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ORIGINAL ARTICLE

Spatial distribution of heavy metals and sources of soil contamination in southern Konya (Turkey): Insights from geochemistry, Pb and Sr–Nd isotope systematics

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Abstract

This geochemical study reports the concentrations, spatial distributions, and sources of heavy metals in soil samples from southern Konya. The investigation focused on topsoil (0–20 cm; $n=65$), two soil profile (20–100 cm; $n=5$), bedrock ($n=12$) and stream sediment ($n=4$) samples. A total of 70 soil samples were collected and in some samples determined to be enriched in Cd (5.38 ppm), Co (86.4 ppm), Cr (342 ppm), Cu (647 ppm), Fe (6.82%), Ni (755 ppm), Mn (2850 ppm), Zn (529 ppm) and As (89.8 ppm) relative to maximum allowable heavy metal concentrations in Turkey's soil. The heavy metals accumulated and enriched in stream sediments are mainly Cr, Ni, Co. The samples of soil profiles collected from different depths show commonly geogenic and partially anthropogenic effects. According to calculated geoaccumulation index (I_{geo}), enrichment factor (EF), and contamination factor (C_f) to evaluate possible metal enrichment in soil, the enrichment of heavy metals in the study area shows in the decreasing order of As > Ni > Cd > Co > Cr > Cu > Mn. The topsoil samples have CIA (Chemical Index of Alteration; 4.34–68.27) and CIW (Chemical Index of Weathering; 4.36–74.37) values ranged indicative of low–medium weathering. The $^{87}Sr/^{86}Sr$ and εNd values ranged from 0.705341 to 0.707491 and − 0.62 to − 4.95 in topsoil samples suggesting their bedrock sources. Lead isotopic data ($^{207}Pb/^{206}Pb = 0.816–0.852$; $^{208}Pb/^{206}Pb = 2.000–2.242$) of the topsoil and profile soil samples show mostly geogenic (natural), partially anthropogenic sources. Ni, Cr, Co, and Cu enrichments in soils and stream sediments are related extremely with weathering of ophiolitic rocks and partially with traffic and agricultural activities (fertilization, irrigation, etc.), while As and Cd enrichments in soils are related commonly with weathering of volcanic rocks and partially with similar human activities. The geochemical results of heavy metals, Pb and Sr–Nd isotope analyses indicate that the most important source of high amounts of As, Cd, Co, Cr, Ni, Cu, Mn in some of soils in southern Konya is dominantly geological materials (natural resources) and rarely human activities (anthropogenic).

Keywords Geochemistry · Heavy metal · Soil · Sr–Nd isotope · Pb isotope · Southern Konya (Turkey)

Introduction

Many scientists focused on heavy metals of the soils and stream sediments as they are very useful tracers of environmental pollution (e.g. Walraven et al. 1997; Manta et al. 2002; Yalçın et al. 2007; Guo et al. 2012; Cicchella et al. 2014, 2015; Tóth et al. 2016; Cuvier et al. 2016, Ungureanu et al. 2017; Rezza et al. 2018). Heavy metal enrichment in soils and stream sediments is related to physical and chemical conditions such as natural weathering, pH, organic matter, etc. (e.g. McLean and Bledsoe 1992; Dube et al. 2001). Some potentially toxic metals (e.g. chromium, nickel, copper, molybdenum, selenium and zinc) at low concentrations are essential to the healthy functioning and reproduction of microorganisms for humans, animals and plants (Alloway 1995). However, these same essential elements at high concentrations may cause direct toxicity effects to biota and human health (Förstner 1995). Some elements (e.g. arsenic, lead and mercury) are also non-essential and even low concentrations of these elements in the environment can cause toxicity to humans, animals, and plants (Alloway 1995). Soils with naturally high concentrations of some elements (e.g. serpentine soils) also cause toxicity (Adamo and Zampella 2008).

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The geochemistry and heavy metal accumulation of stream sediments, which are controlled by various factors such as lithological, geomorphological, hydrological, and climatic (Salomons and Förstner 1984), occur depending on the alteration in the rocks (Patyk-Kara et al. 2001). Stream sediment geochemistry is also used to explore bedrock geochemistry (Van der Oever 2000).

Geoaccumulation index (I_{geo}), Enrichment factor (EF) and Contamination factor (C_f) were used to evaluate the accumulation of heavy metals and to determine anthropogenic sourced accumulations (e.g. Feng et al. 2004; Rajmohan et al. 2014; Vural 2014; Okay et al. 2016; Zhu et al. 2018; Lermi and Sunkari 2020; Solgun et al. 2021; Öztürk and Arıcı 2021).

In addition to the investigation of heavy metals in the soil, the source of these heavy metals and/or soils has been studied by many researchers (e.g. Hansmann and Köppel 2000; Reimann et al. 2012; Sun et al. 2018; Kong et al. 2018; Lermi and Sunkari 2020). Lead (Pb) isotope ratios only vary according to their geological/natural sources, and the isotopic compositions of the samples reflect those of the Pb sources or results of mixing if multiple Pb sources exist (Cheng and Hu 2010). The lead isotope ratios are useful tools to identify the various contributions from natural and anthropogenic sources (e.g. Veysseyre et al. 2001; Ayuso et al. 2008; Shetaya et al. 2019). Pb-isotopic compositions are not affected by industrial and environmental processes such as biological, physical, and chemical in the near-surface environment, and are useful tools to investigate the sources and mobility of lead, and other geochemically similar metals, and always reflects the source of origin (e.g. Ayuso et al. 2008; Cicchella et al. 2014).

The minerals and rocks have distinct $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios depending on their geological derivation. So, the Sr and Nd isotopes are important as source area fingerprints. The Sr–Nd isotope ratios are less altered than elemental composition during transport in the atmosphere or after deposition. So, these elements can be used as traceability indexes to determine their origins (e.g. Asahara 1999; Nakano et al. 2004; Nakano 2016).

Many studies have been carried out on assessment of soil pollution in eastern and northern Konya (Önder et al. 2007; Dursun and Önder 2008; Horasan and Arık 2019; Öztürk and Arıcı 2021). The comprehensive geochemical investigations of the soils in southern Konya were studied for the first time. This study aims to describe the spatial distribution of heavy metals in soils in southern Konya, to determine whether there is the contamination of soils and the degree of contamination, to find out possible sources of soil and pollution, and to evaluate their impact on soil geochemistry and rock-soil relationship. This paper presents the results of comprehensive heavy metal geochemistry, Pb and Sr–Nd isotopes in mainly topsoil, profile soil, stream sediment, and bedrock samples to determine the pedogenesis, geogenic and/or anthropogenic effect of soils in southern Konya.

Description of the study area

Location

The investigation area located in southern part of Konya (Turkey) city covers a surface of 459 km^2 which contains situated between Hatıp-Çayırbağı and Çatören (Fig. 1). The study area is characterized by a semi-arid (steppe) climate with an annual average temperature of 11.6 °C and an average rainfall amount of 323.3 mm (http://www.mgm.gov.tr).

Geological settings

The geology of the investigation area is dominated by sedimentary rocks (carbonated) in the center of the study area, ophiolitic rocks in the northwest of the study area and volcanite in the southwest of the study area (Fig. 1). The morphology of the investigation area can be subdivided into several areas, consisting of volcanic terrains, and hills formed by the sedimentary and ophiolitic rocks.

The Upper Triassic–Lower Cretaceous limestone, dolomitic limestone and dolomite, and the Upper Cretaceous aged clayey limestone, radiolarite, shale and marl are the basements of the study area. These units contain tectonic contact with the Upper Cretaceous ophiolitic melange and ophiolite. The ophiolitic rocks are tectonically overthrusted on Jura–Triassic carbonate, also intercalated by ophiolites. The rocks from the ophiolitic sequence in the area also outcrop northwest of the area, near the village of Hatıp, Çayırbağı and Karadiğin. They comprise peridotite, dunite, gabbro, serpentinite, magnesite, diabase, mudstone, radiolarite and chert. Upper Miocene–lower Pliocene volcanite consisting of andesite, dacite, tuff and tuffite, occur in the southwest part of the area and near Hatunsaray and Çatören towns. The upper Miocene–lower Pliocene marl, claystone, sandstone, conglomerate, and limestone outcrop in the center of the study area. The Quaternary alluvial sediments which are the youngest unit in the region and consist of conglomerate, sandstone, alluvial fans and terrestrial clastics, cover all old deposits with angular unconformity (Hakyemez 1992; Aksoy and Eren 2004; Turan 2010).

Materials and methods

Sampling methodology

For the geochemical data, 65 topsoil (0–20 cm), 5 profile soil in two soil profiles (20–150 cm and 20–130 cm), 12

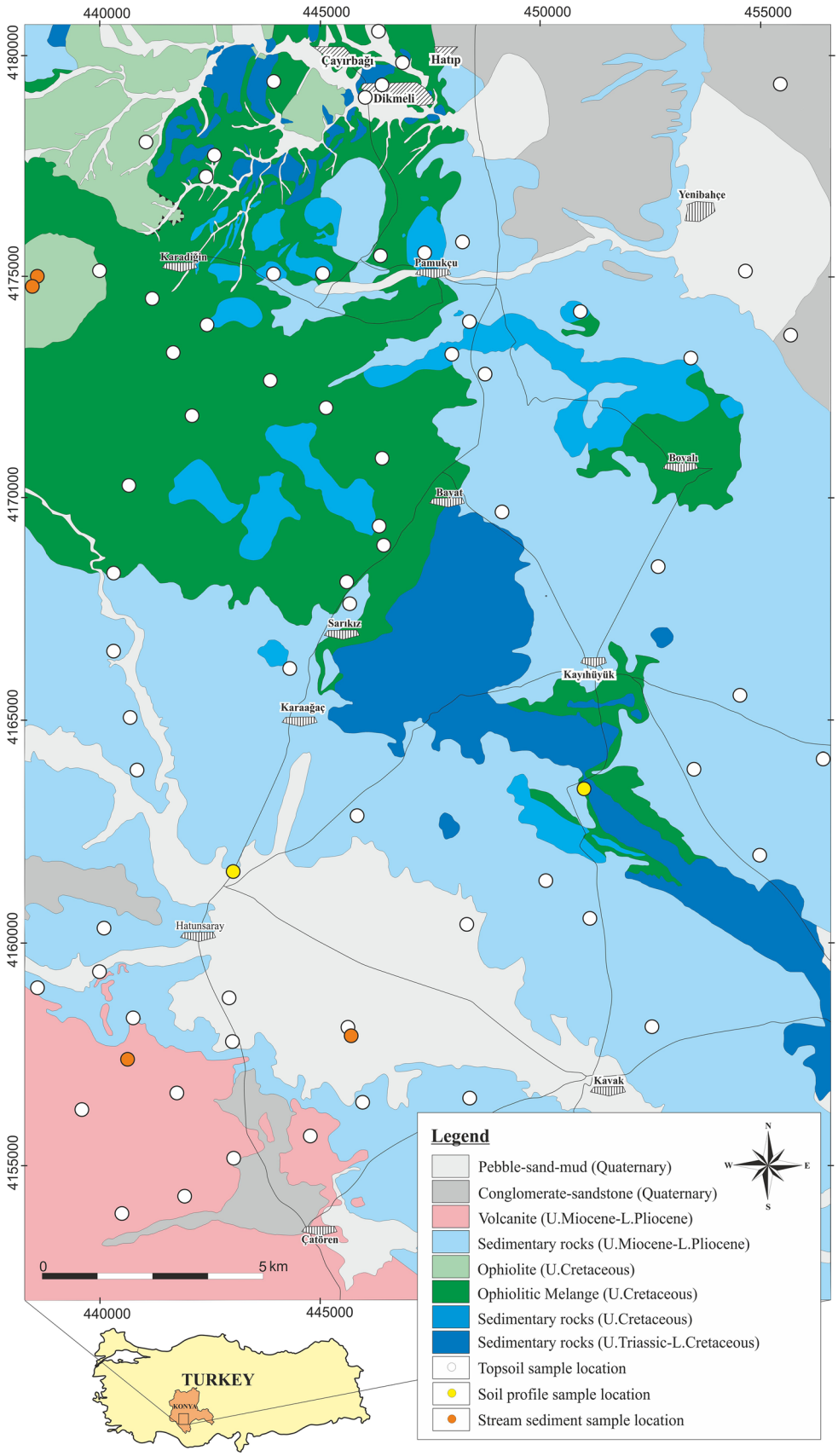

Fig. 1 Geological map of the investigation area (modified after Hakyemez, 1992 and Özen, 2021).

whole-rock, and 4 stream sediment samples were collected in the study area (Fig. 1). About 2–3 kg of soil sample was taken at depths of 0–20 cm for topsoil and of 0–150 cm for profile samples in each sampling location. The 8 soils developed on volcanite, 22 soils developed on ophiolitic rocks, 35 soils occurred on the sedimentary rocks and 5 profile soils from a total of 70 selected soil samples were examined.

