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ORIGINAL PAPER

Spatial distribution of heavy metals in soils around cement factory and health risk assessment: a case study of Canakkale-Ezine (NW Turkey)

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Abstract Sustainable use of agricultural land plays a crucial role in ensuring food security. For sustainable use of soils, it is very important to focus on the pollution status. This study was conducted on the soils in the northern part of the Ezine district in northwestern Turkey. The study aimed to determine the physicochemical properties of the soils in the vicinity of the cement plant, the concentrations of heavy metals, the spatial distribution of heavy metals, and their impact on the health of the local human population. Soil samples were collected from the cement plant in different directions (S,W, N, E, NE, SW) and at different distances (1, 3, 5, and 7 km) from 0–10 cm depth with three replicates. The soil samples were analyzed for texture, pH, electrical conductivity, lime, and heavy metals such as Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn. The soils had different textures (loam, sandy clay loam, loam, sandy loam), slightly alkaline pH, low lime content, and moderate organic matter content. Except for Cd and Pb, the average values of the other heavy metals ($Co = 1.18 < 19$ mg kg^{-1},$Cr = 50.92 < 90$ mg kg^{-1}, $Cu = 31.21 < 45$ mg kg^{-1}, $Fe = 16{,}007 < 47{,}200$ mg kg^{-1}, $Mn = 499.68 < 850$ mg kg^{-1}, $Ni = 41.17 < 68$ mg kg^{-1}, $Zn = 50.91 < 95$ mg kg^{-1}) in the soils were below the normal background level. The heavy metal contents of the soils in the study area are influenced by various sources (geological structure, agrochemicals used in agricultural activities, and vehicle traffic). The prevailing wind direction did not influence the local distribution of heavy metals in soils in the study area. The health risk assessment model studies showed that the hazard quotient values of less than 1 for adults and children indicate that the noncarcinogenic risks were insignificant. People exposed to heavy metals in the soils of the study area contaminated from various sources for a long time could be at carcinogenic risk. Since Cr and Pb exceed the acceptable risk range in children and Cr exceeds the acceptable risk range in adults, geochemical monitoring of soils should be conducted periodically by authorized institutions in the study area.

Keywords Heavy metals · Soil contamination · Human health risk assessment · Sustainable land management

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Introduction

The environment destroyed by uncontrolled urbanization and industrialization in the twentieth century faces various threats. Urbanization and industrialization cause problems such as air pollution, noise, water quality degradation, soil pollution, waste disposal, increased CO_2 emissions, deforestation, soil loss, and desertification (Ahuti, 2015; Parlak et al., 2020; Uttara et al., 2012). Increased urbanization and industrialization lead to more cement production, releasing more CO_2 into the atmosphere (Etim et al., 2021). At the same time, all kinds of wastes generated by urbanization and industrialization mix with the soil and create soil pollution. Heavy metals in the composition of these wastes are among the most important pollutants, and research on heavy metal soil pollution has increased in recent years (Agbede et al., 2022; Coskun et al., 2021; Horasan, 2020; Kelepertzis et al., 2018; Li et al., 2022; Olatunji & Afolabi, 2020; Parlak et al., 2022; Solgun et al., 2021; Turhan et al., 2021). The main industrial activities that affect the dispersion of heavy metals in the environment are cement production, thermal power plants, fertilizer industry, iron and steel industry, glass production, and waste and waste sludge incinerators (Kahvecioğlu et al., 2003).

Global cement production was 4,400,000 tons in 2021 (U.S. Geological Survey, 2022), and China is the largest cement producer, covering more than half of global cement production. India follows China with 330,000 tons, Vietnam with 100,000 tons, the United States with 92,000 tons, and Turkey with 76,000 tons. The cement industry is one of the oldest industries in Turkey. According to 2022 data, a total of 72 cement factories and 54 integrated and 18 grinding plants produce in Turkey (turkcimento, 2022). Cement plants release heavy metals into the environment by emitting cement dust and various gasses (Jafari et al., 2019). Through the combustion of coal used as fuel in the cement plant, the heavy metals in the composition of coal contribute to the pollution of the soil (Dong et al., 2015; Kolo et al., 2018). Cement dust may contain heavy metals such as Cd, Cr, Ni, Pb, and Zn. Cement dust containing heavy metals can be dispersed by wind and rain and accumulate in the soil. Various researchers (Das et al., 2022; Gholinejad et al., 2021; Rahmanian & Safari, 2020) have found an increase in heavy metal concentrations in the soils around the cement plant. Soils contaminated with heavy metals can create human health hazards through the food chain, inhalation, and dermal contact. When heavy metals settle in human tissues and the circulatory system, they trigger respiratory and cardiovascular diseases, including asthma and lung diseases (Kolo et al., 2018).. Although studies have been conducted in Turkey on the impact of the cement industry on the soil (Bilen et al., 2021; Duyar, 2019; Kara & Bolat, 2007; Saltalı et al., 2018; Uysal et al., 2006), there are no published studies on heavy metal contamination and possible health risks in the soils near the cement plant. The objectives of this study are: 1.To determine the physicochemical properties of the surface soils in the vicinity of the Ezine cement plant. 2.To determine the study area’s heavy metal concentration and spatial distribution of Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. 3.To determine the impact of heavy metals on the local human population’s health by calculating non-carcinogenic and carcinogenic health risks.

Material and methods

Study area

The cement plant is at 39 51′ 53″ north latitude and 26 14′ 58″ east longitude. It is located in Mahmudiye village in the Ezine district of Canakkale (Fig. 1a). The cement plant, which has been operating since 1974, produces 5.5 million tons of cement and 4.5 million tons of clinker annually. During the plant’s cement and clinker production, fine dust is released into the atmosphere, which then falls to the ground or appears white on the roofs of houses surrounding the plant (Fig. 1b).

Ezine is a settlement within the borders of the Marmara region. Bayramic borders Ezine to the east, the Aegean Sea to the west, the Ayvacık district to the south, and the central district of Canakkale province to the north (Fig. 2). The climate of Ezine is located in the transition zone between the climate of the Marmara and Aegean regions. Summers in Ezine is hot and dry, and winters are warm and rainy. According to the long-term climate data (1929–2021), the average total annual precipitation is 625.5 mm, and the yearly average temperature is 15.2 ℃ (GDM, 2022). The predominant wind direction in the district is

Fig. 1 **a** Cement plant in Ezine-Canakkale. **b** Cement dust accumulated on the roofs of the houses

