest enrichment factor (EF) at site 22 (6.8), indicating significant enrichment. The EF values for all metals decreased in the following order: Cd (25.05) > Pb (1.37) > Cu (1.17) > As (1.06) > Zn (1.01) > V (0.91) > Mn (0.50) > Co (0.39) > Ni (0.34) > Cr (0.30) (Table 3a; b).

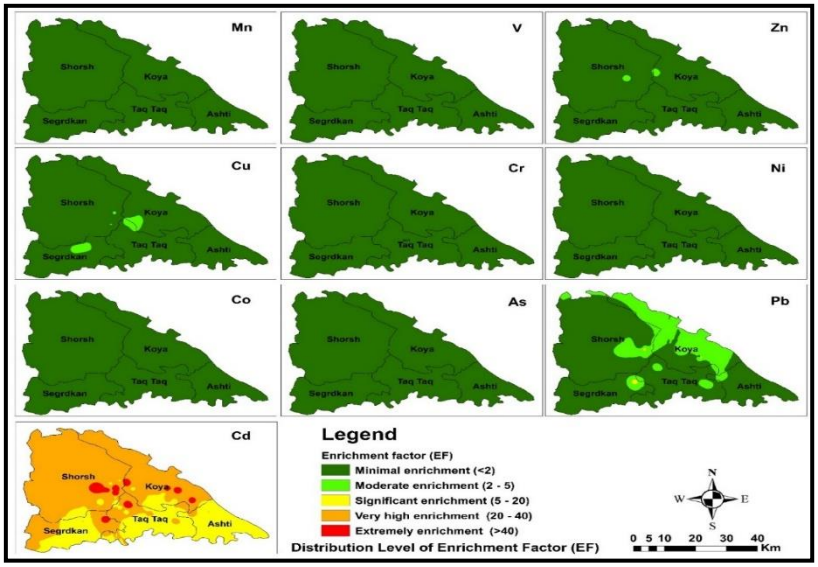


Fig. 2. Distribution levels of Enrichment Factor for the soil of Koy Sanjaq

Table 2. Major elements and heavy metals (ppm) chemical analysis, pH, and CF, I_{geo}, EF, C_{deg} and Er means for the soil samples from Koy Sanjaq, Erbil, Kurdistan Region, Iraq

Sample No.	As	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Cd	Al	Fe	pH	C_{deg}
1	5.6	8.4	39.2	46	373.3	17.2	2.4	82.3	93.2	1.8	6046	57892	7.8	27
2	5.5	8	34.7	41.5	392.9	17.6	2.5	115.8	53.7	1.8	7436	64795	7	26.3
3	5.5	6.7	23.9	30.7	378.7	18.8	2.5	116.1	73.5	1.6	6846	58723	7.1	24
4	6.2	6.7	23	29.8	343.3	19.5	2.5	100.7	70.6	1.8	7046	53741	7.5	25.7
5	5.4	6.1	20.5	27.3	283.3	16.1	2.2	83.8	63.6	1.6	10466	54798	7.6	23.7
6	5.4	6.1	17.9	24.7	303.3	16.6	2.3	97.4	54.2	1.7	6756	58732	7.4	24.7
7	6.7	9.5	25.8	32.6	353.3	22.5	3.1	115.1	60.3	2.3	6766	61782	7.1	32.4
8	6.5	7.5	29.2	36	343.3	19.7	2.7	92.5	70.5	1.7	5786	63548	7.4	25.2
9	6.6	10.7	29.8	36.6	429.3	23.3	3.1	111.2	60.1	2.3	10966	58712	7.3	32.2
10	6.6	11.8	29	35.8	368.3	22.2	2.8	92.7	63.2	1.6	10356	56879	7.1	24.4
11	6.6	7.8	19	25.8	323.3	18.5	2.7	89.8	56.2	1.9	11076	51736	7.9	26.5
12	6.2	10.8	27.4	34.2	348.3	20	2.8	110.4	52.5	1.8	9846	52439	7.5	26.2
13	6.7	8.6	17.9	24.7	368.3	19.5	2.6	74.6	65.2	1.6	9896	50172	7.2	23.9
14	6.7	9.8	24.8	31.6	364.3	20.5	2.8	98.3	47.7	1.6	6196	51217	7.6	23.9
15	7.1	7.5	21	27.8	363.3	20.9	2.9	116.6	57.6	1.8	10926	50903	7.5	26.2
16	7	11.4	27.4	34.2	348.3	21.9	3.2	162.4	62.8	2.2	6156	48108	7.4	32.4
17	5.8	5.6	19	25.8	577	15.4	107.5	72.7	112.1	5.7	7726	49719	7.7	75.9
18	5.8	7.4	30.4	37.2	480.4	17.7	95.5	163.3	104.2	5.6	9846	47680	7.6	75.3
19	5.7	9.3	31.9	38.7	337.4	16.6	88.5	81.5	84.1	3.5	8116	49593	7.4	50.9
20	6.4	9.6	20.4	27.2	303.3	20.6	2.6	80.2	49	1.6	10506	51308	7.9	23.6
21	7	7.8	23.8	30.6	348.3	21.2	3.2	89.4	46.4	1.7	10906	49905	7.8	25.4
22	6.6	9.2	19.4	26.2	348.4	19.5	147.5	80.8	119.9	4.6	9706	50014	7.2	66.7
23	6.1	8.2	23.8	30.6	302.4	19.8	108.5	90.9	101.5	5.5	10366	49906	7.1	74.5
24	6.1	7.8	18.5	25.3	293.4	16.7	117.5	75.1	87.2	2.6	9026	52359	7.1	42
25	6.2	8.4	29.1	35.9	388.3	18.4	100	126.7	74.2	2.7	7576	52608	7.6	42.4
26	6	10	27.2	34	468.3	23.1	3.4	141	70	2.5	8846	51429	7.8	34.7
27	6.6	8.2	34.9	41.7	453.3	22.3	2.9	140	79.8	1.6	7746	50417	7.9	25.7
28	6.4	9	40.4	47.2	460.7	22.2	3.1	137.5	78	1.8	7746	50693	7.8	28.1
29	6.7	9.5	61.8	68.6	440.4	23.8	2.9	153.2	73.3	1.6	7606	50480	7.8	27.4
30	8	10	133.5	140.3	503.2	38.3	3.4	162	87.9	2.5	8326	49807	7.8	41.7
31	8.1	16.3	62.8	69.6	606.4	40.6	138.5	174.8	135.9	5.9	8996	51382	7.9	85.5
32	8.8	10.5	76.9	83.7	658.4	32.5	127.5	197.3	118.9	5.8	9806	51210	7.4	84.2
33	8.4	9.2	46.5	53.3	592.4	28.5	112.5	164	110	5.3	9236	50702	7.5	74.6
34	8.8	10.8	73.8	80.6	465.7	31	5.5	151.8	92.1	5.2	9446	48219	7.4	68.2
35	8.8	8.7	62.6	69.4	475.8	30.4	3.5	161.2	93.2	2.5	9506	47508	7.7	37.9
36	8	10.5	88.1	94.9	533.5	29.6	4.1	188.5	93.2	3.5	8646	44812	7.6	50.7
37	6.6	13.6	135	141.8	386.8	27.3	3	232.2	94.7	2.3	8876	50418	7.7	39.5
38	7.6	10.4	116.6	123.4	443.5	28.4	3	154.9	89.7	2.2	8146	46215	7.1	36.3
39	8.4	8.6	38.5	45.3	776.4	25.5	97.5	128.4	156.1	7.7	8826	50518	7.2	101.5
40	8.5	6.6	35.4	42.2	686.4	23.5	102.5	112.5	138.3	6.9	8606	49790	7.7	91
41	8.3	8.6	36.5	43.3	518.4	24.8	88.5	92.7	125.9	6.6	7896	50001	7.7	87.1
42	7.3	7.4	31.4	38.2	324.3	19.9	2.8	90.5	89.2	1.7	6976	49013	7	25.7
43	8.5	8.2	34	40.8	878.4	23.7	88.9	99.6	219.9	5.8	7546	50500	7	79.6
44	7.5	7	27.3	34.1	953.4	20.5	82.2	103.2	206.9	5.6	6936	50983	7	76.7
45	7.8	6.6	22	28.8	353.3	22.6	2.5	91.7	98.8	1.8	7156	50479	7.3	26.8
46	8.3	9.2	31.3	38.1	363.3	27	3.2	97.6	95.9	2.6	8096	50999	7.3	36.3
47	7.8	7.7	22.6	29.4	313.3	22.7	2.7	75.2	92.9	1.6	6666	47827	7.5	24.6
48	8.2	8.1	26	32.8	1036.4	23.1	77.9	95.6	212.6	6.7	7146	50492	7.8	88.4
49	7.6	13.6	24.9	31.7	443.3	24.2	2.9	129.6	89.9	1.7	9806	51381	7.1	26.2
50	7.5	12.5	31.5	38.3	443.3	24	3.2	180.9	92.9	2.3	6046	50359	7.5	33.8
51	7.4	14.6	60.9	67.7	458.3	25.2	3.2	208.2	94.1	2.4	10446	49753	7.2	37.4
52	7.9	14.5	35.2	43	373.3	15.5	6.2	122.4	97.7	2.8	8792	71893	8.1	39.4
53	6.5	8.7	30.7	38.5	392.9	15.9	6	126.3	100	3	8459	81359	8	41
54	6	7.4	19.9	27.7	378.7	17.1	4.3	127.3	104	2.9	8831	79821	8	38.7
55	6.3	9	19	26.8	343.3	17.8	4	102.7	98.3	2.8	8927	81690	8	38.1
56	5	6.9	16.5	24.3	283.3	14.4	3	95.8	67.1	1.5	6239	55297	7.6	22.5
57	6.8	8.7	13.9	21.7	303.3	14.9	3.7	103.8	100	3.8	8450	77098	8	48.8
58	6.3	11.8	21.8	29.6	353.3	20.8	4.6	113.5	99.3	2.8	8149	80628	8	38.7
59	5.8	8.6	25.2	33	343.3	18	2.4	96.7	99.8	1.8	7137	61051	7.7	26.4
60	6.1	6.8	25.8	33.6	429.3	21.6	4.8	113.2	93.8	3.9	5957	83628	8.1	50.1
average	6.9	9.1	37	43.9	438.4	22	30.4	119.8	92.9	3.1	8450	55252	7.5	43.6
*UCC	4.8	17.3	92	28	632	47	17	97	67	0.09	81503	39176		
STD	1	2.2	26.3	26.2	158.1	5.3	46.5	36.6	36.3	1.7	1475	9806	0.3	
CV%	14.6	24.6	71.2	59.7	36.1	24.2	153	30.6	39.1	56.2	17.5	17.7	4.3	
CF	1.44	0.53	0.4	1.57	0.69	0.47	1.79	1.23	1.39	34.1				
Igeo	-0.1	-1.5	-2.1	-0.1	-1.2	-1.7	-1.7	-0.3	-0.2	4.3				
EF	1.1	0.4	0.3	1.2	0.5	0.3	1.4	0.9	1	25.1				
Er	14.4	2.64	0.8	7.84	0.69	2.34	8.94	2.47	1.39	1022				

*UCC = Rudnick and Gao (2003)

Table 3. a. Heavy metals in ppm, and b. Enrichment factor (EF) for the Koy Sanjaq soil, Kurdistan Region, Iraq

a.