The soil sampling from topsoil was performed with stainless-steel materials to avoid contamination of the samples. A total of 70 soil samples were carefully stored in a thick, clean plastic bag and were labeled with the sampling number and location in the field. The information that can help further interpretations of the final results was noted. Sample locations were identified using a Global Positioning System (GPS).

The soil samples were air-dried in a clean laboratory at room temperature, and roots and animal residues were removed from soil samples. The soil samples were pulverized with an agate pestle and then sieved to 75–125 µm particle size. The sieved soil samples were stored in locked clean small plastic bags and vessels for chemical (trace element), Pb, Sr–Nd isotopes, and X-ray diffractometer (XRD) analyses.

Determination of the pH value

The pH measurements were conducted with soil and pure water, stirring for 1 min, and settling for 30 min. For each sample, the pH of the soil samples was measured using a standard pH meter (SX-620 pH meter) in an aqueous solution using a soil:water ratio of 1:2. Calibration of the pH meter was carried out with buffer solutions of pH 4, 7, and 10 at the beginning of each set of analyses.

X-ray diffraction (XRD)

The mineralogical analyses of the soil samples were performed using XRD analysis for topsoil ($n=35$) and rock ($n=10$) samples in the XRD Laboratory of the General Directorate of Mineral Research and Exploration (MTA, Ankara). The XRD analyses were carried out using the PANalytical X'Pert Powder diffractometer equipped with a Ni-filtered Cu X-ray tube with a wavelength of 1.544 Å between 4 and 70° and max. 60 kV and 50 mA, a real-time multiple strip PIXcel3D detector and at 2θ, 0.039 step interval and 0.25 s count analytical conditions. X-ray patterns were evaluated using Panalytical High Score Plus software and ICSD Database.

The chemical index of alteration (CIA) and chemical index of weathering (CIW)

CIA values calculated the intensity of chemical weathering in soil by comparing the changes in major and trace element concentrations as ratios of mobile and immobile elements in the soil, rock or parent material (Düzgören-Aydın et al. 2002) are controlled by the mineralogy of the source rocks. CIA values were classified as very slightly weathered (50–60), slightly weathered (60–70), moderately weathered (70–80), highly weathered (80–90), and extremely weathered (90–100) by Nesbitt and Young (1982). Worldwide average shale CIA values range between about 70 and 75 (Visser and Young 1990); fresh and unweathered basalt has a CIA of ~30 to 40 (Ryan 2020), whereas granite has CIA values of ~45–50 (Ryan 2020; Visser and Young 1990). Stream sediments have a CIA range of 60–70 because they have experienced some chemical alteration since being eroded from parent rock (Ryan 2020). The difference between CIW index values for source rock and soil reflects the amount of chemical weathering experienced by the weathered material (Harnois 1988). Major oxide values were converted to molecular ratios in the CIA and CIW formulas.

$$\mathrm{CIA} = 100x\left(\frac{\mathrm{Al_2O_3}}{\mathrm{Al_2O_3} + \mathrm{CaO^*} + \mathrm{Na_2O} + \mathrm{K_2O}}\right),$$

$$\mathrm{CIW} = 100x\left(\frac{\mathrm{Al_2O_3}}{\mathrm{Al_2O_3} + \mathrm{CaO^*} + \mathrm{Na_2O}}\right).$$

Geoaccumulation index (I_{geo})

The geoaccumulation index calculated using the equation proposed by Müller (1969, 1986) was used to quantify the degree of anthropogenic contamination and the metal pollution in the soil. The geoaccumulation index was calculated using the following equation:

$$I_{\mathrm{geo}} = \log_2\left(\frac{C_n}{1.5xB_n}\right),$$

C_n is the concentration of the element (n) in the analyzed soil. B_n is the geochemical background value of the element (n). The constant 1.5 is an empirical coefficient suggested to consider the possible natural fluctuations caused by the effects of the soil. Background values can be estimated from in-situ soil or published data on the upper continental crust or the average element contents of the soil. Average upper continental crustal values (Taylor and McLennan, 1995) were used as background values for all calculations in this study. Müller (1986) was defined seven classes for the I_{geo} values: Class 0 ($I_{geo} \leq 0$) is practically unpolluted; class 1 ($0 < I_{geo} < 1$) is unpolluted to moderately polluted; class 2 ($1 < I_{geo} < 2$) is moderately polluted; class 3 ($2 < I_{geo} < 3$) is moderately to heavily polluted; class 4 ($3 < I_{geo} < 4$) is heavily polluted; class 5 ($4 < I_{geo} < 5$) is heavily to extremely polluted; class 6 ($I_{geo} > 5$) is extremely polluted.

Enrichment factor (EF)

Enrichment factor (EF) is one of the valuable indices used in understanding the contribution of metals other than lithogenic origin and estimating the level of anthropogenic input for metal pollution in soils. Several authors used iron to normalize the heavy metals (e.g. Sinex and Helz 1981; Feng et al. 2011; Rajmohan et al. 2014; Okay et al. 2016; Zhu et al. 2018; Öztürk and Arıcı 2021; Coşkun et al. 2021). Fe is used as the element for normalization and EF calculation in this current study because anthropogenic sources are small compared to natural sources (Helz 1976). It was calculated using the equation (Zoller et al. 1974) below:

$$\mathrm{EF} = (\mathrm{Metal/Fe})_{\mathrm{soil}} / (\mathrm{Metal/Fe})_{\mathrm{background}}$$

The background values were obtained from Taylor and McLennan (1995). If an EF value is between 0.5 and 1.5 (i.e., $0.5 < \mathrm{EF} < 1.5$), it suggests that the trace metals may be entirely from crustal material contribution or natural weathering processes (Zhang and Liu, 2002). However, if a value of EF is greater than 1.5, it suggests that a significant portion of trace metal is delivered from non-crustal materials or non-natural weathering processes. Likewise, Andrews and Sutherland (2004) classified EF values as metal pollution evaluation, where $\mathrm{EF} < 2$ indicates minimal pollution; EF 2–5 indicates moderate pollution; EF 5–20 indicates significant pollution; EF 20–40 indicates high pollution; $\mathrm{EF} > 40$ indicates extreme pollution.

Contamination factor (C_f)

Contamination factor (C_f) suggested by Hakanson (1980) is employed in several studies to determine the level of contamination of heavy metals in soils. C_f is a ratio of the metal contents in the soil samples and the background value of the corresponding metal. $C_{\text{metal of sample}}$ is the concentration of a metal in analyzed soil, and $C_{\text{metal of backgraound}}$ is geochemical background value of the metal. Upper continental crust (UCC) values are used for this calculation (Taylor and McLennan 1995) as background values.

$$C_f = C_{\text{metal of sample}} / C_{\text{metal of background}}$$

The C_f was classified into four groups by (Hakanson 1980): low contamination ($C_f < 1$), moderate contamination ($1 \le C_f < 3$), considerable contamination ($3 \le C_f < 6$), and very high contamination ($C_f \ge 6$).

Geochemistry

70 soil samples (topsoil and profile soil), 12 whole-rock and 4 stream sediments selected from the study area were analyzed for super-trace element analysis in ALS Global Laboratories (Vancouver, Canada) with Inductively Coupled Plasma—Mass Spectroscopy (ICP-MS). Samples were leached in 75% aqua regia digestion (3:1 ratio of $HCl:HNO_3$). The samples were analyzed by inductively coupled plasma mass spectroscopy (ICP-MS) after digestion. The analyses included the following 53 elements: Au, Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, Pt, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Zn, Zr, and Pb isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb) and Si were analyzed by Sodium Peroxide Fusion & ICP-AES.

Sr–Nd isotopes

Strontium and Neodymium isotope analyses for the 5 topsoil (0–20 cm), 5 profile soil (20–100 cm) and 4 whole-rock samples were performed at the Radiogenic Isotope Laboratory of Central Laboratory, Middle East Technical University (METU), Ankara, Turkey. Chemical treatment and column chemistry were performed in 100-class clean laboratory with ultrapure chemical agents. Powdered rock samples (approximately 120 mg) were leached with 4 ml of 52% HF for 4 days on the hot plate (> 100 °C). These samples were dried and dissolved overnight in 4 ml 6 N HCl on the hot plate. Afterward, samples were dried, and one-third of the samples were separated, and the remaining parts were dissolved in 2.5 N HCl for Sr and Nd chromatography. Strontium was separated from other elements in 2 ml volume BioRad AG50 W-X8 (100–200 mesh) resin in teflon columns in a 2.5 N HCl medium. After separation of Sr, excessive Ba was removed by using 2.5 N HNO_3. Subsequently, REE fraction was enriched with 6 N HCl in these columns. Neodymium was separated from REE fraction in 2 ml HDEHP (bis-ethyexyl phosphate)-coated biobeads (BioRad) resin by using 0.22 N HCl in teflon columns. Strontium was loaded on single Re flaments with 0.005 N H_3PO_4 and Ta activator to improve efficiency. Neodymium, on the other hand, was loaded on double flaments with 0.005 N H_3PO_4. $^{87}Sr/^{86}Sr$ ratios are normalized with $^{86}Sr/^{88}Sr = 0.1194$, and $^{143}Nd/^{144}Nd$ ratios were normalized with $^{146}Nd/^{144}Nd = 0.7219$. During the analyses, Sr NBS 987 standart and Nd La Jolla standards were measured as $^{87}Sr/^{86}Sr = 0.710252 \pm 12$ ($n = 2$) and $^{143}Nd/^{144}Nd = 0.511849 \pm 5$ ($n = 3$), respectively, and no bias correction was applied on the measured Sr and Nd isotope data. Quality control of the Sr and Nd isotope analyses was checked by applying the same procedures to the USGS rock standards. All isotopic ratios were measured by using a Thermo-Fisher Triton thermal ionization mass spectrometer, and standard errors were presented at a 2-sigma level.

Results and discussion

Soil pH

The soil pH in the study area ranges from 7.45 to 8.45, which indicated slightly-moderately alkaline soils except for one sample (pH = 8.83; strongly alkaline soil).

Soil and bedrock mineralogy (X-ray diffraction)

The X-ray diffractometry analysis was used to identify minerals in the soil samples and support the chemical and isotopic interpretations (Table 1). The volcanic, ophiolitic and sedimentary rocks, which are the bedrock of soils, were also analyzed for mineralogical compositions and are shown in Table 1. The XRD analyses of the soil samples in southern Konya show that soils are dominated by calcite, quartz, dolomite, plagioclase and kaolinite (Table 1). The soils located on ophiolitic units mainly comprise serpentinite (antigorite), magnetite, titanomagnetite, amphibole, chlorite, chloritoid, hematite, goethite, talc, smectite (vermiculite), prehnite, pumpellyite, diopside, quartz, calcite, dolomite, and Cr-rich minerals, indicating ophiolitic rocks (Table 1). The soils located on volcanic rocks mainly comprise quartz, plagioclase, alkali feldspar, amphibole, calcite, jarosite, magnetite, mica/illite, chlorite and kaolinite (Table 1). The XRD spectrum of the soils located on carbonate rocks which consist mostly of limestone was mostly showed the presence of calcite, dolomite and quartz (Table 1).

Geochemistry and spatial distributions of heavy metals

The levels and distributions of heavy metals in the soils, rocks and stream sediments in the investigated area were identified, compare the results with the maximum limits in Turkey legislation (MoEF 2005) were examined, and potential sources (geogenic or anthropogenic) of the pollution.

Distribution of heavy metals in topsoil, bedrock and stream sediment

The statistical summary of the analytical results of the bedrock (volcanic ophiolitic and sedimentary), stream sediment and the topsoil samples are presented in Tables 2 and 3, respectively. The chemical concentrations of the analyzed topsoils were compared with the Regulation on the Control of Soil Pollution of Turkey (MoEF 2005), Earth's crust, the target value of European soil, and the natural concentration of soil (Table 4). The spatial distribution maps of As, Cu, Pb, Zn, Cd, Co, Ni, Cr, Fe, Ca, Al, and Mg are presented in Fig. 2.

The ophiolitic rocks, outcropping in the commonly northwest part of the study area (Hatıp, Çayırbağı, Karadiğin), are associated with soils controlled the spatial distribution of Co, Cr, Fe, Cu, Mn and Ni (Fig. 2). The highest concentrations of Co (86.4 ppm), Cr (342 ppm), Fe (6.82%), Mn (2050 ppm) and Ni (755 ppm) appear in topsoil samples near the occurrences of ophiolitic rocks (Fig. 2).

The volcanite, outcropping near the town of Hatunsaray area in the southwest of the study area is one of the main sources of Fe, Cu, Zn, Ba, Sr, Mn and V and control the spatial distribution of these elements (Table 2). The topsoil samples collected from volcanic region have maximum concentrations of Zn (529 ppm), Ba (522 ppm), Sr (330 ppm), Mn (2850 ppm), V (111 ppm) (Table 3).

