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INVESTIGATION OF HEAVY METAL POLLUTION IN SOIL IN ESKISEHIR LANDFILL DRAINAGE AREA

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Keywords

Eskişehir
Heavy metal
Landfill
Soil pollution
Pollution indices

Abstract

This study assesses the extent of heavy metal contamination in the soil of the Eskişehir landfill drainage area in northwest Türkiye, where long-term waste accumulation and leachate pose potential environmental risks. Two boreholes were drilled to a depth of 30 meters downstream of the landfill site, and soil samples were collected during both wet (May) and dry (September) seasons in 2021. Concentrations of manganese, iron, cobalt, nickel, copper, arsenic, cadmium, lead, zinc, chromium, and mercury were determined together with pH values. Pollution indices, such as the contamination factor, pollution load index, and geoaccumulation index, were used to evaluate contamination levels. To support the geochemical results, geophysical surveys including electrical resistivity tomography, self-potential, and resistance measurements were carried out. Although measured heavy metal concentrations stayed below the legal thresholds set by national soil regulations, the calculated indices indicated localised contamination, particularly for cobalt, nickel, and chromium, which showed high levels during the wet season and remained elevated for chromium during the dry season. The pollution load index suggested a generally low overall pollution risk. Geophysical measurements did not reveal significant subsurface contamination-related anomalies. These findings demonstrate that heavy metal accumulation in the landfill drainage area is both seasonally variable and spatially localised. Periodic monitoring combining geochemical and geophysical approaches is recommended to manage and mitigate long-term risks in such waste storage environments.

ESKİŞEHİR ATIK DEPOLAMA SAHASI DRENAJ ALANINDAKİ TOPRAKTA AĞIR METAL KİRLİLİĞİNİN İNCELENMESİ

Keywords

Eskişehir
Ağır metal
Atık sahası
Toprak kirliliği
Kirlilik indeksi

Öz

Bu çalışmada, Türkiye'nin kuzeybatısında yer alan Eskişehir düzenli depolama sahası drenaj alanındaki topraklarda ağır metal kirliliğinin düzeyi araştırılmıştır. Uzun süreli atık depolama ve sızıntı sularının olası çevresel etkilerini değerlendirmek amacıyla, depolama sahasının mansabında 30 m derinliğe kadar iki adet sondaj kuyusu açılmış ve 2021 yılında yağışlı (Mayıs) ve kurak (Eylül) dönemlerde toprak örnekleri alınmıştır. Toprak örneklerinde Mn, Fe, Co, Ni, Cu, As, Cd, Pb, Zn, Cr ve Hg konsantrasyonları ile pH değerleri belirlenmiştir. Kirlilik düzeylerinin değerlendirilmesinde kontaminasyon faktörü (CF), kirlilik yük indeksi (PLI) ve jeobirikim indeksi (I_geo) kullanılmıştır. Jeokimyasal verileri desteklemek amacıyla elektrik özdirenç tomografisi (ERT), özpotansiyel (SP) ve direnç ölçümlerini içeren jeofizik çalışmalar gerçekleştirilmiştir. Ölçülen ağır metal konsantrasyonları ulusal toprak mevzuatında tanımlanan sınır değerlerin altında kalmasına rağmen, kirlilik indisleri özellikle Co, Ni ve Cr için yerel ölçekte zenginleşmeye işaret etmektedir. Bu elementler yağışlı dönemde yüksek değerler göstermiş, Cr ise kurak dönemde de görece yüksek seviyelerini korumuştur. PLI sonuçları, çalışma alanında genel olarak düşük düzeyde bir kirlilik yüküne işaret etmektedir. Jeofizik veriler, ağır metal kirliliği ile ilişkili belirgin bir yeraltı anomalisi ortaya koymamıştır. Sonuçlar, düzenli depolama sahası drenaj alanındaki ağır metal birikiminin mevsimsel olarak değişken ve mekânsal olarak sınırlı olduğunu göstermektedir. Bu tür alanlarda uzun vadeli çevresel risklerin değerlendirilmesi için jeokimyasal ve jeofizik yöntemlerin birlikte kullanıldığı periyodik izleme çalışmalarının sürdürülmesi önerilmektedir.

