



# Spatial distribution and health risk assessment in urban surface soils of Mediterranean Sea region, Cyprus Island

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## Abstract

Soil pollution with heavy metals (HMs) has become an increasingly serious environmental concern and needs assessment of ecological and human health risks, especially in an urban area. For this purpose, the contents of eight HMs (As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn) in surface (0–5 cm) soil samples from 32 urban sites in the North area of Cyprus were examined using EDXRF spectrometer analysis. The average concentrations for As, Mn, Ni, Pb, Cr, Cu, Hg, and Zn in soil samples were 4.7, 950.6, 230.5, 48.2, 1.8, 186.8, 15.1, and 87.5 mg/kg, respectively. The results showed that the mean concentrations of the HMs in the soil samples followed the order Mn > Cr > Ni > Zn > Cu > Pb > As > Hg, respectively. The mean geo-accumulation index ( $I_{geo}$ ) of Hg was found in strong/extreme contamination. The potential ecological risk index (PERI) mean value was calculated in moderate ecological risk. Also, health risks assessment through three exposures pathways in adults and children showed that the total hazard index (HI) values for children were higher than for adults.

**Keywords** Heavy metals · Soil · Health risk · Ecological risk

## Introduction

The surface soils are widely accepted as part of the environment most show to heavy metals (HMs) contamination. The HMs are metals with densities higher than 5 g/cm<sup>3</sup> (Wu

et al., 2018). The highest contents of HMs generally occur in the topsoil because surface layers, especially organic horizons, have the most significant ability to bond HMs (Acosta et al., 2015). The HMs originate from anthropogenic and natural sources and have potential risks to ecosystems, human health, environmental persistence, and bioaccumulation (Zhuo et al., 2019). In addition, social activities produce most HM substances due to technological development (Wang et al., 2020).

HM pollution of soil is a significant environmental problem that people have faced worldwide in recent decades. Although HMs exist in the Earth's crust, metal elements in ecological matrices are related to human activities. These activities include industrial activity, mining of metalliferous, agricultural and horticultural material usage, sewage sludge, fossil fuel combustion, and waste disposal (Wang et al. 2016). Therefore, the accumulation of HMs in soil and sediments will contaminate the environment, which may affect human health (Islam et al. 2015, 2020; Proshad et al. 2018, 2021; Abbasi and Mirekhtiary 2020; Kabir et al. 2021a, b; Kormoker et al. 2021).

HMs in soil are classified into two categories of essential metals and non-essential metals. The essential metals include iron (Fe), manganese (Mn), and chromium (Cr),

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and non-essential metals such as arsenic (As), mercury (Hg), cadmium (Cd), and lead (Pb) (Jehan et al. 2018). Essential metals are necessary for a fixed level for the normal function of living beings. Coming down or overtaking essential metals than the required range exerts deficiency or harmful effects on living beings. The non-essential metals are toxic in small amounts and produce hazardous health problems in exposed populations (Kamani et al., 2017).

Many studies have shown that HMs have potential hazards for ecological systems and human health (Giri and Singh, 2017; El-Taher et al., 2018; Ali and Khan, 2019; Mehmood et al., 2019; Zakaly et al. 2019, 2021; Jiang et al. 2020; Mostafa et al. 2020; Ramos-Miras et al. 2020; Wu et al. 2020). However, so far, limited reports have been paid to study the HMs level in the soil (Yukselen 2002; Cohen et al. 2012; Baycu et al. 2015) and consequent potential ecological and human health risk assessment in the small section (Yedidalga) of the study area (Barkett and Akün 2018).

The reason for selecting this area was the possibility of pollution by the abandoned copper mine in the area and the high density of tourists and population. This research has been carried out in two parts; in the first part, we measured the radiation level of the radioactive elements using nuclear methods (Abbasi 2013; Abbasi et al. 2020b, 2022; Tawfic et al. 2021). The results are reported. (For more information, see: (Abbasi et al. 2020a)). The aims of the second study part are (1) determination of the heavy metals (As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn) in surface (0–5 cm) soil samples collected from residential regions of North Cyprus and (2)

assessment for the ecological risk, the human health risk of the heavy metal pollutions.

## Materials and methods

### Study area

The study area lies between latitude  $35^{\circ} 07' - 35^{\circ} 41' N$ , longitude  $32^{\circ} 43' - 34^{\circ} 41' E$  coordinates. Cyprus Island is the third largest island in the Mediterranean Sea, located west of Syria and south of Turkey. This island has a maximum width of about 90 km and a maximum length of about 220 km. Cyprus Island area approximately is  $9251 \text{ km}^2$  (Abbasi et al. 2021). The abandoned copper mine, Lefke/North Cyprus Turkish Republic, is located west of the study area. In 1914, they began prospecting in the western coastal area because of the ancient Roman slag heaps rich in Cu, and the company was established in 1916. After the abandonment of the mining industry in 1974, they left behind tons of tailing deposits exposed to the environment in the large flotation ponds (Baycu et al., 2015).

