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RESEARCH ARTICLE

Ecological Indices of the Heavy Metals in the Soil of Shewasoor Sub-Basin, Kirkuk NE Iraq

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Abstract:

The current research aimed to assess contamination levels in the soil of study area by heavy metals. Eight sites were selected for the collection of soil samples. The eight heavy metals namely As, Pb, Cd, Cr, Co, Cu, Ni, and Zn were analyzed in each soil samples by using ICP-MS technology. The measured concentrations of heavy metals were compared with Geochemical Background values, EPA Sediment Quality Guidelines, Ecological Screening values, and WHO Guidelines. The spatial distribution maps of ecological indices were performed using ArcGIS software (version 10.2), which provides an idea of the geographical distribution of heavy metals contamination levels in the soil of Shewasoor sub-basin. The soil contamination by heavy metals assessed using Potential Ecological Risk Index (*RI*), Nemerow Pollution Index (P_N), Hazard Index (*HI*), and Cancer Risk. The RI showed there are high risk of heavy metals in soil and according to P_N the soil has been moderate to severely contaminated by heavy metals. The hazard index of all soil samples was within acceptable range for adults and showed unacceptable risk for children. While the total cancer risk values of As and Cr were within acceptable limits, whereas of Pb, Cd, Co, and Ni were lower than acceptable risk range at all sites for adults and children. Ecological indices which are used to assess the contamination levels in the soil by heavy metals refers to the soil of study area was contaminated moderate to heavily by heavy metals, this attributed to the natural and anthropogenic pollution sources around and within the study area.

Keywords: Ecological, Indices, Heavy Metals, Soil, Shewasoor Sub-basin.

Introduction

The soil is an important component of terrestrial ecosystems, it's very sensitive to environmental change. the soil can contaminate by introducing of pollutants from different pathways [1,2]. The contribution of heavy metals from anthropogenic sources in soil is higher than the contribution from natural sources [3]. The soil contamination with heavy metals is of one the most ecological problems because it's related directly to the human health. [4-6]. The heavy metals are dangerous pollutants unlike other pollutants because they are non-degradable for that accumulate in the soil, the effects of these metals may be reflected in the plant behavior, microbiological processes and transfer of toxic levels of the elements to man and animals, these elements have negative effects on human health and on the environment especially on the children [7-12]. Some heavy metals play an essential role in biochemical processes, most organisms required these metals in a small amount for normally healthy growth (e.g. Zn, Cu, and Cr) [1], but become toxic at higher concentration [13]. Other heavy metals are not essential and do not cause deficiency disorders if absent (e.g. Cd, Pb, and As), these metals toxic at low levels of exposure [1,14]. Absorption of heavy metals by the body for a period of time (years or decades) lead to accumulation these metals in vital organs like brain, liver, bones, and kidneys, then causing serious health consequences [14]. Hence, the study of heavy metals pollution in soil and assess its environmental risks to the agricultural products and human health very important and necessary [15]. The current research aimed to 1) Determine the concentration of heavy metals in the soil of Shewasoor sub-basin. 2) Ecological assessment of the soil of Shewasoor sub-basin using Potential ecological risk index, Nemerow pollution index. 3) Assessment of the potential health risks of heavy metals on the population in the study area by an estimate carcinogenic risk and non-carcinogenic hazard.

Study Area

The study area is located to the northeastern part of Iraq, between (454999.1 mE – 471002.3 mE) and (3949735.6 mN – 3968762.3 mN), apart about 39 Km to the north east of Kirkuk city, covers about 160 Km^2. The study area is bounded by Taqtaq Anticline from north and northeast sides, by Northern ChamChamal Anticline from west and southwest sides, and by topographic elevated area from south and southeast sides. Also, the topographic elevations of the study area ranges between (311-1186) m a.s.l. (Figure 1). The climate of Iraq is generally continental type, its cold rainy in the winter and hot and dry in the summer [16].

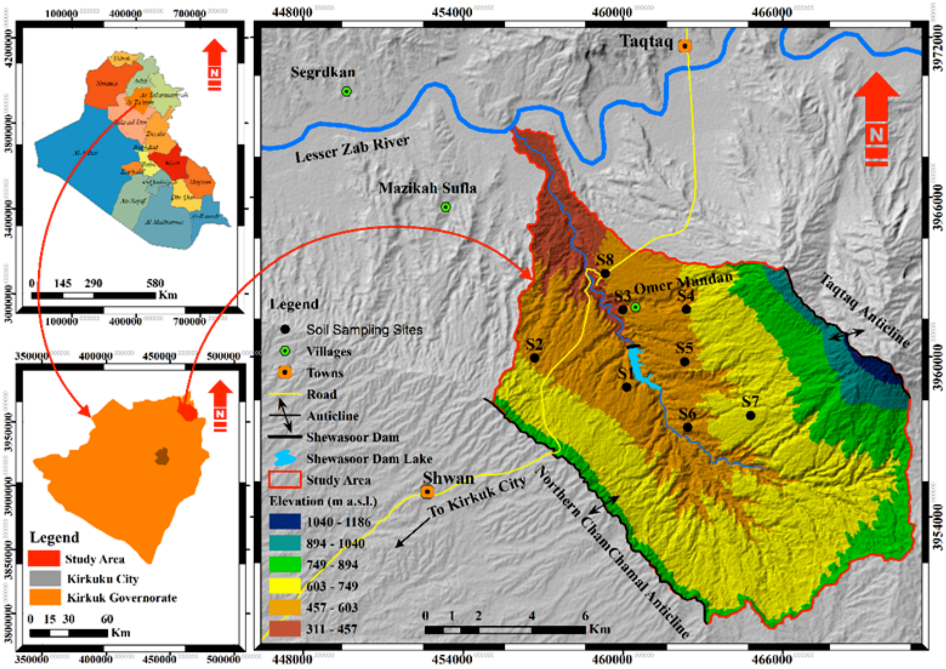

Figure 1. Location Map of Study Area and Soil Sampling Sites.