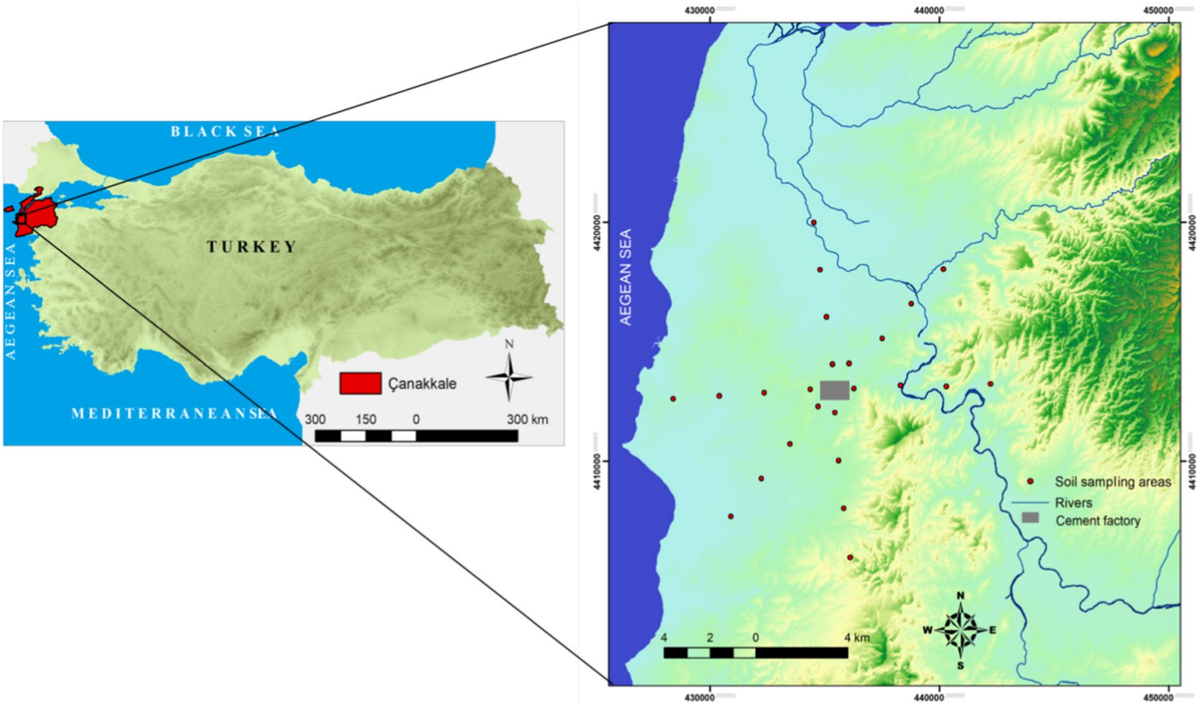

Fig. 2 Location of study area and distribution of sampling areas

north and northeast. The units forming the northern direction of the study area are Quaternary alluvium and upper Miocene continental sediments. In the NE direction are continental clastic and Quaternary alluvial deposits of the upper Miocene age. To the east are limestone units and conglomerates of Miocene and Mesozoic ophiolitic rocks (serpentines). In the southern direction, continental clastic units of the upper Miocene and Oligocene granitoids are densely formed in the Miocene. Towards SW are Quaternary alluvium and continental clastic units of the upper Miocene. To the west are continental clastic of the upper Miocene age (Ilgar et al., 2008). According to the Soil Taxonomy Typic Ustifluvents, the study area soils are Typic Haplustalfs and Typic Ustorthents (Everest, 2015; Soil Survey Staff, 2014). The map showing the land use of the study area is shown in Fig. 3.

Soil sampling

Soil samples were collected at 4 distances (1 km, 3 km, 5 km, and 7 km) from the cement plant and in 6 directions (north, south, east, west, northeast, and southwest). 3 plots of 4 m^2 (2 m×2 m) were established in each sampling area. Soil samples were taken from 0–10 cm depth in June 2021. A global

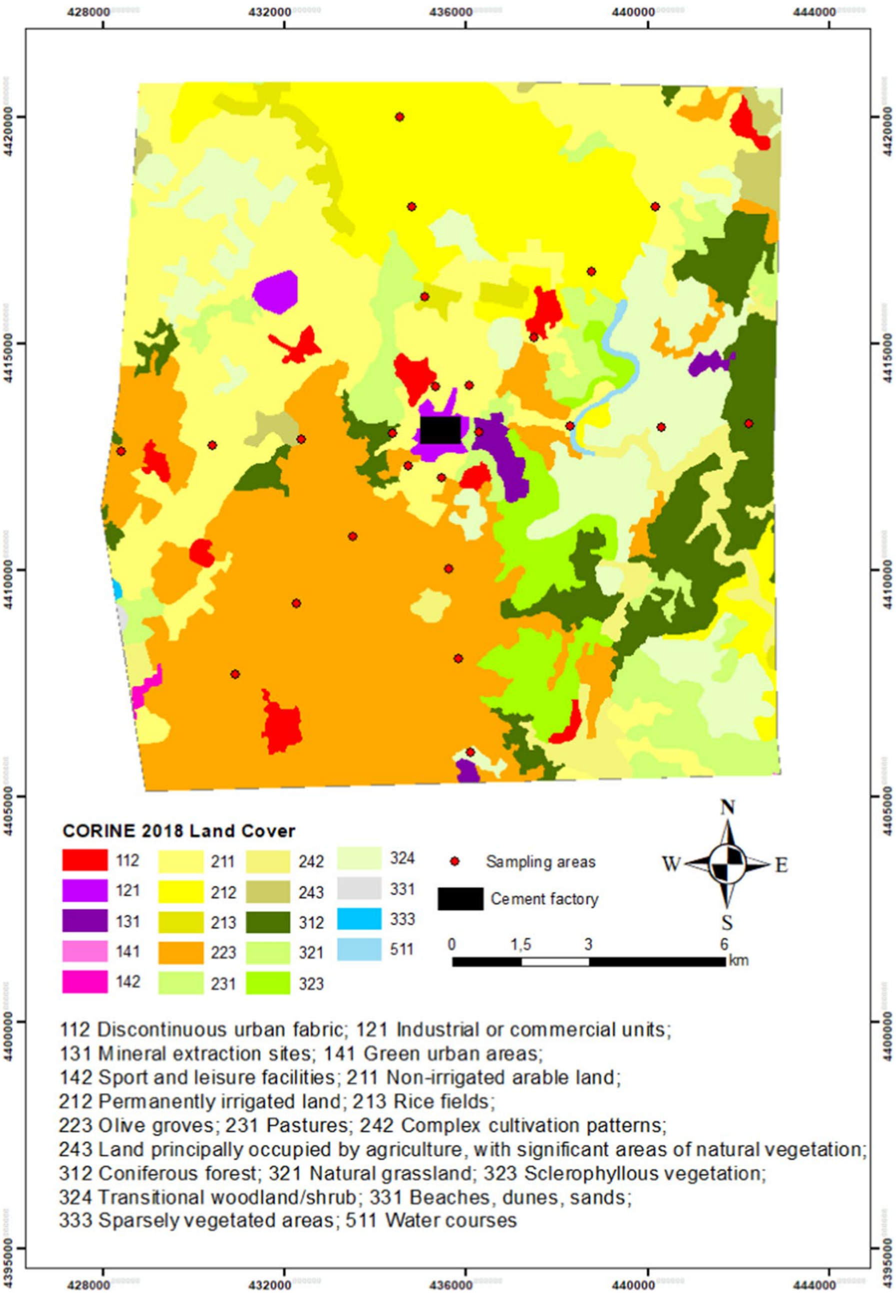

Fig. 3 CORINE 2018 land cover map of the study area

positioning system (GPS) device recorded soil sampling area's coordinates. Each soil samples was a composite of five sub-samples taken from an area of 4 m^2. A total of 72 soil samples (4 distances × 6 directions × 3 replicates) were collected from the study area. The soil samples were packed in polyethylene bags and transported to the laboratory. The soil samples were dried in the laboratory and then sieved through a 2 mm sieve and made ready for analysis.

Soil analysis

The texture of soil samples was determined by the Bouyoucus hydrometer method (Gee & Or, 2002), soil reaction (pH) was determined by pH meter with a glass electrode (Thomas, 1996), electrical conductivity (EC) was determined by EC meter in saturation paste (Rhoades, 1996), lime content was determined volumetrically by Scheibler calcimeter (Loeppert & Suarez, 1996), organic matter was determined by Wakley-Black wet combustion method (Nelson & Sommers, 1996). Soil texture was evaluated according to USDA texture classification(texture triangle) (Soil Survey Division Staff, 1993). The total content of heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in the soil samples was determined by using ICP-OES (Perkin Elmer Optima 2100 DV) after burning (USEPA, 1996) them with a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) (3/1) according to the wet digestion method.

