



The importance of using soil series-based geochemical background values when calculating the enrichment factor in agricultural areas

Halil Aytop · Yakup Kenan Koca ·
Suat Şenol

Received: 26 January 2023 / Accepted: 31 May 2023 / Published online: 6 June 2023
© The Author(s), under exclusive licence to Springer Nature B.V. 2023

Abstract The enrichment factor (EF) is one of the most commonly used indices for determining the source of air, water and soil pollution. However, concerns have been raised about the accuracy of the EF results because the formula leaves the choice of background value to the researcher's discretion. The EF was used in this study to assess the validity of such concerns and to determine heavy metal enrichment in five soil profiles with different parent materials (alluvial, colluvial, and quartzite). Moreover, the upper continental crust (UCC) and specific local background values (sub-horizons) were used as the geochemical backgrounds. When UCC values were applied, the soils were moderately enriched in Cr (2.59), Zn (3.54), Pb (4.50) and Ni (4.69), and significantly enriched in Cu (5.09), Cd (6.54) and As (6.64). Using the sub-horizons of the soil profiles as a background value, it was found that the soils had "moderate enrichment" by As (2.59) and "minimally enrichment" by Cu (0.86), Ni (1.01), Cd (1.11), Zn

(1.23), Cr (1.30), and Pb (1.50). As a result, the UCC reported an inaccurate conclusion indicating that soils were 3.84 times more heavily polluted than they were. In addition, the statistical analyses performed in this study (Pearson correlation analysis and principal component analysis) revealed that the percentage of clay in the soil horizons and the cation exchange capacity had strong positive relationships ($r \geq 0.670$, $p < 0.05$) with certain heavy metals (Al, Zn, Cr, Ni, Pb and Cd). These findings indicated that sampling from the "lowest horizons" or "parent materials" of the soil series would yield the most accurate results in determining the geochemical background values in agricultural areas.

Keywords Heavy metals · Pollution indices · Soil contamination · Soil map

Introduction

Humanity has always exerted pressure on the natural environment (Galuszka, 2007). Especially over the last century, activities resulting from increased industrialization have intensified this pressure (Jalali & Khanlari, 2008; Kim et al., 2020; Loska et al., 2004). Soil is one of the components of the environment essential to the clean water and food that all living things rely upon and it bears its share of the burden caused by pollution (Aytop, 2022; Soil Survey Staff, 2014).

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10653-023-01640-6>.

H. Aytop (✉)
East Mediterranean Transitional Zone Agricultural
Research of Institute, Kahramanmaraş, Turkey
e-mail: halilaytop@gmail.com

Y. K. Koca · S. Şenol
Department of Soil Science and Plant Nutrition, Faculty
of Agriculture, Cukurova University, Adana 01330, Turkey

Besides industrialization, fertilization, pesticide, and irrigation activities are among the causes of agricultural soil pollution (Akbay et al., 2022; Ateş et al., 2022; Aytıp et al., 2023; Kim et al., 2020). When these activities are carried out intensively and carelessly, they leave high levels of heavy metals in the soil (Varol et al., 2020). Heavy Metals are the leading soil pollutants, and even low concentrations have toxic effects on humans, animals, and plants (Elizabeth Rani et al., 2021; Rajendran et al., 2022). For instance, individuals exposed to high arsenic, chrome, and lead may develop hypertension disorders, internal organ failures, and cancers (Adimalla & Wang, 2018; Huang et al., 2018; Rezapour et al., 2022a; World Health Organization, 2019).

Reclamation of metal-contaminated soils is difficult, time-consuming, and costly (Akbay et al., 2022; Grandclément et al., 2017). Therefore, it is necessary to monitor the pollution levels of agricultural areas at regular intervals and to identify possible pollutant sources (Chen et al., 2015; Varol et al., 2020; Ye et al., 2019). Indices such as enrichment factor (EF), geoaccumulation index (Igeo), and contamination factor (CF) are frequently used by researchers in evaluating the pollution status of agricultural areas. This monitoring also significantly contributes to developing pollution prevention strategies (Kumar et al., 2019).

One of the indices most frequently used by researchers to determine whether pollution is human-made is EF, and its first use dates back to the 1980s (Hakanson, 1980). A simple Google Scholar search for the term “enrichment factor” yields around 3,110,000 results (January 9, 2023). This simple search gives a sense of how often researchers use EF. However, some researchers have concerns about the accuracy of EF results (Blaser et al., 2000; Githaiga et al., 2021; Reimann & Caritat, 2005). One such concern is that there is no standard for selecting reference material and this method leaves the choice of reference material to the researcher. For instance, Reimann and Caritat (2005) reported that EF results indicate different pollution levels depending on the reference material selected. In addition, they argued that EFs have as much to do with the distribution patterns of the reference element(s) as with anthropogenic contamination or pollution. While this idea may seem justified, it should be noted that not using the correct

background values in the EF formula may also give spurious results.

The background value is of great importance for accurately estimating metal pollution in soil. Only appropriately selected background values will provide consistency of results. While some researchers consider local background values (Cao et al., 2022; Kowalska et al., 2022; Mavakala et al., 2022; Rezapour et al., 2022b) for their calculations, others use different sources, such as the upper continental crust (UCC) as the basis for their background values (Taşpınar et al., ; Islam et al., 2022; Kafle et al., 2022; Aytıp, 2022; Yılmaz, 2022). Regional—that is, those taken from a wider area than local—background values are also used in many studies (Dytłow & Górka-Kostrubiec, 2021; Hu et al., 2019). However, soil can be found to have different physical and chemical properties from one part to another of even a small area. Even soils classified in the same series may differ in topsoil texture (Aytıp & Şenol, 2022a). In addition, soils have many features that change daily and seasonally (Soil Survey Staff, 2014). Given such complexity, it would not be the right approach to select the background values needed to determine the pollution level of agricultural areas from different regions and countries.

The general opinion accepted by researchers is that heavy-metal concentrations are higher in the topsoil than in the subsoil. One of the reasons for this thought is the ability of organic matter to retain heavy metals in high concentrations (Kavamura & Esposito, 2010; Kwiatkowska-Malina, 2018). Because, in general, the amount of organic matter is higher in the top horizon of the soil. Although this holds true for areas with anthropogenic pollution, concentrations may yet vary depending on the content of the parent material forming the soil and other factors that are instrumental in soil formation. For example, clay percentage and cation exchange capacity (CEC) can also significantly affect heavy-metal distribution in the profile of a given soil horizon. Let us say that the soil's clay content and CEC increase from the A horizon to the C horizon. This increase causes some cations, including metals, to be present in higher concentrations in the sub-horizons. This being the case, it must be realized that using the UCC and regional background values instead of specific local background values can significantly alter EF results. The word "specific" here denotes the lowest horizon of each sampling point.