Locations	Mn	V	Zn	Cu	Cr	Ni	Co	As	Pb	Cd
1	373.30	82.33	93.22	45.99	39.19	17.16	8.40	5.64	2.40	1.80
2	392.85	115.79	53.73	41.53	34.73	17.56	7.97	5.51	2.46	1.77
3	378.68	116.13	73.48	30.74	23.94	18.76	6.72	5.51	2.50	1.59
4	343.30	100.69	70.64	29.78	22.98	19.46	6.67	6.15	2.48	1.76
5	283.30	83.76	63.61	27.26	20.46	16.07	6.07	5.38	2.23	1.65
6	303.30	97.42	54.18	24.75	17.95	16.60	6.07	5.41	2.35	1.74
7	353.30	115.14	60.26	32.58	25.78	22.53	9.47	6.69	3.07	2.32
8	343.30	92.47	70.52	36.04	29.24	19.67	7.48	6.48	2.69	1.68
9	429.30	111.18	60.07	36.63	29.83	23.26	10.66	6.55	3.12	2.27
10	368.30	92.71	63.18	35.83	29.03	22.16	11.85	6.64	2.76	1.58
11	323.30	89.80	56.23	25.79	18.99	18.46	7.78	6.60	2.69	1.86
12	348.30	110.39	52.45	34.23	27.43	19.99	10.78	6.19	2.84	1.77
13	368.30	74.61	65.18	24.74	17.94	19.46	8.60	6.74	2.60	1.62
14	364.30	98.32	47.65	31.64	24.84	20.52	9.80	6.74	2.83	1.59
15	363.30	116.63	57.55	27.79	20.99	20.89	7.45	7.05	2.89	1.79
16	348.30	162.41	62.82	34.24	27.44	21.85	11.45	6.96	3.18	2.24
17	577.01	72.70	112.10	25.82	19.02	15.43	5.57	5.78	107.49	5.70
18	480.41	163.33	104.20	37.17	30.37	17.66	7.37	5.83	95.49	5.58
19	337.41	81.50	84.10	38.67	31.87	16.60	9.30	5.72	88.49	3.53
20	303.30	80.23	48.98	27.25	20.45	20.63	9.62	6.40	2.60	1.61
21	348.30	89.45	46.44	30.63	23.83	21.16	7.84	7.02	3.16	1.74
22	348.41	80.76	119.90	26.23	19.43	19.46	9.20	6.58	147.49	4.62
23	302.41	90.93	101.50	30.58	23.78	19.78	8.20	6.14	108.49	5.55
24	293.41	75.14	87.24	25.34	18.54	16.66	7.83	6.12	117.49	2.64
25	388.30	126.69	74.20	35.87	29.07	18.36	8.42	6.19	99.99	2.67
26	468.30	140.97	70.00	34.05	27.25	23.06	10.00	6.02	3.38	2.47
27	453.30	139.95	79.82	41.72	34.92	22.32	8.16	6.63	2.90	1.62
28	460.66	137.53	78.00	47.21	40.41	22.22	8.96	6.44	3.13	1.81
29	440.42	153.21	73.30	68.61	61.81	23.81	9.52	6.70	2.94	1.65
30	503.16	162.03	87.90	140.29	133.49	38.33	9.99	7.99	3.37	2.53
31	606.41	174.77	135.90	69.58	62.78	40.56	16.28	8.08	138.49	5.93
32	658.41	197.31	118.90	83.68	76.88	32.46	10.49	8.82	127.49	5.84
33	592.41	164.01	110.00	53.27	46.47	28.46	9.21	8.42	112.49	5.26
34	465.72	151.79	92.07	80.64	73.84	30.96	10.76	8.80	5.48	5.16
35	475.84	161.19	93.20	69.43	62.63	30.38	8.65	8.79	3.52	2.50
36	533.52	188.45	93.19	94.90	88.10	29.64	10.45	8.04	4.08	3.52
37	386.78	232.23	94.70	141.79	134.99	27.30	13.64	6.55	3.00	2.31
38	443.45	154.85	89.66	123.40	116.60	28.36	10.35	7.58	3.01	2.16
39	776.41	128.35	156.10	45.33	38.53	25.50	8.64	8.43	97.49	7.75
40	686.41	112.45	138.30	42.24	35.44	23.49	6.59	8.45	102.49	6.86
41	518.41	92.70	125.90	43.28	36.48	24.76	8.56	8.25	88.49	6.62
42	324.30	90.47	89.22	38.20	31.40	19.86	7.40	7.32	2.77	1.68
43	878.41	99.59	219.90	40.75	33.95	23.66	8.20	8.52	88.89	5.77
44	953.41	103.18	206.90	34.06	27.26	20.46	7.04	7.50	82.19	5.61
45	353.30	91.67	98.83	28.81	22.01	22.64	6.57	7.76	2.54	1.80
46	363.30	97.61	95.88	38.14	31.34	26.99	9.20	8.34	3.25	2.57
47	313.30	75.19	92.92	29.45	22.65	22.75	7.75	7.82	2.71	1.61
48	1036.41	95.61	212.60	32.78	25.98	23.06	8.15	8.23	77.89	6.65
49	443.30	129.62	89.85	31.67	24.87	24.23	13.63	7.57	2.87	1.65
50	443.30	180.92	92.87	38.30	31.50	23.96	12.47	7.52	3.18	2.26
51	458.30	208.15	94.10	67.73	60.93	25.16	14.61	7.37	3.19	2.42
52	373.30	122.38	97.68	42.99	35.19	15.46	14.48	7.85	6.21	2.79
53	392.85	126.32	100.21	38.53	30.73	15.86	8.69	6.51	5.98	3.00
54	378.68	127.29	103.57	27.74	19.94	17.06	7.41	6.01	4.35	2.86
55	343.30	102.70	98.27	26.78	18.98	17.76	8.96	6.27	3.95	2.83
56	283.30	95.83	67.09	24.26	16.46	14.37	6.85	5.03	3.02	1.54
57	303.30	103.81	100.02	21.75	13.95	14.90	8.65	6.81	3.69	3.81
58	353.30	113.51	99.28	29.58	21.78	20.83	11.84	6.28	4.60	2.83
59	343.30	96.73	99.83	33.04	25.24	17.97	8.55	5.84	2.37	1.77
60	429.30	113.24	93.80	33.63	25.83	21.56	6.84	6.09	4.81	3.87

b.