Certified reference material (NIM-GBW07425, soil) was used in the study to test the method's accuracy. The recoveries obtained ranged from 96.58% to 108.72% (Table S1), and the results were considered satisfactory.

Human health risk assessment

The health risk assessment of heavy metals in soil is a multi-step process divided into carcinogenic and non-carcinogenic effects (Kolo et al., 2018; Ozturk and Arıcı, 2021; Silva et al., 2021; Parlak et al., 2022). Both non-carcinogenic and carcinogenic risk assessments assume that people are exposed to heavy metals in 3 ways (i.e. oral ingestion, inhalation, and dermal absorption). The health risk assessment model has been developed by USEPA (1986) and used by various researchers (Botsou et al., 2020; Das et al., 2022; Jafari et al., 2019). Equations 1, 2, 3, 4, 5, 6, 7, and 8 were used to calculate the health risk assessment.

$$\mathrm{ADD}_{\mathrm{ingestion}}\left(\mathrm{mg\,kg^{-1}\,day^{-1}}\right) = C \times \frac{IngR \times EF \times ED}{BW \times AT} \times CF \tag{1}$$

$$\mathrm{ADD}_{\mathrm{inhalation}}\left(\mathrm{mg\ kg^{-1}\ day^{-1}}\right) = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \tag{2}$$

$$\mathrm{ADD}_{\mathrm{dermal}}(\mathrm{mg\ kg^{-1}\ day^{-1}}) = C \times \frac{SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times CF \tag{3}$$

The variables used in calculating health risk assessment through oral ingestion, inhalation, and dermal absorption are shown in Table S2 and Table 2. The ADD in Table S2 is the average daily dose. The hazard index (HI) was calculated from the sum of the HQs (ingestion, inhalation, and dermal) according to Eq. 7. If the HI value is <1, there is no carcinogenic risk (USEPA, 2011).

The hazard quotient (HQ) for each heavy metal was calculated using Eqs. 4, 5, and 6. The hazard quotient (HI) is calculated from the sum of the HQs (ingestion, inhalation, and dermal) according to Eq. 7. If HQ and HI values are <1, it is stated to be in the reliable range

Table 1 Reference doses of heavy metals and slope factors (Ferreira-Baptista and De-Miguel, 2005; Soltani-Gerdefaramarzi et al., 2021)

Heavy metals	Cd	Co	Cr	Cu	Mn	Zn	Ni	Pb
R_fD_{ing} ($mg\ kg^{-1}\ day^{-1}$)	1.00E−03	2.00E−02	3.00E−03	4.00E−02	4.60E−02	3.00E−01	2.00E−02	3.50E−03
R_fD_{inh} ($mg\ kg^{-1}\ day^{-1}$)	1.00E−03	5.71E−06	2.86E−05	4.02E−02	1.43E−05	3.00E−01	2.06E−02	3.52E−03
R_fD_{derm} ($mg\ kg^{-1}\ day^{-1}$)	1.00E−05	1.60E−02	6.00E−05	1.20E−02	1.84E−03	6.00E−02	5.40E−03	5.25E−04
SF ($mg\ kg^{-1}\ day^{-1}$)	6.30E−01	9.80E−00	4.20E+01	–	–	–	8.40E−01	4.20E−02

Table 2 Physico-chemical properties and heavy metal content of the soils in the vicinity of the cement plant

	Mean ± standard deviation	Minimum	Maximum
Clay (%)	22.60 ± 7.29	8.98	35.88
Silt (%)	23.27 ± 7.51	8.18	39.58
Sand (%)	54.13 ± 10.33	34.07	76.86
pH	7.63 ± 0.22	6.93	8.04
EC (dS m^{-1})	0.65 ± 0.44	0.27	3.41
Lime (%)	7.24 ± 5.39	1.60	22.80
Organic matter (%)	2.02 ± 0.94	0.56	4.57
Total Cd (mg kg^{-1})	1.39 ± 0.21	0.86	1.71
Total Co (mg kg^{-1})	1.18 ± 1.24	0.12	5.76
Total Cr (mg kg^{-1})	50.92 ± 19.01	111.35	27.42
Total Cu (mg kg^{-1})	31.20 ± 10.22	15.65	81.85
Total Fe (mg kg^{-1})	16,007 ± 2300	12,460	21,810
Total Mn (mg kg^{-1}	499.68 ± 208.22	212.40	1 199
Total Ni (mg kg^{-1})	41.17 ± 23.40	15.49	130.65
Total Pb (mg kg^{-1})	22.08 ± 14.22	7.51	82.66
Total Zn (mg kg^{-1})	50.91 ± 19.84	31.34	156.80

(USEPA, 2011). The reference doses and slope factors of each heavy metal are shown in Table 1. The carcinogenic risk (CR) was obtained by multiplying the average daily doses (ADD) by the slope factor (Eq. 8).

$$\mathrm{HQ}_{\mathrm{ing}} = \frac{ADD\mathrm{ing}}{RfDing} \tag{4}$$

$$\mathrm{HQ}_{\mathrm{inh}} = \frac{ADD\mathrm{inh}}{RfDinh} \tag{5}$$

$$\mathrm{HQ}_{\mathrm{dermal}} = \frac{ADD\mathrm{dermal}}{RfDdermal} \tag{6}$$

$$\mathrm{HI} = \sum_{i=1}^{n} HQ \tag{7}$$

$$\begin{aligned} Carcinogenic\ risk\ (CR)\ &= Average\ Daily\ Dose\ (ADD) \\ &\times Slope\ Factor\ (SF) \end{aligned} \tag{8}$$

If the calculated carcinogenic risk values are $< 1 \times 10^{-6}$, there is no cancer risk. If it is $1 \times 10^{-6} <$ carcinogenic risk $< 1 \times 10^{-4}$, the risk is within the acceptable range. If the carcinogenic risk is $> 1 \times 10^{-4}$, human tolerance has been exceeded (USEPA, 2011; Kolo et al., 2018; Silva et al., 2021).

Statistical analysis

Two-way ANOVA was performed to determine the differences between location and distance, and Duncan's multiple comparison tests were used to compare the means. In addition, the Pearson correlation test was used to determine the relationships between soil properties and heavy metal levels. Principal component analysis and other statistical analyses were performed using a IBM SPSS statistics software, v. 17 (2007). The spatial distribution of heavy metals in the analyzed samples was performed using ArcGIS10.1 software (ESRI, 2009).