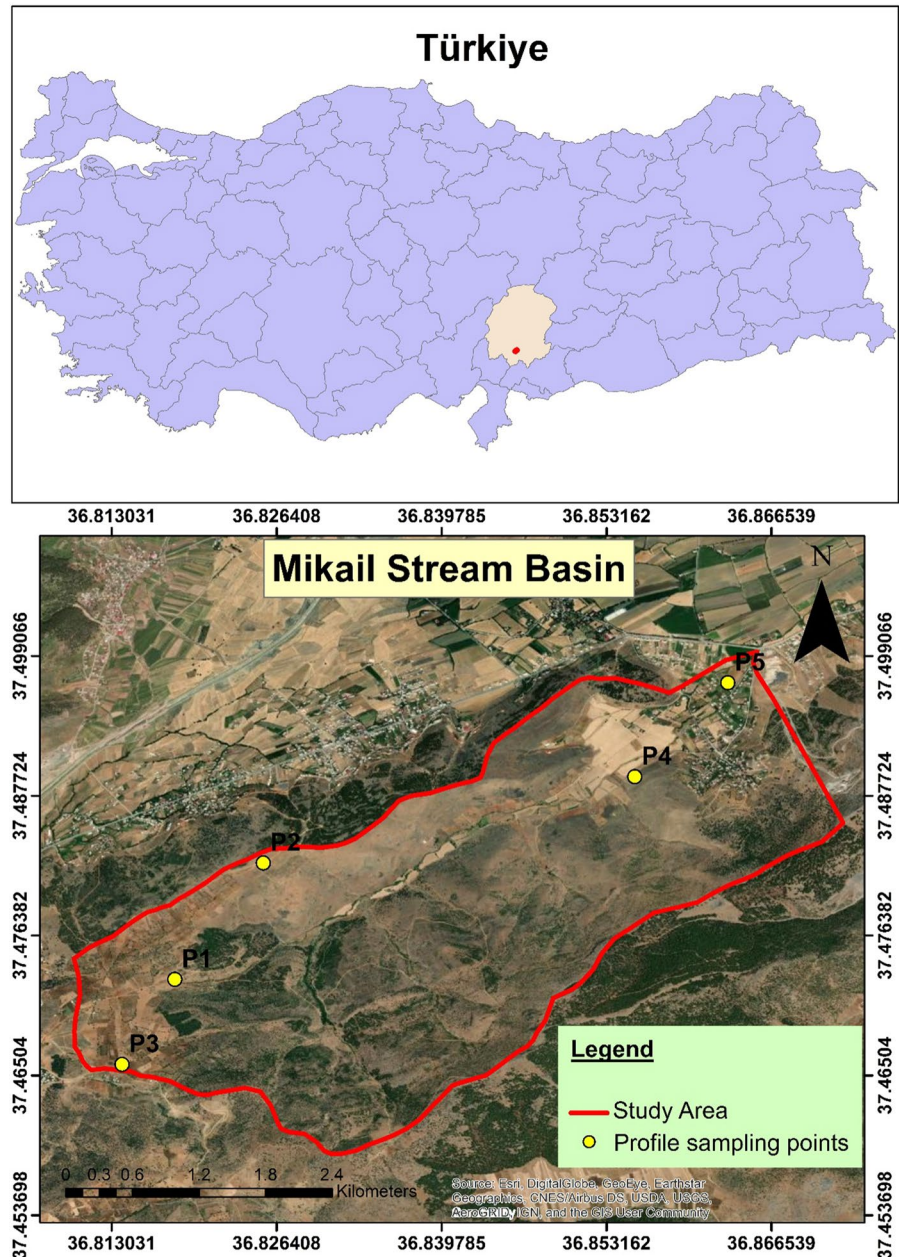
The main aims of our study were: (a) to use both background values obtained from the sub-horizon of each soil profile and UCC background values and to show how different background values affect degrees of contamination, and (b) to discuss vertical heavy-metal distribution in soil profiles and the relationship between clay percentages and that distribution.

Materials and methods

Study area

The study was carried out in the Mikail Stream Basin located in the Mediterranean region of Türkiye. The Mikail Stream Micro Basin is found between 37° 27' and 37° 27' E and 36° 48' and 36° 51' N (Fig. 1). The basin is 462 to 886 m above sea level and covers

Fig. 1 Location of the study area and soil profile sampling points (P1-P5)



an area of 11.80 km². The Mediterranean climate is dominant in the study area. The climate is characterised by humid, cool winters and hot, dry summers. The annual average precipitation and temperature in the study area are 719 mm and 16.7 °C, respectively (Aytop & Şenol, 2022a). The soil temperature regime is thermic, and the soil moisture regime is xeric of study (Soil Survey Staff, 2014). Three different parent materials have been identified in the basin: alluvial, colluvial and quartzite (Fig. 2). While the soils formed on the alluvial parent material are located in the flat and nearly flat areas in the north-eastern part of the basin, the soils formed on the quartzite and colluvial parent material are mainly in the upper parts of the basin.

The study area has been classified into six slope classes based on the slope percentage, which varies from 0 to 73.4%. Most of the study area (78.21%) has a slope of 12%. The basin's flat and nearly flat areas are 10.88% of the total area. Five land-use types were identified in the study area: forest (69.20%), annual plants (10.48%), orchards (9.53%), pasture (9.13%) and settlement (1.04%). Dominant crops in the basin include wheat, barley, maize, vegetables, grapes and olives. The irrigation source of the basin is a stream passing through the middle of the study area. The dominant irrigation system in the study area is flood irrigation. Irrigation is possible in the lower parts of the basin, where the slope is flat, and wheat, corn and

vegetables are grown predominantly in these regions. Türkiye's fertility and its irrigation of olive and grape fields are more limited than in European countries (İrget et al., 2007). There is a similar situation in the study area. There is no irrigation in the higher parts, and mainly olive, barley and grape cultivation is done. There is a more intensive use of fertilizers and pesticides in annual plants in the basin. The basin soils are nonsaline, noncalcareous and have good drainage. There are no mining or industrial activities in the basin.

Soil series were determined according to the traditional soil survey method. First, the slope map, elevation map, geological map and satellite images of the study area were examined. After these examinations, the regions where profile pits would be opened were determined in the field. Later, profile pits were opened in the field and soils with different parent materials and morphological characteristics were defined. Finally, the soil profiles were classified according to the Soil Taxonomy (Soil Survey Staff, 2014). The subgroup of the soil series is presented in Table 1.

Soil sampling and analyses

This study excavated and sampled five soil profiles. According to the soil taxonomy (Soil Survey Staff, 2014), the soils were classified as entisols

Fig. 2 Parent material **a** and elevation **b** map of the study area

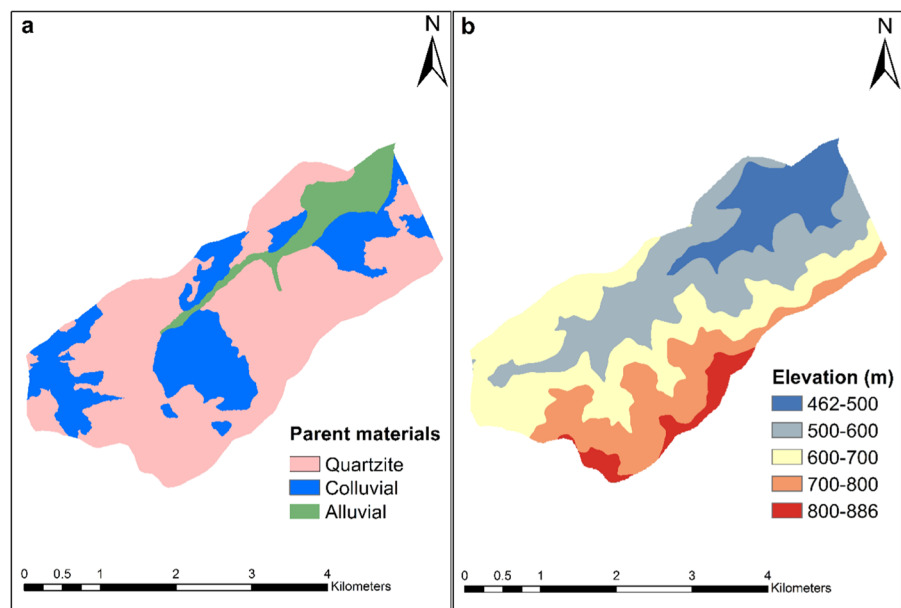


Table 1 Basic morphological, physical and chemical properties of soil profiles (Aytop & Şenol, 2022b)

Soil Profiles	Hor	Depth (cm)	Parent Materials	Subgroup of soil series	Soil color (moist)	Texture	CaCO ₃ (%)	EC (dS/m)	pH	OM (%)	Clay (%)	CEC (me/100 g)
P1	A	0–12	Quartzite	Typic Xerorthents	2.5 YR4/6	CL	0.40	0.160	6.55	1.35	27.30	8.70
	C	12–80			2.5 YR4/6	C	0.40	0.099	6.11	0.34	50.00	13.16
P2	A	0–12	Quartzite	Inceptic Haploxeralfs	7.5 YR4/4	SL	0.56	0.075	6.11	1.08	19.50	5.08
	BA	12–32			2.5 YR4/6	SCL	0.48	0.077	5.73	0.40	26.90	7.76
P3	Bt	32–60		Typic Xerorthents	2.5 YR3/6	C	0.56	0.083	5.68	0.56	52.10	19.81
	A	0–9	Quartzite		5 YR4/6	SCL	0.64	0.247	6.91	1.97	28.90	11.28
P4	C	9–28		Ultic Haploxeralfs	2.5 YR4/8	C	0.64	0.244	6.88	0.50	54.30	15.17
	A	0–15	Colluvial		10 YR3/4	SL	0.56	0.115	5.67	1.69	17.40	5.75
P5	E	15–42		Typic Xerofluvents	10 YR5/6	SL	0.56	0.117	5.53	0.44	16.40	4.24
	Bt1	42–79			2.5 YR4/8	CL	0.48	0.091	5.50	0.43	37.40	12.87
P5	Bt2	79–110			2.5 YR5/8	C	0.48	0.078	4.92	0.54	45.80	12.83
	Ap	0–20	Alluvial		10 YR4/3	L	0.56	0.249	6.73	1.04	22.70	11.76
P5	A2	20–33			10 YR4/4	SCL	0.64	0.208	6.62	1.41	22.70	9.26
	C1	33–72			10 YR5/6	SCL	0.72	0.170	6.87	0.73	20.60	9.24
P5	C2	72–100			10 YR5/6	L	0.48	0.161	6.89	0.31	16.40	6.56