Sample No.	Mn	V	Zn	Cu	Cr	Ni	Co	As	Pb	Cd
1	0.4	0.6	0.9	1.1	0.3	0.2	0.3	0.8	0.0	13.5
2	0.4	0.7	0.5	0.9	0.2	0.2	0.3	0.7	0.1	11.9
3	0.4	0.8	0.7	0.7	0.2	0.3	0.3	0.8	0.1	11.8
4	0.4	0.8	0.8	0.8	0.2	0.3	0.3	0.9	0.1	14.2
5	0.3	0.6	0.7	0.7	0.2	0.2	0.3	0.8	0.1	13.1
6	0.3	0.7	0.5	0.6	0.1	0.2	0.2	0.8	0.1	12.9
7	0.4	0.8	0.6	0.7	0.2	0.3	0.3	0.9	0.1	16.3
8	0.3	0.6	0.6	0.8	0.2	0.3	0.3	0.8	0.1	11.5
9	0.5	0.8	0.6	0.9	0.2	0.3	0.4	0.9	0.1	16.8
10	0.4	0.7	0.6	0.9	0.2	0.3	0.5	1.0	0.1	12.1
11	0.4	0.7	0.6	0.7	0.2	0.3	0.3	1.0	0.1	15.7
12	0.4	0.9	0.6	0.9	0.2	0.3	0.5	1.0	0.1	14.7
13	0.5	0.6	0.8	0.7	0.2	0.3	0.4	1.1	0.1	14.1
14	0.4	0.8	0.5	0.9	0.2	0.3	0.4	1.1	0.1	13.5
15	0.4	0.9	0.7	0.8	0.2	0.3	0.3	1.1	0.1	15.3
16	0.4	1.4	0.8	1.0	0.2	0.4	0.5	1.2	0.2	20.3
17	0.7	0.6	1.3	0.7	0.2	0.3	0.3	0.9	5.0	49.9
18	0.6	1.4	1.3	1.1	0.3	0.3	0.4	1.0	4.6	51.0
19	0.4	0.7	1.0	1.1	0.3	0.3	0.4	0.9	4.1	31.0
20	0.4	0.6	0.6	0.7	0.2	0.3	0.4	1.0	0.1	13.7
21	0.4	0.7	0.5	0.9	0.2	0.4	0.4	1.1	0.1	15.2
22	0.4	0.7	1.4	0.7	0.2	0.3	0.4	1.1	6.8	40.2
23	0.4	0.7	1.2	0.9	0.2	0.3	0.4	1.0	5.0	48.4
24	0.3	0.6	1.0	0.7	0.2	0.3	0.3	1.0	5.2	22.0
25	0.5	1.0	0.8	1.0	0.2	0.3	0.4	1.0	4.4	22.1
26	0.6	1.1	0.8	0.9	0.2	0.4	0.4	1.0	0.2	20.9
27	0.6	1.1	0.9	1.2	0.3	0.4	0.4	1.1	0.1	14.0
28	0.6	1.1	0.9	1.3	0.3	0.4	0.4	1.0	0.1	15.5
29	0.5	1.2	0.8	1.9	0.5	0.4	0.4	1.1	0.1	14.2
30	0.6	1.3	1.0	3.9	1.1	0.6	0.5	1.3	0.2	22.2
31	0.7	1.4	1.5	1.9	0.5	0.7	0.7	1.3	6.2	50.3
32	0.8	1.6	1.4	2.3	0.6	0.5	0.5	1.4	5.7	49.6
33	0.7	1.3	1.3	1.5	0.4	0.5	0.4	1.4	5.1	45.2
34	0.6	1.3	1.1	2.3	0.7	0.5	0.5	1.5	0.3	46.6
35	0.6	1.4	1.1	2.0	0.6	0.5	0.4	1.5	0.2	22.9
36	0.7	1.7	1.2	3.0	0.8	0.6	0.5	1.5	0.2	34.1
37	0.5	1.9	1.1	3.9	1.1	0.5	0.6	1.1	0.1	20.0
38	0.6	1.4	1.1	3.7	1.1	0.5	0.5	1.3	0.2	20.3
39	1.0	1.0	1.8	1.3	0.3	0.4	0.4	1.4	4.4	66.7
40	0.9	0.9	1.6	1.2	0.3	0.4	0.3	1.4	4.7	59.9
41	0.6	0.7	1.5	1.2	0.3	0.4	0.4	1.3	4.1	57.6
42	0.4	0.7	1.1	1.1	0.3	0.3	0.3	1.2	0.1	14.9
43	1.1	0.8	2.5	1.1	0.3	0.4	0.4	1.4	4.1	49.7
44	1.2	0.8	2.4	0.9	0.2	0.3	0.3	1.2	3.7	47.9
45	0.4	0.7	1.1	0.8	0.2	0.4	0.3	1.3	0.1	15.5
46	0.4	0.8	1.1	1.0	0.3	0.4	0.4	1.3	0.1	21.9
47	0.4	0.6	1.1	0.9	0.2	0.4	0.4	1.3	0.1	14.6
48	1.3	0.8	2.5	0.9	0.2	0.4	0.4	1.3	3.6	57.3
49	0.5	1.0	1.0	0.9	0.2	0.4	0.6	1.2	0.1	14.0
50	0.5	1.5	1.1	1.1	0.3	0.4	0.6	1.2	0.1	19.6
51	0.6	1.7	1.1	1.9	0.5	0.4	0.7	1.2	0.1	21.2
52	0.0	0.7	0.8	0.8	0.2	0.2	0.5	0.9	0.2	16.9
53	0.3	0.6	0.7	0.7	0.2	0.2	0.2	0.7	0.2	16.0
54	0.3	0.6	0.8	0.5	0.1	0.2	0.2	0.6	0.1	15.6
55	0.3	0.5	0.7	0.5	0.1	0.2	0.2	0.6	0.1	15.1
56	0.3	0.7	0.7	0.6	0.1	0.2	0.3	0.7	0.1	12.1
57	0.2	0.5	0.8	0.4	0.1	0.2	0.3	0.7	0.1	21.5
58	0.3	0.6	0.7	0.5	0.1	0.2	0.3	0.6	0.1	15.3
59	0.3	0.6	1.0	0.8	0.2	0.2	0.3	0.8	0.1	12.7
60	0.3	0.5	0.7	0.6	0.1	0.2	0.2	0.6	0.1	20.1
Average	0.50	0.91	1.01	1.17	0.30	0.34	0.39	1.06	1.37	25.05

The geo-accumulation index (Igeo) was used to evaluate sediment quality, with the results for all sampling sites illustrated in Fig. 3. Igeo values indicated that the Koy Sanjaq was not contaminated by Pb, Cr, Co, Ni, Mn Ni, V, As and Cu ($Igeo < 0$) in all sites, except some samples for Pb were moderately contaminated (1<Igeo≤2) at site 17, 18, 19, 22, 23, 24, 25, 32, 33, 34, 39, 40,41, 43, 44 and 48. Heavily to extremely contaminated by Cd all sites (4<Igeo>5) (Table 4).

Table 4. Geoaccumulation index (I_{geo}) for the Koy Sanjaq soil, Kurdistan Region, Iraq

Sample no.	Mn	V	Zn	Cu	Cr	Ni	Co	As	Pb	Cd
1	-1.3	-0.8	-0.1	0.1	-1.8	-2.0	-1.6	-0.4	-3.4	3.7
2	-1.3	-0.3	-0.9	0.0	-2.0	-2.0	-1.7	-0.4	-3.4	3.7
3	-1.3	-0.3	-0.5	-0.5	-2.5	-1.9	-1.9	-0.4	-3.4	3.6
4	-1.5	-0.5	-0.5	-0.5	-2.6	-1.9	-2.0	-0.2	-3.4	3.7
5	-1.7	-0.8	-0.7	-0.6	-2.8	-2.1	-2.1	-0.4	-3.5	3.6
6	-1.6	-0.6	-0.9	-0.8	-2.9	-2.1	-2.1	-0.4	-3.4	3.7
7	-1.4	-0.3	-0.7	-0.4	-2.4	-1.6	-1.5	-0.1	-3.1	4.1
8	-1.5	-0.7	-0.5	-0.2	-2.2	-1.8	-1.8	-0.2	-3.2	3.6
9	-1.1	-0.4	-0.7	-0.2	-2.2	-1.6	-1.3	-0.1	-3.0	4.1
10	-1.4	-0.7	-0.7	-0.2	-2.2	-1.7	-1.1	-0.1	-3.2	3.6
11	-1.6	-0.7	-0.8	-0.7	-2.9	-1.9	-1.7	-0.1	-3.2	3.8
12	-1.4	-0.4	-0.9	-0.3	-2.3	-1.8	-1.3	-0.2	-3.2	3.7
13	-1.4	-1.0	-0.6	-0.8	-2.9	-1.9	-1.6	-0.1	-3.3	3.6
14	-1.4	-0.6	-1.1	-0.4	-2.5	-1.8	-1.4	-0.1	-3.2	3.6
15	-1.4	-0.3	-0.8	-0.6	-2.7	-1.8	-1.8	0.0	-3.1	3.7
16	-1.4	0.2	-0.7	-0.3	-2.3	-1.7	-1.2	0.0	-3.0	4.1
17	-0.7	-1.0	0.2	-0.7	-2.9	-2.2	-2.2	-0.3	2.1	5.4
18	-1.0	0.2	0.1	-0.2	-2.2	-2.0	-1.8	-0.3	1.9	5.4
19	-1.5	-0.8	-0.3	-0.1	-2.1	-2.1	-1.5	-0.3	1.8	4.7
20	-1.6	-0.9	-1.0	-0.6	-2.8	-1.8	-1.4	-0.2	-3.3	3.6
21	-1.4	-0.7	-1.1	-0.5	-2.5	-1.7	-1.7	0.0	-3.0	3.7
22	-1.4	-0.8	0.3	-0.7	-2.8	-1.9	-1.5	-0.1	2.5	5.1
23	-1.6	-0.7	0.0	-0.5	-2.5	-1.8	-1.7	-0.2	2.1	5.4
24	-1.7	-1.0	-0.2	-0.7	-2.9	-2.1	-1.7	-0.2	2.2	4.3
25	-1.3	-0.2	-0.4	-0.2	-2.2	-1.9	-1.6	-0.2	2.0	4.3
26	-1.0	0.0	-0.5	-0.3	-2.3	-1.6	-1.4	-0.3	-2.9	4.2
27	-1.1	-0.1	-0.3	0.0	-2.0	-1.7	-1.7	-0.1	-3.1	3.6
28	-1.0	-0.1	-0.4	0.2	-1.8	-1.7	-1.5	-0.2	-3.0	3.7
29	-1.1	0.1	-0.5	0.7	-1.2	-1.6	-1.4	-0.1	-3.1	3.6
30	-0.9	0.2	-0.2	1.7	0.0	-0.9	-1.4	0.2	-2.9	4.2
31	-0.6	0.3	0.4	0.7	-1.1	-0.8	-0.7	0.2	2.4	5.5
32	-0.5	0.4	0.2	1.0	-0.8	-1.1	-1.3	0.3	2.3	5.4
33	-0.7	0.2	0.1	0.3	-1.6	-1.3	-1.5	0.2	2.1	5.3
34	-1.0	0.1	-0.1	0.9	-0.9	-1.2	-1.3	0.3	-2.2	5.3
35	-1.0	0.1	-0.1	0.7	-1.1	-1.2	-1.6	0.3	-2.9	4.2
36	-0.8	0.4	-0.1	1.2	-0.6	-1.3	-1.3	0.2	-2.6	4.7
37	-1.3	0.7	-0.1	1.8	0.0	-1.4	-0.9	-0.1	-3.1	4.1
38	-1.1	0.1	-0.2	1.6	-0.2	-1.3	-1.3	0.1	-3.1	4.0
39	-0.3	-0.2	0.6	0.1	-1.8	-1.5	-1.6	0.2	1.9	5.8
40	-0.5	-0.4	0.5	0.0	-2.0	-1.6	-2.0	0.2	2.0	5.7
41	-0.9	-0.7	0.3	0.0	-1.9	-1.5	-1.6	0.2	1.8	5.6
42	-1.5	-0.7	-0.2	-0.1	-2.1	-1.8	-1.8	0.0	-3.2	3.6
43	-0.1	-0.5	1.1	0.0	-2.0	-1.6	-1.7	0.2	1.8	5.4
44	0.0	-0.5	1.0	-0.3	-2.3	-1.8	-1.9	0.1	1.7	5.4
45	-1.4	-0.7	0.0	-0.5	-2.6	-1.6	-2.0	0.1	-3.3	3.7
46	-1.4	-0.6	-0.1	-0.1	-2.1	-1.4	-1.5	0.2	-3.0	4.2
47	-1.6	-1.0	-0.1	-0.5	-2.6	-1.6	-1.7	0.1	-3.2	3.6
48	0.1	-0.6	1.1	-0.4	-2.4	-1.6	-1.7	0.2	1.6	5.6
49	-1.1	-0.2	-0.2	-0.4	-2.5	-1.5	-0.9	0.1	-3.2	3.6
50	-1.1	0.3	-0.1	-0.1	-2.1	-1.6	-1.1	0.1	-3.0	4.1
51	-1.0	0.5	-0.1	0.7	-1.2	-1.5	-0.8	0.0	-3.0	4.2
52	-1.3	-0.2	0.0	0.0	-2.0	-2.2	-0.8	0.1	-2.0	4.4
53	-1.3	-0.2	0.0	-0.1	-2.2	-2.2	-1.6	-0.1	-2.1	4.5
54	-1.3	-0.2	0.0	-0.6	-2.8	-2.0	-1.8	-0.3	-2.6	4.4
55	-1.5	-0.5	0.0	-0.6	-2.9	-2.0	-1.5	-0.2	-2.7	4.4
56	-1.7	-0.6	-0.6	-0.8	-3.1	-2.3	-1.9	-0.5	-3.1	3.5
57	-1.6	-0.5	0.0	-0.9	-3.3	-2.2	-1.6	-0.1	-2.8	4.8
58	-1.4	-0.4	0.0	-0.5	-2.7	-1.8	-1.1	-0.2	-2.5	4.4
59	-1.5	-0.6	0.0	-0.3	-2.5	-2.0	-1.6	-0.3	-3.4	3.7
60	-1.1	-0.4	-0.1	-0.3	-2.4	-1.7	-1.9	-0.2	-2.4	4.8
Average	-1.2	-0.3	-0.2	-0.1	-2.1	-1.7	-1.5	-0.1	-1.7	4.3