The Sr and Ca are characterized by maximum concentrations (Sr = 707 ppm, Ca = > 25%) in sedimentary rocks of the study area (Table 2). The highest values of Ca (> 25%), Ba (1225 ppm), Sr (2670 ppm) and Mn (981 ppm) are found in the sedimentary soil collected from near the limestones (Table 3).

In stream sediment samples collected from the studied region, the average concentrations of Cr (141.5 ppm), Ni (355.15 ppm) and Co (30.1 ppm) are relatively enriched (Table 2). Ni, Cr and Co are higher in stream sediments in ophiolitic region of the study area, while Ba and Mn are higher in stream sediments in volcanic region of the study area (Table 2).

Some topsoil samples from the present study contain maximum concentrations of Fe (6.82%), As (89.8 ppm), Co (86.4 ppm), Cr (342 ppm), Cu (647 ppm), Mn (2850 ppm), Ni (755 ppm), Cd (5.38 ppm), Zn (529 ppm), and Cu (647 ppm) exceeding the maximum limit values of both Turkey and European soils (Tables 3, 4).

Arsenic (As) concentration in topsoil ranges from 0.87 to 89.8 ppm, with a mean of 10.13 ppm, a median of 7.14 ppm (Tables 3, 4). The highest As concentrations in topsoils have been determined in associated with volcanic rocks (89.8 ppm) (Tables 3, 4, Fig. 2). Approximately 7.7% of the topsoil samples have As values higher than 20 ppm determined by Regulation on Control of Soil Pollution of Turkey (MoEF, 2005).

In topsoil samples, Cd ranges from 0.05 to 5.38 ppm with a median of 0.20 ppm (Tables 3, 4). Only one soil sample (5.38 ppm) associated with volcanic rocks is higher than MoEF (2005) for Cd.

Cobalt content in the topsoil ranges from 6.08 to 86.4 ppm with a median of 16.45 ppm (Tables 3, 4). About 26.2% of samples exceed the maximum limit value of the MoEF (2005) (20 ppm) for Co. The higher Co values are observed in soils associated with the ophiolitic rocks (Fig. 2).

Table 1 Summary of the soil and bedrock mineralogy in southern Konya according to X-ray diffraction analysis (Qz: quartz, Cal: calcite, Dol: dolomite, Amp: amphibole, Feld: feldspar, Pl: plagioclase, Kfs: K-feldspar, Mag: magnetite, Hem: hematite, Gt: goethite, Sme: smectite, Chl: chlorite, Kln: kaolinite, Srp: serpentinite, Talc: Tlc; Pump: pumpellite, Prx: pyroxene, Prh: prehnite; Ol: olivine, Jrs: jarosite, Zeo: zeolite)

Soil and bedrock descriptions	Sample	Qz	Cal	Dol	Amp	Feld		Fe-oxides		Gt	Mica/Ilt	Sme	Chl	Kln	Serp	Tlc	Pmp	Prh	Amorf	Jrs	Ol	Prx	Zeo
						Pl	Kfs	Mag	Hem														
Soil	Sedimentary	AP-3	•	•			•						•		•								
		VY-3	•	•		•	•		•				•										
		KHY-2	•	•		•	•	•					•		•								
		HPPR-1	•	•		•	•	•	•			•	•		•								
		YB-3	•	•	•	•	•	•	•			•	•		•								
		KV-4	•	•		•	•		•				•		•								
		ALT-1	•	•			•					•	•		•								
		KYT-10	•	•		•	•		•		•		•										
		KYT-12	•	•		•	•		•			•	•	•									
		BT-3	•	•	•	•	•		•				•	•									
		SRKT-1	•	•		•	•		•	•				•									
	Ophiolitic	KHPR-1	•	•					•	•			•	•	•	•							
		KDT-2	•		•	•	•						•		•	•							
		KDT-4	•	•		•	•		•	•				•									
		KYT-3	•	•		•	•	•	•	•			•	•	•	•							•
		KYT-4	•	•	•	•	•		•	•			•	•	•	•							
		KYT-5	•	•	•	•	•		•	•	•			•	•		•	•						
		KYT-6	•	•		•	•		•	•	•			•	•	•	•	•						
		KYT-8	•	•		•	•		•	•	•		•	•	•		•							
	Volcanic	KYT-14	•	•		•	•	•	•				•	•	•						•			
		Ha-1	•			•	•	•								•								
		HC-3	•	•			•		•					•		•								
		HC-4	•			•	•		•							•								
		HC-5	•			•	•	•	•							•								
		KV-1	•			•	•	•	•				•	•		•								

Table 1 (continued)

Soil and bedrock descriptions	Sample	Qz	Cal	Dol	Amp	Feld		Fe-oxides		Gt	Mica/Ilt	Sme	Chl	Kln	Serp	Tlc	Pmp	Prh	Amorf	Jrs	Ol	Prx	Zeo
						Pl	Kfs	Mag	Hem														
Bedrock	Sedimentary	MD-1	•	•																			
		LO-1	•	•																			
	Ophiolitic	KDK-1					•		•				•	•		•							
		KYK-1	•	•									•		•	•		•					
		HK-2		•		•	•						•		•	•			•				
		HK-4				•								•									
	Volcanic	HCK-2	•			•						•	•	•							•		
		HCK-3	•			•	•		•			•											
		Ha-K-3				•	•		•			•		•		•				•			
		EVK-1	•	•		•	•	•	•	•		•											

Cr concentrations in topsoils range from 11.95 to 342 ppm with a median of 46.4 ppm and a mean of 66.23 ppm (Tables 3, 4). About 16.9% of samples exceed the maximum limit value of the MoEF (2005) (100 ppm). The higher Cr concentrations in topsoils were determined in soils associated with ophiolitic rocks (Fig. 2). Copper (Cu) concentrations range from 6.72 to 647 ppm with median of 24.0 ppm (Tables 3, 4). Only one soil sample (647 ppm) associated with the ophiolitic rocks is higher than the upper limit of MoEF (2005) (140 ppm) for Cu (Fig. 2).

Mn concentrations in topsoils range from 191 to 2850 ppm with a median of 640 ppm (Tables 3, 4). About 14% of samples exceed the average Earth's crust value (950 ppm) and 83% of samples exceed the average natural concentration of soil (500 ppm). The highest Mn concentrations occur in soils associated with ophiolitic and volcanic rocks (Table 3, Fig. 2).

Lead, which is naturally present in rocks and soils, in topsoil samples of the study area varies from 1.18 to 32.3 ppm with a mean of 11.22 and median of 10.65 ppm (Tables 3, 4). The lead values in the topsoil are not exceeded the upper limit determined by MoEF (2005) (Table 4, Fig. 2).

Mercury (Hg) concentrations in topsoils range from 0.004 to 0.93 ppm (Tables 3, 4) with a median value of 0.02 ppm. All of the samples have lower Hg concentrations than MoEF (2005) (Table 4). Selenium (Se) in soils ranges from values < 0.1 up to 1.4 ppm with median of 0.5 ppm (Tables 3, 4). Se values in the topsoil are not also exceeded the upper limit of the determined by MoEF (2005).

Nickel in topsoils ranges from 7.01 to 755 ppm with a mean of 125.69 ppm and a median of 81.20 ppm (Tables 3, 4). About 52.3% of samples exceed the upper limit of MoEF (2005). The highest Ni concentrations occur in soils associated with ophiolitic and sedimentary rocks (Fig. 2).

Zn concentrations in soils vary from 22.2 to 529 ppm, with a median of 55.2 ppm (Tables 3, 4). The maximum Zn value (529 ppm) is observed in the soil associated with volcanic and ophiolitic rocks (Fig. 2). Only two samples exceed the uppermost limit of the MoEF (2005) for Zn (Table 4).

Distribution of heavy metals in soil profiles

The vertical distribution of element concentrations for two different soil profiles is presented in Fig. 3. While KHPR soil profile (0–130 cm) is mainly located at the ophiolitic area, HPPR soil profile (0–150 cm) is mainly located at the sedimentary area. The element contents of the profile soil samples show a progressive decrease with depth (Table 5, Fig. 3). Fe and Mn are also dominant metals in the profile soil samples, which was expected based on their higher abundances in the Earth's crust. Ni and Co in the soil profile samples are higher than the uppermost limits defined by MoEF (2005) (Table 4). Co content in the KHPR soil

Table 2 Summary statistics of analyzed elements from bedrock and stream sediment samples from southern Konya

	Sedimentary rocks ($n=4$)			Ophiolitic rocks ($n=4$)			Volcanic rocks ($n=4$)			Stream sediments ($n=4$)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Al (%)	0.1	0.02	0.35	3.53	0.30	8.41	1.81	0.40	2.78	1.89	1.40	2.85
Fe (%)	0.26	0.07	0.64	4.41	2.26	6.26	6.76	3.37	15.55	3.62	2.95	4.00
Ca (%)	> 24.0	21.80	> 25.0	5.21	0.06	13.0	0.73	0.21	1.42	3.08	0.69	7.76
Mg (%)	2.29	0.18	10.55	5.91	1.12	19.15	0.26	0.05	0.38	3.59	0.44	6.16
Na (%)	0.01	0.01	0.02	0.13	0.004	0.47	0.20	0.03	0.32	0.03	0.01	0.04
K (%)	0.03	0.01	0.07	0.1	< 0.01	0.19	1.09	0.14	3.43	0.22	0.08	0.32
P (%)	0.01	0.004	0.03	0.09	0.004	0.21	0.22	0.05	0.69	0.13	0.07	0.20
Si (%)	0.70	0.70	0.70	19.63	18.0	19.80	24.2	19.4	26.4	–	–	–
Ti (ppm)	0.001	< 0.001	0.007	0.24	0.004	0.48	0.18	0.17	0.18	0.14	0.09	0.18
Mn (ppm)	45.58	31.60	77.70	617.8	485	721	10,209	171	39,700	779.25	658.0	1035.0
Cr (ppm)	4.23	1.52	7.18	198.9	64.60	508	19.24	14.75	27.90	141.50	19.0	252.0
Ni (ppm)	4.73	2.20	11.15	548.8	28.2	2060	12.56	4.20	27.90	355.15	22.1	688.0
Cd (ppm)	0.23	0.02	0.6	0.11	0.02	0.24	2.80	0.03	10.95	0.14	0.06	0.22
Co (ppm)	0.75	0.29	1.42	35.96	11.65	88.5	39.72	2.51	143.5	30.10	11.80	41.60
Mo (ppm)	0.19	0.04	0.65	0.45	0.13	1.24	9.44	0.91	29.4	0.26	0.14	0.43
Pb (ppm)	1.17	0.62	1.83	2.30	0.5	5.36	139.01	2.40	544.0	8.20	2.59	13.45
Zn (ppm)	4.1	2.3	8.1	36.35	20.40	52.40	222.10	8.20	774.0	58.83	39.40	75.00
Cu (ppm)	3.59	1.17	7.89	31.52	6.29	54.10	38.81	6.38	100.5	41.91	17.45	54.80
As (ppm)	2.10	0.38	4.93	2.15	0.17	4.08	115.8	1.05	450.0	3.45	1.43	5.87
Rb (ppm)	1.92	0.17	6.97	0.55	0.06	1.88	14.02	6.51	23.10	16.97	3.57	45.70
Ba (ppm)	15.52	2.90	35.50	34.5	0.9	62.2	744.6	50.1	2500	147.00	66.80	282.00
Sr (ppm)	289.9	149	707	47.7	0.79	91.5	1114.3	229	3340	78.03	53.30	125.00
Se (ppm)	0.78	0.5	0.9	0.47	< 0.1	0.70	0.17	< 0.1	0.2	0.33	0.20	0.50
Th (ppm)	0.26	0.05	0.74	1.47	0.01	4.25	17.41	4.41	48.10	4.06	0.96	10.65
U (ppm)	1.02	0.12	3.83	0.65	0.005	1.57	1.86	1.15	3.28	0.68	0.27	1.48
V (ppm)	5.0	1.2	10.8	106	25.3	186	152.95	83.20	239.0	71.48	54.20	89.40
Zr (ppm)	1.73	0.6	3.12	14.14	0.36	41.5	14.13	3.82	22.7	7.97	4.35	12.90

profile ranges from 22.5, 15.7, and 15.2 ppm from upper to bottom (Table 5). The topsoil sample (KHPR-1) exceeds the maximum limit value of the MoEF (2005) for Co. Ni content in HPPR soil profile ranges from 77.2 to 69.1 ppm from topsoil to deep soil (Table 5). A topsoil sample (HPPR-1) relatively exceeds the maximum limit value of the MoEF (2005) for Ni.