(P1, P3 and P5) and alfisols (P2 and P4). Soil horizons and their thicknesses were determined in the study area—see Table 1. From the horizons of each soil profile, 15 degraded soil samples were taken on a horizon basis. Combining three random sub-samples created a composite soil sample at each horizon. The collected samples were put in polythene bags and taken to the laboratory for some physical and chemical analysis. The soils were dried (in the air and in the oven) to remove moisture and crushed with a wood mallet. The dried soil samples were sieved through sieves (2 mm and 0.5 mm). The sieved soils were used to determine the organic matter (OM) percentage with the Walkley–Black method, texture (percent clay, percent sand and percent silt) with the hydrometer method (Gee & Bauder, 1979), and pH with a glass electrode (in saturated soil). The sodium acetate method (Rhoades, 1982) determined the cation exchange capacity, and the lime analysis was determined using the Scheibler calcimeter (Soil Survey Lab. Staff, 1992). EC (in saturated soil) measurement was determined using an EC meter (Soil Survey Lab. Staff, 1992). The moist Munsell colour was described in the study area (Soil Survey Staff, 2014).

In addition, in this study, eight heavy metals, including Pb, As, Cr, Ni, Al, Cu and Zn, were analyzed in the soil samples. These metals were chosen due to their substantial role in soil pollution (Aytöp, 2022; Rinklebe et al., 2019). The samples were digested in teflon vessels, including a mixture of concentrated 10 ml HCl and HNO₃ (3:1) (USEPA, 1998) the Cem Mars 6 microwave device. After the digested solutions were passed through Whatman filter paper (Grade 42, 2.5 µm), their final volume was made up to 50 ml with ultrapure water. Concentrations of elements were measured by an ICP-OES (Agilent 5100, USA).

Quality control was accomplished using certified reference material (LGC6187, river sediment). Certified Reference Material (CRM) was digested and analyzed with every 15 samples in this study. The data were analyzed using mean values. The recovery of elements in the CRM varied from 88.8 to 101.4%. Standard solutions were provided by ICP multi-element standard solution IV (Merck, Germany).

Enrichment factor (EF)

The Enrichment Factor is a frequently used tool to determine whether metals sources in soil, sediment and water are of lithogenic or anthropogenic origin. EF is calculated using the formula below.

$$EF = \text{sample} \left(\frac{C_i}{C_{ref}} \right) \setminus \text{background} \left(\frac{C_i}{C_{ref}} \right) \quad (1)$$

Here, C_i denotes metal concentration in the soil sample, and C_{ref} denotes the geological background concentration. Since it is more stable, Al was chosen as the reference element (Varol et al., 2020) for this study. The geochemical background is generally referred to as the elemental content of the environment not affected by human activities (Gałuszka, 2007; Gough, 1993). Therefore, in this study, together with The Upper Continental Crust (UCC) values (Rudnick & Gao, 2004), the background values of the sub-horizons dominated by lithogenic effects rather than human activities were used. The background values of the upper continental crust (UCC) were taken as 81,500 mg kg⁻¹, 92 mg kg⁻¹, 67 mg kg⁻¹, 47 mg kg⁻¹, 28 mg kg⁻¹, 17 mg kg⁻¹, 4.8 mg kg⁻¹ and 0.09 mg kg⁻¹ for Al, Cr, Zn, Ni, Cu, Pb, As and Cd, respectively. EF values can be classified under five groups: (I) $EF < 2$, minimal enrichment; (II) $2 \leq EF < 5$, moderate enrichment; (III) $5 \leq EF < 20$, significant enrichment; (IV) $20 \leq EF < 40$, very high enrichment; (V) $40 \leq EF$, extremely high enrichment (Aytöp, 2022; Sutherland, 2000).

Statistical analysis

This study used Principal Component Analysis (PCA) and Pearson correlation analysis to reveal the relationships between heavy metals and some soil properties. The data set was suitable for PCA based on the KMO score (0.64) and Bartlett's sphericity test value ($p < 0.001$). Varimax rotation and Kaiser normalization were used to perform PCA. Varimax rotation reduces the amount of variables that place heavy stress on each component, making it easier to interpret PCA results. Two components with eigenvalues > 1 were found by PCA in the current investigation and accounted for 78.13% of the

total variance. All examined data were standardised using z-scale transformation before PCA.