### Sample collection and preparation

Thirty-two surface (0–5 cm) (Dodd et al. 2017) soil samples from dwelling areas were collected in the spring season of 2019 from the Turkish Republic of Northern Cyprus (North area of Cyprus) Fig. 1. The composite soil samples (approximately 1 kg) were brought to the sample preparation



Fig. 1 Geographical location of the study area and sampling points (source: Google Maps)

laboratory and allowed to dry in the laboratory for 2 weeks. Each sample was ground, homogenized, and then placed for drying at 105 °C for 1 day to obliterate moisture.

### Heavy metals (HMs) analysis

Analyses of the HMs in the soil samples were carried out using energy dispersive X-ray fluorescence (EDXRF) spectrometry (Spectro Xepos), including a thick binary lead/cobalt alloy anode of X-ray tube (power: 50 W, energy: 60 kV). The EDXRF spectrometer has a highly annealed, pyrolytic graphite (HAPG) polariser to improve the sensitivity to elements in the Na–Cl range and a bandpass filter to enhance the performance of elements detection in the K–Mn range. The EDXRF spectrometer optimizes the excitation using polarization and secondary targets. It has an autosampler for up to 12 items and software modules. The target changer with up to eight polarization and secondary targets offers many different excitation conditions, ensuring the optimal determination of all elements from K to U.

The EDXRF spectrometer employs sophisticated calibration techniques such as “standardless” calibration, usually based on the fundamental parameters (FP) method. Soil certified reference material (NIST SRM 2709) (Mackey et al. 2010) was used for the quality assurance of the EDXRF system. The analysis procedures were completed by placing the sample cups prepared for each soil sample into the automatic sampler and counting them once for 2 h. The overall uncertainty of the analytical procedure is between 4 and 15%. The detection limit of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn was determined as 0.5, 2, 1, 0.5, 1, 0.5, 0.8, and 0.5 mg/kg, respectively.

### Ecological risk assessment

The potential ecological risk index (PERI) parameter was applied to estimate the potential risks caused by HMs pollution in the study area. This procedure was introduced by Hakanson (1980) to evaluate the characteristics and environmental behavior of HMs pollution in the soil. The PERI in soil (Diami et al. 2016) from pollution sites can be calculated as:

$$PERI = \sum_{i=1}^M E_i^r = \sum_{i=1}^M T_i^r C_i^r = \sum_{i=1}^M T_i^r \frac{c_i^i}{c_n^i} \tag{1}$$

where  $E_i^r$  shows the PERI of an individual HM and  $T_i^r$  is the toxic response factor of each HM for As, Mn, Cu, Cr, Hg, Ni, Pb, and Zn are 10, 1, 5, 2, 40, 5, 5, and 1, respectively (Chai et al. 2017; Kadhum et al. 2020). Also,  $C_i^r$ ,  $c_i^i$ , and  $c_n^i$  are the contamination factor, the concentration in the soil, and the reference level of background for the element  $i$ , respectively. The reference level of background for each

elements  $i$  is according to Earth’s crust average value (Taylor and McLennan 1995). The relationships between  $E_i^r$  and the pollution level can be classified into the following categories: (i) low ecological risk ( $E_i^r < 40$ ); (ii) moderate ecological risk ( $40 \leq E_i^r < 80$ ); (iii) considerable ecological risk ( $80 \leq E_i^r < 160$ ); (iv) high ecological risk ( $160 \leq E_i^r < 320$ ), (v) very high ecological risk ( $E_i^r \geq 320$ ) (Guan et al. 2018; Zhuo et al. 2019).

### Geo-accumulation index ( $I_{geo}$ )

The  $I_{geo}$  parameter was calculated to evaluate the level of HM contamination using the following equation:

$$I_{geo} = \log_2 \left( \frac{C_n^i}{1.5 B_n^i} \right) \tag{2}$$

where  $C_n^i$  is the concentration of HM  $i$  in soil (mg/kg) and  $B_n^i$  is the background value of the element  $i$  in the soil of the study area (mg/kg). The constant value of 1.5 was applied due to potential variations in the baseline data (Tian et al., 2020). For lack of soil, background values in the study area were selected, and world reference amounts were to calculate  $I_{geo}$  values (Caridi et al. 2016).

### Human health risk assessment

Human health risk potential evaluation is a suitable applied method for surveying the risk of HMs contamination to humans. The risk assessment was separated into two categories: children and adults (Gu et al. 2016). Four processes, including hazard identification, exposure assessment, dose-response assessment, and risk characterization, are needed to estimate the human health risk assessment (Luo et al., 2012). HMs exposure to human pathways is through direct ingestion, inhalation, and dermal absorption by skin (Diami et al. 2016). The average daily intake of ingestion ( $ADI_{ing}$ ), dermal ( $ADI_{der}$ ), and inhalation ( $ADI_{inh}$ ) (mg/kg/day) for adults and children were expressed as follows:

$$ADI_{ing} = C_{soil} \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{3}$$

$$ADI_{der} = C_{soil} \times \frac{SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{4}$$

$$ADI_{inh} = C_{soil} \times \frac{InhR \times EF \times ED}{BW \times AT \times PEF} \tag{5}$$

where the symbol, description, and values of these parameters are shown in Table 1.