Geoaccumulation index (I_{geo})

Table 6 shows the I_{geo} values and classes of ophiolitic, volcanic and sedimentary topsoil samples collected from the study area. I_{geo} values of all topsoil samples are − 2.48 to 4.11 for Cu, − 1.37 to 5.32 for As, − 2.24 to 1.66 for Mn, − 2.14 to 2.70 for Cr, − 4.67 to 0.11 for Pb, − 2.26 to 2.31 for Zn, − 1.30 to 2.53 for Co, − 2.10 to 4.65 for Ni, − 1.56 to 5.19 for Cd. As, Co, Cr, Cu, Ni have generally positive values in the ophiolitic soils, while As, Ni have positive values in the sedimentary soils and commonly As has positive values in the volcanic soils. Cd has slightly positive values in soils in southern Konya. In the study area, heavy metals such as Pb and Zn have extensively I_{geo} index less than zero which suggests that the soils are not polluted by these metals (Table 6). In contrast, some soils have positive I_{geo} index of As, Co, Cr, Cu, Ni and Cd, indicating that these metals also may be enriched from a different source besides lithogenic origin. Positive I_{geo} values are reported for Ni in all ophiolitic and commonly sedimentary soil samples, and in two samples (KYT-13, HC-3) from volcanic soils. I_{geo} values for Cu indicate unpolluted and moderately polluted (I_{geo} values < 0, 0–1 and 1–2) in commonly ophiolitic soils. I_{geo} values for As indicate the unpolluted—moderately polluted to extremely polluted soils. I_{geo} values for Pb and Zn indicate the unpolluted soils except for HK-1 and HK-5 soil samples. The sampling point for HK-5 is located near a thin and small Cu vein in ophiolitic rocks. The average I_{geo} values of the heavy metals in soil samples are in the order of As > Ni > Cd > Co.

At different depths in profile 1 (HPPR), I_{geo} values indicate unpolluted to moderately polluted soils for As and Ni.

Table 3 Summary statistics of analyzed and classified topsoil samples (0–20 cm) associated with bedrocks of southern Konya (S.D.: standard deviation)

$N=65$		Topsoil associated with sedimentary rock ($N=35$)					Topsoil associated with ophiolitic rock ($N=22$)					Topsoil associated with volcanic rock ($N=8$)				
Element	Unit	Mean	Median	S.D	Min	Max	Mean	Median	S.D	Min	Max	Mean	Median	S.D	Min	Max
Al	%	2.32	2.16	0.58	1.39	3.53	2.63	2.70	0.61	1.60	3.56	1.82	1.96	0.61	0.67	2.94
Fe	%	2.65	2.66	0.81	1.23	4.35	3.91	3.95	1.00	2.85	6.82	2.54	2.53	0.28	2.04	3.00
Ca	%	12.84	12.00	5.77	1.41	> 25.00	6.64	6.68	3.57	1.42	14.20	1.20	0.95	0.96	0.35	3.50
Mg	%	1.01	0.83	0.54	0.33	3.47	2.36	1.77	1.45	0.76	5.12	0.39	0.36	0.26	0.00	0.93
Na	%	0.02	0.01	0.01	0.00	0.07	0.02	0.02	0.02	0.01	0.06	0.04	0.04	0.02	0.00	0.05
K	%	0.28	0.26	0.18	0.00	1.17	0.28	0.26	0.14	0.02	0.52	0.26	0.32	0.13	0.00	0.39
P	%	0.06	0.05	0.04	0.00	0.26	0.10	0.08	0.07	0.04	0.31	0.08	0.08	0.03	0.05	0.14
Si	%	16.13	15.90	2.66	12.40	20.20	19.83	19.85	3.25	13.90	25.10	23.95	24.55	1.43	21.30	25.00
Ti	%	0.04	0.03	0.04	0.00	0.14	0.12	0.13	0.08	0.02	0.29	0.08	0.09	0.03	0.02	0.10
Mn	ppm	599.16	583.00	173.95	191.00	981.00	884.00	811.00	333.35	503.00	2050.00	1025.0	605.0	954.7	254.0	2850.0
Cr	ppm	43.71	44.90	17.07	15.85	111.00	133.02	130.50	88.38	24.80	342.00	17.76	17.70	3.27	11.95	21.40
Ni	ppm	80.78	74.00	48.49	23.50	309.00	261.51	188.50	203.30	29.60	755.00	23.68	21.90	11.81	7.01	43.0
Cd	ppm	0.20	0.21	0.05	0.08	0.31	0.22	0.18	0.14	0.07	0.73	0.73	0.14	1.75	0.05	5.38
Co	ppm	14.80	14.95	4.10	7.95	24.10	31.28	26.10	16.73	13.55	86.40	10.67	11.10	2.18	6.08	14.20
Sn	ppm	0.78	0.78	0.18	0.39	1.09	0.85	0.67	0.49	0.43	2.55	0.90	0.90	0.17	0.53	1.05
Mo	ppm	0.42	0.40	0.25	0.00	1.44	0.38	0.33	0.19	0.12	0.93	0.50	0.37	0.52	0.00	1.69
Pb	ppm	11.01	10.85	2.84	4.31	18.40	10.18	9.50	5.75	1.18	21.90	14.33	13.30	7.46	5.51	32.30
Zn	ppm	50.05	52.50	10.81	22.20	68.50	71.96	67.40	29.90	45.20	175.50	108.36	51.40	159.07	41.1	529.0
Cu	ppm	26.74	21.60	16.78	10.75	88.90	77.72	42.50	139.60	22.40	647.00	14.69	15.25	3.78	6.72	20.40
As	ppm	10.81	8.46	10.76	2.27	57.30	7.51	7.05	4.84	1.31	18.75	12.91	3.58	28.87	0.87	89.80
Sb	ppm	0.28	0.27	0.09	0.00	0.48	0.32	0.30	0.13	0.08	0.66	0.26	0.20	0.16	0.11	0.64
Hg	ppm	0.05	0.02	0.15	0.01	0.93	0.02	0.02	0.01	0.00	0.07	0.02	0.02	0.02	0.01	0.05
Nb	ppm	0.71	0.69	0.28	0.26	1.57	0.94	1.03	0.49	0.13	2.06	0.60	0.46	0.29	0.18	1.00
Rb	ppm	19.62	20.50	7.46	5.08	35.90	14.92	9.84	10.82	1.46	34.10	38.44	41.80	14.70	10.5	61.40
Ba	ppm	274.83	243.00	178.84	80.80	1225.00	182.36	183.00	88.04	82.20	337.00	280.21	251.00	145.39	81.9	522.0
Sr	ppm	286.09	208.00	426.01	25.20	2670.00	104.14	80.30	60.23	31.50	253.00	107.48	75.30	87.45	40.9	330.0
Se	ppm	0.68	0.60	0.32	0.10	1.40	0.46	0.50	0.17	0.10	0.80	0.21	0.10	0.20	0.10	0.70
Th	ppm	3.72	3.63	1.63	1.47	8.10	3.03	2.52	1.98	0.78	6.73	8.82	9.00	2.66	4.26	13.65
U	ppm	0.55	0.51	0.35	0.00	1.92	0.47	0.44	0.16	0.20	0.72	1.14	1.01	0.52	0.50	2.26
V	ppm	66.54	60.30	28.46	29.70	137.50	77.00	68.60	26.10	52.10	165.00	76.04	72.00	15.91	51.8	111.0
W	ppm	0.11	0.10	0.05	0.00	0.25	0.14	0.13	0.07	0.05	0.37	0.34	0.17	0.57	0.00	1.85
Zr	ppm	5.76	4.94	3.87	1.75	23.10	7.03	6.44	3.31	1.73	14.85	9.62	9.77	2.65	4.63	12.85

Table 4 Summary statistics of topsoil (0–20 cm) samples of southern Konya (S.D.: standard deviation, S.E.: standard error) and comparison with the maximum allowable limit values for soils of Turkey, the target value for soils of European, Earth's crust, natural concentration of soil

Element		Mean	Median	S.D	S.E	Min	Max	Maximum limit value for soils of Turkey[I]	Target value for soils of European[II]	Earth's crust[III]	Natural concentration of soil[III]
Al	%	2.34	2.27	0.63	0.08	0.67	3.56	–	–	–	–
Fe	%	2.99	2.81	1.01	0.12	1.23	6.82	–	–	–	–
Ca	%	9.42	8.65	6.41	0.79	0.35	> 25.00	–	–	–	–
Mg	%	1.32	0.95	1.12	0.14	0.15	5.12	–	–	–	–
Na	%	0.02	0.02	0.01	0.00	0.01	0.07	125	–	–	–
K	%	0.29	0.27	0.15	0.02	0.02	1.17	–	–	–	–
P	%	0.07	0.05	0.05	0.01	0.03	0.31	–	–	–	–
Si	%	19.19	19.80	4.07	0.81	12.40	25.10	–	–	–	–
Ti	%	0.07	0.04	0.06	0.01	0.01	0.29	–	–	0.56	0.4–0.5
Mn	ppm	741.38	640.0	437.33	54.24	191.0	2850.0	–	–	950	300–500
Cr	ppm	66.23	46.40	65.65	8.14	11.95	342.0	100	100	150	60–200
Ni	ppm	125.69	81.20	145.15	18.00	7.01	755.0	30*–75**	35	80	20–90
Cd	ppm	0.28	0.20	0.65	0.08	0.05	5.38	1*–3**	0.8	–	–
Co	ppm	19.06	16.45	12.39	1.54	6.08	86.40	20	–	22	3–15
Sn	ppm	0.82	0.80	0.30	0.04	0.39	2.55	20	–	–	–
Mo	ppm	0.43	0.38	0.26	0.03	0.12	1.69	10	–	1.5	1–2
Pb	ppm	11.22	10.65	4.74	0.59	1.18	32.30	50*–300**	85	65	18
Zn	ppm	64.53	55.20	62.35	7.73	22.20	529.0	150*–300**	50	70	30–70
Cu	ppm	39.97	24.00	79.09	9.81	6.72	647.0	50*–140**	36	55	15–40
As	ppm	10.13	7.14	13.39	1.66	0.87	89.80	20	–	2	2
Sb	ppm	0.30	0.28	0.11	0.01	0.08	0.66	–	–	–	–
Hg	ppm	0.03	0.02	0.11	0.01	0.004	0.93	1*–1.5**	–	–	–
Nb	ppm	0.76	0.69	0.37	0.05	0.13	2.06	–	–	–	–
Rb	ppm	20.85	20.50	12.09	1.50	1.46	61.40	–	–	–	–
Ba	ppm	248.54	231.0	157.02	19.48	80.80	1225.0	200	–	–	–
Sr	ppm	208.17	134.0	334.98	41.55	25.20	2670.0	–	–	–	–
Se	ppm	0.54	0.50	0.31	0.04	< 0.10	1.40	5	–	0.05	0.01
Th	ppm	4.23	3.63	2.65	0.33	0.78	13.65	–	–	–	–
U	ppm	0.63	0.52	0.38	0.05	0.20	2.26	5	–	–	–
V	ppm	70.90	68.30	26.55	3.29	29.70	165.0	–	–	110	100
W	ppm	0.16	0.12	0.22	0.03	0.05	1.85	–	–	–	–
Zr	ppm	6.67	5.62	3.76	0.47	1.73	23.10	–	–	–	–

[I]Regulation on control of soil pollution of Turkey (MoEF, 2005) (ppm); *pH = 5–6; **pH > 6

[II]Denneman and Robberse 1990; Ministry of Housing Netherlands 1994 (ppm)

[II]Komatina 2004 (ppm)

In profile 2 (KHPR), I_{geo} values have unpolluted to moderately polluted soils for As and Co (Table 7). I_{geo} values of the analyzed stream sediment samples indicate in order of Ni > Cr > Co > As > Cd. KDPL-1, KDPL-2 collected from a stream in the ophiolitic region have mainly Co, Cr, Ni and Cu enrichments. HCP-2 collected from a stream in the volcanic region has mainly As and Cd enrichments. KVPL-1 collected from close to the volcanic and sedimentary region has mainly As, Co, Cr, Ni, Mn, Cu and Cd enrichments (Table 8).