Results

Basic chemical and physical properties of soil profiles

For this study, five different soil profiles (SPs) were

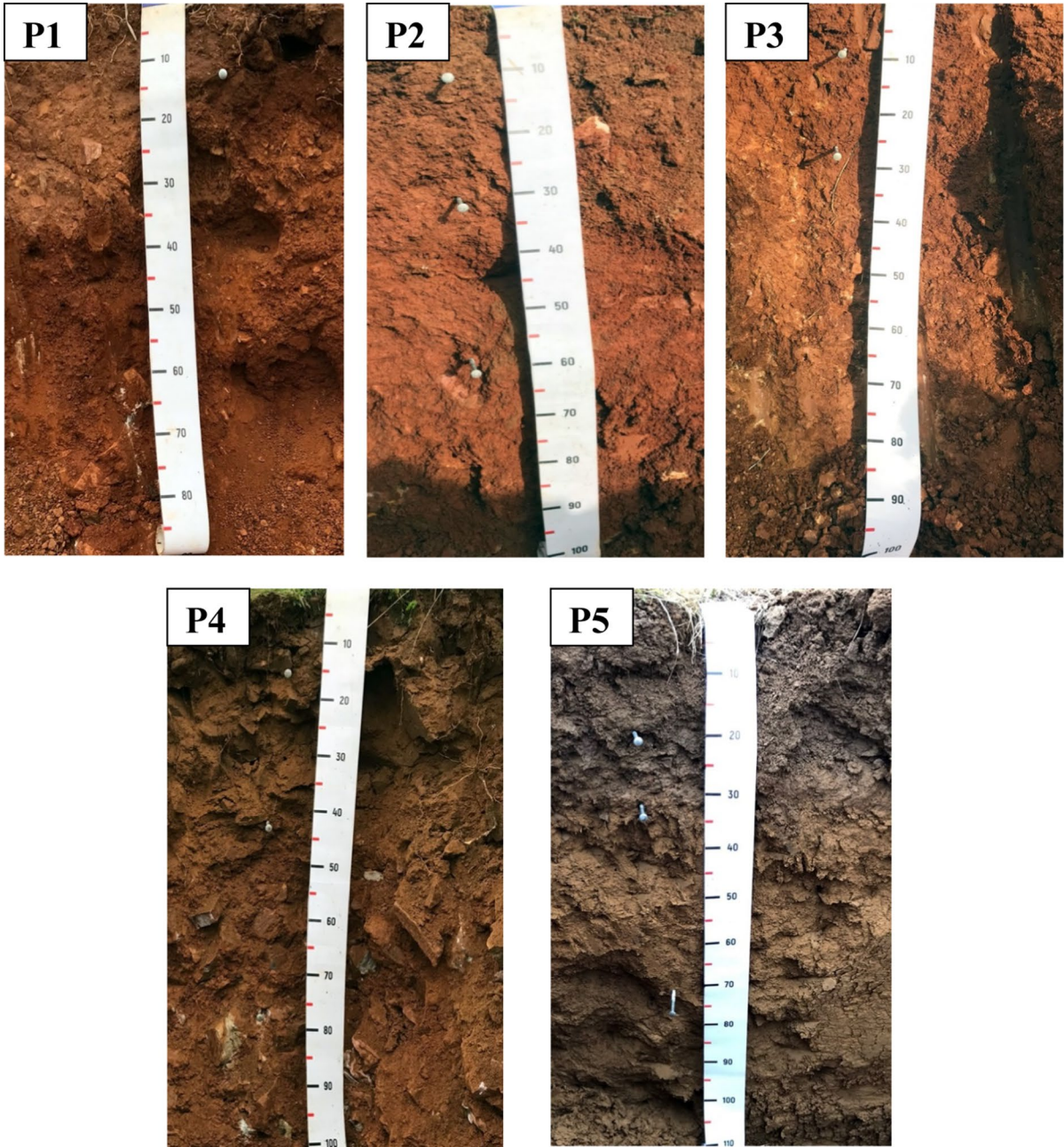


Fig. 3 Photographs of analysed five soil profiles

examined (Fig. 3). The studied SPs were classified (Soil Survey Staff, 2014) into the following ordos: entisols and alfisols (Table 1). Soils formed on P1, P2 and P3 quartzite parent material, P4 coluvial parent material and P5 alluvial parent material. Since P1, P3 and P5 are very young soils, they do not have a defining horizon other than the ochric epipedon. P2 and P4 have an argillic horizon representing clay deposition. Also, among the defining horizons of P4 is the eluvial horizon albic. The pH of the soil profiles varies between 4.51 and 6.91. The organic matter (OM) content of the soils is very low. Soils are non-saline ($EC < 1 \text{ dS m}^{-1}$) and non-calcareous ($\text{CaCO}_3 < 1\%$) throughout the profile (Table 1). Clay percentages and cation exchange capacities (CEC) increase from the top-horizons to the subhorizons in soils except for P5. P5 represents alluvial soils with flat and nearly flat slopes where intensive agricultural practices are performed. These soils consist of materials brought by rivers at different times. Some of the physical and chemical analysis results of the SPs are presented in Table 1 (Aytop & Şenol, 2022b).

Total metal content of soils

The total metal content of the soils and basic statistical data are shown in Table 2. The mean concentrations of the metals in the SPs in the study area are listed as $\text{Al} (21,982) > \text{Ni} (57) > \text{Zn} (52) > \text{Cr} (51) > \text{Cu} (41) > \text{Pb} (16) > \text{As} (5.98) > \text{Cd} (0.26)$ from the most abundant to the least abundant (Table 2). The concentration of Al in the soil was higher compared to Ni, Zn, Cr, Cu, Pb, As and Cd; it possibly originates explicitly from natural sources. The metal content of the soils increases gradually towards the sub-horizons, except for P5. In P5, the metal concentrations in the horizons were irregular. In soil P5, the A2 horizon revealed enrichment with As, while in the C2 horizon, a significant decrease in As was observed. There was an albic horizon in P4. This horizon is a mineral layer where clay and some metals suffer eluvial loss (Soil Survey Staff, 2014; WRB, 2015). Therefore, it is expected that some metal contents are less in other horizons than in the E horizon.

Table 2 Heavy metal concentrations and introductory statistics in the horizons of soil profiles

Soil Profiles	Hor	Al	Zn	Cr mg/kg	Ni	Cu	Pb	As	Cd
P1	A	19,203	56.35	61.36	77.36	18.06	17.51	3.17	0.003
	C	33,423	88.73	86.82	136.65	32.68	21.84	3.37	0.173
P2	A	14,270	30.24	46.00	35.26	8.76	10.24	2.19	0.043
	BA	21,732	39.75	57.12	57.49	14.70	14.04	2.83	0.087
	Bt	44,289	85.33	91.20	109.60	89.51	15.57	5.78	0.938
P3	A	25,973	57.10	50.32	51.43	76.18	20.79	17.63	0.433
	C	48,036	84.92	73.58	85.62	86.42	26.61	18.43	1.088
P4	A	8553	27.67	32.13	19.82	5.65	10.88	1.88	0.027
	E	6758	28.37	24.80	25.12	7.94	10.33	0.44	0.065
	Bt ₁	25,936	45.51	49.96	58.10	18.23	16.20	0.75	0.278
	Bt ₂	15,191	41.32	41.89	54.61	19.60	17.93	10.16	0.141
P5	Ap	14,226	57.97	35.55	38.63	51.23	14.15	10.49	0.187
	A2	18,652	43.84	39.39	37.54	62.45	15.03	1.51	0.094
	C1	18,579	50.81	45.54	42.36	69.32	14.52	9.65	0.317
	C2	14,913	39.67	34.62	31.24	61.67	9.76	1.36	0.046
Mean		21,982	52	51	57	41	16	5.98	0.261
Maximum		48,036	89	91	137	90	27	18.43	1.088
Minimum		6758	28	25	20	6	10	0.44	0.003
SD		11,944	20.31	19.60	32.56	30.58	4.75	5.96	0.33
CV		54.33	39.18	38.16	56.74	73.69	30.24	99.72	125.86

Analysis of enrichment factor

When calculating EF, each profile’s top horizon was considered. These horizons were the A horizon for P1, P2, P3, and P4 and the Ap horizon for P5. In this study, two different background values were used. The upper continental crust (UCC) values described by Rudnick and Gao (2004) and metal concentrations of the sub-horizons of each profile were used as the geochemical background value. EF values calculated according to different background values and their basic statistical data are given in Table 3. When UCC was used as the background value, the mean EF values of the metals ranged from 2.59 to 6.64. The maximum EF values were recorded for As, Cd and Cu. According to these results, the soils were moderately enriched in Zn, Cr, Ni and Pb, and significantly enriched in Cu, As and Cd (Table 3). When sub-horizontal soils were used as background values, minimal EF values (< 1) were found for metals except for Arsenic (Table 3). The mean EF values of the metals are listed as As (2.59) > Pb (1.50) > Cr (1.30) > Zn (1.23) > Cd (1.11) > Ni (1.01) > Cu (0.86).

It was determined that the soils were “moderately enrichment” by As and “minimal enrichment” by Pb, Cr, Zn, Cd, Ni and Cu. In this study, when UCC was used as the background value instead of the sub-horizon, It was observed that metals enriched on average 3.84 times in soils. This ratio was highest in Cd (5.89 times) and Cu (5.92 times). These results showed how different background values could change the EF results.

Statistical analysis

This study used Pearson correlation analysis and principal component analysis to determine the relationships between metal contents in soil profiles and some physical and chemical soil properties. The results showed that strong positive correlations existed among Clay, CEC, Al, Zn, Cr, Ni, Pb and Cd ($r > 0.7$; $p < 0.01$), indicating that these soil properties in the soil profiles were derived from similar sources (Table 4).

The first component (C1) had strong positive loadings (> 0.7) on Clay, Al, Cr, Ni, Zn, CEC,

Table 3 The enrichment factor values of soil profiles according to different background values

Soil Profiles	EF values calculated using UCC*						
	Zn	Cr	Ni	Cu	Pb	As	Cd
P1	3.57	2.83	6.99	2.74	4.37	2.80	0.14
P2	2.58	2.86	4.29	1.79	3.44	2.60	2.73
P3	2.67	1.72	3.43	8.54	3.84	11.52	15.10
P4	3.94	3.33	4.02	1.92	6.10	3.72	2.86
P5	4.96	2.21	4.71	10.48	4.77	12.52	11.88
Mean	3.54	2.59	4.69	5.09	4.50	6.64	6.54
Min	2.58	1.72	3.43	1.79	3.44	2.60	0.14
Max	4.96	3.33	6.99	10.48	6.10	12.52	15.10
SD	0.98	0.63	1.37	4.11	1.03	4.95	6.53
CV	27.70	24.26	29.18	80.59	22.77	74.63	99.89
	EF values calculated using sub-horizons						
P1	1.11	1.23	0.99	0.96	1.40	1.64	0.03
P2	1.10	1.57	1.00	0.30	2.04	1.18	0.14
P3	1.24	1.26	1.11	1.63	1.44	1.77	0.74
P4	1.19	1.36	0.64	0.51	1.08	0.33	0.34
P5	1.53	1.08	1.30	0.87	1.52	8.06	4.29
Mean	1.23	1.30	1.01	0.86	1.50	2.59	1.11
Min	1.10	1.08	0.64	0.30	1.08	0.33	0.03
Max	1.53	1.57	1.30	1.63	2.04	8.06	4.29
SD	0.18	0.18	0.24	0.51	0.35	3.11	1.80
CV	14.21	13.94	23.87	59.68	23.20	119.65	162.39