Results and discussion

Physicochemical properties and heavy metal content of the soils

The physicochemical properties and heavy metal contents of the soils sampled in the study area are shown in Table 2. The texture components of the soils are 22.60% clay, 23.27% silt, and 54.13% sand. According to the USDA soil texture classification, 12.5% of the soils are clay loam, 41.66% are sandy clayey loam, 20.84% are loam, and 25% are sandy loam. Across all sites, pH was 7.63, EC was 0.65 dS m^{-1}, lime was 7.24%, and organic matter was 2.02%. The mean concentrations of total Cd, total Co, total Cr, total Cu,

Table 3 Some physicochemical properties and heavy metal concentrations (in mg kg^{-1}) of the soils sampled in different directions and at different distances from the cement plant in Ezine district*

Location	Clay (%)	Silt (%)	Sand (%)	pH	EC (dS m^{-1})	Lime (%)	Organic matter (%)
S	$28.46^{a}\pm3.82$	$26.44^{a}\pm7.17$	$44.62^{d}\pm5.72$	$7.64^{b}\pm0.20$	$0.66^{b}\pm0.12$	$8.70^{b}\pm8.38$	$3.17^{a}\pm0.73$
W	$22.76^{c}\pm5.08$	$18.76^{d}\pm3.92$	$58.86^{a}\pm4.41$	$7.53^{c}\pm0.28$	$0.61^{bc}\pm0.10$	$10.53^{a}\pm6.12$	$2.02^{bc}\pm1.01$
N	$19.19^{de}\pm7.76$	$26.93^{a}\pm4.78$	$53.92^{b}\pm9.42$	$7.52^{c}\pm0.27$	$1.15^{a}\pm0.90$	$5.61^{c}\pm2.56$	$1.65^{cd}\pm0.76$
E	$17.82^{e}\pm5.22$	$22.88^{bc}\pm9.06$	$57.69^{a}\pm13.08$	$7.70^{ab}\pm0.07$	$0.45^{d}\pm0.11$	$4.33^{d}\pm2.67$	$1.52^{d}\pm0.65$
NE	$20.33^{d}\pm6.63$	$24.34^{ab}\pm8.39$	$57.94^{a}\pm9.34$	$7.72^{a}\pm0.19$	$0.47^{cd}\pm0.16$	$5.55^{c}\pm3.66$	$1.47^{d}\pm0.50$
SW	$27.04^{b}\pm8.34$	$20.80^{cd}\pm7.55$	$51.72^{c}\pm11.42$	$7.68^{ab}\pm0.21$	$0.55^{bcd}\pm0.09$	$8.75^{b}\pm4.62$	$2.30^{b}\pm0.78$
Distance							
1 km	$22.28^{b}\pm6.10$	$26.74^{a}\pm5.23$	$50.98^{c}\pm9.70$	$7.67^{a}\pm0.29$	$0.61^{b}\pm0.10$	$9.58^{a}\pm6.28$	$2.44^{a}\pm0.78$
3 km	$25.29^{a}\pm3.88$	$19.15^{b}\pm3.18$	$55.56^{a}\pm6.40$	$7.52^{b}\pm0.23$	$0.65^{b}\pm0.11$	$5.07^{d}\pm2.56$	$2.07^{b}\pm0.87$
5 km	$22.25^{b}\pm8.69$	$21.17^{b}\pm9.07$	$56.96^{a}\pm11.42$	$7.65^{a}\pm0.17$	$0.54^{b}\pm0.13$	$7.79^{b}\pm7.26$	$1.73^{b}\pm0.81$
7 km	$20.56^{c}\pm9.07$	$26.38^{a}\pm8.02$	$53.01^{b}\pm12.56$	$7.68^{a}\pm0.15$	$0.81^{a}\pm0.85$	$6.53^{c}\pm3.35$	$1.86^{b}\pm1.16$

Location	Total Cd	Total Co	Total Cu	Total Cr	Total Fe	Total Mn	Total Ni	Total Pb	Total Zn
S	$1.33^{b}\pm0.17$	$0.61^{de}\pm0.60$	$31.71^{b}\pm6.97$	$55.17^{b}\pm14.40$	$17630^{a}\pm2967$	$652^{a}\pm374$	$40.07^{c}\pm11.01$	$24.87^{b}\pm11.53$	$56.52^{b}\pm17.27$
W	$1.32^{b}\pm0.18$	$0.36^{e}\pm0.33$	$19.56^{c}\pm2.74$	$29.60^{e}\pm1.88$	$12863^{d}\pm273$	$345.40^{e}\pm84.90$	$18.98^{e}\pm2.21$	$15.84^{e}\pm6.64$	$34.59^{f}\pm2.74$
N	$1.22^{c}\pm0.19$	$0.85^{cd}\pm0.27$	$33.57^{b}\pm6.19$	$48.02^{c}\pm9.21$	$16453^{b}\pm1395$	$453.60^{d}\pm88.20$	$39.75^{c}\pm8.31$	$20.62^{c}\pm5.43$	$68.60^{a}\pm36.60$
E	$1.39^{b}\pm0.27$	$1.00^{c}\pm0.41$	$30.78^{b}\pm6.71$	$56.04^{b}\pm11.44$	$16483^{b}\pm2092$	$534.40^{c}\pm143.70$	$53.17^{b}\pm16.21$	$18.40^{d}\pm2.58$	$44.38^{e}\pm6.88$
NE	$1.50^{a}\pm0.12$	$1.58^{b}\pm1.03$	$32.99^{b}\pm4.82$	$74.81^{a}\pm24.92$	$17265^{a}\pm833$	$588^{b}\pm139.70$	$69.30^{a}\pm34.70$	$13.82^{f}\pm5.03$	$52.36^{c}\pm6.14$
SW	$1.56^{a}\pm0.10$	$2.65^{a}\pm2.09$	$38.64^{a}\pm17.12$	$41.85^{d}\pm4.20$	$15320^{c}\pm1054$	$424.60^{d}\pm123.30$	$25.74^{d}\pm6.95$	$36.69^{a}\pm16.97$	$48.96^{d}\pm9.57$
Distance									
1 km	$1.28^{b}\pm0.26$	$1.52^{a}\pm1.70$	$32.39^{a}\pm15.99$	$41.79^{c}\pm9.87$	$15424^{b}\pm2361$	$488.50^{b}\pm214.90$	$30.51^{d}\pm11.79$	$25.38^{a}\pm7.48$	$45.15^{c}\pm8.63$
3 km	$1.47^{a}\pm0.13$	$1.39^{a}\pm1.44$	$28.70^{b}\pm4.53$	$56.21^{a}\pm21.18$	$15512^{b}\pm1575$	$453.80^{b}\pm141.20$	$42.60^{b}\pm21.82$	$18.67^{b}\pm4.43$	$46.79^{b}\pm10.07$
5 km	$1.34^{b}\pm0.22$	$0.70^{c}\pm0.49$	$32.03^{a}\pm8.88$	$47.29^{b}\pm11.40$	$15804^{b}\pm2226$	$413.40^{b}\pm137.10$	$36.86^{c}\pm14.24$	$16.49^{c}\pm3.66$	$44.28^{c}\pm7.76$
7 km	$1.44^{a}\pm0.15$	$1.08^{b}\pm0.91$	$31.71^{a}\pm8.48$	$58.37^{a}\pm25.33$	$17292^{a}\pm2584$	$643.20^{a}\pm253.20$	$54.71^{a}\pm33.66$	$26.28^{a}\pm20.47$	$67.41^{a}\pm31.94$

*Means in the same column followed by the different letter for each criterion are significantly different at the 0.05 level total Fe, total Mn, total Ni, total Pb, and total Zn in the soil were 1.39, 1.18, 50.92, 31.20, 16 007, 499.68, 41.17, 22.08, and 50.91 mg kg^{-1}, respectively.