Geological Setting and Tectonic

The exposed formations in the study area extending from oldest (Upper Miocene) up to youngest (Quaternary deposits) [17], (Figure 2) are:

Injana Formation: (Upper Miocene), it consists of gray, brown sandstone, brown claystone and siltstone of the same colour [17]. The thickness of this formation is 2000m in the center of depositional basin within Foothill zone [18].

Mukdadiya Formation: (Uppermost Miocene-Pliocene), it consists of brown claystone with gray coarse-grained sandstone, brown and gray siltstone, and pebbly sandstone [17]. Its thickness is more than 2500m in the center of the depositional basin within Foothill zone [18].

Bai-Hassan Formation: (Pliocene), it consists of thick and coarse conglomerates, thick brown claystone and thin sandstone [17]. Its thickness is more than 2000m in the center of depositional basin within Foothill zone [18].

Quaternary Deposition: (Pliocene-Holocene), Six types of quaternary deposits are developed in the study area, are River terraces, Polygenetic deposits, Slope deposits, Residual gravels, Floodplain, and Valley-fill deposits [17].

Tectonically the study area lies in the Unstable shelf within Foothill zone in Chamchamal-Arbil subzone according to tectonic division of Iraq [19].

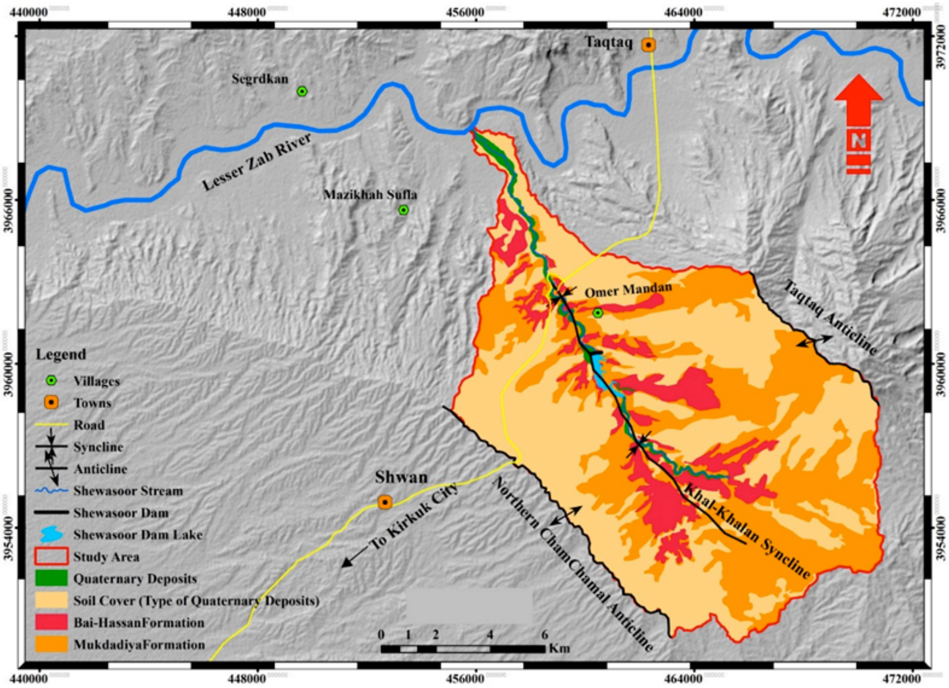

Figure 2. Geological Map of Study Area

Soil of the Study Area

The study area represents deep valley contain ephemeral stream coming down from the high areas. The soil of the study area formed as a result of intensive erosion processes of rock formations that are exposed at the surface mainly Bai-Hassan and Mukdadiya Formations. Two soil types were recognized in the area are [20]:

Reddish-Brown Soil: This type of soil represents the hill slopes soils, which is characterized by reddish-brown surface soil which at little depth turns up from brown colour into red colour, lime accumulation begins at depth 15 cm, also its soft soil easily eroded, the biological activity and chemical weathering are rather low, and its highly permeable soil causing infiltration of water into subsurface.

Brown Soil: This soil has a brown surface layer of about (25-30) cm, grading into a brownish-gray to the whitish horizon of lime accumulation, which consists of silt loam mixed with some gravels, grading into brown silt loam at 14 cm, with lime accumulation beginning at a depth of 30 cm. The topsoil is alkaline and may have (1 or 2) % of organic matter. The process of chemical weathering becomes more important in this type of soil.

Materials and Methods

Sampling and Analysis

Collection of Samples: Soil samples were collected from eight sites within the study area as shown in (Figure 1) at Oct 2016. Before the sampling (Fieldwork) start, the stratified random sampling method was selected, where the study area is divided into a grid of egalitarian squares and soil samples were taken randomly from each square from (0-20) cm depth, the samples were placed in clean and new polythene bags. The large empty area in the sampling map represent the geological outcrops.

Preparation of Samples: Soil samples were air-dried at room temperature and sieved by (200 mesh) sieve in order to separate and remove all course materials. The weighted 2 gm of samples and placed in small polythene bags, then they were transferred to the laboratory.

Analysis of Samples: The eight heavy metals As, Pb, Cd, Cr, Co, Cu, Ni, and Zn, were analyzed in all samples. The concentrations of heavy metals were determined using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) at Acme labs/ Vancouver, BC Canada V6P 6E5. The physicochemical characteristics of soil samples were analyzed in the Environmental Research Unit Laboratory/ College of Science/ University of Kirkuk.

Statistical Analysis

The calculation of descriptive statistical parameters (median, average, max, and min) and Pearson's correlation coefficients analysis were performed between heavy metals using the SPSS software, version 22.

Spatial Distribution Analysis

The spatial distribution maps of ecological indices were mapped (scale 1:88000) carried through Inverse Distance Weighted (IDW) method by using ArcGIS software (version 10.2).