*UCC Upper continental crust

Table 4 Pearson's correlation coefficients (r) between heavy metal concentrations with soil properties of different soil profiles

	pH	OM	Clay	CEC	Al	Zn	Cr	Ni	Cu	Pb	As	Cd
pH	1	–	–	–	–	–	–	–	–	–	–	–
OM	0.314	1	–	–	–	–	–	–	–	–	–	–
Clay	–0.227	–0.376	1	–	–	–	–	–	–	–	–	–
CEC	–0.043	–0.223	0.877**	1	–	–	–	–	–	–	–	–
Al	0.170	–0.264	0.849**	0.837**	1	–	–	–	–	–	–	–
Zn	0.283	–0.215	0.803**	0.835**	0.885**	1	–	–	–	–	–	–
Cr	0.022	–0.266	0.817**	0.748**	0.886**	0.874**	1	–	–	–	–	–
Ni	–0.041	–0.343	0.842**	0.733**	0.801**	0.887**	0.952**	1	–	–	–	–
Cu	0.618*	0.026	0.351	0.610*	0.639*	0.636*	0.389	0.291	1	–	–	–
Pb	0.219	–0.025	0.788**	0.670**	0.760**	0.772**	0.645**	0.683**	0.442	1	–	–
As	0.407	0.209	0.413	0.481	0.466	0.479	0.226	0.176	0.617*	0.695**	1	–
Cd	0.178	–0.175	0.707**	0.783**	0.877**	0.729**	0.631*	0.502	0.742**	0.624*	0.640*	1

** $P < 0.01$, * $P < 0.05$

Cd, and Pb, and C1 accounted for 60.1% of the total variance (Table 5). These eight soil properties exhibited strong positive correlations with each other. Thus, they were mainly controlled by natural sources.

The second component (C2) had strong positive loading (>0.734) on pH, Cu and As, and C1 accounted for 17.9% of the total variance (Table 5). As a result of these data, it was concluded that the

source of Cu and As, which is dominant in the second component, is anthropogenic and lithogenic.

Discussion

The present study sought to reveal the inconsistencies that may arise when using different background values to calculate EFs. For this purpose, a number of soil properties and the heavy metal contents of five soil profiles formed from different parent materials were investigated. The geochemical background values of the heavy metals used in this study were obtained from the upper continental crust (UCC) and heavy metal concentrations of the lowest horizons of the soil profiles. In addition, both a Pearson correlation analysis and a principal component analysis were performed to determine the relationships between the heavy metals and certain other soil properties.

The strong correlation between the examined heavy metals indicated that they originated from similar sources or were interdependent (Baltas et al., 2020; Tholkappian et al., 2018; Wang et al., 2020). The Pearson correlation analysis showed that the presence of Al, Zn, Cr, Ni, Pb, and Cd in the soil profiles was significantly correlated with the lithogenic properties (clay content and CEC) of the soils (Table 4). Similarly, Rajmohan et al. (2014) reported that clay exhibits a strong positive correlation with certain heavy metals ($p \leq 0.01$) and that a high clay content increases heavy metal concentrations in soils.

Table 5 Principal component analysis of pH, OM, Clay, CEC and heavy metals in soil profiles

	C1	C2
pH	–0.052	0.834
OM	–0.400	0.539
Clay	0.957	–0.090
CEC	0.897	0.147
Al	0.936	0.226
Zn	0.912	0.265
Cr	0.917	–0.037
Ni	0.914	–0.141
Cu	0.485	0.734
Pb	0.769	0.351
As	0.398	0.734
Cd	0.773	0.408
Eigenvalues	7.216	2.159
% of Variance	60.137	17.995
Cumulative %	60.137	78.132

Using Kaiser normalization varimax

As a result of this relationship, as the clay percentage increases, the heavy metal concentrations in the soils also increase. This increase is also related to the cation exchange capacity, as soils with high cation exchange capacities can contain high metal concentrations.

The PCA analysis performed using varimax rotation enabled the identification of two main components with eigenvalues > 1 (Table 5). The first was loaded by Al, Zn, Cr, Ni, Pb, Cd, clay content, and CEC. The aforementioned heavy metals were positively correlated with clay content and CEC ($r \geq 0.670$, $p < 0.05$). PC1 can be better explained by the natural accumulation of heavy metals in soils due to the chemical process occurring in the bedrock. The second component was loaded by As, Cu, and pH. PC2 can be explained by anthropogenic effects (Baltas et al., 2020; Chandrasekaran et al., 2015; Taşpınar et al., 2022). As the pH decreased, the solubility of heavy metals in the soil solution increases (Kiekens, 1983). Many other researchers have found a strong relationship between Cu and pH in soil (Bayraklı et al., 2023; Sungur et al., 2015; Wei et al., 2020). Heavy metals can be released into the environment by anthropogenic processes, such as industrialization, urbanization, and agriculture (Aytop, 2022; Rezapour et al., 2022b), as well as by many natural processes and sources, such as rock weathering and parent material (Wuana & Okieimen, 2011; Durand, 2012; Otunola & Ololade, 2020). No industrial operations occur in the study area, where agriculture is the primary activity. It is also located far from the city center (Aytop & Şenol, 2022a). Therefore, the anthropogenic sources of As and Cu in the soil are thought to be agricultural activities. Some researchers have reported that agricultural soils often have high As and Cu concentrations due to using fertilizers, animal manures and pesticides (Chen et al., 1997; Kabata-Pendias, 2011; Varol et al., 2020; Ateş et al., 2022; Aytop, 2022).

The texture analysis results revealed that the amount of clay increased towards the sub-horizons in all of the profiles except P5, which indicated that the clays in the soil profiles were leaching towards the sub-horizons. The movement of the clay particles to the lower layers is a complex process and is more common in climates with abundant rainfall (Ciolkosz et al., 1996; Elliott & Drohan, 2009). As further evidence of this, an argillic horizon was observed in both

P2 and P4 which is an indicator of clay illuviation (Soil Survey Staff, 2014). The parent material is very effective on clay minerals variety and amounts of the soils (Kome et al., 2019). For instance, soils with the parent material of limestone can be richer by the percentage of clay than soil with serpentine parent material (Soil Survey Staff, 2014).

Similar to our results, those of numerous other researchers indicated that the heavy metal concentration in soil increases in direct proportion to the percentage of clay (Bayraklı et al., 2023; Li et al., 2019; Rajmohan et al., 2014; Tian et al., 2023; Wang et al., 2022). Because there are cations in heavy metals, they can be retained in substantial amounts in clay soils. Clays are often used for water filtration given their heavy metal binding properties (Foorginezhad et al., 2022; Ghasemi et al., 2023; Kinoti et al., 2022; Senanu et al., 2023). They also appear to be one of the most important indicators of soil quality (Blanco-Canqui & Lal, 2008) and heavy metal availability in soil (Kim et al., 2015; Kome et al., 2019). Given that clays are mineral soil colloids with negative electrical charges (Kerr, 1952; Kumari & Mohan, 2021), they retain the nutrients (positively charged cations) necessary for the survival of plants on their surfaces. Hence, soils rich in clay have a high cation exchange capacity (Drake & Motto, 1982). In this study, the accumulation of heavy metals in the subsoil rather than the topsoil pointed to the leaching of mobilized metals into the soil profiles together with the clays (Table 2). Li et al. (2017) reported that certain heavy metals accumulate in the sub-horizons by means of leaching.

In addition, heavy metal concentration and CEC increased in direct proportion to the percentage of clay toward the lower layers of the first four profiles. The amount of clay in P5 did not increase toward the lower horizons and was instead irregularly distributed. These findings are consistent with those of Sağlam and Dengiz (2015), who discovered that the percentages of clay in the horizons of soils with alluvial parent materials are more unevenly distributed than in soils composed of different parent materials. Characteristic differences between profiles indicate the diversity of natural processes involved in forming and developing soils (Hazelton & Murphy, 2016; Rezapour et al., 2022b). Here, P5 comprised soil with alluvial parent materials, which are distinguished by the complexity of their development on the basis of

geological and climatic factors (Kumar et al., 2007; Loaiza-Usuga et al., 2022; Villar, 1996). Soils consisting of alluvial parent materials are young soils whose horizons generally reflect the properties of the materials deposited by rivers or streams at different times (Soil Survey Staff, 2014; WRB, 2015). Moreover, considering that P5 is located in the basin area with the most intensive agricultural production, it should not be forgotten that human activities (Aytop, 2022; Rezapour et al., 2022b) can effectively cause differences between profiles. Consequently, the textures of soils with alluvial parent materials may be non-uniform throughout a profile, which can cause irregularities in clay percentage and heavy metal concentration in horizons.