Enrichment factor (EF)

The *EF* values calculated for the topsoil samples of the study area are given in Table 6. The *EF* values from this study show that enrichment factors of Cu, Pb and Zn are generally lower than 1.5 (Table 6). The average values of *EF* show that heavy metals in the study area are in the order of As > Ni > Cd > Co > Cr. While *EF* values in ophiolitic topsoils are in the order of Ni > As > Cr > Co > Cu, in volcanic soils *EF* values are in

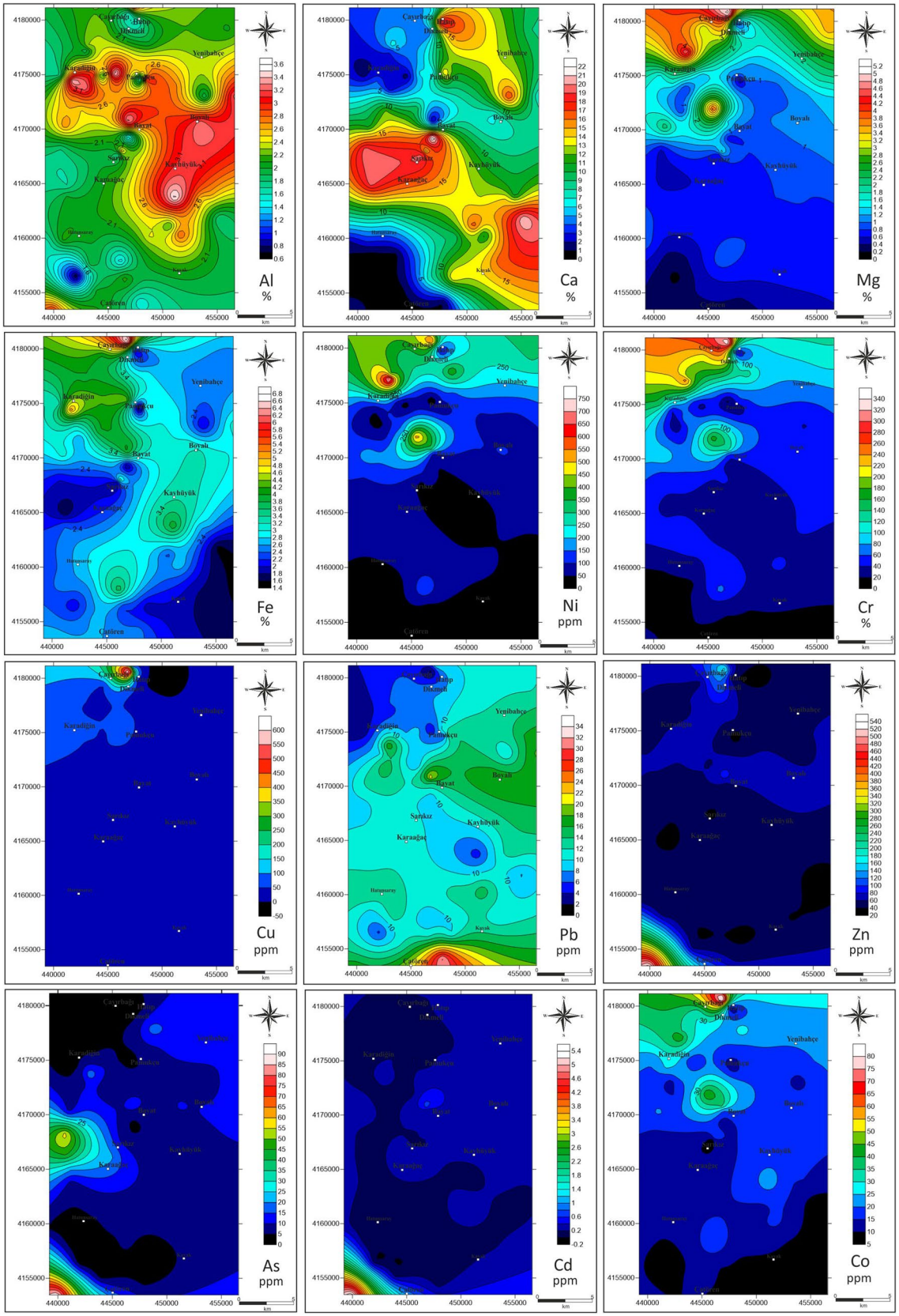

Fig. 2 Spatial distribution maps for As, Cu, Pb, Zn, Al, Cd, Co, Fe, Ni, Cr, Ti, Mn, Ca and Mg in topsoils

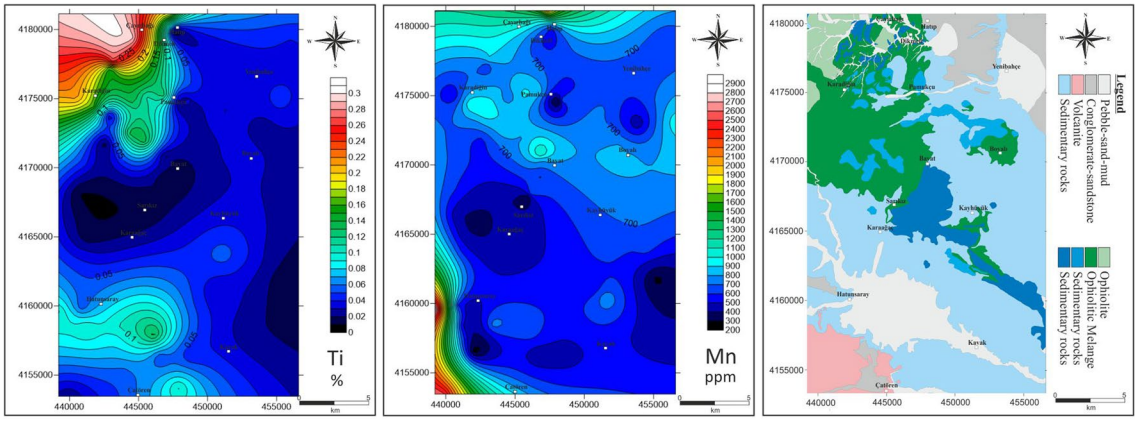

Fig. 2 (continued)

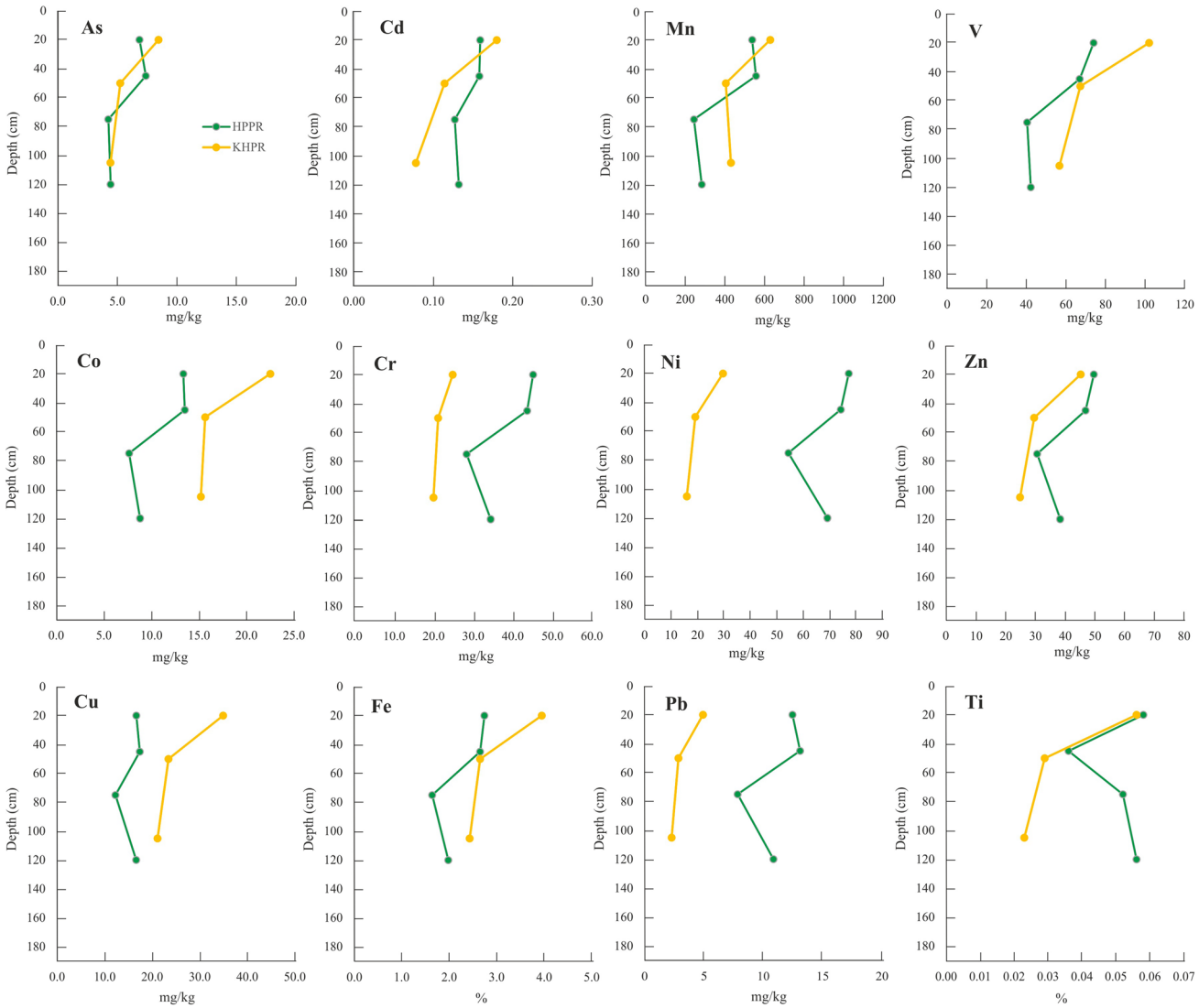

Fig. 3 Heavy metal concentrations in soil profiles at different depths

Table 5 Heavy metal concentrations in soil profile samples

Sample	Profile depth	Sampling depth (cm)	Si %	Al %	Fe %	Ca %	Mg %	Na %	K %	P %	Ti %	Mn ppm	Cr ppm	Ni ppm	Cd ppm	Co ppm	Sn ppm	Mo ppm	Pb ppm	Zn ppm	Cu ppm	As ppm	Sb ppm	Hg ppm	Nb ppm	Rb ppm	Ba ppm	Sr ppm	Se ppm	Th ppm	U ppm	V ppm	W ppm	Zr ppm
HPPR-1	0–20	20	20.2	2.08	2.74	7.20	0.73	0.03	0.30	0.07	0.06	537	45.10	77.20	0.16	13.35	1.01	0.42	12.45	49.60	16.65	6.86	0.26		0.03	0.74	24.50	243.0	130.5	0.70	5.14	0.60	74.0	0.15	3.95
HPPR-2	20–55	45		2.32	2.65	7.77	0.70	0.02	0.27	0.05	0.04	557	43.60	74.20	0.16	13.50	0.96	0.39	13.10	46.80	17.35	7.39	0.27		0.01	0.47	22.90	273.0	114.5	0.50	5.90	0.58	66.9	0.11	4.34
HPPR-3	55–85	75		1.45	1.64	19.50	0.59	0.04	0.21	0.07	0.05	243	28.30	54.40	0.13	7.64	0.50	0.23	7.83	30.50	12.25	4.24	0.24		<0.004	0.89	16.95	359.0	248.0	1.10	5.31	1.00	40.4	0.16	6.44
HPPR-4	85–150	120		1.92	1.98	15.55	0.74	0.03	0.28	0.09	0.06	283	34.40	69.10	0.13	8.80	0.75	0.25	10.85	38.30	16.60	4.44	0.18		0.01	0.57	24.50	336.0	197.5	0.90	8.70	1.12	42.3	0.12	12.55
KHPR-1	0–20	20	13.9	3.56	3.95	13.00	0.80	0.06	0.33	0.04	0.06	629	24.80	29.60	0.18	22.50	0.43	0.26	4.91	45.20	34.90	8.46	0.22		0.02	0.44	8.73	86.3	253.0	0.80	1.42	0.36	102.0	0.05	4.07
KHPR-2	20–60	50		2.69	2.65	19.85	0.58	0.03	0.21	0.03	0.03	404	21.10	19.15	0.11	15.65	0.27	0.16	2.84	29.50	23.40	5.25	0.16		0.06	0.30	5.68	53.7	286.0	1.40	0.90	0.40	67.3	0.05	3.20
KHPR-3	60–130	105		2.84	2.43	19.05	0.55	0.03	0.17	0.02	0.02	430	19.95	15.95	0.08	15.20	0.21	0.10	2.28	24.80	21.10	4.42	0.13		0.01	0.17	4.43	55.2	829.0	1.20	1.01	0.51	56.7	0.03	3.15

order of As > Mn > Zn > Ni. In sedimentary soils, *EF* values range from As > Ni > Cd > Co > Cr. In topsoil samples, *EF* values mostly indicate that the soils ranged from minimal pollution to extremely pollution. In soil profile 1 (HPPR), *EF* values indicate moderate to significant pollution for As, Ni, and Cd. In soil profile 2 (KHPR), *EF* values indicate moderate to significant pollution for As and Co (Table 7).

While KDPL-1, KDPL-2 collected from a stream in the ophiolitic region have mainly Co, Cr, Ni and Cu enrichments, HCP-2 collected from a stream in the volcanic region have mainly As and Cd enrichments. KVPL-1 collected from close to the volcanic and sedimentary region has mainly Co, Cr, Ni, Mn, Cu and Cd enrichments (Table 8).