Ecological Assessment Methods

The ecological assessment of the soil of Shewasoor sub-basin was performed by using the following ecological indices:

Nemerow Pollution Index (P_N):

The Nemerow pollution index (P_N) was used to assess the total contamination level of heavy metals in the soil of study area and evaluate environment quality. The Nemerow pollution index was calculated by using the following equation [21], see (Table 1):

$$PI = \frac{C_n}{S_n} \quad (1)$$

$$P_N = \sqrt[2]{(PI_{max})^2 + (PI_{average})^2/2} \quad (2)$$

Where: PI is Pollution Index of heavy metal (n), C_n is Measured concentration of heavy metal (n), S_n is Background concentration of heavy metal (n), according to [22] (Table 5), P_N is Nemerow pollution index, PI_{max} is Maximum pollution index value for all of the pollutant, $PI_{average}$ is Average pollution index value for all of the pollutant.

Table 1: Nemerow Pollution Index (P_N)) and Contamination Level [21].

P_N value	Contamination Level
$P_N \leq 1$	Soil has not been contaminated
$1 < P_N \leq 2$	Soil has been slightly contaminated
$2 < P_N \leq 3$	Soil has been moderately contaminated
$P_N > 3$	Soil has been severely contaminated

Potential Ecological Risk Index (*RI*)

The contaminated soil with heavy metal can enter the human body through several pathways and various exposure approaches [23]. Elevated levels of toxic heavy metals in agricultural soil can influence food chain, hence lead to increase the exposure of severing dangerous diseases, such as cancer, leukemia, and kidney or liver damage [24]. Therefore, the assessment of potential ecological risks (*RI*) is necessary, which developed by [25], represent the toxicity of heavy metals and their risks level to the environment, (*RI*) value is calculated by the following [25], see (Table 2):

$$RI = \sum_{i=1}^{n} \frac{(T_i * C_i)}{B_i} \tag{3}$$

Where: T_i is Toxicity factor of heavy metals are (Cd= 30, As = 10, Pb = 5, Cu = 5, Cr = 2, Zn = 1, Ni = 5), C_i is Measured concentration of heavy metal (i), B_i is Background concentration of heavy metal (i) (Table 5) [22].

Table 2: Potential Ecological Risk Index (RI) and Level of Risk [25].

RI value	Risk Level
$RI \leq 50$	Low risk
$50 < RI \leq 100$	Moderate risk
$100 < RI \leq 150$	High risk
$150 < RI \leq 200$	Very high risk
$200 < RI$	Extreme risk

Health Risk Assessment

Health risk assessment was employed to estimate the adverse health effects of exposure to the carcinogenic and non-carcinogenic heavy metals on the human health [26]. The risk assessment consisted of four basic steps [26,27]: hazard identification, exposure assessment, toxicity (dose-response) assessment, and risk characterization.

A) Chronic Daily Intake (CDI):

The human can expose to heavy metals in soil through three pathways are [28]: 1) Ingestion of soil 2) Dermal absorption of heavy metals 3) Inhalation of heavy metals that emitted with soil particles. The Chronic Daily Intake (CDI) of heavy metals in the soil of study area by three pathways was calculated by using the following equations [28], see (Table 3):

For non-carcinogenic:

$$CDI_{ing-nc} = \frac{C_{soil} * IngR * EF * ED * CF}{BW * AT_{nc}} \tag{4}$$

$$CDI_{dermal-nc} = \frac{C_{soil} * SA * AF * ABS * EF * ED * CF}{BW * AT_{nc}} \tag{5}$$

$$CDI_{inh-nc} = \frac{C_{soil} * InhR * EF * ED}{PEF * BW * AT_{nc}} \tag{6}$$

For carcinogenic:

$$CDI_{ing-c} = \frac{C_{soil} * IngR * EF * ED * CF}{BW * AT_{c}} \tag{7}$$

$$CDI_{dermal-c} = \frac{C_{soil} * SA * AF * ABS * EF * ED * CF}{BW * AT_{c}} \tag{8}$$

$$CDI_{inh-c} = \frac{C_{soil} * InhR * EF * ED}{PEF * BW * AT_{c}} \tag{9}$$

Where: CDI_{ing}, CDI_{dermal}, and CDI_{inh} were the chronic daily intake through ingestion of soil (mg/kg-day), dermal contact with soil particles (mg/kg-day), and inhalation of heavy metals via soil particles (mg/m^3 for non-carcinogenic and µg/m^3 for carcinogenic), and other parameters are clarified in (Table 3).

Table 3: Parameters Used in the Health Risk Assessment of Soil of Study Area for Adult and Children [29,30].

Parameter	Unit	Adult	Child
Concentration of metals (C_{soil})	ppm	-	-
Exposure Duration (*ED*)	year	30	6
Exposure Frequency (*EF*)	days/ year	350	350
Ingestion Rate (*IngR*)	mg/ day	100	200
Inhalation Rate (*InhR*)	m^3/ day	20	10
Body Weight (*BW*)	kg	70	15
Average Time (*AT*): For Non-carcinogenic For Carcinogenic	days	 ED * 365 70 * 365	 ED * 365 70 * 365
Conversion Factor (*CF*)	kg/mg	10^{-6}	10^{-6}
Skin Surface Area (*SA*)	cm^2	5700	2800
Soil Adherence Factor (*AF*)	mg/cm^{2}.day	0.07	0.2
Particle Emission Factor (*PEF*)	m^3/kg	$1.4*10^9$	$1.4*10^9$
Dermal Absorption Factor (*ABS*)	-	0.03 for As and 0.001 for other elements	

B) Non-carcinogenic Risk Assessment:

The non-carcinogenic risk evaluated by using the hazard quotient (*HQ*). *HQ* value indicates the degree of exposure (*CDI*) greater or less than the (*RfD*). The *HQ* value represents the ratio of *ADI* to *RfD* of the toxic metals in soil samples were calculated by using the following equation [28], see (Table 4):

$$THQ = HQ_{ing} + HQ_{drmal} + HQ_{inh} = \frac{CDI_{ing-nc}}{RfD_{ing}} + \frac{CDI_{dermal-nc}}{RfD_{dermal}} + \frac{CDI_{inh-nc}}{RfC_{inh}} \quad (10)$$