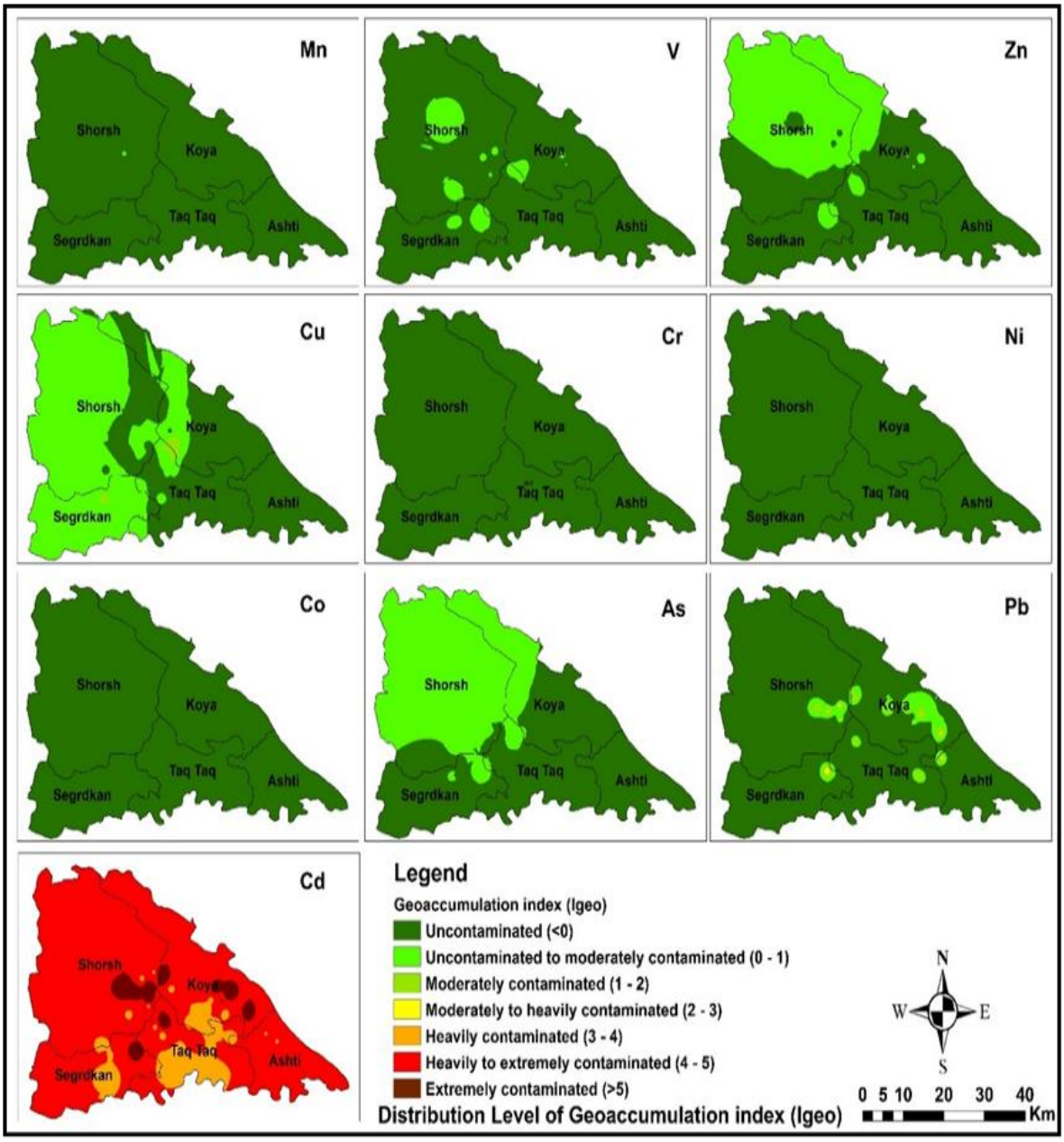


Fig. 3. Distribution levels of Geoaccumulation Index for the soil of Koy Sanjaq

The average contamination factor (CF) values for Cd, Pb, Cu, As, Zn, and V were 34.07, 1.79, 1.57, 1.44, 1.39, and 1.23, respectively, indicating moderate contamination. CF values for Mn, Cr, Ni, and Co were less than 1.0, indicating low contamination. Among all heavy metals, Ni had the lowest value at site 5 (0.13), and Cd had the highest value at site 39 (86.06). According to average values of CF, all metals were ordered as follows: $ACd > Pb >$ Cu > As > $Zn >$ V > Mn > Co > Ni > Cr (Table 5). The highest PLI at site 31 (436.48) and 32 (351.57) indicated extremely polluted conditions, while the lowest value was at sites 5, 6, and 56 (0.00). The C_{deg} was nearly at all sites more than 24, indicating very high contamination, except for site 56 (22.50). The highest value for mC_{deg} at site 39 (5.34) indicated High contamination, the lowest at site 25 (1.23) indicated very low contamination (Table 5).

Potential ecological risk (Er) of individual metals, as well as the overall risk index (RI) for combined metals, was measured. The results are demonstrated in Fig. 5. All sites for all metals Er <40, this means all were Low ecological risk, except Cd, for all sites Er ≥320, were very high ecological risk (Table 6).

Table 5. Contamination factor, PLI, C_{deg}, and mC_{deg} for the Koy Sanjaq soil, Kurdistan Region, Iraq