The noncarcinogenic risk assessment was defined by the hazard quotient (HQ) that was used to assess the risk of a

**Table 1** Input parameters and values to calculate of the ADIs (USEPA 2002)

Parameter (unit)	Description	Value	
		Adults	Children
IngR (mg/day)	Ingestion rate	100	200
EF (day/year)	Exposure frequency	350	350
ED (year)	Exposure duration	24	6
BW (kg)	Body weight	60	16
AT (day)	Average time of dose	ED × 365	ED × 365
SA (cm <sup>2</sup> )	Exposed skin surface area	5700	2800
AF (mg/cm <sup>2</sup> )	Skin adherence factor for soil	0.07	0.07
ABS (unitless)	Dermal absorption factor	0.001	0.001
InhR (m <sup>3</sup> /day)	Inhalation rates	20	20
PEF (m <sup>3</sup> /kg)	Particle emission factor	1.36 × 10 <sup>9</sup>	1.36 × 10 <sup>9</sup>
C <sub>soil</sub> (mg/kg)	Concentration in soil	-	-

single heavy metal to the human body. Also, the summation of HQ is called hazard index (HI), which can apply to calculate the total potential noncarcinogenic effects of numerous heavy metals. Besides, the probability of a cancer case resulting from exposure to carcinogenic hazards is called carcinogenic risk (CR). The parameters of HQ, HI, and CR were calculated as follows (Zhuo et al., 2019):

$$HQ_i = \frac{ADI_i}{RfD_i} \quad (6)$$

$$HI = \sum_i HQ_i = \sum_i \frac{ADI_i}{RfD_i} \quad (7)$$

$$CR = \sum_i ADI_i \times SF_i \quad (8)$$

where  $RfD_i$  is the chronic reference dose and  $SF_i$  is the cancer slope factor (mg/(kg.day)), see Table 2. For evaluation of  $HI < 1$  or  $HQ < 1$  indicates no adverse health effects, and  $HI > 1$  or  $HQ > 1$  indicates adverse health effects. The

following levels of CR indicate  $CR < 10^{-6}$ , noncarcinogenic risk;  $10^{-6} < CR < 10^{-4}$ , acceptable levels of carcinogenic risk; and  $CR > 10^{-4}$ , high risk of carcinogenesis.

## Results and discussion

### Levels of HMs contamination in soils

The HM concentrations and total mean value of Mn, As, Hg, Cr, Pb, Cu, Ni, and Zn in soil samples are shown in Table 3. The Earth crust averages (reference values) of the surveyed HMs (Taylor and McLennan 1995) are also presented in this table. The ranges of concentrations for As, Mn, Ni, Pb, Cr, Cu, Hg, and Zn in soil samples were 0.5–11.8, 233.0–1739.0, 52.7–296.5, 5.0–29.2, 44.5–354.4, 11.9–113.2, 1–3.2, and 16.1–117.5 mg/kg, respectively.

It was observed that Mn had the highest mean value (950.6 mg/kg) followed by Cr (230.5 mg/kg), Ni (186.8 mg/kg), Zn (87.5 mg/kg), Cu (48.2 mg/kg), Pb (15.1 mg/kg), As (4.7 mg/kg), and Hg (1.8 mg/kg).

As the level in the soil from the SS-11 site was found to be higher than other sites because this place is a high traffic area and is the intersection of two highways. The concentration mean values of this study for As (4.7 mg/kg) were higher than the Poland report value (0.9 to 3.4 mg/kg) (Kabata-Pendias 2000) and less than (9.53 mg/kg) of Gebze area in Turkey (Yaylalı-Abanuz 2011), and (8 mg/kg) in Thrace region in Turkey (Coşkun et al. 2006).

As shown in Table 3, the value of Mn and Zn in soil from SS-29 was higher than the other soil samples. This site is closed to a municipal wastewater area, and it may be the reason for pollution. The finding results for Mn and Zn elements were higher than the other research report of Mn (617 mg/kg) and Zn (60.5 mg/kg), Lefkosa, Cyprus (Zisisimos et al. 2018).

The mean values of Cr, Cu, Hg, Ni, and Pb were higher than 71.42, 30.11, 0.13, 32.40, and 23.92 mg/kg, respectively (Pan et al. 2016). The mean values for As, Cu, Pb, and Zn for the soil samples investigated were less than 29, 1218,

**Table 2** The reference dose (RfD) and carcinogenic slope factor (SF) value of HMs in three pathways (Adimalla 2020; USEPA 2002)