The texture(clay, silt, sand), pH, EC, lime content, and organic matter content of the soils sampled in different directions and at different distances around the cement plant differed statistically (Table 3). The main reason for the different particle size distribution of the soils is the Karamenderes River, which flows into the study area from SE and influences the formation of the soils in the W and NE directions. While sand-sized particles were predominant in these regions near the river, the clay and silt fractions increased as they moved away from the river. The particle size distribution of soils in other areas and the geological structure are compatible. The soils in the study area are slightly alkaline in all directions (Soil Survey Division Staff, 1993). The average value of soil electrical conductivity was measured to be less than 4 dS m^{-1} in the study area, showing no salinity problem (FAO, 2006). It was found that the lime contents of all the soils in the study area were moderately calcareous (Soil Survey Division Staff, 1993). Especially the soils in the W direction and then in the SW direction had higher lime contents than the other directions. This is related to the geological structure and clastic sediments and rocks in the areas where these soils are found. The contents of organic matter in the soils of the study area differed according to the directions. The organic matter content was higher in the southern areas than in the other areas. This is because all these areas are composed of olive fields, and good agricultural practices are applied in the villages where these olive groves are located. The use of organic fertilizers is higher in these areas than in other areas. Similarly, the lands in the SW have a higher organic matter content than the others, and the land management conditions in these lands are similar to those in the south. The clay content of the lands in the directions N, E, and NE, where the organic matter is lower, is lower than in the others.

The total content of heavy metals (Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, and Zn) in the soils sampled from different directions and at different distances around the cement plant showed statistically significant changes according to direction and distance (Table 4). However, the heavy metal concentrations showed uneven distribution in terms of direction and distance. The Cd concentration was highest in NE and SW (1.50 and 1.56 mg kg^{-1}, respectively) and lowest in N (1.22 mg kg^{-1}); Co was highest in SW (2.65 mg kg^{-1}) and lowest in W (0.36 mg kg^{-1}); Cu concentration was highest in SW (38.64 mg kg^{-1}) and lowest in W (19.56 mg kg^{-1}); Cr was highest in NE (74.81 mg kg^{-1}) and lowest in W (29.60 mg kg^{-1}); Fe was highest in S and NE (17,630 and 17,265 mg kg^{-1}, respectively) and lowest in SW (15,320 mg kg^{-1}); Mn concentration was highest in S (652 mg kg^{-1}) and lowest in W (345.40 mg kg^{-1}); Ni concentration was highest in NE (69.30 mg kg^{-1}) and lowest in W (18.98 mg kg^{-1}); Pb concentration was highest in SW (36.69 mg kg^{-1}) and lowest in NE (13.82 mg kg^{-1}); the highest Zn concentration was found in N (68.60 mg kg^{-1}) and the lowest in W (34.59 mg kg^{-1}). Considering the different distances, the highest Cd concentration was found at the 3rd and 7th km (1.47 and 1.44 mg kg^{-1}, respectively) and the lowest at 1st and 5th km (1.28 and 1.34 mg kg^{-1}); the highest Co concentration was found at the 1st and 3rd km (1.52 and 1.39 mg kg^{-1}, respectively) and the lowest at the 5th km (0.70 mg kg^{-1}); Cu concentration was highest at 1st, 5th, and 7th km (32.39, 32.03 and 31.71 mg kg^{-1}) and lowest at 3rd km (28.70 mg kg^{-1}); Cr concentration was highest at 3rd and 7th km (56.21 and 58.37 mg kg^{-1}, respectively) and at lowest at 1st km (41.79 mg kg^{-1}); Fe concentration was highest at 7th km (17,292 mg kg^{-1}) and lowest at 1st, 3rd, and 5th km (15,424, 15,512, and 15,804 mg kg^{-1}, respectively); Mn concentration was highest at 7th km (643.20 mg kg$^{-1)}$ and lowest at 1st, 3rd and 5th km (488.5, 453.80 and 413.40 mg kg^{-1}); Ni concentration was highest at 7th km (54.71 mg kg^{-1}) and the lowest at 1st km (30.51 mg kg^{-1}); Pb concentration was highest at 1st and 7th km (25.38 and 26.28 mg kg^{-1}, respectively) and lowest at 5th km (16.49 mg kg^{-1}); Zn concentration was highest at 7th km (67.41 mg kg^{-1}) and lowest at km 1 and 5 (45.15 and 44.28 mg kg^{-1}).

The reason for the uneven distribution of heavy metal levels in the soils in terms of direction and distance could be related to the geological structure of the area, intensive agricultural activity, and vehicular traffic. The reason for the highest Cu concentration in the SW could be related to the intensive olive cultivation in this region. This is because copper preparations (especially the Bordeaux mixture) are used intensively in olive cultivation. It is known that copper preparations increase soil Cu content in

Table 4 Pearson correlation coefficients between soil properties and heavy metal concentrations

	Sand	Clay	Silt	pH	EC	Lime	Organic matter	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb
Clay	− 0.69*														
Silt	− 0.71*	− 0.03													
pH	− 0.06	− 0.20	0.28*												
EC	− 0.10	− 0.08	0.22	− 0.23											
Lime	− 0.13	0.12	0.07	− 0.12	− 0.07										
Organic matter	− 0.33*	0.39*	0.08	− 0.27*	− 0.11	0.32*									
Cd	0.11	0.01	− 0.17	− 0.15	− 0.10	− 0.18	− 0.09								
Co	0.01	− 0.18	0.16	0.43*	− 0.13	0.20	− 0.13	0.22							
Cr	0.03	− 0.26*	0.22	− 0.11	− 0.24*	− 0.11	0.22	0.22	0.22						
Cu	− 0.03	− 0.23	0.27*	0.32*	0.14	0.15	− 0.13	0.21	0.51*	0.20					
Fe	− 0.16	− 0.21	0.42*	0.24*	0.03	− 0.50*	− 0.10	0.22	0.07	0.65*	0.20				
Mn	− 0.35*	− 0.07	0.54*	0.46*	− 0.07	− 0.24*	− 0.02	0.13	0.18	0.62*	0.16	0.69			
Ni	0.01	− 0.32*	0.31*	0.34*	− 0.13	− 0.22	− 0.28*	0.14	0.19	0.90*	0.24*	0.55*	0.62*		
Pb	− 0.43*	0.27*	0.32*	0.07	− 0.01	0.08	0.38*	0.33*	0.20	− 0.16	0.28*	0.14	0.27*	− 0.23	
Zn	− 0.23	− 0.17	0.47*	0.04	0.72*	− 0.22	− 0.12	0.11	0.07	0.34*	0.38*	0.56*	0.44*	0.29*	0.26*

*$p < 0.05$

olive-growing soils (Vitanovic, 2012). The high Cd concentration in NE and later in SW could be related to agricultural activities. In particular, the areas that constitute the NE part of the study area are where irrigated agriculture and intensive chemical fertilization are practiced. Several studies reported that the Cd content in the soils is elevated, especially due to using phosphorus fertilizers (Atafar et al., 2010; Li et al., 2020). The high Cr and Ni concentrations in NE can be explained by lithology. Serpentines located near these soils can cause high concentrations (Cheng et al., 2011; Oze et al., 2004). In addition, Özcan et al., (2022) reported in their study they conducted on the serpentines of Canakkale-Ezine that the Cr and Ni contents of the soils in the study area reflected the characteristics of the environmental geology. It is believed that the reason for the highest Co concentration in SW is lithology. Various studies have reported that cobalt is abundant in sedimentary rocks (Banerjee & Bhattacharya, 2021; Mahey et al., 2020). The high Pb concentration in SW could be due to the Geyikli-Ezine highway near this sample point. This highway is intensively used by tourism, especially in summer. It has also been determined by other researchers that Pb is caused by the use of motor vehicles (Horasan et al., 2019, 2020). It is suggested that the reason for the high Zn concentration in N could be the intensive agricultural activities (especially fertilization and agricultural control) carried out, especially in irrigated agriculture. Other studies also support this idea (Chen et al., 1997; Manta et al., 2002).