Sample no.	Mn	V	Zn	Cu	Cr	Ni	Co	As	Pb	Cd	PLI	C_{deg}	mC_{deg}
1	0.59	0.85	1.39	1.64	0.43	0.37	0.49	1.18	0.14	19.95	0.03	27.01	1.42
2	0.62	1.19	0.80	1.48	0.38	0.37	0.46	1.15	0.14	19.67	0.02	26.27	1.38
3	0.60	1.20	1.10	1.10	0.26	0.40	0.39	1.15	0.15	17.67	0.01	24.00	1.26
4	0.54	1.04	1.05	1.06	0.25	0.41	0.39	1.28	0.15	19.52	0.01	25.70	1.35
5	0.45	0.86	0.95	0.97	0.22	0.34	0.35	1.12	0.13	18.29	0.00	23.69	1.25
6	0.48	1.00	0.81	0.88	0.20	0.35	0.35	1.13	0.14	19.35	0.00	24.69	1.30
7	0.56	1.19	0.90	1.16	0.28	0.48	0.55	1.39	0.18	25.73	0.03	32.42	1.71
8	0.54	0.95	1.05	1.29	0.32	0.42	0.43	1.35	0.16	18.72	0.02	25.23	1.33
9	0.68	1.15	0.90	1.31	0.32	0.49	0.62	1.36	0.18	25.20	0.06	32.22	1.70
10	0.58	0.96	0.94	1.28	0.32	0.47	0.68	1.38	0.16	17.57	0.03	24.35	1.28
11	0.51	0.93	0.84	0.92	0.21	0.39	0.45	1.38	0.16	20.68	0.01	26.46	1.39
12	0.55	1.14	0.78	1.22	0.30	0.43	0.62	1.29	0.17	19.68	0.02	26.17	1.38
13	0.58	0.77	0.97	0.88	0.20	0.41	0.50	1.40	0.15	18.02	0.01	23.89	1.26
14	0.58	1.01	0.71	1.13	0.27	0.44	0.57	1.40	0.17	17.64	0.01	23.92	1.26
15	0.57	1.20	0.86	0.99	0.23	0.44	0.43	1.47	0.17	19.87	0.01	26.24	1.38
16	0.55	1.67	0.94	1.22	0.30	0.46	0.66	1.45	0.19	24.94	0.07	32.39	1.70
17	0.91	0.75	1.67	0.92	0.21	0.33	0.32	1.20	6.32	63.30	1.11	75.95	4.00
18	0.76	1.68	1.56	1.33	0.33	0.38	0.43	1.21	5.62	62.04	5.91	75.33	3.96
19	0.53	0.84	1.26	1.38	0.35	0.35	0.54	1.19	5.21	39.27	1.25	50.91	2.68
20	0.48	0.83	0.73	0.97	0.22	0.44	0.56	1.33	0.15	17.89	0.01	23.61	1.24
21	0.55	0.92	0.69	1.09	0.26	0.45	0.45	1.46	0.19	19.34	0.01	25.41	1.34
22	0.55	0.83	1.79	0.94	0.21	0.41	0.53	1.37	8.68	51.35	2.18	66.66	3.51
23	0.48	0.94	1.51	1.09	0.26	0.42	0.47	1.28	6.38	61.64	1.92	74.48	3.92
24	0.46	0.77	1.30	0.90	0.20	0.35	0.45	1.28	6.91	29.38	0.35	42.02	2.21
25	0.61	1.31	1.11	1.28	0.32	0.39	0.49	1.29	5.88	29.69	1.54	42.37	2.23
26	0.74	1.45	1.04	1.22	0.30	0.49	0.58	1.25	0.20	27.44	0.08	34.71	1.83
27	0.72	1.44	1.19	1.49	0.38	0.47	0.47	1.38	0.17	18.02	0.07	25.74	1.35
28	0.73	1.42	1.16	1.69	0.44	0.47	0.52	1.34	0.18	20.10	0.11	28.06	1.48
29	0.70	1.58	1.09	2.45	0.67	0.51	0.55	1.40	0.17	18.28	0.24	27.40	1.44
30	0.80	1.67	1.31	5.01	1.45	0.82	0.58	1.66	0.20	28.16	5.56	41.66	2.19
31	0.96	1.80	2.03	2.48	0.68	0.86	0.94	1.68	8.15	65.91	436.48	85.50	4.50
32	1.04	2.03	1.77	2.99	0.84	0.69	0.61	1.84	7.50	64.88	351.57	84.19	4.43
33	0.94	1.69	1.64	1.90	0.51	0.61	0.53	1.75	6.62	58.46	54.69	74.65	3.93
34	0.74	1.56	1.37	2.88	0.80	0.66	0.62	1.83	0.32	57.37	5.09	68.17	3.59
35	0.75	1.66	1.39	2.48	0.68	0.65	0.50	1.83	0.21	27.78	1.00	37.93	2.00
36	0.84	1.94	1.39	3.39	0.96	0.63	0.60	1.68	0.24	39.06	4.43	50.73	2.67
37	0.61	2.39	1.41	5.06	1.47	0.58	0.79	1.36	0.18	25.68	4.36	39.54	2.08
38	0.70	1.60	1.34	4.41	1.27	0.60	0.60	1.58	0.18	24.01	2.03	36.27	1.91
39	1.23	1.32	2.33	1.62	0.42	0.54	0.50	1.76	5.73	86.06	60.33	101.51	5.34
40	1.09	1.16	2.06	1.51	0.39	0.50	0.38	1.76	6.03	76.17	23.22	91.04	4.79
41	0.82	0.96	1.88	1.55	0.40	0.53	0.49	1.72	5.21	73.53	15.48	87.07	4.58
42	0.51	0.93	1.33	1.36	0.34	0.42	0.43	1.53	0.16	18.68	0.02	25.70	1.35
43	1.39	1.03	3.28	1.46	0.37	0.50	0.47	1.78	5.23	64.06	35.70	79.57	4.19
44	1.51	1.06	3.09	1.22	0.30	0.44	0.41	1.56	4.83	62.33	14.90	76.74	4.04
45	0.56	0.95	1.48	1.03	0.24	0.48	0.38	1.62	0.15	19.96	0.02	26.84	1.41
46	0.57	1.01	1.43	1.36	0.34	0.57	0.53	1.74	0.19	28.50	0.11	36.25	1.91
47	0.50	0.78	1.39	1.05	0.25	0.48	0.45	1.63	0.16	17.88	0.01	24.55	1.29
48	1.64	0.99	3.17	1.17	0.28	0.49	0.47	1.71	4.58	73.90	22.76	88.41	4.65
49	0.70	1.34	1.34	1.13	0.27	0.52	0.79	1.58	0.17	18.39	0.08	26.22	1.38
50	0.70	1.87	1.39	1.37	0.34	0.51	0.72	1.57	0.19	25.14	0.23	33.78	1.78
51	0.73	2.15	1.40	2.42	0.66	0.54	0.84	1.54	0.19	26.91	1.23	37.37	1.97
52	0.59	1.26	1.46	1.54	0.38	0.33	0.84	1.64	0.37	30.99	0.33	39.39	2.07
53	0.62	1.30	1.50	1.38	0.33	0.34	0.50	1.36	0.35	33.29	0.15	40.97	2.16
54	0.60	1.31	1.55	0.99	0.22	0.36	0.43	1.25	0.26	31.74	0.04	38.71	2.04
55	0.54	1.06	1.47	0.96	0.21	0.38	0.52	1.31	0.23	31.48	0.03	38.14	2.01
56	0.45	0.99	1.00	0.87	0.18	0.31	0.40	1.05	0.18	17.09	0.00	22.50	1.18
57	0.48	1.07	1.49	0.78	0.15	0.32	0.50	1.42	0.22	42.35	0.02	48.78	2.57
58	0.56	1.17	1.48	1.06	0.24	0.44	0.68	1.31	0.27	31.49	0.08	38.71	2.04
59	0.54	1.00	1.49	1.18	0.27	0.38	0.49	1.22	0.14	19.72	0.02	26.44	1.39
60	0.68	1.17	1.40	1.20	0.28	0.46	0.40	1.27	0.28	42.98	0.10	50.12	2.64
Average	0.69	1.23	1.39	1.57	0.40	0.47	0.53	1.44	1.79	34.07	17.59	43.58	2.29
UCC	632.0	97	67	28	92	47	17.3	4.8	17	0.09			

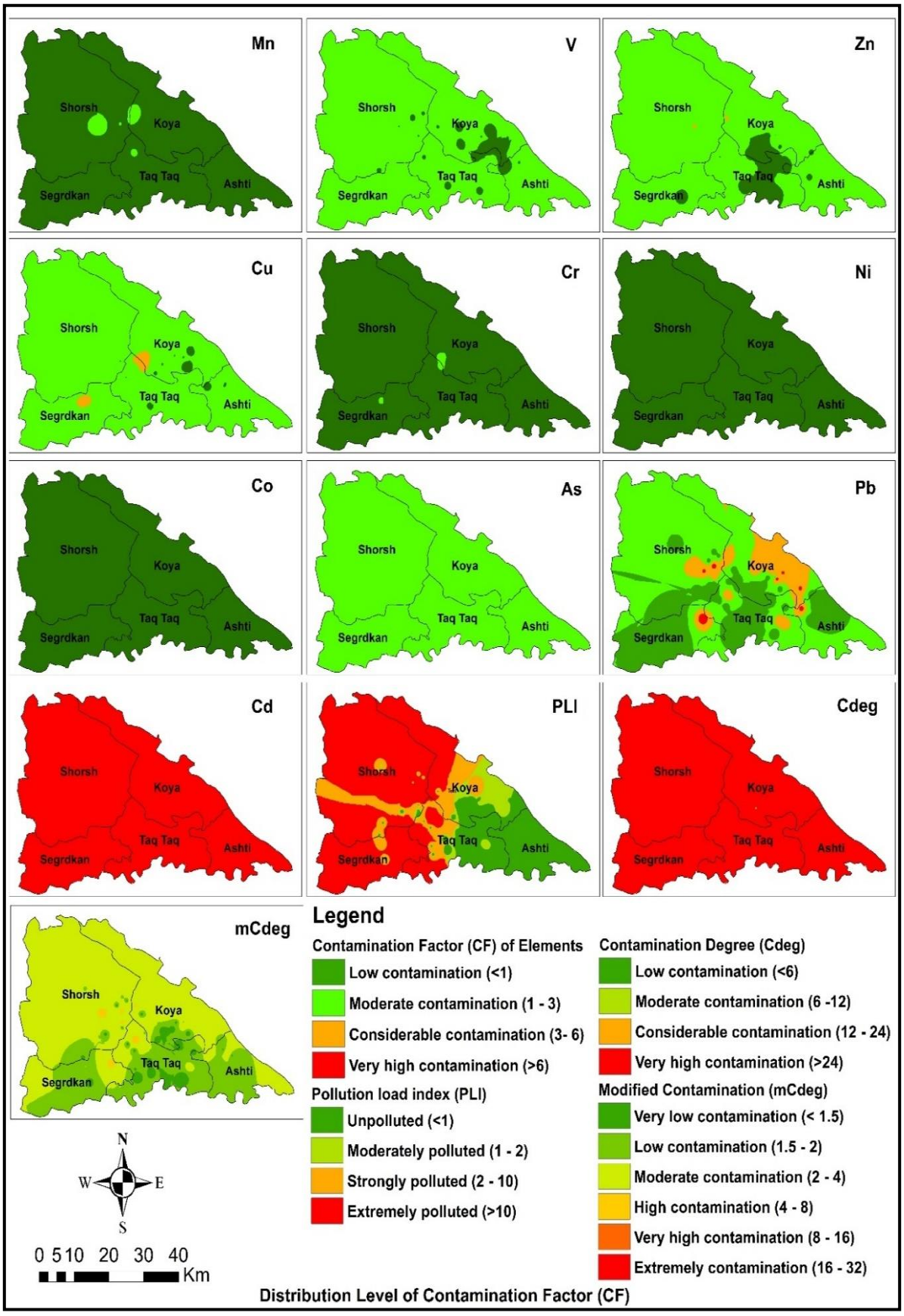


Fig. 4. Distribution levels of Contamination Factor for the soil of Koy Sanjaq

Table 6. Potential Ecological Risk (Pr) and Overall Risk Index (RI) of Soils in Koy Sanjaq, Kurdistan Region, Iraq