	RfD			SF		
	Ing.	Inh.	Der.	Ing.	Inh.	Der.
As	3.00 × 10 <sup>-4</sup>	1.23 × 10 <sup>-4</sup>	1.23 × 10 <sup>-4</sup>	1.50	4.30 × 10 <sup>-3</sup>	3.66
Mn	0.14	0.14	0.14	-	-	-
Cr	3.00 × 10 <sup>-3</sup>	2.86 × 10 <sup>-5</sup>	3.00 × 10 <sup>-3</sup>	5.01 × 10 <sup>-1</sup>	4.20 × 10 <sup>1</sup>	2.00 × 10 <sup>1</sup>
Cu	4.00 × 10 <sup>-2</sup>	4.00 × 10 <sup>-2</sup>	1.20 × 10 <sup>-2</sup>	-	-	-
Hg	1.60 × 10 <sup>-4</sup>	1.60 × 10 <sup>-4</sup>	1.60 × 10 <sup>-4</sup>	-	-	-
Ni	2.00 × 10 <sup>-2</sup>	2.06 × 10 <sup>-2</sup>	5.40 × 10 <sup>-3</sup>	1.70	-	4.25 × 10 <sup>1</sup>
Pb	1.40 × 10 <sup>-3</sup>	3.52 × 10 <sup>-3</sup>	5.24 × 10 <sup>-4</sup>	8.50 × 10 <sup>-3</sup>	-	-
Zn	3.00 × 10 <sup>-1</sup>	0.30	6.00 × 10 <sup>-2</sup>	-	-	-

**Table 3** The HMs concentrations in the soil samples of the study area and Earth's crust average value (Taylor and McLennan 1995)

Sites	HMs (mg/kg, dw)*							
	As	Mn	Cr	Cu	Hg	Ni	Pb	Zn
SS-1	3.4	998.3	257.2	51.4	1.9	226.1	17.7	82.9
SS-2	4.5	678.2	305	48	1.6	253.9	8.0	79.0
SS-3	3.4	979.5	245.6	50.8	2.1	219.5	18.2	82.3
SS-4	5.7	1058	257	41.2	1.2	157.3	12.6	84.6
SS-5	1.5	1708	158.3	68.0	2.0	91.2	10.9	114.5
SS-6	8.6	957.1	262.6	34.6	1.2	166.6	26.4	99.3
SS-7	4.9	413.8	206.1	21.2	0.7	187.7	9.3	50.8
SS-8	3.4	967.6	224.1	49.9	2.4	225.8	17.5	82.5
SS-9	3.5	981.3	234	51.3	1.6	226.5	17.3	83.4
SS-10	6	1059.0	211.7	41.8	1.7	170	16.0	85.7
SS-11	11.8	991.2	347.7	43.1	0.4	185.7	28.2	109.8
SS-12	0.6	1545.0	164.9	65.4	3.0	105	12.0	105.8
SS-13	1.4	1529.0	155	66.6	1.9	99.8	11.7	108.3
SS-14	8.8	929.3	239.2	40.1	1.7	170.6	27.2	100.1
SS-15	5.2	666.8	260.3	61.7	2.4	296.5	7.7	98.3
SS-16	6.0	1037.0	195	43.4	1.7	158.4	15.6	85.6
SS-17	4.8	396.0	194.9	65.1	0.4	179.3	9.5	50
SS-18	5.4	628.3	233.5	58.6	1.7	280.7	6.9	88.7
SS-19	3.2	891.2	202.7	63.4	2.0	197.9	19.4	114.8
SS-20	< 0.5	1590.0	130.5	71.0	1.6	94.6	12.2	110.8
SS-21	5.1	806.2	341.4	43.4	2.0	222.3	16.6	75.4
SS-22	2.0	865.4	186.7	53.8	2.7	175.6	17.1	97.9
SS-23	5.8	760.5	345.1	113.2	2.2	214.9	16.9	72.5
SS-24	5.4	1067.0	207.4	40.3	1.9	158.2	16.3	84.6
SS-25	5.6	700.2	320	55.8	2.0	266.1	10.6	93.6
SS-26	3.2	910.2	228.5	44.2	2.0	202.7	15.4	74
SS-27	3.3	233.0	44.5	11.9	< 1.0	52.7	5.0	16.1
SS-28	4.7	747.6	354.4	45.7	2.4	215.7	17.8	75.8
SS-29	1.7	1739.0	126.7	67.8	2.0	90.2	10.7	117.5
SS-30	4.2	649.5	229.3	53.2	1.5	282.4	5.5	86.3
SS-31	9.4	934.4	252.8	41.6	1.1	178.8	29.2	107.2
SS-32	3.6	1003.0	254.4	49.7	3.2	226.7	16.9	83.2
Min-Max	< 0.5–11.8	233.0–1739.0	44.5–354.4	11.9–71.0	< 1–3.2	52.7–296.5	5.0–29.2	16.1–117.5
Mean	4.7	950.6	230.5	48.2	1.8	186.8	15.1	87.5
Kurtosis	1.18	0.49	0.60	4.64	0.42	−0.28	0.14	3.12
Skewness	0.83	0.57	−0.23	1.01	−0.02	−0.32	0.63	−1.30
Earth's crust average value	1.5	600	35	25	0.08	20	20	71