Where: THQ is Total Hazard Quotient, HQ_{ing} is Ingestion Hazard Quotient, HQ_{drmal} is Dermal Hazard Quotient, HQ_{inh} is Inhalation Hazard Quotient CDI_{ing-nc} $CDI_{dermal-nc}$ and CDI_{inh-nc} were non-carcinogenic chronic daily intake through three pathways ingestion (mg/kg-day), dermal (mg/kg-day), and inhalation (mg/m^3), respectively, RfD_{ing}, RfD_{dermal}, and RfC_{inh} were Ingestion Reference Dose (mg/ kg-day), Dermal Reference Dose (RfD_{ing}* Fraction of contaminant absorbed in the skin (ABS_{GI})) (mg/ kg-day), and Inhalation Reference Concentration (mg/m^3), respectively.

The hazard index (*HI*) estimated the risk of a mixture of contaminant (e.g. Heavy metal), which represents the sum of more than one *HQ* for heavy metals, the *HI* calculated by using the following equation [28]:

$$HI = \sum THQ \quad (11)$$

Where, THQ and HI are total hazard quotient and hazard index, respectively. If the HI value is less than one ($HI < 1$) mean there is no non-carcinogenic risks, if the HI value exceeds one ($HI > 1$) mean there is non-carcinogenic adverse effects [28].

C) Carcinogenic Risk Assessment:

Cancer risk estimates the probability of an individual lifetime health risk as a result of exposure to the carcinogens. The cancer risk calculated by using the following equation [28], see (Table 4):

$$Total\ Cancer\ Risk = Risk_{ing} + Risk_{dermal} + Risk_{inh}$$
$$= CDI_{ing-c} * CSF_{ing} + CDI_{dermal-c} * CSF_{dermal} + CDI_{inh-c} * IUR \quad (12)$$

Where: $Risk_{ing}$, $Risk_{dermal}$, and $Risk_{inh}$ are cancer risks through ingestion, dermal, and inhalation pathways, CSF_{ing}, CSF_{dermal},, and IUR are ingestion chronic slope factor (mg/kg-day) $^{-1}$, dermal chronic slope factor (CSF_{ing}/ABS_{GI}) (mg/kg-day) $^{-1}$, and inhalation unit risk (µg/m^3) $^{-1}$, respectively. The acceptable or tolerable total risk for regulatory purposes is in the range of (10^{-6} – 10^{-4}), [30,32].

Table 4: Parameters Used for the Non-carcinogenic Hazard and Carcinogenic Risk. Assessment of Study Area Soil for Adult and Children. [30].

Metal	RfD_{ing}	RfD_{dermal}	RfC_{inh}	CSF_{ing}	CSF_{dermal}	IUR	ABS_{GI}
As	$3*10^{-4}$	$3*10^{-4}$	$1.5*10^{-5}$	1.5	1.5	$4.3*10^{-3}$	1
Pb	$3.5*10^{-3}$	$3.5*10^{-3}$	-	$8.5*10^{-3}$	$8.5*10^{-3}$	$1.2*10^{-5}$	1
Cd	$5*10^{-4}$	$2.5*10^{-5}$	$1*10^{-5}$	-	-	$1.8*10^{-3}$	0.05
Cr	$3*10^{-3}$	$7.5*10^{-5}$	$1*10^{-4}$	$5*10^{-1}$	20	$8.4*10^{-2}$	0.025
Co	$3*10^{-4}$	$3*10^{-4}$	$6*10^{-6}$	-	-	$9*10^{-3}$	1
Cu	$4*10^{-2}$	$4*10^{-2}$	-	-	-	-	1
Ni	$2*10^{-2}$	$8*10^{-4}$	$9*10^{-5}$	-	-	$2.6*10^{-4}$	0.04
Zn	$3*10^{-1}$	$3*10^{-1}$	-	-	-	-	1

Results and Discussion

Concentrations of Heavy Metals in Soil Samples

The concentration of heavy metals in the Shewasoor's sub-basin soil shown in (Table 5). The abundance trend of median concentrations of heavy metals in the soil samples in order of Ni> Cr> Zn> Cu> Co> Pb> As> Cd, the concentrations of As, Cd, and Ni in the all samples highest than geochemical background values, while the concentrations of Pb, Cr, Co, and Zn in all samples lower than geochemical background values, except Zn at site (S7), higher than same value. The concentration of Cu at (S1, S2, and S4) lower than geochemical background value, but its concentration higher than the compared value at other sites.

According to Ecological Screening values [33] (Table 5), the concentrations of As, Pb, Cd, and Cu are lower than Ecological Screening values, while the concentrations of Cr, Co, and Ni are higher than the Ecological Screening values at all soil sampling sites. But Zn at sites (S1, S2, and S4) is lower than Ecological Screening value and at other sites its concentration higher than the same value.

The concentrations of As, Pb, Cd, Cr, Co, Cu, and Zn at all sites did not exceed the WHO Guidelines [34], except the Ni, exceeded the same guidelines (Table 5).