Sample no.	Mn	V	Zn	Cu	Cr	Ni	Co	As	Pb	Cd	RI
1	0.59	1.70	1.39	8.21	0.85	1.83	2.43	11.75	0.70	598.38	627.84
2	0.62	2.39	0.80	7.42	0.76	1.87	2.30	11.48	0.72	590.00	618.36
3	0.60	2.39	1.10	5.49	0.52	2.00	1.94	11.48	0.74	529.96	556.21
4	0.54	2.08	1.05	5.32	0.50	2.07	1.93	12.81	0.73	585.65	612.69
5	0.45	1.73	0.95	4.87	0.44	1.71	1.76	11.21	0.66	548.74	572.51
6	0.48	2.01	0.81	4.42	0.39	1.77	1.75	11.27	0.69	580.55	604.14
7	0.56	2.37	0.90	5.82	0.56	2.40	2.74	13.94	0.90	771.77	801.95
8	0.54	1.91	1.05	6.44	0.64	2.09	2.16	13.50	0.79	561.52	590.65
9	0.68	2.29	0.90	6.54	0.65	2.47	3.08	13.65	0.92	756.15	787.32
10	0.58	1.91	0.94	6.40	0.63	2.36	3.42	13.83	0.81	527.20	558.10
11	0.51	1.85	0.84	4.61	0.41	1.96	2.25	13.75	0.79	620.31	647.28
12	0.55	2.28	0.78	6.11	0.60	2.13	3.12	12.90	0.84	590.27	619.56
13	0.58	1.54	0.97	4.42	0.39	2.07	2.49	14.04	0.76	540.45	567.72
14	0.58	2.03	0.71	5.65	0.54	2.18	2.83	14.04	0.83	529.32	558.71
15	0.57	2.40	0.86	4.96	0.46	2.22	2.15	14.69	0.85	596.14	625.31
16	0.55	3.35	0.94	6.11	0.60	2.32	3.31	14.50	0.94	748.20	780.82
17	0.91	1.50	1.67	4.61	0.41	1.64	1.61	12.04	31.61	1899.12	1955.13
18	0.76	3.37	1.56	6.64	0.66	1.88	2.13	12.15	28.09	1861.22	1918.44
19	0.53	1.68	1.26	6.90	0.69	1.77	2.69	11.92	26.03	1178.01	1231.48
20	0.48	1.65	0.73	4.87	0.44	2.19	2.78	13.33	0.76	536.75	564.00
21	0.55	1.84	0.69	5.47	0.52	2.25	2.27	14.63	0.93	580.16	609.30
22	0.55	1.67	1.79	4.68	0.42	2.07	2.66	13.71	43.38	1540.50	1611.43
23	0.48	1.87	1.51	5.46	0.52	2.10	2.37	12.79	31.91	1849.32	1908.33
24	0.46	1.55	1.30	4.52	0.40	1.77	2.26	12.75	34.56	881.38	940.96
25	0.61	2.61	1.11	6.41	0.63	1.95	2.43	12.90	29.41	890.75	948.81
26	0.74	2.91	1.04	6.08	0.59	2.45	2.89	12.54	0.99	823.07	853.32
27	0.72	2.89	1.19	7.45	0.76	2.37	2.36	13.81	0.85	540.48	572.88
28	0.73	2.84	1.16	8.43	0.88	2.36	2.59	13.42	0.92	603.07	636.40
29	0.70	3.16	1.09	12.25	1.34	2.53	2.75	13.96	0.87	548.42	587.08
30	0.80	3.34	1.31	25.05	2.90	4.08	2.89	16.65	0.99	844.91	902.91
31	0.96	3.60	2.03	12.42	1.36	4.31	4.71	16.83	40.73	1977.35	2064.31
32	1.04	4.07	1.77	14.94	1.67	3.45	3.03	18.38	37.50	1946.44	2032.30
33	0.94	3.38	1.64	9.51	1.01	3.03	2.66	17.54	33.09	1753.85	1826.65
34	0.74	3.13	1.37	14.40	1.61	3.29	3.11	18.33	1.61	1721.15	1768.74
35	0.75	3.32	1.39	12.40	1.36	3.23	2.50	18.31	1.04	833.26	877.56
36	0.84	3.89	1.39	16.95	1.92	3.15	3.02	16.75	1.20	1171.72	1220.82
37	0.61	4.79	1.41	25.32	2.93	2.90	3.94	13.65	0.88	770.46	826.91
38	0.70	3.19	1.34	22.04	2.53	3.02	2.99	15.79	0.89	720.16	772.65
39	1.23	2.65	2.33	8.10	0.84	2.71	2.50	17.56	28.67	2581.82	2648.40
40	1.09	2.32	2.06	7.54	0.77	2.50	1.90	17.60	30.14	2285.06	2350.99
41	0.82	1.91	1.88	7.73	0.79	2.63	2.47	17.19	26.03	2205.80	2267.26
42	0.51	1.87	1.33	6.82	0.68	2.11	2.14	15.25	0.81	560.32	591.85
43	1.39	2.05	3.28	7.28	0.74	2.52	2.37	17.75	26.14	1921.87	1985.39
44	1.51	2.13	3.09	6.08	0.59	2.18	2.04	15.63	24.17	1869.76	1927.16
45	0.56	1.89	1.48	5.15	0.48	2.41	1.90	16.17	0.75	598.90	629.67
46	0.57	2.01	1.43	6.81	0.68	2.87	2.66	17.38	0.96	855.11	890.48
47	0.50	1.55	1.39	5.26	0.49	2.42	2.24	16.29	0.80	536.28	567.21
48	1.64	1.97	3.17	5.85	0.56	2.45	2.35	17.15	22.91	2217.00	2275.07
49	0.70	2.67	1.34	5.66	0.54	2.58	3.94	15.77	0.84	551.61	585.65
50	0.70	3.73	1.39	6.84	0.68	2.55	3.60	15.67	0.94	754.09	790.19
51	0.73	4.29	1.40	12.09	1.32	2.68	4.22	15.35	0.94	807.19	850.23
52	0.59	2.52	1.46	7.68	0.76	1.64	4.19	16.35	1.83	929.77	966.79
53	0.62	2.60	1.50	6.88	0.67	1.69	2.51	13.56	1.76	998.77	1030.56
54	0.60	2.62	1.55	4.95	0.43	1.81	2.14	12.52	1.28	952.33	980.24
55	0.54	2.12	1.47	4.78	0.41	1.89	2.59	13.06	1.16	944.28	972.31
56	0.45	1.98	1.00	4.33	0.36	1.53	1.98	10.48	0.89	512.74	535.74
57	0.48	2.14	1.49	3.88	0.30	1.58	2.50	14.19	1.08	1270.55	1298.21
58	0.56	2.34	1.48	5.28	0.47	2.22	3.42	13.08	1.35	944.84	975.05
59	0.54	1.99	1.49	5.90	0.55	1.91	2.47	12.17	0.70	591.52	619.25
60	0.68	2.33	1.40	6.01	0.56	2.29	1.98	12.69	1.41	1289.48	1318.84
Average	0.69	2.47	1.39	7.84	0.80	2.34	2.64	14.40	8.94	1022.09	1063.60

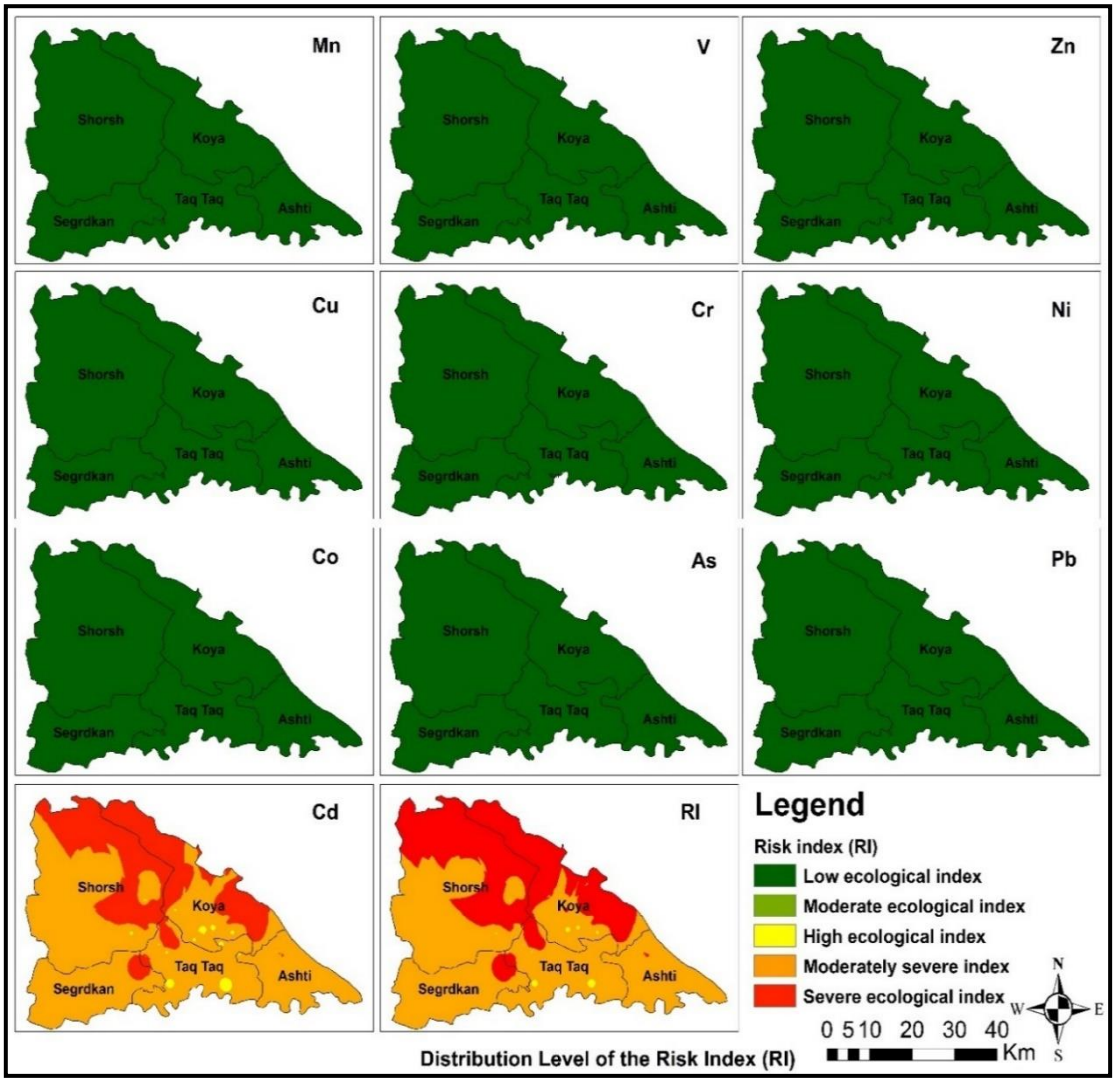


Fig. 5. Distribution levels of the Risk Index for the soil of Koy Sanjaq District