The distribution of heavy metals in the soils around the cement plant was uneven in terms of location and distance. The accumulation of heavy metals did not increase in the prevailing wind direction. The highest heavy metal enrichment was not observed at the closest distance from the plant. The highest concentration of some heavy metals (Fe, Mn, Ni, and Zn) was observed at the farthest distance from the plant. The heavy metals in cement dust accumulate in the soil at different distances depending on wind speed, particle size, and stack fumes (Ameraoui et al., 2017; Plak et al., 2016). Saltalı et al., (2018) found in their study that there was no variation in the heavy metal content in soil depending on the proximity and distance from the cement plant. In addition to these assessments, the complex structure of the study area also affects these processes. The intensive agricultural activity, complex lithology, and traffic load could be the main reasons for the lack of homogeneity in terms of distance and direction.

The correlation coefficients between the soils' physicochemical properties in the cement plant's vicinity and the heavy metal contents are given in Table 4. It is known that soil texture, especially the clay content of soils, affects metal mobility and retention in terrestrial environments (Sungur et al., 2023). There was a negative relationship between sand and clay (r = 0.69), sand and silt (r = 0.71), sand and organic material (r = 0.33), sand and Mn (r = 0.35), sand and Pb (r = 0.43), and a positive relationship between clay and organic material (r = 0.39), clay and Pb (r = 0.27). There was a negative relationship between clay and Cr(r = 0.26); a positive relationship between silt and pH (r = 0.28), silt and Cu (r = 0.27), silt and Fe (r = 0.42), silt and Mn (r = 0.54), silt and Ni (r = 0.31), silt and Pb (r = 0.32), silt and Zn (r = 0.47); a negative relationship between pH and organic matter(r = 0.27) and a positive relationship between pH and Co (r = 0.43), pH and Cu (r = 0.32), pH and Fe (r = 0.24), pH and Mn (r = 0.46), pH and Ni (r = 0.34). The solubility of metals in soil is predominantly controlled by pH. In general, soil pH seems to have the greatest effect of any single factor in the solubility or retention of metal in soils. It

Table 5 Eigenvalues of heavy metals in soils around the cement plant, number of dependent factors, and percentage of variance explained

	Factor 1	Factor 2
Mn	**0.785**	0.209
Cr	**0.929**	0.011
Cd	0.126	**0.572**
Pb	– 0.203	**0.857**
Zn	**– 0.692**	**– 0.531**
Ni	**0.958**	– 0.062
Cu	0.424	**0.603**
Fe	**0.823**	0.244
Co	0.475	0.447
Eigenvalues	4.464	1.565
% of variance	49.603	17.394
% cumulative variance	49.603	66.997
Kaiser–Meyer–Olkin measure of sampling adequacy		0.738
Bartlett's test of sphericity		0.000

Bold values are factor loadings of the principal components is recorded that greater retention and lower solubility of metal cations occurred at high soil pH (Orhue & Frank, 2011). There was a negative relationship between EC and Cr (r = 0.24); a positive relationship between EC and Zn (r = 0.72); a positive relationship between organic matter and lime (r = 0.32); a negative relationship between organic matter and Ni (r = 0.28); a positive relationship between organic matter and Pb (r = 0.38); a positive correlation between Cd and Pb (r = 0.33); a positive relationship between Co and Cu (r = 0.51); a positive relationship between Cr and Fe (r = 0.65), Cr and Mn (r = 0.62), Cr and Ni (r = 0.90), Cr and Zn (r = 0.34); a positive relationship between Cu and Ni (r = 0.24), Cu and Pb (r = 0.28), Cu and Zn (r = 0.38); a positive relationship between Fe and Ni (r = 0.55), Fe and Zn (r = 0.56); and a positive relationship between Mn and Ni (r = 0.62), Mn and Pb (r = 0.27); and a positive relationship between Mn and Zn (r = 0.44), between Ni and Zn (r = 0.29), and between Pb and Zn (r = 0.26). Plak et al. (2016) found a relationship between heavy metal content and the finest fractions of soil or organic matter in the soils around the cement plant in Poland. Olowoyo et al. (2015) found positive correlations between some trace metals such as Pb, Zn, Cu, Mn, Ni, and Cr. This showed that most heavy metals could enter the soil from different pollution sources (cement plants or vehicular emissions) (Ogunkunle & Fatoba, 2014; Kolo et al., 2018; Olatunde et al., 2020; Das et al., 2022). This situation also confirms the situation in our study area.

The number of factors formed for heavy metals in the study area soils and the percentage of variance explained are given in Table 5. Factor 1 accounted for the most variance (49.60%) and had the highest eigenvalue (4.464). This factor had high loadings on the metals Mn, Cr, Zn, Ni, and Fe. Factor 2 accounted for 17.394% of the total variance and was composed of the metals Cd, Pb, Zn and Cu. The Kaiser- Meyer Olkin (KMO) measure and Barlett's Test were used to examine the appropriateness of factor analysis. The KMO statistic of 0.738 was also large (greater than 0.50) (Table 5). Heavy metals' origin in the cement plant soils may be anthropogenic or lithogenic. Other researchers have found a similar situation (Das et al., 2022; Estifanos, 2014; Kolo et al., 2018).

The spatial distribution of the average values of heavy metals in the soils around the cement plant is shown in Fig. 4. The Cd content in the study area was

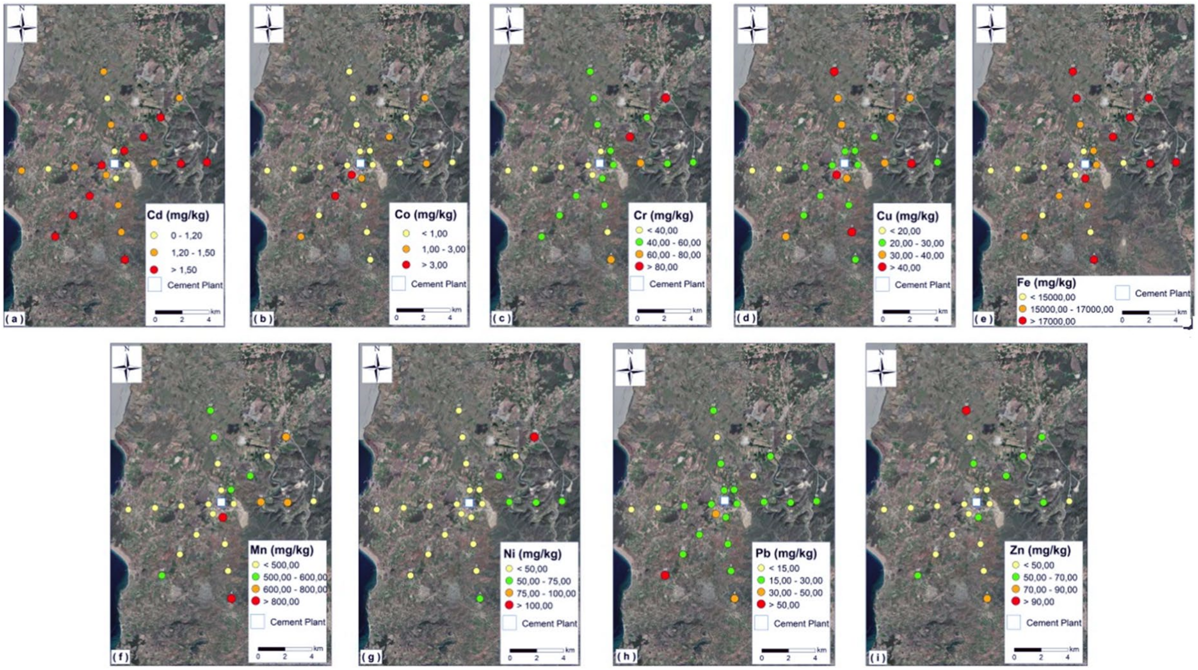

Fig. 4 **a** Cd, **b** Co, **c** Cr, **d** Cu, **e** Fe, **f** Mn, **g** Ni, **h** Pb, and **i** Zn mean values in the soils around the cement plant