Table 5: Concentrations of Heavy Metals in Soil Samples of Study Area, Geochemical Background values of Heavy Metals, and Maximum Allowable Limit of Concentrations of Heavy Metals in Soil for Several Guidelines. (ppm)

Site Name	As	Pb	Cd	Cr	Co	Cu	Ni	Zn	pH
S1	6.7	10.07	0.25	79.8	17.6	23.15	118	49.2	7.5
S2	5.3	8.08	0.17	61.6	20.2	25.56	94.5	36.1	7.7
S3	8.7	13.56	0.15	78.4	19.1	29.98	129.7	56.7	8
S4	9.7	10.92	0.16	64.6	14.4	19.55	82	39.4	8
S5	7.3	11.53	0.15	69.5	16.3	25.08	108.9	52.5	8.1
S6	6.9	12.59	0.27	80.1	17.1	27.77	132	57	7.8
S7	7.1	14.66	0.27	99.1	21.8	33.72	143.2	76	7.9
S8	6.1	11.29	0.27	79.1	17.5	27.39	128.9	51.2	8.2
Median	7.0	11.41	0.21	78.75	17.55	26.475	123.45	51.85	7.95
Average	7.225	11.587	0.211	76.525	18	26.525	117.15	52.263	7.9
Min	5.3	8.08	0.15	61.6	14.4	19.55	82	36.1	7.5
Max	9.7	14.66	0.27	99.1	21.8	33.72	143.2	76	8.2
Geochemical Background Value [a]	1.7	14.8	0.1	136	24	25	56	65	-
EPA [b]	10	16	0.38	0.4	9	36	30	50	-
WHO Guidelines [c]	20	100	3	100	50	100	50	300	-

a [22]; b [33]; c [34].

The heavy metals concentrations in the soil of study area were assessed by comparing with the EPA Sediment Quality Guidelines (SQGs) [35] shown in (Table 6). The results showed all sites are non-polluted with Pb, Cd, and Zn, but polluted heavily by Ni, the soil at S6, S7, and S8 is polluted moderately with As and Cu, whereas polluted heavily by Cr. also the S5 and S2 considered as polluted moderately by As, Cr, and Cu, while S3 showed heavy pollute by As and Cr and moderate pollute for Cu. The moderate pollution observed at S1 for As, and heavy pollution for Cr, but it non-polluted with Cu, as well as S4 heavily polluted by As, and exhibit moderate pollute with Cr, also it non-polluted by Cu.

Table 6: EPA Sediment Quality Guidelines (SQGs) [35].

Metal	Non-polluted	Moderately Polluted	Heavily Polluted	Present Study
As (ppm)	< 3	3 – 8	>8	5.3 – 9.7
Pb (ppm)	< 40	40 – 60	>60	8.08 – 14.66
Cd (ppm)	*	*	>6	0.15 – 0.27
Cr (ppm)	< 25	25 – 75	>75	61.6 – 99.1
Cu (ppm)	< 25	25 – 50	>50	19.55 – 33.72
Ni (ppm)	< 20	20 – 50	>50	82 – 143.2
Zn (ppm)	< 90	90 – 200	>200	36.1 – 76

*Lower limits not established.

Correlation Coefficient of Heavy Metals in Soil of the Study Area

The Pearson's correlation coefficient is a statistical method which describe the strength and direction of the relationship between two variables (Table 7), [36], were employed to evaluate the relations among heavy metals (Table 8), showed strong positive relationships between heavy metals pairs of Pb-Zn (r = 0.894), Cr-Ni (r = 0.891), Cr-Zn (r = 0.942), Cu-Ni (r = 0.859), Cu-Zn (r = 0.835), Ni-Zn (r = 0.872), and Co-Cu (r = 0.810). While, the moderate positive relationships observed between heavy metals pairs of Pb-Cr (r = 0.783), Pb-Ni (r = 0.733), Cr-Cu (r = 0.774), Pb-Cu (r = 0.7), Cd-Cr (r = 0.705), Cd-Ni (r = 0.663), Cd-Zn (r = 0.509), Cr-Co (r = 0.549), Co-Ni (r = 0.547), Co-Zn (r = 0.520). The strong positive relationships among heavy metals indicate to the heavy metals are originated from the same common pollution source is mostly anthropogenic, whereas the weak relationships denoted to differences in geochemical behavior and source of heavy metals [37,38], while the correlations coefficient of pH with other heavy metals showed no association between them in the soil of the study area, this attributed to the alkaline soil of Shewasoor sub-basin (Table 5) [1], also [20] refers to the soil of study area is brown and alkaline soil which content about (1-2)% of organic matter, where the chemical weathering is play an important role in this layer and potentially affects the bioavailability of heavy metals in the soil of study area.

Table 7: Interpretation of Pearson's Correlation Coefficient [36].

Correlation value	Strength and Direction of Correlation
(-0.8) – (-1.0)	Strongly negative
(-0.5) – (-0.8)	Moderately negative
(-0.2) – (-0.5)	Weakly negative
(+0.2) – (-0.2)	No association
(+0.2) – (+0.5)	Weakly positive
(+0.5) – (+0.8)	Moderately positive
(+0.8) – (+1.0)	Strongly positive

Table 8: Pearson's Correlation Matrix Among Heavy Metals in Soil of Study Area.

Metal	As	Pb	Cd	Cr	Co	Cu	Ni	Zn	pH
As	1								
Pb	0.420	1							
Cd	-0.448	0.269	1						
Cr	-0.062	0.783	0.705	1					
Co	-0.488	0.255	0.271	0.549	1				
Cu	-0.260	0.700	0.395	0.774	0.810	1			
Ni	-0.233	0.733	0.663	0.891	0.547	0.859	1		
Zn	0.035	0.894	0.509	0.942	0.520	0.835	0.872	1	
pH	0.315	0.380	-0.206	-0.017	-0.253	0.152	0.070	0.148	1
*Weak relation or No relation *Moderate relation *Strong relation									

Nemerow Pollution Index (P_N)

Degree of heavy metals contamination was evaluated by using Nemerow pollution index (P_N). The results of Nemerow pollution index listed in (Table 9), and spatial distribution of P_N shown in (Figure 3). According to [21] the, soil has been moderately contaminated at sites (S1, S2, and S8), whereas the soil has been severely contaminated at all other sites.

Table 9: Ecological Risk Index and Nemerow Pollution Index of Heavy Metals in the Soil of Study Area.