The correlation can recognize the origin and movement of metals among heavy metals. Relationships between heavy metals were determined by pearson correlation analysis. The results show that Ca is significantly and positively correlated with Mg (r = 0.595), V (r= 0.862), Cu (r= 0.726), Cr (r= 0.727), Ni (r= 0.831), Co (r= 0.567), and As (r= 0.612) at the level of p <0.01 (Table 7). Also V is significantly and positively correlated with Cu (r = 0.723), Cr(r =0.722), Th (r = 0.708), Ni (r= 0.624). Many metal pairs had positive correlations (P < 0.01): Pb-Cd (0.792), Ni-Th (0.611), Mg-Th (0.804), Mg-Ni (0.592), Mg- Co (0.538), K-As (0.535), Mn-Zn (0.508), and Mn-As (0.563). Fe showed significant positive correlations with Na (r = 0.391) and pH (r = 0.445). The results of the principal component analysis (PCA) for heavy metal concentrations are presented in Table 8 and Fig. 6. PCA was performed to confirm the sources of metals, with sampling adequacy verified by the Kaiser–Meyer–Olkin (KMO) measure and statistical significance assessed using Bartlett's test. In the rotated component space, five principal components with eigenvalues greater than one accounted for 79.08% of the total variance. PC1 (eigenvalue = 5.96) explained 35.04% of the variance and was dominated by Cr (0.942), Cu (0.941), Ni (0.837), and Ca (0.875). PC2 explained 19.51%, featuring high loadings of Cd (0.942), Zn (0.889), Mn (0.835), and Pb (0.810). PC3 contributed 10.30%, driven by significant loadings of pH (0.814) and Fe (0.796) (Table 6). PC4 accounted for 7.81% of the variance, with K loading at 0.745, and PC5 contributed 6.42%, with Al loading at 0.893.

Table 7. Correlation matrix for the major and trace elements and pH values for the Koy Sanjaq soil, Kurdistan Region, Iraq

"Bold designates a significant correlation at $p < 0.05$, and underline shows a significant correlation at $p < 0.01$"

	Ca	**Al**	**Fe**	**Mg**	**Na**	**K**	**Mn**	**V**	**Zn**	**Cu**	**Cr**	**Ni**	**Co**	**As**	**Pb**	**Th**	**Cd**	**pH**
Ca	1																	
Al	.177	1																
Fe	-.296	-.177	1															
Mg	.595	.201	-.253	1														
Na	.288	.159	.391	.176	1													
K	.319	.034	-.199	.254	.246	1												
Mn	.330	-.069	-.248	.176	-.093	.415	1											
V	.862	.196	-.163	.417	.389	.275	.224	1										
Zn	.167	-.141	-.063	.006	-.031	.444	.850	.057	1									
Cu	.726	.071	-.286	.402	.123	.117	.205	.723	.089	1								
Cr	.727	.073	-.297	.404	.117	.118	.207	.722	.088	1.000	1							
Ni	.831	.172	-.404	.592	.092	.272	.397	.624	.227	.721	.724	1						
Co	.567	.330	-.043	.538	.425	.147	.016	.592	-.020	.436	.435	.498	1					
As	.612	.164	-.345	.343	.192	.535	.563	.362	.506	.410	.413	.721	.329	1				
Pb	.014	.107	-.278	.036	-.268	.253	.496	-.020	.582	-.030	-.027	.153	-.055	.235	1			
Th	.809	.172	-.202	.804	.291	.223	.191	.708	.001	.562	.563	.611	.508	.368	-.103	1		
Cd	.216	.069	-.118	.076	-.063	.317	.732	.114	.777	.087	.087	.283	-.027	.479	.792	.026	1	
pH	-.040	.001	.445	-.066	.238	-.229	-.094	.100	-.082	.022	.015	-.047	.058	-.099	-.178	-.028	-.011	1

Table 8. Principal components analysis: rotated matrix, variance explained with eigenvalues, five components extracted in the soil of Koy Sanjaq

Rotated Component Matrix[a]					
variables	**Component**				
	1	2	3	4	5
Ca	0.875	0.128	-0.053	0.264	0.128
Al	0.082	0.01	-0.037	-0.007	0.893
Fe	-0.305	-0.149	0.796	0.138	-0.146
Mg	0.542	-0.004	-0.18	0.281	0.343
Na	0.184	-0.165	0.538	0.656	0.179
K	0.123	0.359	-0.242	0.745	-0.041
As	0.49	0.495	-0.18	0.42	0.075
Co	0.563	-0.097	0.15	0.316	0.476
Cr	0.942	0.03	-0.034	-0.1	-0.079
Cu	0.941	0.029	-0.023	-0.099	-0.081
Mn	0.228	0.835	-0.099	0.161	-0.163
Ni	0.837	0.249	-0.179	0.111	0.136
Pb	-0.089	0.81	-0.198	-0.158	0.234
V	0.829	0.028	0.146	0.203	0.139
Zn	0.05	0.889	0.019	0.216	-0.209
Cd	0.067	0.942	0.042	-0.001	0.099
pH	0.081	0.001	0.814	-0.22	0.044
Eigenvalues	5.956	3.317	1.751	1.328	1.091
% Total Variance	35.036	19.509	10.302	7.814	6.417
Cumulative % variance	35.036	54.545	64.847	72.661	79.078

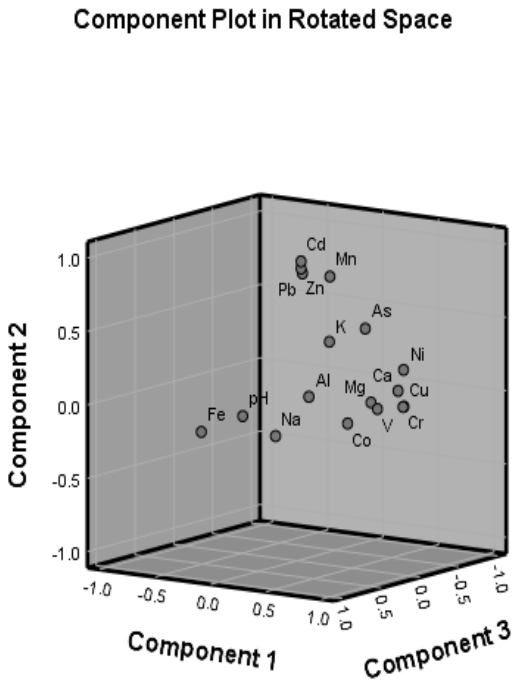


Fig. 6. Rotated component plot of heavy metals in soils from Koy Sanjaq

5. Discussion

According to Jiang et al. (2014), most soil samples were mildly alkaline ($7.5 \leq pH \leq 8.5$), likely due to elevated contents of carbonate, ash, and industrial slag, as well as alkaline atmospheric depositions (Al Obaidy et al., 2013). The study area's soils are also predominantly fine-textured, rich in silts and clays. High iron (Fe) concentrations were observed in samples collected from depths 50–55 cm in the SE Shorsh area and 57–60 cm in the NW Ashti area (Fig. 1), correlating with the zones of elevated pH. In contrast, aluminium (Al) peaked in samples 5, 9–11, 15, 20, 21, 23, and 51 (Table 1). When compared to upper continental crust (UCC) averages, As, Cu, Pb, V, Zn, and Cd were enriched, whereas Co, Cr, Ni, and Mn were depleted. The enrichment of As, Cu, Pb, V, Zn, and Cd relative to UCC values does indicate contamination at those sites, specifically in TaqTaq, Shorsh, Segrdkan, and Koya. Elevated concentrations compared to the natural crustal background suggest that anthropogenic sources (like industrial activity, traffic emissions, or localized pollution) have influenced their presence in the soil (Table 2). Coefficients of variation (CV) for As, Co, Mn, Ni, V, and Zn were low (< 50%), indicating predominantly geogenic origins with limited anthropogenic influence. In comparison, higher CV values for Pb, Cr, Cu, and Cd suggest a dual influence from both natural processes and human activities.