Contamination factor (C_f)

C_f values of topsoil samples in the study area range between 0.58 and 59.87 for As, 0.61 and 8.64 for Co, 0.34 and 9.77 for Cr, 0.32 and 4.75 for Mn, 0.35 and 37.75 for Ni, 0.27 and 25.88 for Cu, 0.06 and 1.62 for Pb, 0.31 and 7.45 for Zn, and 0.51 and 54.90 for Cd (Table 6). According to Hakanson (1980) classification, C_f values of the soil samples in the study area indicate that the soils ranged from low contamination to very high contamination (Table 6). The average C_f values of the heavy metals in soil samples are in the order of As > Ni > Cd > Co > Cr > Cu > Mn. While C_f values in ophiolitic topsoils are in the order of Ni > As > Cr > Cu ≥ Co, C_f values in volcanic soils are in order of As > Cd > Mn > Zn > Ni > Co. In sedimentary soils, C_f values range from As > Ni > Cd > Co > Cr > Cu > Mn.

C_f values of soil samples at different depths in soil profile 1 (HPPR) indicate considerable contamination for As and Ni, and moderate contamination for Cd. Soil profile 2 (KHPR) indicates considerable contamination for As, and moderate contamination for Co and Cd (Table 7).

In the stream sediment samples, KDPL-1, KDPL-2 in the ophiolitic region have mainly As, Co, Cr, Ni, Mn and Cu enrichments, HCP-2 in the volcanic region have mainly As, Co, Mn, Ni and Cd. KVPL-1 collected from a stream close to the volcanic and sedimentary region has mainly As, Co, Cr, Ni, Mn, Cu and Cd enrichments (Table 8).

Chemical weathering index (CIA, CIW)

The degree of weathering in source rocks can be obtained by various chemical indices, based on their major element compositions. In the present study, the CIA (Chemical Index of Alteration calculated as $CIA = (100*Al_2O_3)/(Al_2O_3 + CaO* + Na_2O + K_2O)$]; Nesbitt and Young 1982) and CIW (Chemical Index of Weathering calculated as $CIW = [Al_2O_3/(Al_2O_3 + CaO + Na_2O)] \times 100$; Harnois 1988) indexes were used to measure the degree of weathering. The CIA and CIW indexes of topsoils and profile

Table 6 Average, minimum (min) and maximum (max) geoaccumulation index (I_{geo}), enrichment factor (EF) and contamination factor (CF) of the topsoil samples in southern Konya

		As	Co	Cr	Mn	Ni	Cu	Pb	Zn	Cd
$Igeo_{All\ topsoils}$	Average	1.63	0.15	− 0.14	− 0.44	1.40	− 0.48	− 1.56	− 0.92	0.39
	Min	− 1.37	− 1.30	− 2.14	− 2.24	− 2.10	− 2.48	− 4.67	− 2.26	− 1.56
	Max	5.32	2.53	2.70	1.66	4.65	4.11	0.11	2.31	5.19
$Igeo_{ophiolitic\ topsoils}$	Average	1.44	0.79	0.90	− 0.16	2.61	0.29	− 1.77	− 0.68	0.40
	Min	− 0.78	− 0.41	− 1.08	− 0.84	0.24	− 0.78	− 4.67	− 1.37	− 1.03
	Max	3.06	2.53	2.70	1.19	4.65	4.11	− 0.45	0.72	2.31
$Igeo_{volcanic\ topsoils}$	Average	0.88	− 0.55	− 1.58	− 0.25	− 0.51	− 1.44	− 1.23	− 0.62	0.33
	Min	− 1.37	− 1.30	− 2.14	− 1.83	− 2.10	− 2.48	− 2.44	− 1.37	− 1.56
	Max	5.32	− 0.08	− 1.29	1.66	0.52	− 0.88	0.11	2.31	5.19
$Igeo_{sedimentary\ topsoils}$	Average	1.91	− 0.08	− 0.42	− 0.64	1.14	− 0.73	− 1.49	− 1.12	0.40
	Min	0.01	− 0.92	− 1.73	− 2.24	− 0.58	− 1.80	− 2.80	− 2.26	− 0.82
	Max	4.67	0.68	1.08	0.12	3.36	1.25	− 0.71	− 0.64	1.07
$EF_{All\ topsoils}$	Average	9.26	2.14	2.06	1.48	6.83	1.58	0.73	1.10	3.64
	Min	0.64	1.04	0.36	0.73	0.60	0.46	0.03	0.56	0.68
	Max	75.10	4.43	6.60	7.39	33.45	13.28	2.25	9.35	68.87
$EF_{ophiolitic\ topsoils}$	Average	5.28	2.64	3.26	1.34	11.41	2.34	0.55	0.95	2.25
	Min	0.64	1.45	0.74	0.91	1.90	1.01	0.03	0.65	0.80
	Max	14.12	4.43	6.60	2.14	33.45	13.28	1.04	1.78	6.38
$EF_{volcanic\ topsoils}$	Average	11.94	1.48	0.72	2.49	1.69	0.80	1.01	2.17	10.36
	Min	1.00	1.04	0.59	0.73	0.60	0.46	0.47	0.80	0.88
	Max	75.10	2.21	0.87	7.39	3.34	1.02	2.25	9.35	68.87
$EF_{sedimentary\ topsoils}$	Average	10.99	2.00	1.65	1.34	5.29	1.31	0.77	0.95	2.96
	Min	2.05	1.25	0.36	0.91	0.95	0.62	0.17	0.56	0.68
	Max	65.54	3.46	4.55	2.02	22.16	2.86	1.23	1.29	7.26
$C_{f\ All\ topsoils}$	Average	6.75	1.91	1.89	1.24	6.28	1.60	0.56	0.91	2.85
	Min	0.58	0.61	0.34	0.32	0.35	0.27	0.06	0.31	0.51
	Max	59.87	8.64	9.77	4.75	37.75	25.88	1.62	7.45	54.90
$C_{f\ ophiolitic\ topsoils}$	Average	5.02	2.93	3.60	1.42	12.44	2.94	0.53	0.99	2.25
	Min	0.87	1.13	0.71	0.84	1.78	0.87	0.06	0.58	0.73
	Max	12.50	8.64	9.77	3.42	37.75	25.88	1.10	2.47	7.42
$C_{f\ volcanic\ topsoils}$	Average	9.27	1.05	0.51	1.76	1.21	0.58	0.72	1.61	8.07
	Min	0.58	0.61	0.34	0.42	0.35	0.27	0.28	0.58	0.51
	Max	59.87	1.42	0.61	4.75	2.15	0.82	1.62	7.45	54.90
$C_{f\ sedimentary\ tosoils}$	Average	7.20	1.50	1.20	1.01	3.82	1.05	0.55	0.71	2.05
	Min	1.51	0.80	0.45	0.32	1.01	0.43	0.22	0.31	0.85
	Max	38.20	2.41	3.17	1.64	15.45	3.56	0.92	0.96	3.14

soils are given in Tables 9 and 10, respectively. The topsoil samples of southern Konya have CIA between 4.34 and 68.27 indicative of low-medium weathering. The Chemical Index of Weathering (CIW) values are ranged between 4.36 and 74.37. While the CIA values of the profile soils are between 5.24 and 18.07, the CIW values of the profile soils are between 5.26 and 18.34 (Table 10). The CIA values of the stream sediments are ranged between 21.99 and 63.93, and CIW values are ranged between 22.36 and 69.54. The CIA and CIW indices for soils and stream sediments developed from different parent materials show similar values in southern Konya.

Sr–Nd isotopes

The $^{87}Sr/^{86}Sr$ ratios of topsoil and profile soil samples range from 0.705341 to 0.707491 and 0.705827 to 0.707890, respectively (Table 11). The $^{87}Sr/^{86}Sr$ ratios of volcanic rock in the studied region is 0.705032. The $^{87}Sr/^{86}Sr$ ratios of ophiolitic rock in the studied region is 0.704913 (Table 11). The $^{87}Sr/^{86}Sr$ ratios of sedimentary rocks in the studied region range from 0.707779 to 0.708066. The $^{143}Nd/^{144}Nd$ values of topsoil samples vary between 0.512384 and 0.512610, and the εNd ranged from − 4.95 to − 0.62. The $^{143}Nd/^{144}Nd$ values of profile soil samples vary between

Table 7 Geoaccumulation index (I_{geo}), enrichment factor *(EF)* and contamination factor (C_f) of the profile soil samples in southern Konya

	As	Co	Cr	Mn	Ni	Cu	Pb	Zn	Cd
SOIL PROFILE 1									
I_{geo}									
HPPR-1	1.61	− 0.17	− 0.22	− 0.75	1.36	− 1.17	− 1.27	− 1.10	0.11
HPPR-2	1.72	− 0.15	− 0.27	− 0.69	1.31	− 1.11	− 1.20	− 1.19	0.10
HPPR-3	0.91	− 0.97	− 0.89	− 1.89	0.86	− 1.61	− 1.94	− 1.80	− 0.21
HPPR-4	0.98	− 0.77	− 0.61	− 1.67	1.20	− 1.18	− 1.47	− 1.48	− 0.16
EF									
HPPR-1	5.84	1.71	1.65	1.14	4.93	0.85	0.80	0.89	2.07
HPPR-2	6.51	1.78	1.65	1.23	4.90	0.92	0.87	0.87	2.13
HPPR-3	6.03	1.63	1.73	0.86	5.80	1.05	0.84	0.92	2.77
HPPR-4	5.23	1.56	1.74	0.83	6.11	1.17	0.96	0.95	2.38
C_f									
HPPR-1	4.57	1.34	1.29	0.90	3.86	0.67	0.62	0.70	1.62
HPPR-2	4.93	1.35	1.25	0.93	3.71	0.69	0.66	0.66	1.61
HPPR-3	2.83	0.76	0.81	0.41	2.72	0.49	0.39	0.43	1.30
HPPR-4	2.96	0.88	0.98	0.47	3.46	0.66	0.54	0.54	1.35
SOIL PROFILE 2									
I_{geo}									
KHPR-1	1.91	0.58	− 1.08	− 0.52	− 0.02	− 0.10	− 2.61	− 1.24	0.29
KHPR-2	1.22	0.06	− 1.32	− 1.16	− 0.65	− 0.68	− 3.40	− 1.85	− 0.37
KHPR-3	0.97	0.02	− 1.40	− 1.07	− 0.91	− 0.83	− 3.72	− 2.10	− 0.91
EF									
KHPR-1	5.00	1.99	0.63	0.93	1.31	1.24	0.22	0.56	1.63
KHPR-2	4.62	2.07	0.80	0.89	1.26	1.24	0.19	0.55	1.54
KHPR-3	4.24	2.19	0.82	1.03	1.15	1.22	0.16	0.50	1.15
C_f									
KHPR-1	5.64	2.25	0.71	1.05	1.48	1.40	0.25	0.64	1.84
KHPR-2	3.50	1.57	0.60	0.67	0.96	0.94	0.14	0.42	1.16
KHPR-3	2.95	1.52	0.57	0.72	0.80	0.84	0.11	0.35	0.80

Table 8 Geoaccumulation index (I_{geo}), enrichment factor (EF) and contamination factor (C_f) of the stream sediment samples in southern Konya

	As	Co	Cr	Mn	Ni	Cu	Pb	Zn	Cd
I_{geo}									
KDPL-1	− 0.10	1.46	1.99	− 0.44	4.14	0.52	− 2.72	− 0.69	− 0.91
KDPL-2	− 0.65	1.47	2.26	− 0.45	4.52	0.16	− 3.53	− 1.43	− 1.29
KVPL-1	1.38	0.78	0.71	0.20	2.60	0.55	− 1.16	− 0.51	0.58
HCP-2	0.96	− 0.35	− 1.47	− 0.25	− 0.44	− 1.10	− 1.30	− 0.95	0.33
EF									
KDPL-1	1.24	3.65	5.29	0.98	23.39	1.90	0.20	0.82	0.71
KDPL-2	0.93	4.07	7.04	1.07	33.63	1.63	0.13	0.54	0.60
KVPL-1	3.42	2.26	2.15	1.51	7.98	1.92	0.59	0.92	1.96
HCP-2	3.46	1.40	0.64	1.50	1.31	0.83	0.72	0.92	2.24
C_f									
KDPL-1	1.40	4.12	5.97	1.11	26.40	2.14	0.23	0.93	0.80
KDPL-2	0.95	4.16	7.20	1.10	34.40	1.67	0.13	0.55	0.61
KVPL-1	3.91	2.58	2.46	1.73	9.13	2.19	0.67	1.06	2.23
HCP-2	2.92	1.18	0.54	1.27	1.11	0.70	0.61	0.78	1.89

Table 9 CIA (Chemical Index of Alteration) and CIW (Chemical Index of Weathering) values of topsoils and stream sediments in southern Konya

	Ophiolitic soils	Volcanic soils	Sedimentary soils	Stream sediments
CIA				
Max	57.01	68.27	52.58	63.93
Min	9.56	30.68	4.34	21.99
CIW				
Max	60.53	74.37	54.64	69.54
Min	9.67	31.91	4.36	22.36

Table 10 CIA (Chemical Index of Alteration) and CIW (Chemical Index of Weathering) values of profile soils in southern Konya

Sample	Profile depth (cm)	CIA	CIW
HPPR-1	0–20	17.59	17.91
HPPR-2	20–55	18.07	18.34
HPPR-3	55–85	5.24	5.26
HPPR-4	85–150	8.41	8.48
KHPR-1	0–20	16.76	16.94
KHPR-2	20–60	9.12	9.16
KHPR-3	60–130	9.94	9.98

0.512285 and 0.512617, and the εNd ranged from − 6.89 to − 0.41. The $^{143}Nd/^{144}Nd$ ratios of volcanic rock in the studied region is 0.512630 and εNd is -0.16. The $^{143}Nd/^{144}Nd$ ratios of ophiolitic rock in the studied region are 0.512716 and εNd is 1.52. The $^{143}Nd/^{144}Nd$ ratios of sedimentary rocks in the studied region range from 0.512275 to 0.512399 with the εNd ranging from − 7.08 to − 4.66. The isotopic data of the analyzed samples were compared with several regions using the $^{87}Sr/^{86}Sr$ vs. εNd diagram. The Sr–Nd isotope diagram (Fig. 4a) and $^{87}Sr/^{86}Sr$ vs. $^{208}Pb/^{206}Pb$ diagram (Fig. 4b) show that the analyzed samples were extensively formed by the weathering of parent rocks.