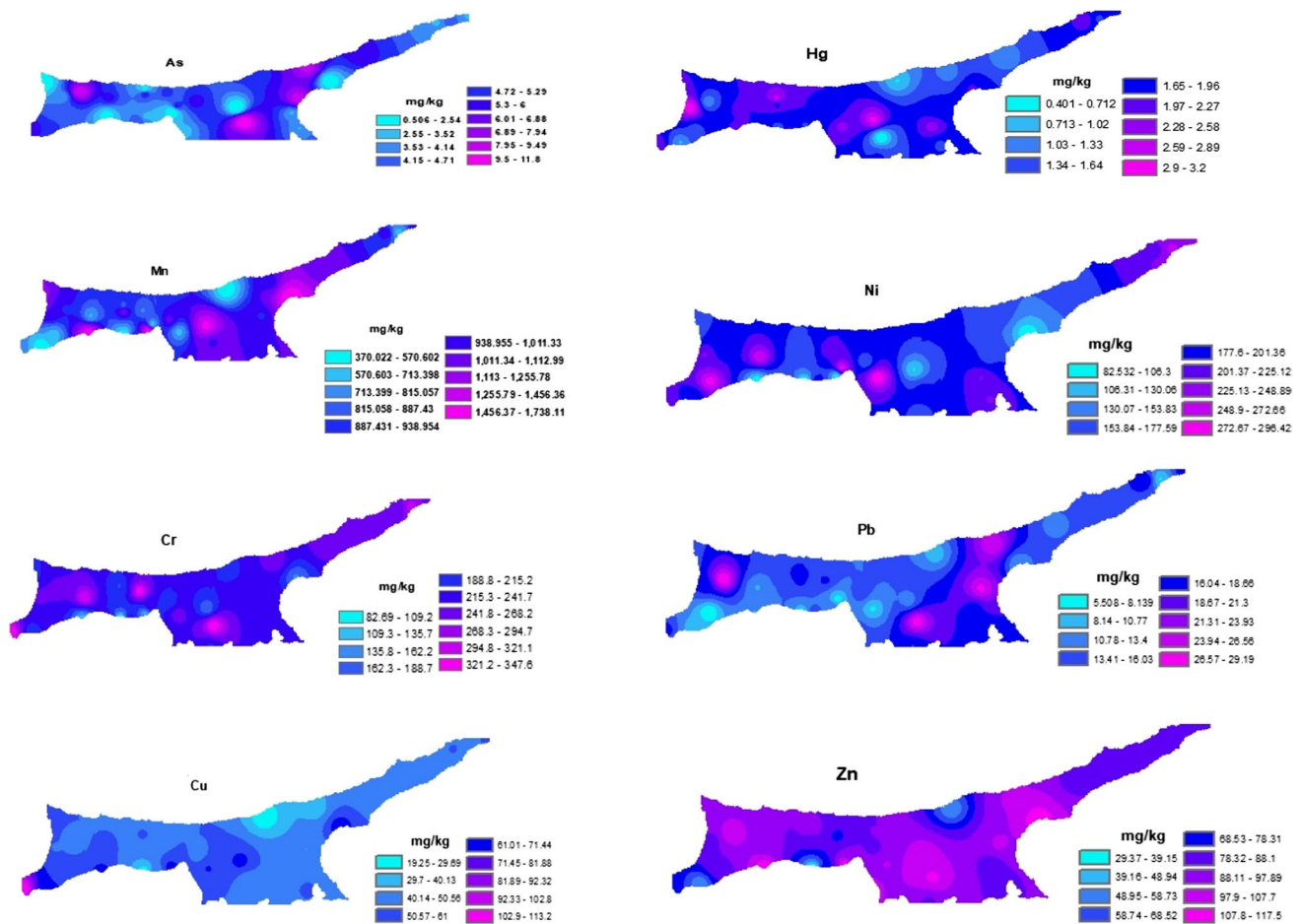
\*Uncertainties are given within 1 standard deviation

119, and 188 (mg/kg), while the mean values for Cr and Ni elements in the soil samples were higher than 40, and 50 (mg/kg) value reported in Cyprus (Yukselen 2002). Moreover, the concentration of Cu, Ni, and Pb have measured in abandoned copper mine, Lefke, Cyprus (Baycu et al. 2015), which all of those elements were higher than our results.

Also, the finding results of this study were compared with Earth's crust average values (Taylor and McLennan 1995).

The observed effects were higher than the Earth's crust average for all heavy metals (Table 3).

The distribution of HMs, taken from the geostatistical procedure that evaluates parameters at locations without sampling, is beneficial for recognizing hotspot areas with high element concentrations. The spatial variations of the HM contents in the soils from the study region of North Cyprus are shown in Fig. 2. All eight elements had different



**Fig 2** Spatial distribution of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn in soils of the study area

patterns of spatial distribution. A significant point with a high concentration of Cu was observed in the South-west edge. Also, the Ni and Cr distributions approximately had similar geographical patterns, which indicate that the two elements were released from the same source.