The sources of heavy metal concentrations in soils can be determined using the EF (Rezapour et al., 2022b; Varol et al., 2020), but the selection of background values in EF calculations is left to the discretion of researchers (Anderson & Kravitz, 2010; Githaiga et al., 2021). This approach raises concerns about the accuracy of results (Githaiga et al., 2021). Although no significant heavy metal contamination was found in the soils in this study, the EF values calculated using the UCC revealed that the soils were significantly contaminated (Table 3). Indeed, the concentrations derived using the UCC gave the highest enrichment values for all of the heavy metals, while the sub-horizon background values gave the lowest EFs. Use of the UCC suggested that the soils were 3.84 times more contaminated with heavy metals on average. This result justified our concerns that the use of background values that do not reflect the properties of the parent material will give rise to inaccurate EF results.

Some researchers stated that the use of average concentrations obtained using the UCC overlooks the natural geochemical variation and may yield unrealistic results (Anderson & Kravitz, 2010; Dytłow & Górka-Kostrubiec, 2021; Githaiga et al., 2021). However, to address this problem, they suggested the use of the mean local background values. While this suggestion may appear valid, the use of a single background value for an entire agricultural area is not appropriate because the relief, time, vegetation, climate (precipitation, temperature) and parent material all come to the fore during soil formation processes (Aytop & Şenol, 2022a; Wilson, 2019). These processes also determine the chemical content of soils.

Therefore, choosing the background values from the parent materials of the soil series would be a more appropriate approach. Furthermore, if there is heavy metal contamination in the soils caused by the parent material, it would indicate that the contamination is of lithogenic rather than anthropogenic origin.

Conclusion

The present study's results revealed that using different background values in agricultural soils changes the EF results. Heavy metal concentrations in the sub horizons of the soil profiles provided the lowest contamination values, whereas the UCC values resulted in the highest EF values. More specifically, using UCC as a background value generated false results, showing that the soils were, on average, 3.84 times more severely contaminated with heavy metals. The statistical methods used in this study revealed that the clay content and cation exchange capacity was strongly related to ($r \geq 0.670$, $p < 0.05$) the heavy metal concentrations in the soils. It was also determined that the vertical distributions of heavy metals in the horizons of soils with different parent materials differed according to their clay percentages and cation exchange capacities.

Based on the results of this study, we offer researchers two suggestions for selecting the background values required when making EF calculations in agricultural areas. First, on the basis of the region's soil series map, a separate background value should be determined for each series. If the region in question does not have a soil series map, samples should be taken from the lowest horizon of each sampling point with the help of a soil auger and then point-wise background values should be calculated. These recommendations are expected to minimise concerns regarding the consequences of using the EFs in agricultural areas. For young soils that do not have a defining horizon other than the A horizon, the background values of similar parent materials could be used.

This study is one of the first attempts to put forward the argument that the background values used for EF calculations in agricultural areas should be determined according to soil series. This study also explained the relationships between heavy metal concentration, clay percentage, and cation exchange

capacity. Nevertheless, because clay types are also effective indicators of the chemical properties of soils, similar studies should perform clay-type analyses in soils to more comprehensively shed light on the association between heavy metals and other soil properties.

Author contributions HA put forward the original idea and wrote the manuscript. HA, SŞ and YKK collected the soil samples. YKK and SŞ supervised the work and revised the manuscript. All the authors contributed to the manuscript writing.

Funding The data of this study was obtained from the project numbered FDK-2019-11716, supported by Cukurova University Research Projects Unit.

Availability of data and material The datasets used during the current study are available from the first author on reasonable request.

Declarations

Conflict of interest The authors declare that there are no known competing interests.

Ethical statement We have conducted ourselves with integrity, idelity and honesty. The submitted work is original and has not been published elsewhere in any form or language.

Consent to participate Not applicable.

Consent for publication Not applicable.

References

- Adimalla, N., & Wang, H. (2018). Distribution, contamination, and health risk assessment of heavy metals in surface soils from northern Telangana India. *Arabian Journal of Geosciences*, 11(21), 1–15.
- Akbay, C., Aytop, H., & Dikici, H. (2022). Evaluation of radioactive and heavy metal pollution in agricultural soil surrounding the lignite-fired thermal power plant using pollution indices. *International Journal of Environmental Health Research*. <https://doi.org/10.1080/09603123.2022.2102157>
- Anderson, R. H., & Kravitz, M. J. (2010). Evaluation of geochemical associations as a screening tool for identifying anthropogenic trace metal contamination. *Environmental Monitoring and Assessment*, 167(1), 631–641.
- Ateş, Ö., Taşpınar, K., Yalçın, G., Kızılaslan, F., Pınar, M. Ö., Toprak, S., Alveroğlu, V., Yavuz, R., & Özen, D. (2022). Ecological and contamination assessment of soil in the region of coal-fired thermal power plant. *International Journal of Environmental Health Research*. <https://doi.org/10.1080/09603123.2022.2108384>
- Atik, M. (2017). Zeytinde değişken düzeyli azot ihtiyacının sensör ve yaprak analizleriyle belirlenip karşılaştırılması (Master's thesis, Namık Kemal Üniversitesi).
- Aytop, H., & Şenol, S. (2022a). The effect of different land use planning scenarios on the amount of total soil losses in the Mikail Stream Micro-Basin. *Environmental Monitoring and Assessment*, 194(4), 1–19. <https://doi.org/10.1007/s10661-022-09937-2>
- Aytop, H., & Şenol, S. (2022b). Farklı Ana Materyaller Üzerinde Oluşmuş Mikail Çayı Mikro Havzası Toprakları. *Türk Tarım Ve Doğa Bilimleri Dergisi*, 9(1), 85–96. <https://doi.org/10.30910/turkjans.1014874>
- Aytop, H., Ateş, Ö., Dengiz, O., Yılmaz, C. H., & Demir, Ö. F. (2023). Environmental, ecological and health risks of boron in agricultural soils of Amik Plain under Mediterranean conditions. *Stochastic Environmental Research and Risk Assessment*. <https://doi.org/10.1007/s00477-023-02380-w>
- Aytop, H. (2022). Evaluation of environmental and ecological risks caused by metals in agricultural areas: an example in the Amik Plain of South Turkey. *International Journal of Environmental Health Research*. <https://doi.org/10.1080/09603123.2022.2097203>
- Baltas, H., Sirin, M., Gökbayrak, E., & Ozcelik, A. E. (2020). A case study on pollution and a human health risk assessment of heavy metals in agricultural soils around Sinop province Turkey. *Chemosphere*, 241, 125015. <https://doi.org/10.1016/j.chemosphere.2019.125015>
- Bayraklı, B., Dengiz, O., Özyazıcı, M. A., Koç, Y., Kesim, E., & Türkmen, F. (2023). Assessment of heavy metal concentrations and behavior in cultivated soils under humid-subhumid environmental condition of the Black Sea region. *Geoderma Regional*, 32, e00593.
- Blanco-Canqui, H., & Lal, R. (2008). *Principles of Soil Conservation and Management* (p. 564). Springer.
- Blaser, P., Zimmermann, S., Luster, J., & Shotyk, W. (2000). Critical examination of trace element enrichments and depletions in soils: As, Cr, Cu, Ni, Pb, and Zn in Swiss forest soils. *Science of the Total Environment*, 249(1–3), 257–280.
- Bouyoucos, G. J. (1951). A recalibration of the hydrometer method for making mechanical analysis of soils. *Agronomy Journal*, 43(9), 434–438.
- Cao, X., Li, W., Song, S., Wang, C., & Khan, K. (2022). Source apportionment and risk assessment of soil heavy metals around a key drinking water source area in northern China: multivariate statistical analysis approach. *Environmental Geochemistry and Health*, 1–15.
- Chandrasekaran, A., Ravisankar, R., Harikrishnan, N., Sathapathy, K. K., Prasad, M. V. R., & Kanagasabapathy, K. V. (2015). Multivariate statistical analysis of heavy metal concentration in soils of Yelagiri Hills, Tamilnadu, India—Spectroscopical approach. *Spectrochimica Acta—Part a: Molecular and Biomolecular Spectroscopy*, 137, 589–600. <https://doi.org/10.1016/j.saa.2014.08.093>
- Chen, T. B., Wong, J. W. C., Zhou, H. Y., & Wong, M. H. (1997). Assessment of trace metal distribution and contamination in surface soils of Hong Kong. *Environmental Pollution*, 96(1), 61–68.