Table 6 Comparison of heavy metals in soils affected by cement plants in other countries (in mg kg^{-1})

Country	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	References
Meftah, Algeria	1.75	–	–	43.96	–	–	–	145.46	282.82	Ameraoui et al. (2017)
Grupo Bambui, Brazil	0.06	3.88	27.83	9.05	–	338.2	3.99	17.96	20.47	Silva et al. (2021)
Xuzhou, China	0.8	22.3	235.8	71.08	–	1796.9	88.4	56.6	216.5	Liu et al. (2019)
Volta Region, Ghana	–	54.54	961.24	27.97	–	544.92	245.26	13.13	35.02	Addo et al. (2012)
Bhagwanpur Town, India	–	–	16.59	35.58	–	128.10	18.39	11.49	–	Kaur et al. (2019)
Doroud, Iran	–	–	115.77	80.47	–	–	139.07	56.27	135.73	Jafari et al. (2019)
Babylon Governorate, Iraq	0.10	–	–	23.6	307	–	112.8	92.1	63.8	Khwedim et al., (2015)
Rockfort, Jamaica	5.24	–	57.21	–	27,000	–	–	31.47	132.03	Mandal & Voutchkov (2011)
Ashaka, Nigeria	–	–	76.4	5.03	–	466	29.1	19.3	10.1	Kolo et al. (2018)
Catalonia, Spain	0.3	4	10.3	27.6	–	213.7	11.3	16.4	38.2	Schuhmacher et al., (2002)
Kahramanmaras, Turkey	0.89	–	194.8	36.7	–	–	285.1	0.7	178.8	Saltalı et al. (2018)
Continental crust	0.3	19	90	45	47,200	850	68	20	95	Turekian & Wedepohl (1961)
Turkish Soil Pollution Control Regulation, Turkey	–	–	100	140	–	–	75	300	300	SPC Regulation (2005)
Worldwide soils	0.41	11.3	59.5	38.9	35,000	488	29	27	70	Kabata-Pendias (2011)
Canakkale, Turkey	1.39	1.18	50.92	31.21	16,007	499.69	41.17	21.70	50.91	This study

higher by 1.5 mg kg^{-1} in the northeast and southwest directions than in the other directions, and the Co concentration was lower than 3 mg kg^{-1} in most of the study area. However, it was higher than 3 mg kg^{-1} in the southwest and the 1st and 3rd directions. The Cr content was between 40–60 mg kg^{-1} in most of the study area, and the Cu content was between 20–30 mg kg^{-1} in almost half of the study area. Fe content was > 15,000 mg kg^{-1} in most parts of the study area, and Mn content was < 800 mg kg^{-1} in almost all of the study area. Ni, Pb, and Zn concentrations were also below 50 mg kg^{-1}, 30 mg kg^{-1}, and 70 mg kg^{-1}, respectively, in most of the study area.

The average heavy metal contents determined in this study were compared with other studies, and the comparison is shown in Table 6. Cd concentration was lower than the concentration in Algeria and Jamaica, higher than the concentration in other countries(Brazil, China, Iraq, Spain, Turkey, continental crust and worldwide soils), Co concentration was lower than the concentration in Brazil, China, Ghana, Spain, continental crust, and global soils, and Cr concentration was lower than the concentration in the other countries(Brazil, China, Ghana, Iran, Jamaica, Nigeria, Spain, Kahramanmaras, Turkish Soil Pollution Control Regulation,

Table 7 Daily intake levels of heavy metals in the soils around the cement plant for children and adults (in mg kg^{-1} day^{-1})

Heavy metals	Children				Adults			
	$ADD_{ingestion}$	$ADD_{inhalation}$	ADD_{dermal}	ADD_{total}	$ADD_{ingestion}$	$ADD_{inhalation}$	ADD_{dermal}	ADD_{total}
Cd	3.95E−06	1.10E−10	1.10E−08	3.96E−06	3.80E−07	2.23E−10	8.02E−09	3.88E−07
Co	3.35E−06	9.36E−11	9.39E−09	3.36E−06	3.22E−07	1.89E−10	6.80E−09	3.31E−07
Cr	1.45E−04	4.05E−09	4.06E−07	1.45E−04	1.39E−05	8.21E−09	2.95E−07	1.42E−05
Cu	8.89E−05	2.48E−09	2.49E−07	8.92E−05	8.55E−06	5.03E−09	1.80E−07	8.74E−06
Mn	1.42E−03	3.97E−08	3.98E−06	1.42E−03	1.37E−04	8.05E−08	2.89E−06	1.40E−04
Ni	1.17E−04	3.28E−09	3.28E−07	1.17E−04	1.13E−05	6.64E−09	2.38E−07	1.15E−05
Pb	6.18E−05	1.72E−09	1.73E−07	6.2E−05	5.95E−06	3.49E−09	1.25E−07	6.08E−06
Zn	1.45E−04	1.60E−09	4.06E−07	1.45E−04	1.39E−05	1.53E−09	2.94E−07	1.42E−05

continental crust and worldwide soils) except for India. Cu concentration was higher compared to Brazil, Ghana, Iraq, and Nigeria, lower compared to Algeria, China, India, Iran, Turkey, continental crust, and Turkish Soil Pollution Control Regulation, and Fe concentration was higher compared to Iraq, Jamaica, continental crust, and global soils. Mn concentration was higher compared to Brazil, India, Nigeria, and Spain and lower compared to China, Ghana, continental crust, and global soils; Ni was higher compared to Brazil, India, Nigeria, Spain, and global soils. Pb concentration was lower compared to China, Ghana, Iran, Iraq, Turkey, continental crust, and Turkish Soil Pollution Control Regulation(SPC Regulation) and higher compared to Ghana, India, Nigeria, Spain, Turkey, and continental crust. Ni concentration was lower compared to Algeria, China, Iran, Iraq, Jamaica, and Turkish Soil Pollution Control Regulation and global soils and higher compared to Brazil, India, Nigeria, Spain, and global soils. It was lower compared to China, Ghana, Iran, Iraq, Turkey, continental crust, and Turkish Soil Pollution Control Regulations. Zn concentration was lower compared to Algeria, China, Iran, Iraq, Jamaica, Turkey, continental crust, and Turkish Soil Pollution Control Regulation and higher compared to Brazil, Ghana, Nigeria, and Spain. The differences in heavy metal concentrations in soils sampled around cement plants in different countries may be due to the depth of sampling, type of fuel used in the cement plant, chemical composition of the raw material, current land use, soil management, and geological structure (Rahmanian & Safari, 2020).