Pb isotopic compositions

The amount of Pb in the analyzed soils in southern Konya does not exceed the limit values, and Pb isotope analysis was performed to evaluate it in terms of the origin of the lead. The Pb isotope ratios of the soils and bedrock are shown in Table 12. The Pb isotopic ratios of the soil samples vary from 0.816 to 0.852 for $^{207}Pb/^{206}Pb$, and from 2.000 to 2.242 for

Table 11 Sr–Nd isotopes of the topsoils, profile soils and bedrocks from southern Konya region

Sample		$^{87}Sr/^{86}Sr$		std. error	$^{143}Nd/^{144}Nd$		std. error	εNd	Rb/Sr	CIA
Profile soil										
HPPR										
HPPR-1		0.706120	±	6×10^{-6}	0.512460	±	2×10^{-6}	− 3.47	0.188	27.29
HPPR-2		0.707615	±	16×10^{-6}	0.512459	±	2×10^{-6}	− 3.49	0.200	28.08
HPPR-3		0.705970	±	14×10^{-6}	0.512527	±	9×10^{-6}	− 2.17	0.068	9.03
HPPR-4		0.705827	±	8×10^{-6}	0.512285	±	5×10^{-6}	− 6.89	0.124	14.08
KHPR-1		0.707890	±	19×10^{-6}	0.512543	±	2×10^{-6}	− 1.85	0.035	26.49
KHPR										
KHPR-2		0.707028	±	15×10^{-6}	0.512522	±	8×10^{-6}	− 2.26	0.020	15.33
KHPR-3		0.706838	±	15×10^{-6}	0.512617	±	6×10^{-6}	− 0.41	0.005	16.63
Topsoil										
KYT-5 (Ophiolitic)		0.706433	±	5×10^{-6}	0.512610	±	2×10^{-6}	− 0.55	0.108	51.98
KDT-4 (Ophiolitic)		0.705485	±	4×10^{-6}	0.512606	±	2×10^{-6}	− 0.62	0.099	38.09
SRT-1 (Sedimentary)		0.707491	±	14×10^{-6}	0.512384	±	2×10^{-6}	− 4.95	0.067	10.96
YBT-3 (Sedimentary)		0.705341	±	5×10^{-6}	0.512525	±	5×10^{-6}	− 2.20	0.106	22.41
HÇT-4 (Volcanic)		0.705951	±	4×10^{-6}	0.512530	±	2×10^{-6}	− 2.11	0.257	66.28
Bedrock										
Volcanic	EV-1	0.705032	±	6×10^{-6}	0.512630	±	3×10^{-6}	− 0.16	0.028	
Ophiolitic	H-4	0.704913	±	15×10^{-6}	0.512716	±	2×10^{-6}	1.52	0.024	
Sedimentary	L-1	0.707779	±	9×10^{-6}	0.512275	±	3×10^{-6}	− 7.08	0.002	
	P-2	0.708066	±	19×10^{-6}	0.512399	±	8×10^{-6}	− 4.66	0.001	

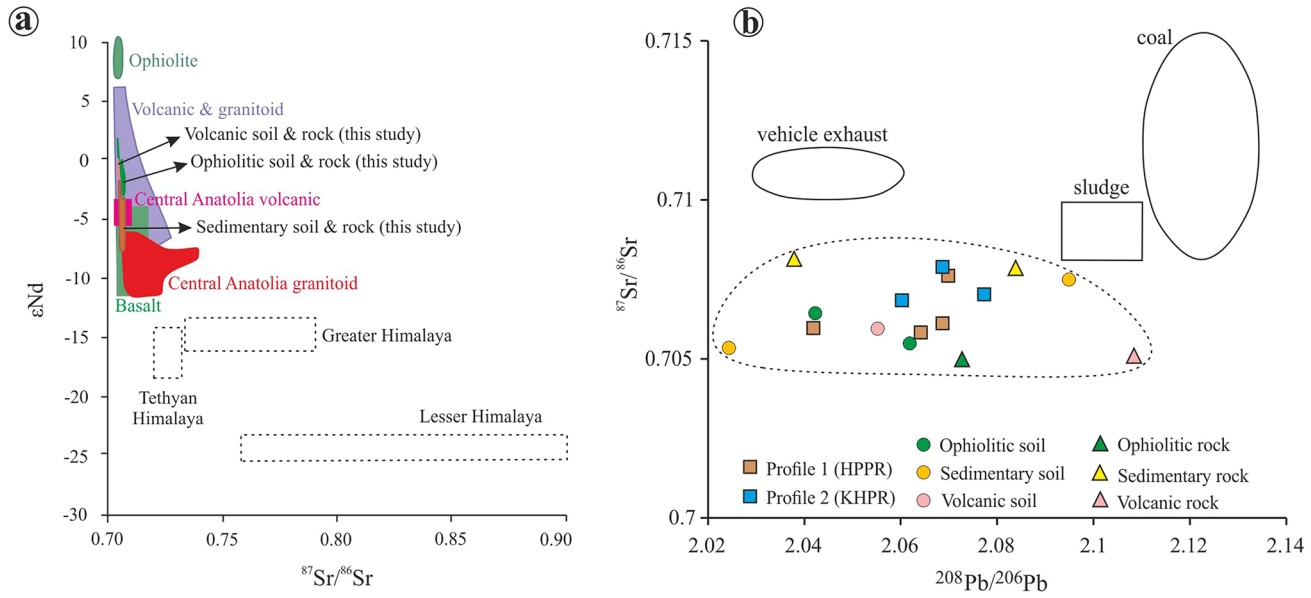

Fig. 4 (**a**) $^{87}Sr/^{86}Sr$ vs. εNd for soil and rock samples from southern Konya (this study) and whole-rock Sr and Nd isotopic data plotted along with compositional fields of potential source rocks from the Himalaya–Tibet region (Singh et al. 2008 Wu et al. 2010) and Central Anatolia volcanic rocks (Alpaslan et al. 2004), Central Anatolia granitoid (Köksal and Göncüoğlu, 2007), Greater Himalaya, Tethyan Himalaya and Lesser Himalaya (Bracciali et al. 2015); (**b**) $^{208}Pb/^{206}Pb$ vs. $^{87}Sr/^{86}Sr$ for soil and rock samples from southern Konya (this study) comparison with vehicle exhaust, coal and sludge (Sun et al. 2018)

Table 12 Pb isotope ratios of the soil, bedrock and stream sediment samples in southern Konya region

	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{208}Pb/^{207}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
Soil							
All	18.111–19.322	15.167–16.000	37.444–41.954	1.174–1.226	2.430–2.689	0.816–0.852	2.000–2.242
Volcanic	18.763–19.322	15.581–15.736	38.701–41.954	1.198–1.216	2.463–2.672	0.823–0.835	2.053–2.209
Ophiolitic	18.111–18.983	15.167–15.845	37.444–41.796	1.174–1.212	2.444–2.689	0.825–0.852	2.042–2.243
Sedimentary	18.409–19.322	15.455–16.000	37.969–40.439	1.191–1.226	2.430–2.537	0.816–0.834	2.000–2.105
Bedrock							
Volcanic	18.512–19.599	15.357–16.235	38.214–41.656	1.200–1.210	2.488–2.566	0.827–0.833	2.064–2.125
Ophiolitic	18.290–19.143	15.273–16.429	37.895–40.000	1.165–1.230	2.435–2.542	0.813–0.858	2.033–2.090
Sedimentary	18.267–19.522	15.111–15.870	38.667–39.783	1.186–1.230	2.507–2.563	0.813–0.843	2.038–2.131
Stream sediment	18.436–18.895	15.179–15.698	37.692–38.895	1.192–1.215	2.469–2.483	0.823–0.839	2.045–2.072

$^{208}Pb/^{206}Pb$ (Table 12, Fig. 5). The $^{207}Pb/^{206}Pb$ values of the volcanic, ophiolitic and sedimentary rock samples vary from 0.827 to 0.833, 0.813 to 0.858, 0.813 to 0.843, respectively (Table 12). The $^{208}Pb/^{206}Pb$ values of the volcanic, ophiolitic and sedimentary rock samples vary from 2.064 to 2.125, 2.033 to 2.090, 2.038 to 2.131, respectively (Table 12). The lead isotopic ratios of the stream sediment samples range from 0.823 to 0.839 for $^{207}Pb/^{206}Pb$, and 2.045 to 2.072 for $^{208}Pb/^{206}Pb$ (Table 12). Figure 5a shows the Pb isotopic ratios of the soil samples and stream sediments in comparison to bedrocks (volcanic, ophiolitic and sedimentary) from southern Konya. There is an overlap between the bedrock field and the soil field. Figure 5b shows Pb isotope ratios of the soils, stream sediments and bedrocks in southern Konya in comparison to Neapolitan rocks, soils and leaded gasoline from western Europe. Figure 5b commonly represents the natural geological components (geogenic) for Pb isotopic ratios. The Pb isotope ratio values of this study are commonly similar to those of the geogenic values as well as a small number of anthropogenic components.

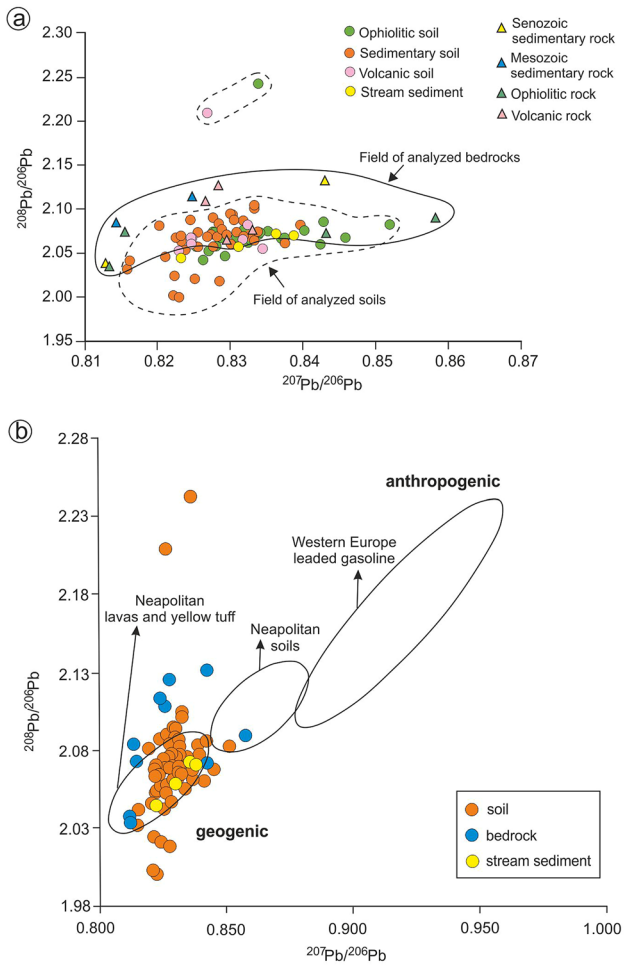

Fig. 5 $^{207}Pb/^{206}Pb$ vs. $^{208}Pb/^{206}Pb$ isotope ratios (**a**) in soils, bedrocks and stream sediments from southern Konya (this study), (**b**) in ophiolitic, volcanic and sedimentary soils and rocks, and stream sediments from southern Konya (in this study), Neapolitan rocks and soils (Cicchella, 2008), and leaded gasoline from western Europe (Monna et al. 1999; Teutsch et al. 2001; Ayuso et al. 1998; Gilg et al. 2001; Somma et al. 2001; D'Antonio et al. 1995; Cicchella 2008)

Discussion

Spatial distribution and origin of heavy metals, topsoil-bedrock relationship

The topsoil samples of southern Konya have CIA between 4.34 and 68.27 indicative of low–medium weathering. The CIW index values, which reflect the chemical weathering amount exposed to the decomposed material (Harnois, 1988), show similar values to the CIA values and vary between 4.36 and 74.37 in the topsoils in southern Konya. Low-medium CIA values are associated with arid or temperate climates with little rainfall while high CIA values are associated with humid tropical or temperate climates with heavy rainfall, favoring the development of extensive vegetation (Goldberg and Humayun, 2010). The CIA in sediments primarily reflects the integrated chemical weathering history from source areas (Potter et al. 2005; Li et al. 2010). The average CIA of soil and stream sediment samples is generally lower-moderate, suggesting slightly-moderate weathering processes.