- Chen, H., Teng, Y., Lu, S., Wang, Y., & Wang, J. (2015). Contamination features and health risk of soil heavy metals in China. *Science of the Total Environment*, 512, 143–153.
- Ciolkosz, E. J., Waltman, W. J., Thurman, N. C., Cremeens, D. L., & Svoboda, M. D. (1996). Argillic horizons in Pennsylvania soils. *Soil Survey Horizons*, 37(1), 20–44.
- Drake, E. H., & Motto, H. L. (1982). An analysis of the effect of clay and organic matter content on the cation exchange capacity of New Jersey soils. *Soil Science*, 133(5), 281–288.
- Durand, J. F. (2012). The impact of gold mining on the Witwatersrand on the rivers and karst system of Gauteng and North West Province, South Africa. *Journal of African Earth Sciences*, 68, 24–43.
- Dytłow, S., & Górka-Kostrubiec, B. (2021). Concentration of heavy metals in street dust: An implication of using different geochemical background data in estimating the level of heavy metal pollution. *Environmental Geochemistry and Health*, 43(1), 521–535.
- Elizabeth Rani, C., Balaji Ayyadurai, V., & Kavitha, K. K. (2021). Bioremediation of Heavy Metals and Toxic Chemicals from Muttukadu Lake, Chennai by Biosurfactant and Biomass Treatment Strategies. In *Bioremediation and Green Technologies* (pp. 67–85). Springer, Cham.
- Elliott, P. E., & Drohan, P. J. (2009). Clay accumulation and argillic-horizon development as influenced by aeolian deposition vs local parent material on quartzite and limestone-derived alluvial fans. *Geoderma*, 151(3–4), 98–108.
- Foorginezhad, S., Zerafat, M. M., Mohammadi, Y., & Asadnia, M. (2022). Fabrication of tubular ceramic membranes as low-cost adsorbent using natural clay for heavy metals removal. *Cleaner Engineering and Technology*, 10, 100550.
- Gałuszka, A. (2007). A review of geochemical background concepts and an example using data from Poland. *Environmental Geology*, 52(5), 861–870.
- Gee, G. W., & Bauder, J. W. (1979). Particle size analysis by hydrometer: a simplified method for routine textural analysis and a sensitivity test of measurement parameters. *Soil Science Society of America Journal*, 43(5), 1004–1007.
- Ghasemi, H., Afshang, M., Gilvari, T., Aghabarari, B., & Mozaffari, S. (2023). Rapid and effective removal of heavy metal ions from aqueous solution using nanostructured clay particles. *Results in Surfaces and Interfaces*, 100097.
- Githaiga, K. B., Njuguna, S. M., & Yan, X. (2021). Local geochemical baselines reduce variation caused by the use of different conservative elements in predicting Cu and Zn enrichment in agricultural soils Kenya. *Chemistry Africa*, 4(4), 869–880.
- Gough, L. P. (1993). Understanding our fragile environment. Lessons from geochemical studies. *US Geological Survey Circular*, 1105, 1–34.
- Grandclément, C., Seyssiecq, I., Piram, A., Wong-Wah-Chung, P., Vanot, G., Tiliacos, N., Roche, N., & Doumenq, P. (2017). From the conventional biological wastewater treatment to hybrid processes, the evaluation of organic micropollutant removal: a review. *Water Research*, 111, 297–317.
- Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research*, 14(8), 975–1001.
- Hazelton, P., & Murphy, B. (2016). Interpreting soil test results: What do all the numbers mean?. CSIRO publishing.
- Hu, J., Lin, B., Yuan, M., Lao, Z., Wu, K., Zeng, Y., Liang, Z., Li, H., Li, Y., Zhu, D., Liu, J., & Fan, H. (2019). Trace metal pollution and ecological risk assessment in agricultural soil in Dexing Pb/Zn mining area China. *Environmental Geochemistry and Health*, 41(2), 967–980.
- Huang, Y., Chen, Q., Deng, M., Japenga, J., Li, T., Yang, X., & He, Z. (2018). Heavy metal pollution and health risk assessment of agricultural soils in a typical peri-urban area in southeast China. *Journal of Environmental Management*, 207, 159–168.
- İrget, M. E., Kiliç, C. C., Bayaz, M., & Özer, K. (2007). Azotlu gübrelemenin zeytinde (*Olea europaea* L. cv. Memecik) verim ve kaliteye etkisi. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi*, 4(1/2), 27–33.
- Islam, M. M., Akther, S. M., Hossain, M. F., & Parveen, Z. (2022). Spatial distribution and ecological risk assessment of potentially toxic metals in the Sundarbans mangrove soils of Bangladesh. *Scientific Reports*, 12(1), 1–14.
- Jackson, M. L., 1979, Soil Chemical Analysis-Advanced Course. 2nd Ed, 11th Printing. Published by The Author, Madison.
- Jalali, M., & Khanlari, Z. V. (2008). Environmental contamination of Zn, Cd, Ni, Cu, and Pb from industrial areas in Hamadan Province, Western Iran. *Environmental Geology*, 55(7), 1537–1543.
- Kafle, H. K., Khadgi, J., Ojha, R. B., & Santoso, M. (2022). Concentration, sources, and associated risks of trace elements in the surface soil of Kathmandu Valley Nepal. *Water, Air, & Soil Pollution*, 233(2), 1–18.
- Kavamura, V. N., & Esposito, E. (2010). Biotechnological strategies applied to the decontamination of soils polluted with heavy metals. *Biotechnology Advances*, 28(1), 61–69.
- Kerr, P. F. (1952). Formation and occurrence of clay minerals. *Clays and Clay Minerals*, 1, 19–32.
- Kiekens, L. (1983). *Behavior of heavy metals in soils. Utilization of sewage sludge on land: Rates of application and long-term effects of metals*. Dordrecht: D. Reidel Publishing.
- Kim, R. Y., Yoon, J. K., Kim, T. S., Yang, J. E., Owens, G., & Kim, K. R. (2015). Bioavailability of heavy metals in soils: Definitions and practical implementation—A critical review. *Environmental Geochemistry and Health*, 37, 1041–1061.
- Kim, H., Lee, M., Lee, J. H., Kim, K. H., Owens, G., & Kim, K. R. (2020). Distribution and extent of heavy metal (loid) contamination in agricultural soils as affected by industrial activity. *Applied Biological Chemistry*, 63(1), 1–8.
- Kinoti, I. K., Karanja, E. M., Nthiga, E. W., M’thiruaine, C. M., & Marangu, J. M. (2022). Review of clay-based nanocomposites as adsorbents for the removal of heavy metals. *Journal of Chemistry*, 2022.
- Kome, G. K., Enang, R. K., Tabi, F. O., & Yerima, B. P. K. (2019). Influence of clay minerals on some soil fertility attributes: A review. *Open Journal of Soil Science*, 9(9), 155–188.