The  $I_{geo}$  value for As ranged from  $-2.73$  to  $2.39$ , with a mean value of  $1.01$  which indicated moderate contamination. The  $I_{geo}$  index for Mn and Cu ranged from  $-1.95$  to  $0.95$ ,  $-1.66$  to  $0.92$  with main value of  $0.08$  and  $0.36$ , respectively. This shows no/moderate contamination for Mn and Cu on average. This index for Cr and Ni ranged from  $-0.24$  to  $2.75$  and  $0.81$  to  $3.30$ , with main values of  $2.13$  and  $2.64$ , respectively. So, Cr and Ni  $I_{geo}$  indexes indicated moderate/strong contamination. The  $I_{geo}$  value of Hg was ranged from  $1.74$  to  $4.74$  with main value of  $3.91$ , where in the category of strong contamination. The  $I_{geo}$  indexes for Pb and Zn ranged from  $-2.58$  to  $-0.04$  and  $-2.73$  to  $0.14$  with main value of  $-1.00$  and  $-0.28$ , respectively. Therefore, Pb and Zn were in no contamination category. The  $I_{geo}$  value (Barkett and Akün 2018) reported in the abandoned copper mine, Yedidalga, Cyprus, showed the  $I_{geo}$  value of

$4.32$  for Cu,  $2.47$  for Pb, and  $1.94$  for Zn, while higher than our results.

According to (Jiang et al. 2013), there is four potential ecological risk index (PERI) classification, low ecological risk is represented by  $PERI < 150$ , moderate ecological risk by  $150 \leq PERI \leq 300$ , high ecological risk by  $300 \leq PERI \leq 600$ , and extremely high ecological danger by  $PERI \geq 600$ . The mean potential ecological risk index (PERI) in the soil samples of the study area was ranged from  $108$  to  $357$ , with main value of  $284$ , which indicated the moderate ecological risk category (Table 4). The corresponding relation of  $I_{geo}$  and the contamination levels are shown in Table 4.

Table 5 shows the results of human health risks through three exposure pathways in adults and children. The obtained results were in the order of ingestion  $>$  dermal contact  $>$  inhalation, except for the noncarcinogenic risk of Cr were the subjects of this study. Cr noncarcinogenic risk was in the order of ingestion  $>$  inhalation  $>$  dermal contact. The HQ, HI, and total HI for both adults and children were lower than the unit (Table 5). As a result, all HMs in the soil via ingestion, skin contact, and inhalation exhibited no substantial

**Table 4** The geo-accumulation index ( $I_{geo}$ ) and potential ecological risk index (PERI) in the soil samples of the study area

Elements	$I_{geo}^*$			PERI**		
	Min	Max	Mean	Min	Max	Mean
As	-2.17	2.39	1.06	108	357	284
Mn	-1.95	0.95	0.08			
Cr	-0.24	2.75	2.13			
Cu	-1.66	0.92	0.36			
Hg	1.74	4.74	3.91			
Ni	0.81	3.30	2.64			
Pb	-2.58	-0.04	-1.00			
Zn	-2.73	0.14	-0.28			

\*No contamination,  $I_{geo} \leq 0$ ; no/moderate contamination,  $0 < I_{geo} \leq 1$ ; moderate contamination,  $1 < I_{geo} \leq 2$ ; moderate/strong contamination,  $2 < I_{geo} \leq 3$ ; strong contamination,  $3 < I_{geo} \leq 4$ ; strong/extreme contamination,  $4 < I_{geo} \leq 5$ ; and extreme contamination,  $I_{geo} > 5$  (Jiang et al. 2013). \*\*PERI < 150 is low ecological risk,  $150 \leq PERI < 300$  is moderate ecological risk,  $300 \leq PERI < 600$  is high ecological risk, and  $PERI \geq 600$  is very high ecological risk (Zhuo et al. 2019)

**Table 5** The non-carcinogenic and carcinogenic risks assessment results for children and adults with ingestion, inhalation, and dermal pathways in the study area

	Noncarcinogenic risks for adult				Noncarcinogenic risks for the child				Carcinogenic risks			
	HQing	HQinh	HQder	HI	HQing	HQinh	HQder	HI	CRing	CRinh	CRder	TCR
As	2.50E-02	8.98E-06	2.44E-04	2.53E-02	4.69E-02	8.42E-06	4.49E-04	4.74E-02	3.24E-05	9.20E-12	4.04E-07	3.27E-05
Mn	1.09E-02	1.60E-06	4.33E-05	1.09E-02	2.03E-02	1.50E-06	7.98E-05	2.04E-02	-	-	-	-
Cr	1.23E-01	1.89E-03	4.90E-04	1.25E-01	2.30E-01	1.78E-03	9.03E-04	2.33E-01	5.31E-04	4.41E-08	1.08E-04	6.14E-04
Cu	1.93E-03	2.83E-07	2.56E-05	1.95E-03	3.61E-03	2.66E-07	4.72E-05	3.66E-03	-	-	-	-
Hg	1.80E-02	2.64E-06	7.17E-05	1.81E-02	3.37E-02	2.48E-06	1.32E-04	3.38E-02	-	-	-	-
Ni	1.49E-02	2.13E-06	2.21E-04	1.51E-02	2.80E-02	2.00E-06	4.06E-04	2.84E-02	1.46E-03	-	1.87E-04	1.60E-03
Pb	1.72E-02	1.01E-06	1.84E-04	1.74E-02	3.23E-02	9.45E-07	3.38E-04	3.27E-02	5.90E-07	-	-	5.90E-07
Zn	4.66E-04	6.85E-08	9.30E-06	4.76E-04	8.74E-04	6.43E-08	1.71E-05	8.91E-04	-	-	-	-
Total	2.11E-01	1.91E-03	1.29E-03	2.14E-01	3.96E-01	1.80E-03	2.37E-03	4.00E-01	2.02E-03	4.41E-08	2.95E-04	2.25E-03