Natural soil pH, whose spatial distribution is largely dependent on the nature of the parent material (Reuter et al. 2008), reflects the combined effects of soil-forming factors (e.g. parent material, topography, climate). Soils from arid climates are commonly alkaline with a high soil pH, overlying areas of mostly limestone (Fabian et al. 2014) consistent with soils of southern Konya, while soils from humid climates are commonly acidic with a low soil pH due to leaching from heavy rainfall (Brady and Weil 2002). The studied soils in southern Konya have an average pH value of 8.08, which indicated slightly-moderately alkaline soils. Because of the neutral subalkaline environment (Manta et al. 2002) and low annual precipitation, and low average annual temperature (Li et al. 2008), soil samples are slightly-moderately alkaline in southern Konya. Many sorption processes for metals are pH-dependent. Sorption is highest in less acidic soils, while acidic conditions favor desorption and release of the metals back into solution (Rodríguez-Eugenio et al. 2018). This shows that heavy metals are mostly absorbed in topsoils and their release into the solution is reduced due to the alkalinity of the soils in southern Konya.

While parent material and climatic conditions are dominant factors on element distribution in soil (Kabata-Pendias 2011), anthropogenic actions (e.g. mining, fossil fuel and waste burning, fertilizers, volcanic emissions, atmospheric emissions) may also be effective factors for arsenic enrichment (e.g. Kabata-Pendias and Pendias 2001; Bhattacharya et al. 2002; Kabata-Pendias 2011). The volcanic rocks are rich in As and Cd in the study area and therefore their weathering can also be a source of As and Cd in high concentrations. So, according to the Regulation on the Control of Soil Pollution of Turkey (MoEF 2005), As (max. 89.8 ppm) and Cd (max. 5.38 ppm) are higher in soils around the volcanic rocks in southern Konya. This suggests that the high amounts of As and Cd in the studied soils in volcanic region commonly originate from volcanic rocks. At the same time, as Cd absorbed in soils is generally immobile in soils above pH 7.5 (Kabata-Pendias and Pendias 2001), higher Cd concentrations were observed in alkaline soil samples from southern Konya.

The ultramafic rocks and soils in southern Konya are mostly composed of serpentinite. The serpentine soil derived from ultramafic rock or serpentinite is known to contain high concentrations of potentially harmful elements including Cr, Ni, Co and Mn (e.g. Brooks 1987; Oze et al. 2008; Cheng et al. 2011; Kanellopoulos et al. 2015). The higher Co, Ni and Cr values are observed in soils associated extensively

with the ophiolitic rocks in southern Konya. Serpentinite, magnetite, amphibole, chlorite, hematite, goethite, talc, smectite, prehnite, pumpellyite, Cr-rich minerals which are signs for ophiolitic rocks, were identified in soil samples in ophiolitic region. According to Garnier et al. (2008), these minerals derived from ultramafic rocks are a typical source of Cr in soil. In analyzed soils, the higher Cr concentrations (11.95–342 ppm) according to maximum allowable limits for Turkey's soil (MoEF 2005) are mainly associated with the ophiolitic rocks in the region.

Ni enrichment occurred in southern Konya soils are associated with mainly ophiolitic and rarely sedimentary rocks. In soils of southern Konya, Mn concentrations which are commonly higher than the average Earth's crust value (Komatina 2004) and the average natural concentration of soil (Komatina 2004) are mainly associated with mafic rocks. Mn is also accumulated in soils as a result of its fixation with organic matter. High Mn levels are often reported for soils over mafic rocks, for soils rich in Fe and/or organic matter and for soils from arid or semi-arid regions. It is known that highly alkaline soils (at about pH 8) can also produce Mn toxicity (Kabata-Pendias and Pendias 2001). It is concluded that the high Mn content in the majority of the soils in southern Konya is due to the ophiolitic and volcanic rocks containing high amounts of Mn in the semi-arid climate. While it tends to be excluded from sedimentary rocks, Cu, which is most abundant in mafic and intermediate rocks (Kabata-Pendias and Pendias 2001), varies between 6.72 and 647 ppm in the soils of southern Konya. Cu was enriched in a small amount of soil samples in the north of the study area due to ophiolitic rocks containing thin and small Cu vein. Zn distributed uniformly in igneous rocks (Kabata-Pendias and Pendias 2001), in two soil samples in the volcanic and ophiolitic soils southern Konya is higher than the maximum allowable limit values for Turkish soil.

While As, Cd, Ni, Cr, Mn, Cu and Zn values, which are higher than the maximum allowable limit values for Turkey's soil, are observed in a small part of the analyzed soils, these heavy metals are also high according to *Igeo, EF* and C_f values calculated using the background values. According to the calculated *Igeo*, *EF* and C_f values, As, Ni, Cd pollution in the topsoil of the HPPR profile and As and Co pollution in the topsoil of the KHPR profile indicate partially anthropogenic pollution. The heavy metals can be derived from not only geogenic origin but also from other sources such as fertilization, irrigation, etc. in the agricultural field, traffic. These elements may be transported to the soils by wind, rain and therefore may cause pollution. Stream sediment samples collected from the ophiolitic region (KDPL-1 and KDPL-2) were enriched in Co, Cr, Ni and Cu similar to ophiolitic soil samples. Stream sediment samples collected from the volcanic region (HCP-2) were enriched in As and Cd similar to volcanic soil samples. Heavy metal enrichments in stream sediments are geologically (geogenic) originated by rocks containing heavy minerals (Solgun et al. 2021). It is observed that heavy metals, which are commonly found in the soil (As, Cd, Cr, Ni, Co, Cu, Mn) and partially in the stream sediments (Cr, Ni, Cu), are partially enriched due to the weathering, transport, erosion and deposition factors of the volcanic, ophiolitic and sedimentary rocks in the region. So, these heavy metals have mostly of geogenic origin. There is no urban area with a dense population in the study area. At the same time, according to geochemical evaluations, the effect of the anthropogenic factor on the heavy metal accumulation in the study area, where there are small settlements with less population and relatively agricultural activities, is seen to be less than the geogenic factor.

Evaluation of the Pb and Sr–Nd isotope signature in soils and bedrocks

Based on the isotopic data of the soil and rock samples in southern Konya, all possible sources for soils are divided into three isotopic regions. Whereas $^{87}Sr/^{86}Sr$ ratios of the ophiolitic rock (0.7049) and ophiolitic soil (0.7055–0.7064) are similar, the εNd of the ophiolitic rock (1.52) is higher than ophiolitic soils (−0.62 to −0.55). The $^{87}Sr/^{86}Sr$ ratios of the volcanic rock (0.7050) are similar to volcanic soil (0.7060) whereas εNd of the volcanic rock (−0.16) is higher than soil (− 2.11). The $^{87}Sr/^{86}Sr$ ratios of the sedimentary rock (0.7078–0.7081) and one of the sedimentary soil sample (0.7075) is similar. The other sedimentary topsoil sample does not show a very different $^{87}Sr/^{86}Sr$ ratio to sedimentary soil and rock, but a ratio of $^{87}Sr/^{86}Sr$ (0.7053) closer to volcanic and ophiolitic soil and rock. The εNd of sedimentary topsoil [(−4.95)–(−2.20)] is generally similar to sedimentary rocks' [(−7.08)–(−4.66)]. So, the comparison of Sr–Nd isotope ratios of one of the sedimentary topsoil and bedrocks shows differences explained mainly by the different chemical and mineralogical compositions of the two topsoil samples. The granitic rocks (continental crust) have higher Rb/Sr and $^{87}Sr/^{86}Sr$ ratios while the mantle-derived basalts (oceanic crust) have lower Rb/Sr and $^{87}Sr/^{86}Sr$ ratios. Volcanic rocks within island arc and continental settings also have low $^{87}Sr/^{86}Sr$ ratios, again reflecting their derivation from mantle material (Nakano 2016). Based on this, comparing the volcanic and ophiolitic rocks in Konya, it is seen that the $^{87}Sr/^{86}Sr$ ratios are similar, while the Rb/Sr ratio of the volcanic rock is higher than that of the ophiolitic rocks. The variation in topsoil $^{87}Sr/^{86}Sr$ ratios (0.7053–0.7075) in southern Konya indicates that bedrocks play a complex role in these topsoils that is partially dependent on the location of the soil sample.

While bedrock, groundwater, atmospheric dry and wet depositions are among natural resources, fertilizers, vehicle exhausts, and smokestacks from industrial plants are

among anthropogenic sources (Castorina and Masi 2013). It is observed that the topsoils in southern Konya are widely affected by the parent materials, except for a small number of anthropogenic sources.

In southern Konya, analyzed topsoil samples except for five samples [1.17 ($n=1$), 1.18 ($n=1$); 1.19 ($n=3$)] have 1.20 and above $^{206}Pb/^{207}Pb$ ratios. In European agricultural soil (2106 samples, topsoil: 0–20 cm), the $^{206}Pb/^{207}Pb$ isotope ratio ranges between 1.12 and 1.73 with a median of 1.20 (Reimann et al. 2012; Reimann et al. 2016). This median of 1.20 numerically coincides with the literature value most frequently used for "average continental crust" (Komàrek et al. 2008). The $^{206}Pb/^{207}Pb$ isotope ratios of the topsoils in southern Konya, ranging from 1.17 to 1.23 with a median of 1.21, are quite similar to the European topsoils. Most non-metamorphic sediments in central Western Europe have $^{206}Pb/^{207}Pb$ ratios ranging from 1.18 to 1.22 indicating that their Pb content is derived from geogenic/natural origin and can be regarded as the natural $^{206}Pb/^{207}Pb$ range for Western Europe (Elbaz-Poulichet et al. 1986; Monna et al. 1995; Steinmann and Stille 1997). At the same time, the soils and bedrocks have quite similar lead isotope signatures. In the present study, topsoil samples yield $^{206}Pb/^{207}Pb$ ratios ranging from 1.17 to 1.23 which is clearly the natural/geogenic Pb. The anthropogenically affected samples deviate from the unaffected samples towards lower $^{208}Pb/^{207}Pb$ and higher $^{206}Pb/^{207}Pb$ (Oskierski et al. 2009). Also, the $^{206}Pb/^{207}Pb$ ratios of the anthropogenic sources of Pb generally range from 0.96 to 1.20, whereas the $^{206}Pb/^{207}Pb$ ratios of naturally occurring Pb have generally higher values (> 1.20; Sturges and Barrie 1987). So, the $^{206}Pb/^{207}Pb$ values of topsoils in southern Konya are mostly controlled by the natural/geogenic component.

Conclusions

As, Cd, Co, Cr, Ni enrichments were identified in some soil samples in southern Konya region. Ni, Cr, Cu, Co and Mn mostly have the highest value in ophiolitic soils while As, Cd, Zn mostly have the highest value in volcanic soils. Similar distributions and concentrations of the trace elements in soils and bedrocks indicate in situ weathering of the bedrock as well as anthropogenic effects. Also, soils have low-medium weathering according to chemical weathering indices (CIA and CIW). The pH values of soil samples indicate slightly moderately alkaline. According to the C_f, EF and Igeo values of heavy metal concentrations in the southern Konya, the heavy metals show the order of As > Ni > Cd > Co > Cr > Cu > Mn. The higher enrichment of As, Co, Ni and Cd in topsoils than deep soils indicates that slightly-moderately alkaline soils partially adsorb heavy metals in topsoils, and anthropogenic factors are partially effective. While Co, Cr, Ni and Cu enrichments were observed in the stream sediments located in the ophiolitic region, as in the ophiolitic soils, As and Cd enrichments were observed in the stream sediments in the volcanic region, as in the volcanic soils. The results of soil assessment suggest that the soils were mostly defined to be uncontaminated to moderately contaminated. Pb and Sr–Nd isotopes indicate that bedrock plays the main role in the soils of southern Konya that is partially dependent on the location of the soil samples. It is shown that the soils in southern Konya are mostly controlled by geogenic (natural) resources besides the partially anthropogenic effect such as fertilizer, irrigation, traffic and other human effects.

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Declarations

Conflict of interest None.

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