- Kowalska, J. B., Nicia, P., Gąsiorek, M., Zadrożny, P., Węgrzyn, M. H., & Waroszewski, J. (2022). Are natural or anthropogenic factors influencing potentially toxic elements' enrichment in soils in proglacial zones? An example from Kaffiøyra (Oscar II Land, Spitsbergen). *International Journal of Environmental Research and Public Health*, 19(20), 13703.
- Kumar, R., Suresh, N., Sangode, S. J., & Kumaravel, V. (2007). Evolution of the Quaternary alluvial fan system in the Himalayan foreland basin: Implications for tectonic and climatic decoupling. *Quaternary International*, 159(1), 6–20.
- Kumar, V., Sharma, A., Kaur, P., Sidhu, G. P. S., Bali, A. S., Bhardwaj, R., Thukral, A. K., & Cerda, A. (2019). Pollution assessment of heavy metals in soils of India and ecological risk assessment: a state-of-the-art. *Chemosphere*, 216, 449–462.
- Kumari, N., & Mohan, C. (2021). Basics of clay minerals and their characteristic properties. *Clay Clay Miner*, 24, 1–29.
- Kwiatkowska-Malina, J. (2018). Functions of organic matter in polluted soils: The effect of organic amendments on phytoavailability of heavy metals. *Applied Soil Ecology*, 123, 542–545.
- Li, Y., Zhang, H., Tu, C., Song, F., & Luo, Y. (2017). Occurrence of red clay horizon in soil profiles of the Yellow River Delta: Implications for accumulation of heavy metals. *Journal of Geochemical Exploration*, 176, 120–127.
- Li, S., Yang, L., Chen, L., Zhao, F., & Sun, L. (2019). Spatial distribution of heavy metal concentrations in peri-urban soils in eastern China. *Environmental Science and Pollution Research*, 26, 1615–1627.
- Loaiza-Usuga, J. C., Toro-Quijano, M. I., & Weber, M. B. (2022). Alluvial soils as paleoenvironmental indicator in fluvial environments: A case study from Colombia. *Soil Science Annual*, 73(3), 157400.
- Loska, K., Wiechuła, D., & Korus, I. (2004). Metal contamination of farming soils affected by industry. *Environment International*, 30(2), 159–165.
- Mavakala, B. K., Sivalingam, P., Laffite, A., Mulaji, C. K., Giuliani, G., Mpiana, P. T., & Poté, J. (2022). Evaluation of heavy metal content and potential ecological risks in soil samples from wild solid waste dumpsites in developing country under tropical conditions. *Environmental Challenges*, 7, 100461.
- USEPA Method 3051A (1998). Microwave assisted acid digestion of sediments, sludges, soils and oils; United States Environmental Protection Agency: Washington, DC, USA, 1998
- Otunola, B. O., & Ololade, O. O. (2020). A review on the application of clay minerals as heavy metal adsorbents for remediation purposes. *Environmental Technology & Innovation*, 18, 100692.
- Rajendran, S., Priya, T. A. K., Khoo, K. S., Hoang, T. K., Ng, H. S., Munawaroh, H. S. H., Karaman, C., Orooji, Y., & Show, P. L. (2022). A critical review on various remediation approaches for heavy metal contaminants removal from contaminated soils. *Chemosphere*, 287, 132369.
- Rajmohan, N., Prathapar, S. A., Jayaprakash, M., & Nagaranjan, R. (2014). Vertical distribution of heavy metals in soil profile in a seasonally waterlogging agriculture field in Eastern Ganges Basin. *Environmental Monitoring and Assessment*, 186(9), 5411–5427.
- Reimann, C., & de Caritat, P. (2005). Distinguishing between natural and anthropogenic sources for elements in the environment: Regional geochemical surveys versus enrichment factors. *Science of the Total Environment*, 337(1–3), 91–107.
- Rezapour, S., Asadzadeh, F., Nouri, A., Khodaverdiloo, H., & Heidari, M. (2022a). Distribution, source apportionment, and risk analysis of heavy metals in river sediments of the Urmia Lake basin. *Scientific Reports*, 12(1), 17455. <https://doi.org/10.1038/s41598-022-21752-w>
- Rezapour, S., Siavash Moghaddam, S., Nouri, A., & Khosravi Aqdam, K. (2022b). Urbanization influences the distribution, enrichment, and ecological health risk of heavy metals in croplands. *Scientific Reports*, 12(1), 3868. <https://doi.org/10.1038/s41598-022-07789-x>
- Rhoades, J., 1982, Cation Exchange Capacity, Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties (Methodsofsoil2), 149–157.
- Rinklebe, J., Antoniadis, V., Shaheen, S. M., Rosche, O., & Altermann, M. (2019). Health risk assessment of potentially toxic elements in soils along the Central Elbe River, Germany. *Environment International*, 126, 76–88.
- Rudnick, R. L., & Gao, S. (2004). Composition of the continental crust. In H. D. Holland & K. K. Turekian (Eds.), *Treatise on Geochemistry* (pp. 1–51). Elsevier.
- Sağlam, M., & Dengiz, O. (2015). Similarity analysis of soils formed on limestone/marl-alluvial parent material and different topography using some physical and chemical properties via cluster and multidimensional scaling methods. *Environmental Monitoring and Assessment*, 187, 100. <https://doi.org/10.1007/s10661-014-4226-3>
- Senanu, L. D., Kranjac-Berisavljevic, G., & Cobbina, S. J. (2023). The use of local materials to remove heavy metals for household-scale drinking water treatment: A review. *Environmental Technology & Innovation*, 103005.
- Soil Survey Lab. Staff, 1992. Soil Survey Laboratory Methods Manual, USDA-SCS-NSSC, 42.
- Soil Survey Staff. (2014). Keys to Soil Taxonomy. 12th Edition, USDA-Natural Resources Conservation Service, Washington D.C.
- Sungur, A., Soylak, M., Yilmaz, E., Yilmaz, S., & Ozcan, H. (2015). Characterization of heavy metal fractions in agricultural soils by sequential extraction procedure: The relationship between soil properties and heavy metal fractions. *Soil and Sediment Contamination: An International Journal*, 24(1), 1–15.
- Sutherland, R. A. (2000). Bed sediment-associated trace metals in an urban stream, Oahu Hawaii. *Environmental Geology*, 39(6), 611–627.
- Taşpınar, K., Ateş, Ö., Özge Pinar, M., Yalçın, G., Kızılaslan, F., & Fidantemiz, Y. F. (2022). Soil contamination assessment and potential sources of heavy metals of alpu plain Eskişehir Turkey. *International Journal of Environmental Health Research*, 32(6), 1282–1290. <https://doi.org/10.1080/09603123.2021.1876218>
- Taşpınar, K., Ateş, Ö., Yalçın, G., Kızılaslan, F., & Pinar, M. Ö. (2021). Soil contamination and healthy risk assessment of peach orchards soil of Bilecik Province Turkey.

- International Journal of Environmental Health Research*, 1–10.
- Tholkappian, M., Ravisankar, R., Chandrasekaran, A., Jebakumar, J. P. P., Kanagasabapathy, K. V., Prasad, M. V. R., & Satapathy, K. K. (2018). Assessing heavy metal toxicity in sediments of Chennai Coast of Tamil Nadu using energy dispersive X-Ray fluorescence spectroscopy (EDXRF) with statistical approach. *Toxicology Reports*, 5, 173–182. <https://doi.org/10.1016/j.toxrep.2017.12.020>
- Tian, Z., Pan, Y., Chen, M., Zhang, S., & Chen, Y. (2023). The relationships between fractal parameters of soil particle size and heavy-metal content on alluvial-proluvial fan. *Journal of Contaminant Hydrology*, 254, 104140.
- Varol, M., Sünbül, M. R., Aytıp, H., & Yılmaz, C. H. (2020). Environmental, ecological and health risks of trace elements, and their sources in soils of Harran Plain Turkey. *Chemosphere*, 245, 125592.
- Villar, A. G. (1996). Abanicos aluviales: Aportación teórica a sus aspectos más significativos. *Cuatern. Geomorfol.*, 10(3–4), 77–124.
- Wang, Y., Zhang, X., Sun, W., Wang, J., Ding, S., & Liu, S. (2022). Effects of hyperspectral data with different spectral resolutions on the estimation of soil heavy metal content: From ground-based and airborne data to satellite-simulated data. *Science of the Total Environment*, 838, 156129.
- Wang, X., Dan, Z., Cui, X., Zhang, R., Zhou, S., Wenga, T., ... Zhong, L. (2020). Contamination, ecological and health risks of trace elements in soil of landfill and geothermal sites in Tibet. *Science of the Total Environment*, 715, 136639. <https://doi.org/10.1016/j.scitotenv.2020.136639>.
- Wei, B., Yu, J., Cao, Z., Meng, M., Yang, L., & Chen, Q. (2020). The availability and accumulation of heavy metals in greenhouse soils associated with intensive fertilizer application. *International Journal of Environmental Research and Public Health*, 17(15), 5359.
- Wilson, M. J. (2019). The importance of parent material in soil classification: A review in a historical context. *Catena*, 182, 104131, ISSN 0341–8162.
- World Health Organization. (2019). Preventing disease through healthy environments: exposure to arsenic: a major public health concern (No. WHO/CED/PHE/EPE/19.4. 1). World Health Organization.
- WRB, (2015). World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.
- Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Notices*, 2011.
- Ye, S., Zeng, G., Wu, H., Liang, J., Zhang, C., Dai, J., Song, B., Wu, S., & Yu, J. (2019). The effects of activated biochar addition on remediation efficiency of co-composting with contaminated wetland soil. *Resources, Conservation and Recycling*, 140, 278–285.
- Yılmaz, C. H. (2022). Heavy metals and their sources, potential pollution situations and health risks for residents in Adıyaman province agricultural lands, Türkiye. *Environmental Geochemistry and Health*, 1–19.
- Kabata-Pendias, A. (2011). Trace Elements in Soils and Plants. CRC Taylor and Francis Group, London New York.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.