non-carcinogenic concerns. The results were consistent with previous research by (Praveena et al. 2018) and (Varol et al. 2020) that studied surface soils of Klang district, Malaysia, and Harran Plain, Turkey, respectively. They reported the THI values < 1 for adults and children. Although, a study of health risk in soils of Jiangsu Province in China, showing that the THI values were more than the unit (3.62 for adults and 6.21 for children) (Jiang et al. 2017).

HI values indicated in the order of  $Cr > As > Hg > Pb > Ni > Mn > Cu > Zn$  for both adults and children. The total HI values for children (4.00E-01) was higher than for adults (2.14E-01). So, we concluded that children are more sensitive in the case of health effects due to HMs in soils. Also, some studies were reported high THI values for children (Edogbo et al. 2020; Mama et al. 2020; Wu et al. 2020).

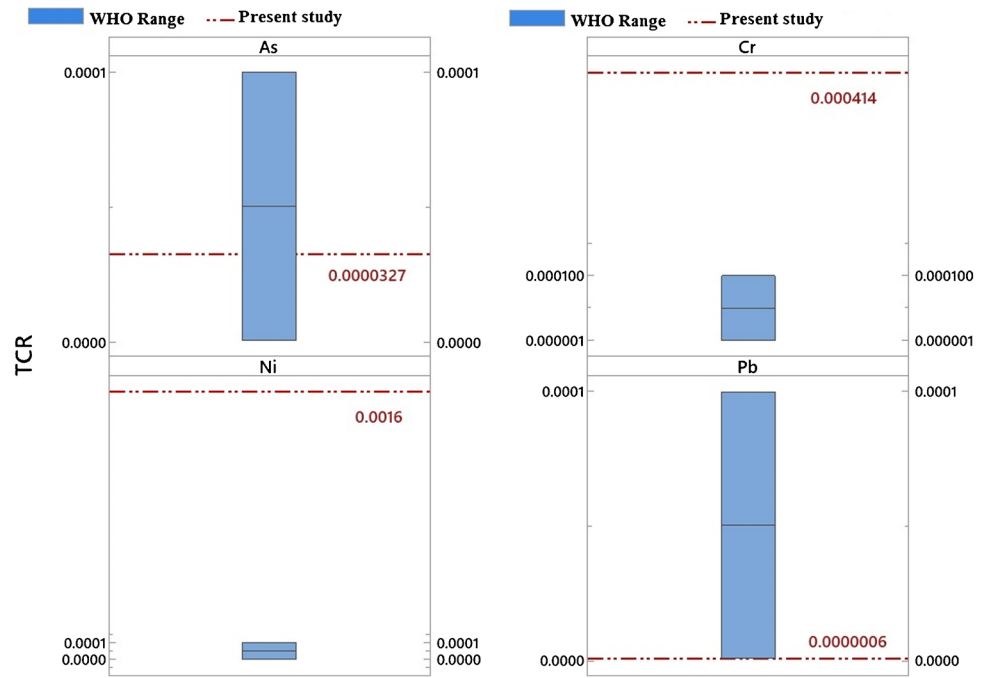
The total carcinogenic risk (TCR) values for three exposure pathways followed the order of  $TCR_{ing} > TCR_{der} > TCR_{inh}$ . CRing values followed the order of  $Ni > Cr > As > Pb$ , CRinh values were found in the order of  $Cr > As$ , and CRder  $Ni > Cr > As$  (Table 5). In this study, the total

CR (TCR) value was obtained in the order of  $Ni > Cr > As > Pb$  with a cumulative TCR value of 2.25E-03 (Table 5). The CR values of HMs by dermal contact and inhalation pathways were within the EPA standard range of  $1E-04$  to  $1E-06$  (Means 1989), except the CR values for ingestion was a bit more than the standard limit (Fig. 3). Thus, the found results for ingestion, indicating that carcinogenic risks for residential receptors need more investigation.

**Statistics analysis**

According to statistical analysis, the skewness parameter can be a positive or negative value. The HMs skewness sign demonstrates that deviation from mean value is positive or negative. In comparison, this statistical parameter is a symmetry requirement for the mean value (Abbasi 2019). In this study, the skewness of As, Mn, Cu, and Pb concentration in surface soil samples is positive, revealing their asymmetric distribution. The skewness of Cr, Hg, Ni, and Zn concentration in surface soil is negative, revealing that their

**Fig. 3** The total carcinogenic risk (TCR) mean value of As, Cr, Ni, and Pb vis-a-vis the WHO recommendation range



distribution is symmetric (Table 3). The kurtosis statistical parameter shows a measure of peakedness status.