Barbieri (2016) reported that the enrichment factor (EF) of heavy metals serves as a measure to identify the presence and extent of anthropogenic pollution in soils and sediments. The results of EF of the Mn, V, Cr, Ni, and Co metals are within the range of minimal enrichment ($EF \leq 2$, Tables 1 and 3), however, the metals Zn, Cu, and Pb in a few samples are within the range of moderate enrichment ($2 < EF \leq 5$), while about 50% of the samples, the Cd metal is within the range of very high enrichment ($20 < EF \leq 40$, Table 3 and Fig. 2). Based on the results presented in Table 3, the average enrichment factor (EF) of the heavy metals follows the order: Cd > Pb > Cu > As > Zn > V > Mn > Co > Ni > Cr. The classifications of CF index for heavy metal contaminations in the soil of the Koy Sanjaq are shown in Table 4 and Fig. 3. The contamination factor (CF) results indicate that Mn, Cr, Ni, and Co have average values within the low contamination range ($CF < 1$, Tables 1 and 4), while V, Zn, As, Cu, and Pb fall within the moderate contamination range ($1 \leq CF < 3$). In contrast, Cd shows very high contamination

across all samples (CF > 6). The average CF values follow the order: Cd > Pb > Cu > As > Zn > V > Mn > Co > Ni > Cr. "The modified contamination degree (mC_{deg}) of heavy metals in the study area ranged from 1.18 to 5.34, with an average of 2.29, indicating moderate contamination. Most samples (41%) fall into the very low contamination category ($mC_{deg} < 1.5$), 11% which are classified as low contamination ($1.5 < mC_{deg} \leq 2$), and 34% belong to the moderate contamination level ($2 < mCdeg \leq 4$), as illustrated in Fig. 3. The values of C_{deg} for heavy metals in the study area ranged from 22.50 to 101.51 (average 43.58), and it is about 8% of the samples belong to considerable ($12<C_{deg}\leq24$) degree of contamination, and 92% belong to very high contamination (Tables 1 and 4, Fig. 3). Accordingly, in terms of mC_{deg} the study soils are ranged from very low contamination to moderate contamination levels, while in terms of C_{deg} are of considerable degree of contamination.

The geo-accumulation index (I_{geo}) states that the majority of the soil samples are in class 0 (Igeo<0) which means uncontaminated levels for Mn, V, Zn, Cu, Cr, Ni, Co, As, and Pb metals; except for some samples of Pb moderately contaminated and all the samples of Cd are within the heavily contaminated to extremely contaminated classes (Tables 1 and 5, Fig. 4).

Heavy metal pollution levels were evaluated using the Pollution Load Index (PLI). PLI values were calculated following the modified formula of Angulo (1996) and Jorfi et al. (2017). For the ten heavy metals analyzed, 65% of the samples had PLI values ranging from 0.00 to 1.00, corresponding to unpolluted conditions ($0 < PLI \leq 1$). However, about 8% of the studied samples, ranging from 1.11 to 1.92, belong to the moderately polluted level ($1<PLI\leq2$), and about 27% of the samples are in the range of strongly to extremely polluted levels ($2<PLI<10$ to $PLI>10$). These samples are situated in the western parts of the study area (Tables 1 and 4, Fig. 3).

The potential ecological risk (Er) assessment indicated that approximately 97% of the samples have Er values below 40 for all analyzed heavy metals (As, Cr, Co, Cu, Pb, Mn, Ni, V, and Zn), suggesting a low ecological risk (Tables 1 and 2). However, Cd metal is within a very high ecological risk in the study soil ($Er \geq 320$) as shown in Tables 1 and 2. Generally, the results exhibit that the arithmetic mean of Er-values of heavy metals is descending in the order of Cd >As> Pb > Cu > Co > V > Ni > Zn > Cr > Mn.

Furthermore, the potential ecological risk index (RI) for different locations in Koy Sanjaq ranged from 535.74 (high ecological risk) to 2648.40 (severe ecological risk), with an average value of 1063.60, corresponding to a moderately severe risk level. The northern parts of the study area are of higher risk (Table 6 and Fig. 5).

The geographical distribution of several indices (PLI, C_{deg}, mC_{deg}, and RI) used to measure the degree of contamination of the heavy metals (As, Cr, Co, Cu, Mn, Ni, Pb, V, Zn, and Cd) of the soil of Koy Sanjaq shows the elevated level of contamination in the northwestern areas of the district (Figs. 3 and 5).

Elevated arsenic (As) levels may result from various human activities, including the application of arsenic-containing fertilizers and pesticides in agriculture, wood treatment with chromated copper arsenate, and leather tanning processes that utilize arsenic compounds such as arsenic sulfide (Bhuiyan et al., 2011; Fu et al., 2014). Copper and zinc are essential micronutrients for aquatic organisms, supporting vital metabolic functions. However, elevated concentrations of these metals can be toxic, leading to adverse effects such as impaired growth, behavioral changes, and organ damage in aquatic species (Bastami et al., 2014). High copper (Cu) concentrations in soils are also linked to the combustion of wood, coal, and plastic, which releases Cu into the air that subsequently deposits onto the soil. Similarly, the burning of vehicle oils containing Cu and Pb contributes further to soil contamination (Baird, 2001). High cadmium (Cd) levels are primarily associated with human activities such as industrial operations, agricultural practices, and waste disposal (Hazarika et al., 2017). The highest concentrations of these elements were observed at the TaqTaq, Shorsh, Segrdkan, and Koya sites, which are characterized by car trading areas and their location along highways with heavy traffic, particularly

trucks and tankers. These conditions contribute to increased soil contamination due to combustion-related emissions (Teng et al., 2011), as a high percentage of V remains in oil derivatives even after the refining process and is released when the fuel is burned (Hope, 1997). Whereas these sites TaqTaq, Shorsh, and Segrdkan represent a farm, and the increased V content in these sites may be owing to the use of phosphate fertilizers, which are usually rich in V of approximately (90-180) mg/kg (Akoumianaki-Ioannidou et al., 2016), and consuming V-contaminated water for irrigation may increase its concentration in the soil (Naser et al., 2018).

Pearson's correlation coefficient and PCA revealed probable links between various environmental circumstances and can provide information on the heavy metals in sediments and soils (Saha et al., 2022). Also, factor analysis with principal component extraction and Kaiser normalized varimax rotation was performed on the soil analyses (Fig. 6). Principal factors with eigenvalues greater than 1.0 were retained for further analysis (Han et al., 2012). To investigate the properties of the soils, multivariate statistical analyses were conducted using SPSS software (version 26), with a significance threshold set at $p < 0.01$ for this study. Sadeghi (2022) stated that correlation coefficients are statistical measures used to evaluate the strength of the relationship between two variables.

Table 7 displays the heavy metal correlation coefficient (r) results for the soils of Erbil Governorate. The results show that Ca is significantly and positively correlated with Mg, V, Cu, Cr, Ni, Co, and As at the level of $p < 0.01$, which indicates that they are very likely to associate with the carbonate phase. Significant correlations between heavy metals do not necessarily imply a common source, as their origins and transport pathways may differ (Ma et al., 2016; Jørgensen et al., 2005).

The first principal component (PC1), which contained Ca (0.875), Mg (0.542), Co (0.563), Cr (0.942), Cu (0.941), Ni (0.837), and V (0.829) as shown in Table 8, represented the most significant variance (29.42%). This factor may reflect the inherited component of the soil, which consists of detrital and carbonate materials; the mentioned heavy metals (Co, Cr, Cu, Ni, and V) are associated with the detrital component. While Mn (0.835), Pb (0.810), Zn (0.889), and Cd (0.942) comprised the second component (PC2), which accounted for 20.86% of the overall variance (Table 8). This factor represents the pollution metals (Pb, Zn, and Cd) that the fertilizers used in agriculture are enriched in these elements. PC3 accounted for 10.84% of the variance and has a significant positive loading for Fe (0.796), Na (0.538), and pH (0.814), representing 10.84% of the overall variation (Table 8). This reflects the alkalinity factor, which the study soils are alkaline due to their enrichment with carbonate materials, where the increase in Fe and Na is associated with increasing the alkalinity (Mashhady and Rowell, 2006). The fourth factor (PC4) accounts for 9.70% of the variation and represents the effect of the waste (domestic) water, which is enriched in Na (0.656) and K (0.745), and in turn, this water is used for irrigation. The last factor (PC5) represents 8.27% of the variance, which consists of Al (0.893) metal (Table 8), suggesting that this component reflects the influence of aluminosilicate minerals and indicates a primarily geogenic (natural lithological) source.

The PCA results suggest that heavy metals such as Pb, Zn, and Cd in the soil are primarily derived from the application of fertilizers. A distinct alkalinity component reflects the carbonate-rich nature of the soils, linked to elevated iron, sodium, and pH levels. Another factor highlights the impact of domestic wastewater irrigation, contributing sodium and potassium to the soil. Finally, aluminum concentrations appear to reflect natural weathering processes of the underlying source rocks.

6. Conclusions

The geochemical analysis of the samples revealed that human activities in Koy Sanjaq have significantly contributed to the accumulation of heavy metals in the soils. Correlation analysis confirmed the influence of both natural and anthropogenic sources on heavy metal input. In some locations, concentrations of certain heavy metals exceed both to the natural crustal background values

and recognized abnormal thresholds, posing additional risks to plant health and ecosystem stabilityAccording to findings, the EF exposed that Koy Sanjaq soil results are moderate enriched in Zn, Cu, and Pb, while about 50% of the samples, the Cd metal is very high enrichment which seems to be in addition to the accumulation of geological and natural activities in the region there is also anthropogenic accumulation. The overall CF in the investigated area Cd displays very high contamination, while V, Zn, As, Cu, and Pb show moderate contamination. The assessment according to the I-geo index shows categories that all samples are heavily to extremely contaminated by Cd. While Pb shows moderately contaminated. The pollution load index (PLI) indicates that soils in Koy Sanjaq exhibit higher contamination levels, particularly in the northwestern part of the district. The ecological risk (ER) assessment of heavy metals in the soil samples showed that As, Cr, Co, Cu, Pb, Mn, Ni, V, and Zn pose low risk and are not considered a significant threat to human health, whereas Cd presents a very high ecological risk. The PCA results indicate that the accumulation of Pb, Zn, and Cd in the soil mainly originates from fertilizer use, whereas higher levels of Fe, Na, and pH are characteristic of naturally alkaline, carbonate-rich soils. Additional sodium and potassium inputs are linked to irrigation with domestic wastewater, and aluminum levels indicate natural weathering of parent rocks.

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