Human health risk assessment

The health risk assessment of heavy metals in soil was studied in two sections as non-carcinogenic and carcinogenic. ADD values of heavy metals by ingestion, inhalation, and dermal contact pathways are given in Table 7. The highest and lowest daily intake levels of heavy metals for the non-carcinogenic uptake route in children were found for Mn (1.42E−03)

Table 8 Non-carcinogenic risks of heavy metals in soils around cement plants

Heavy metals	Children				Adults			
	$HQ_{ingestion}$	$HQ_{inhalation}$	HQ_{dermal}	HI	$HQ_{ingestion}$	$HQ_{inhalation}$	HQ_{dermal}	HI
Cd	3.95E−03	1.10E−07	1.11E−03	5.06E−03	3.80E−04	2.23E−07	8.02E−04	1.18E−03
Co	1.67E−04	1.64E−03	5.86E−07	1.81E−03	1.61E−05	1.19E−03	4.25E−07	1.21E−03
Cr	4.84E−02	1.42E−04	6.77E−04	4.92E−02	4.65E−03	2.87E−04	4.91E−04	5.43E−03
Cu	2.22E−03	6.18E−07	2.07E−05	2.24E−03	2.14E−04	1.25E−06	1.5E−05	2.3E−04
Mn	3.10E−02	2.78E−03	2.17E−03	3.59E−02	2.98E−03	5.63E−03	1.57E−03	1.02E−02
Ni	5.87E−02	1.59E−07	6.08E−05	5.87E−02	5.64E−03	3.22E−07	4.41E−05	5.68E−03
Pb	1.77E−02	4.90E−07	3.30E−04	1.80E−02	1.7E−03	9.93E−07	2.39E−04	1.94E−03
Zn	4.84E−04	5.33E−09	6.77E−06	4.90E−04	4.65E−05	5.13E−09	4.91E−06	5.14E−05
	$CHQ_{ingestion}$	$CHQ_{inhalation}$	CHQ_{dermal}	THI	$CHQ_{ingestion}$	$CHQ_{inhalation}$	CHQ_{dermal}	THI
	1.59E−01	4.56E−03	3.45E−03	1.71E−01	1.53E−02	7.11E−03	2.5E−03	7.70E−02

Table 9 Carcinogenic risks of heavy metals in soils around cement plants

Heavy metals	Children				Adults			
	$CR_{ingestion}$	$CR_{inhalation}$	CR_{dermal}	CR	$CR_{ingestion}$	$CR_{inhalation}$	CR_{dermal}	CR
Cd	–	6.96E−10	–	6.96E−10	–	1.41E−09	–	1.41E−09
Co	–	9.17E−10	–	9.17E−10	–	1.85E−09	–	1.85E−09
Cr	2.03E−01	5.95E−04	2.84E−03	2.07E−01	1.95E−02	1.21E−03	2.06E−03	2.28E−02
Ni	–	1.34E−07	–	1.34E−07	–	2.71E−07	–	2.71E−07
Pb	7.42E−04	2.06E−08	1.39E−05	7.56E−04	7.14E−05	4.17E−08	1.00E−05	8.14E−05

and Co (3.36E−06). In children, the highest Mn (3.97E−08) and the lowest Co (9.36E−11) uptake by the inhalation route were found. In children, the highest Mn (3.98E−06) and lowest Co (9.39E−09) were detected by the dermal route. For adults, the highest $\text{ADD}_{\text{ingestion}}$, $\text{ADD}_{\text{inhalation}}$ and $\text{ADD}_{\text{dermal}}$ levels were detected for Mn (1.37E−04, 8.05E−08, and 2.89E−06, respectively) and the lowest for Co (3.22E−07, 1.89E−10, and 6.80E−09, respectively. The total ADD values of heavy metals in the study area were determined in the order of Mn > Cr = Zn > Ni > Cu > Pb > Cd > Co for children and adults. It was found that $\text{ADD}_{\text{ingestion}}$ and $\text{ADD}_{\text{total}}$ values were higher in children than in adults(Table 6). Other researchers also found this result (Jafari et al., 2019; Kolo et al., 2018).

The HQ and HI values of heavy metals in the soils from the study area are shown in Table 8. The Index HQ $_{\text{ingestion}}$ value calculated for children was highest for Ni (5.87E−02) and lowest for Co (1.67E−04). The HQ $_{\text{inhalation}}$ value was highest for Mn (2.78E−03) and lowest for Zn (5.33E−09), and the HQ $_{\text{dermal}}$ value was highest for Mn (2.17E−03) and lowest for Co (5.86E−07). Except for Co, $\text{HQ}_{\text{ingestion}}$ values were higher than $\text{HQ}_{\text{inhalation}}$ and $\text{HQ}_{\text{dermal}}$ values in children and adults. This indicates that human uptake of heavy metals is greater with oral intake. The total HI value for children was calculated to be 0.171. In adults, $\text{HQ}_{\text{ingestion}}$ value was highest in Ni (5.64 E−03) and lowest in Co (1.61E−05); $\text{HQ}_{\text{inhalation}}$ value was highest in Mn (5.63 E−03) and lowest in Zn (5.13E−09; $\text{HQ}_{\text{dermal}}$ value was highest in Mn (1.57 E−03) and lowest in Co (4.25E−07). The HI total adult value is 0.077(Table 7). Compared with adults, children are more exposed to non-carcinogenic risks.

The values of carcinogenic risk of heavy metals in the soils from the study area are shown in Table 9. The $\text{CR}_{\text{ingestion}}$ values for Cr and Pb were calculated to be higher than the $\text{CR}_{\text{inhalation}}$ and $\text{CR}_{\text{dermal}}$ values for both children and adults. The carcinogenic risks were determined in the order Cr > Pb > Ni > Co > Cd for both children and adults. The carcinogenic effects of Cd, Co, and Ni in children and adults were negligible. According to calculations, chromium has a carcinogenic effect as it exceeds the limit of Cr and Pb in children, and Cr 1×10^{-4} in adults. Excessive chromium intake in the human body can cause lung and stomach cancer(Rahman et al., 2019). Long-term intake of lead in the body causes neural and gastrointestinal problems, anemia, damage to the kidneys, endocrine system, and immune system, as well as disorders in children's psychophysical development (Pavlovic et al., 2021).

Conclusions

72 surface soils (0–10 cm) were sampled in the vicinity of a cement plant in northwest Turkey. The average heavy metal concentrations in the soils were determined in the order of Fe > Mn > Cr > Zn > Ni > Cu > Pb > Cd > Co. The results show that the HQ values for all heavy metals were higher through ingestion pathway than through inhalation and dermal contact pathways. The CHQ $_{\text{ingestion}}$, CHQ $_{\text{inhalation}}$, and CHQ $_{\text{dermal}}$ values in children are 1.59E−01, 4.56 E−03, 3.45 E−03, respectively; in adults, these values are 1.53E−02, 7.11E−03 and 2.5E−03, respectively. The carcinogenic risks of Cr and Ni in children were greater than 1×10^{-4}, and the carcinogenic risk of Cr in adults was greater than 1×10^{-4}. The sources of heavy metals mentioned in this study may include agrochemicals used in intensive agricultural activities in the region, vehicular traffic on roads, and atmospheric effects and geological structures. Attention should be paid to the permitting and planning processes before locating major industrial facilities such as the cement plant. In this context, a database can be created for the healthy development of future monitoring and assessment processes by taking soil samples at different distances from the region where the plant is to be built. Continuous geochemical monitoring of soils should be conducted in the vicinity of pollutant sources such as cement plants. In further and future detailed studies, geochemical fractionation of heavy metal deposits in the region can be done, and studies can be conducted to interpret the sources more accurately. The heavy metal content of the crops grown in the soils around the cement plant should also be monitored regularly. Then, the results of the heavy metal studies in the soils and plants should be shared with the residents of the villages around the cement plant.

Author contributions Mehmet Parlak and Timuçin Everest collected the soil samples. Tülay Tunçay conducted laboratory analyses of the soil samples. Mehmet Parlak analyzed the data, completed data interpretation, and drafted the manuscript. All the authors contributed to manuscript writing.

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Declarations

Conflict of interest The authors declare no competing interests.

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