Site Name	Nemerow pollution index (P_N)	
	P_N value	Contamination Level
S1	2.99	Soil has been Moderately Contamination
S2	2.36	Soil has been Moderately Contamination
S3	3.80	Soil has been Severely Contamination
S4	4.17	Soil has been Severely Contamination
S5	3.20	Soil has been Severely Contamination
S6	3.10	Soil has been Severely Contamination
S7	3.22	Soil has been Severely Contamination
S8	2.77	Soil has been Moderately Contamination
*2 $< P_N <$ 3 Soil has been Moderately Contamination *$P_N >$ 3 Soil has been Moderately Contamination		

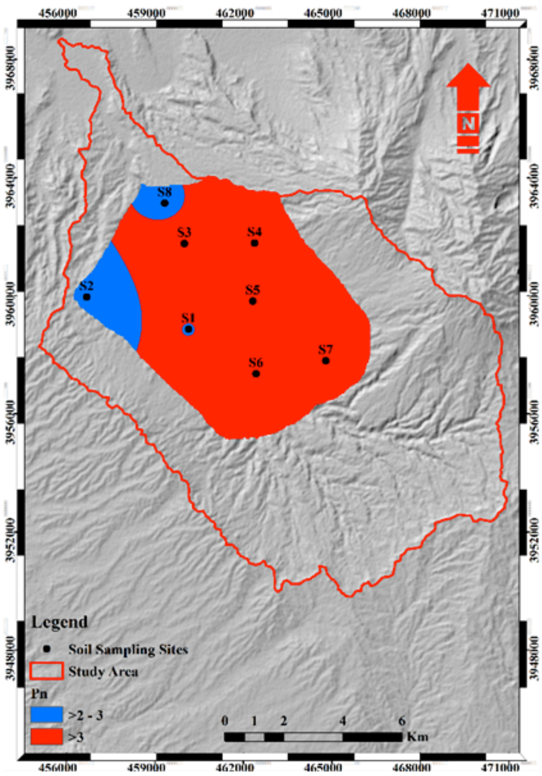

Figure 3. Spatial Distribution of P_N in the Soil of Study Area.

Potential Ecological Risk Index (RI)

The potential ecological risk index (*RI*) was used to evaluate the level of ecological risk in the study area. The results of RI showed in (Table 10), and spatial distribution of *RI* shown in (Figure 4). According to [25], the high level of ecological risk was observed at all sites, except site (S2) which showed moderate ecological risk.

Table 10: Ecological Risk Index and Nemerow Pollution Index of Heavy Metals in the Soil of Study Area.

Site Name	Ecological Risk Index (RI)	
	RI value	Risk Level
S1	134.91	High Risk
S2	98.92	Moderate Risk
S3	120.36	High Risk
S4	121.54	High Risk
S5	108.41	High Risk
S6	145.24	High Risk
S7	149.87	High Risk
S8	139.63	High Risk
*50 < RI <100 Moderate Risk, *100 < RI < 150 High Risk		

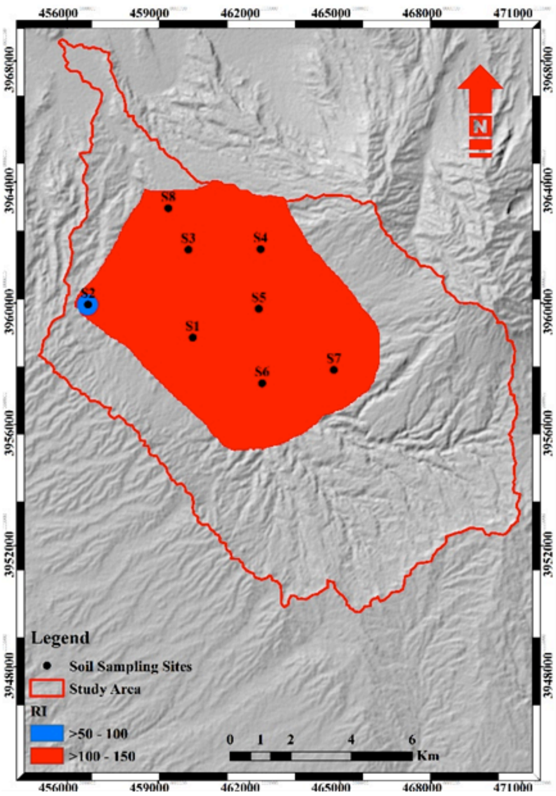

Figure 4. Spatial Distribution of RI in the Soil of Study Area

Non-carcinogenic Risk Assessment of heavy metals for Adults and children

The Total Hazard Quotient (*THQ*) results of heavy metals present in (Table 11). The non-carcinogenic risk was assessed according to calculated values of Hazard Index (*HI*) of soil samples for adults and children through different pathways. The results of HI listed in (Table 11), and spatial distribution of *HI* for adults and children shown in (Figure 5). The *HI* values for adults at all sites were observed lower than one ($HI < 1$), this means there is no non-carcinogenic risk for adults, and the adults population were unlikely to experience adverse effects. Whereas the *HI* values for children higher than one ($HI > 1$) at all sampling sites, this mean the children that reside in the study area were at risk of non-carcinogenic effects of heavy metals.

Table 11: Total Hazard Quotient and Hazard Index of Heavy Metals for Adults and Children in Soil of Study Area.