According to the means of peakedness, it is entitled platykurtic, leptokurtic, and mesokurtic state. The kurtosis value of zero indicates a mesokurtic (normal curve). When the kurtosis parameter value has a positive sign, the curve indicates more peaked than the normal curve (leptokurtic). In contrast, the negative kurtosis value shows that the curve is less peaked than the normal curve (platykurtic) (Abbasi 2019). Table 6 shows the Spearman correlation coefficients of measured elements. A significant positive correlation was observed between the Zn with Cu ( $\rho = 0.809$ ) and Mn ( $\rho = 0.744$ ). According to the Spearman correlation analysis, the cluster analysis of variables is presented in Fig. 4. According to this cluster analysis, elements are categorized in two main similarity groups. Those groups are (As, Pb, Cr, Ni) and (Mn, Cu, Hg, Zn). This classification shows similarity of concentration.

### Conclusions

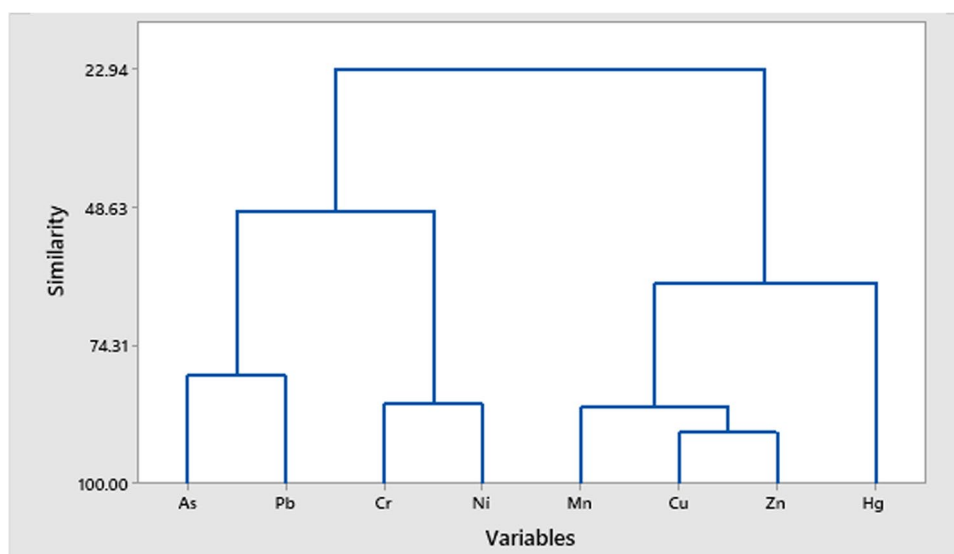
The concentrations of HMs (As, Mn, Cr, Cu, Hg, Ni, Pb, Zn) in the surface soil samples from the North area of Cyprus were investigated. The potential and ecological risks of HMs were estimated in the study area. The mean results value of HMs was found (except Pb elements) higher than the Earth’s crust average value. The mean concentration of Hg was twenty times as high as that of the background value of Earth’s crust average. Also, the Igeo value of the Hg element indicated a strong contamination level. Cr and Ni geo-accumulation indexes were obtained in moderate/strong contamination levels. The PERI results showed that 34% of the sampling sites exhibited is high ecological risk level, and the mean results showed a moderate ecological risk category. So, pollution indices-based calculation demonstrated a no contamination to a strong contamination level of contamination of the studied area

**Table 6** Correlations of the heavy metals (As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn) in the study area (Spearman’s correlation coefficients)

Parameter	As	Mn	Cr	Cu	Hg	Ni	Pb	Zn
As	1							
Mn	-0.387	1						
Cr	0.570	-0.289	1					
Cu	-0.478	0.712	-0.053	1				
Hg	-0.541	0.317	0.033	0.550	1			
Ni	0.299	-0.527	0.704	0.036	0.149	1		
Pb	0.598	0.155	0.397	-0.095	-0.092	-0.014	1	
Zn	-0.010	0.744	0.071	0.809	0.255	-0.062	0.366	1



**Fig. 4** Cluster analysis of variables of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn concentration



whereas ecological indices represented moderate ecological risk.

Potentialities of non-carcinogenic and carcinogenic health risks are from the ingestion, dermal contact, and inhalation except for the noncarcinogenic risks of Cr were ingestion, inhalation, and dermal contact of soil samples though the children are more vulnerable than the adults to any possible health risks. Also, human health risks estimation by three exposure pathways in adults and children indicated that the total HI values for children 46.5% were higher than for adults. The total CR values for the ingestion pathway were more than the standard level. Thus, the hazard indexes of the study area should be more investigated in the future.

**Author contribution** AA: Writing, modeling, and proofing. FM: Project management. ŞT: Experimental contribution. AK: Experimental contribution. YR: Sample preparation, Analysis. SA: Proofing, graphing. HZ: project supporting.

**Data availability** Not applicable.

**Code availability** Not applicable.

## Declarations

**Ethics approval** Not applicable.

**Consent to participate** Yes.

**Consent for publication** Yes, I have consent to publication.

**Conflict of interest** The authors declare no competing interests.

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