	Site Name	Total Hazard Quotient (THQ)								Hazard Index (HI)
		As	Pb	Cd	Cr	Co	Cu	Ni	Zn	
Adults	S1	3.8E-02	4.0E-03	9.0E-04	4.2E-02	8.1E-02	8.0E-04	9.1E-03	2.3E-04	0.177
	S2	,3.0E-02	3.2E-03	6.2E-04	3.3E-02	9.3E-02	8.8E-04	7.3E-03	1.7E-04	0.168
	S3	4.9E-02	5.3E-03	6.0E-04	4.2E-02	8.8E-02	1.0E-03	1.0E-02	2.6E-04	0.196
	S4	5.5E-02	4.3E-03	6.0E-04	3.4E-02	6.6E-02	6.7E-04	6.4E-03	1.8E-04	0.168
	S5	4.1E-02	4.5E-03	5.8E-04	3.7E-02	7.5E-02	8.6E-04	8.4E-03	2.4E-04	0.168
	S6	3.9E-02	4.9E-03	9.6E-04	4.3E-02	7.9E-02	9.5E-04	1.0E-02	2.6E-04	0.178
	S7	4.0E-02	5.8E-03	9.9E-04	5.3E-02	1.0E-01	1.2E-03	1.1E-02	3.5E-04	0.213
	S8	3.5E-02	4.4E-03	9.5E-04	4.2E-02	8.1E-02	9.4E-04	1.0E-02	2.3E-04	0.174
Children	S1	3.1E-01	3.7E-02	6.8E-03	3.8E-01	7.5E-01	7.4E-03	8.1E-02	2.1E-03	1.576
	S2	2.5E-01	3.0E-02	4.6E-03	2.9E-01	8.6E-01	8.2E-03	6.5E-02	1.5E-03	1.511
	S3	4.0E-01	5.0E-02	4.1E-03	3.7E-01	8.2E-01	9.6E-03	8.9E-02	2.4E-03	1.747
	S4	4.5E-01	4.0E-02	4.3E-03	3.1E-01	6.2E-01	6.3E-03	5.7E-02	1.7E-03	1.480
	S5	3.4E-01	4.2E-02	4.1E-03	3.3E-01	7.0E-01	8.0E-03	7.5E-02	2.2E-03	1.497
	S6	3.2E-01	4.6E-02	7.3E-03	3.8E-01	7.3E-01	8.9E-03	9.1E-02	2.4E-03	1.587
	S7	3.3E-01	5.4E-02	7.3E-03	4.7E-01	9.3E-01	1.1E-02	9.9E-02	3.2E-03	1.905
	S8	2.8E-01	4.1E-02	7.3E-03	3.8E-01	7.5E-01	8.8E-03	8.9E-02	2.2E-03	1.555

*HI<1 mean there is no non-carcinogenic risk.

*HI> 1 mean there is non-carcinogenic adverse effects risk.

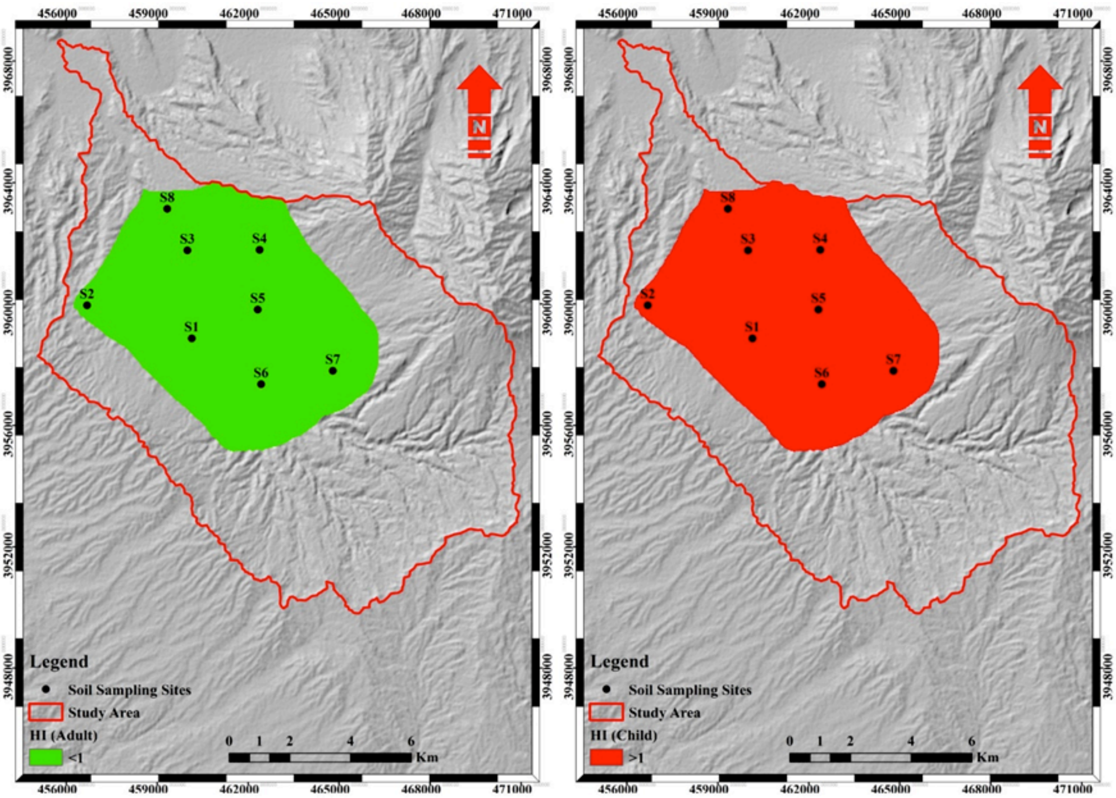

Figure 5. Spatial Distribution of *HI* for Adults and Children in the Soil of Study Area.

Carcinogenic Risk Assessment of Heavy Metals for Adults and Children

The cancer risk for heavy metals As, Pb, Cd, Cr, Co, and Ni were calculated, these metals are most contributors to the cancer risk, the results were shown in (Table 12). The total cancer risk values of As and Cr for adults and children were in acceptable risk range at all sampling sites, while the total cancer risk of Pb, Cd, Co, and Ni was lower than tolerable risk range at all sites. These values mean there is no cancer risk for adults and children, which they residing in the study area.

Table 12: Total Cancer Risk of Heavy Metals in Soil of Study Area.

	Site Name	Total Cancer Risk							
		As	Pb	Cd	Cr	Co	Cu	Ni	Zn
Adults	S1	6.6E-06	5.0E-08	3.8E-14	2.7E-05	1.3E-11	-	2.6E-12	-
	S2	5.2E-06	4.0E-08	2.6E-14	2.1E-05	1.5E-11	-	2.1E-12	-
	S3	8.6E-06	6.8E-08	2.3E-14	2.7E-05	1.4E-11	-	2.8E-12	-
	S4	9.6E-06	5.5E-08	2.4E-14	2.2E-05	1.1E-11	-	1.8E-12	-
	S5	7.2E-06	5.8E-08	2.3E-14	2.4E-05	1.2E-11	-	2.4E-12	-
	S6	6.8E-06	6.3E-08	4.1E-14	2.7E-05	1.3E-11	-	2.9E-12	-
	S7	7.0E-06	7.3E-08	4.1E-14	3.4E-05	1.6E-11	-	3.1E-12	-
	S8	6.0E-06	5.7E-08	4.1E-14	2.7E-05	1.3E-11	-	2.8E-12	-
Children	S1	1.2E-05	9.4E-08	1.8E-14	4.9E-05	6.2E-12	-	1.2E-12	-
	S2	9.4E-06	7.5E-08	1.2E-14	3.8E-05	7.1E-12	-	9.6E-13	-
	S3	1.6E-05	1.3E-07	1.1E-14	4.8E-05	6.7E-12	-	1.3E-12	-
	S4	1.7E-05	1.0E-07	1.1E-14	3.9E-05	5.1E-12	-	8.3E-13	-
	S5	1.3E-05	1.1E-07	1.1E-14	4.2E-05	5.7E-12	-	1.1E-12	-
	S6	1.2E-05	1.2E-07	1.9E-14	4.9E-05	6.0E-12	-	1.3E-12	-
	S7	1.3E-05	1.4E-07	1.9E-14	6.0E-05	7.7E-12	-	1.5E-12	-
	S8	1.1E-05	1.1E-07	1.9E-14	4.8E-05	6.2E-12	-	1.3E-12	-

Conclusion

In the current research several environmental indices were used to the assessment of heavy metals contamination levels in the soil of study area, the results of this study summarized as follow:

1) The abundance trend of median concentrations of heavy metals increasing in order of Ni> Cr> Zn> Cu> Co> Pb> As> Cd. The concentrations of As, Cd, and Ni highest than geochemical background values at all sites, whereas concentrations of Pb, Cr, Co, and Zn are lower than the geochemical background values, except Zn at S7 exceeded the same background value. The comparison of heavy metals concentration with U.S. SQGs, where all sites non-polluted with Pb, Cd, and Zn, and polluted heavily by Ni, whereas S6, S7, and S8 are polluted moderately with As and Cu, but polluted heavily by Cr. The Concentrations of As, Pb, Cd, and Cu are lower than Ecological Screening values, and concentrations of Cr, Co, Ni, and Zn are higher than Ecological Screening values at all sites, except Zn at S1, S2, and S4 is lower than the same value. The concentrations of As, Pb, Cd, Cr, Co, Cu, and Zn at all sites lower than WHO guidelines, except Ni its concentrations higher than the same guidelines.

2) The Pearson's correlation coefficient analysis showed there are strong positive relationships among Pb, Co, Cu, Zn, Cr, and Ni indicates to these heavy metals originated from the same pollution source which is mostly anthropogenic, while the weak positive relationships were observed between pairs (As-Pb), (Cd-Cu), (Pb-Cd), (Cd-Co), and (Pb-Co) which indicate to these heavy metals come from different pollution source, whereas the weak negative relationship found between As with Cd, Co, Cu, and Ni, also there is no association between pH and heavy metals which attributed to the alkaline soil of study area.

3) The RI showed high risk at all sites, except site (S2), while according to P_N the soil has been moderately contaminated at sites (S1, S2, and S8), and severely contaminated at other sites.

4) The HI showed there are no noncarcinogenic adverse effects for adults, but the children are at risk of non-carcinogenic effects. While the total cancer risk values of As and Cr within acceptable range for adults and children, whereas for Pb, Cd, Co, and Ni were lower than tolerable risk range at all sites.

Ecological indices in the current study gives similar results, which refers to the soil of study area contaminated moderate to heavily by heavy metals, this attributed to many pollution sources which are enrich the study area by heavy metals. The natural pollution sources are: 1) weathering, erosion, and leaching processes of rocks and sediments, 2) atmospheric deposition of pollutants (i.e. dust particles and rainwater). In other hand, the Anthropogenic pollution sources are: 1) agricultural activities (i.e. using of organic or inorganic fertilizers, pesticides, and nutrients) these materials contain amounts of heavy metals, 2) livestock breeding, the animal wastes also contribute to pollute the soil of study area, 3) because of there is no wastewater and sewage sludge discharge nets in the area, the population are discharge these wastes to open areas, hence pollute areas of soil in the study area. The soil pollution at these levels have negative effects on the human health which are residing in the study area.

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List of Abbreviation

Abbreviation	Meaning
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
C	Concentration
CDI	Chronic Daily Intake
Cm	Centimeter
CR	Carcinogenic Risks
CSF	Chronic Slope Factor
gm	Gram
HI	Hazard Index
HQ	Hazard Quotient
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
IDW	Inverse Distance Weighted
IUR	Inhalation Unit Risk
Km	Kilometer
m	Meter
m a.s.l.	Meter Above Sea level
Max	Maximum
mE	Meter to East
Mg/m^3	Milligram/ Cubic meter
Min	Minimum
MOE	Ministry of Environment
mN	Meter to North
µg/m^3	Microgram/ Cubic meter
NRC	National Research Council
PI	Pollution Index
P_N	Nemerow Pollution Index
ppm	Part Per Million
RfD	Reference Dose
RI	Potential Ecological Risk Index
SQGs	Sediment Quality Guidelines
Km^2	Square Kilometer
T_i	Toxicity factor
U.S. EPA	United States Environmental Protection Agency
WHO	World Health Organization