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1. Introduction

The global effort to establish sanitary landfills aims to prevent slope failures, explosions, and soil and groundwater contamination associated with uncontrolled waste disposal. As of 2019, Turkey operated 89 sanitary solid waste facilities serving 82% of the population. The Eskişehir facility, which operated as a wild disposal site before 2017, was converted into a sanitary landfill and now handles household, construction, ash, and medical waste. Since 2018, it has also produced biogas, supplying electricity to about 95,000 households. The facility processes 800 tons of municipal waste daily.

Metals with a density above 5 g/cm^3, such as manganese, iron, cobalt, nickel, copper, arsenic, cadmium, lead, zinc, chromium, and mercury, pose health risks due to their potential to bioaccumulate. This study investigates heavy metal pollution near the Eskişehir landfill. Two boreholes were drilled to a depth of 30 meters, and soil samples were collected during wet and dry seasons in 2021 to analyze heavy metal concentrations and pH levels. Additionally, self-potential and electrical resistivity tomography measurements were conducted between the boreholes to detect possible contamination along the drainage area.

1.1. Study Area

The study area is located at the border of Gülpınar neighborhood in the Odunpazarı district of Eskişehir, Türkiye. The landfill lies near the Eskişehir-Seyitgazi D665 highway, about 7.6 km west of the city center and 4.2 km east of Gülpınar (Fig. 1). The seasonally flowing Takahasan Stream runs north for about 1.7 km, joins the Ayrıklı Stream, and then the Sarısungur Stream, which connects to the Porsuk River via the Eskişehir Waste Water Treatment Plant channel. These streams have a sparse dendritic drainage pattern, indicating permeable soil. The surrounding land is mainly used for agriculture. Geologically, the landfill and streams lie within the Eocene Mamuca Formation’s conglomerate, sandstone, clay, marl, and the Porsuk Formation’s limestone and alluvial deposits. Faults are present near the landfill (Gözler, Cevher and Küçükkayman, 1985; Fig. 2). Groundwater mapping from 13 wells shows a northeast flow direction along Takahasan Stream.

Before 2016, the area operated as a wild landfill. The waste thickness ranges from 7 to 37 meters, with excavation material higher at the edges and more domestic waste in the center. Takahasan Stream’s bed was filled during waste deposition. The municipality rehabilitated the site by building drainage ditches and reshaping slopes (Ilbank, 2016). In borehole BH1, groundwater was found at 1.6 m depth and at 4.6 m in BH2. Sandy silty clay extends to 10.5 m in both boreholes, underlain by weathered claystone (Figs. 3–4).

2. Literature Review

One of the most important factors in environmental pollution is heavy metals. The term heavy metal is used for metals with specific gravity greater than 5gr/cm3 and atomic number greater than 20 (Cabrera, Clemente, Díaz Barrientos, López and Murillo, 1999; Müller et al. 2003; Üstbaş, Taşan and Geçgel, 2009; Yerli, Çakmakcı, Şahin and Tüfenkçi, 2020). Biologically, heavy metals are the name given to pollutants that create pollution on the environment and have a high toxicity effect (Duffus, 2002). There are about 70 heavy metals, with varying effects on air, soil and water resources and on living metabolism. Heavy metals such as copper, zinc, iron, manganese and nickel act as micronutrients for plants as long as they do not exceed the permissible limit. Additionally, some heavy metals play important roles in human and animal metabolisms when the threshold values are not exceeded. Heavy metal accumulation poses a mortal danger to soil, vegetation and human health (Liu et al. 2007; Krishna and Govil 2008).

3. Materials and Methods

3.1. Heavy Metals Analysis in Soil

Soil pH indicates acidity or alkalinity. A pH below 7 is acidic; above 7 is alkaline. Carbonates and bicarbonates increase alkalinity, while low pH can enhance the dissolution of toxic substances. Soil samples were taken from Kadirbey Farm (KF), BH1 and BH2. The KF is located upstream part of the landfill, so it is not affected by landfill drainage.

The parameters analyzed in soil samples are pH and heavy metal contents. For the analysis, 200 gr soil and water samples were taken. Soil samples were collected on 13.05.2021 during the wet period and on 22.09.2021 during the dry period in the study area (Table 1). Heavy metal analysis in soil and water samples was held at the Central Research Laboratory Application and Research Center (ARUM, Eskisehir). EN ISO 10523 (2012), TS 2789+T1 (2011) and SM 2510-B (2021). Samples were collected and preserved in accordance with TS ISO 5667-10 (2021).

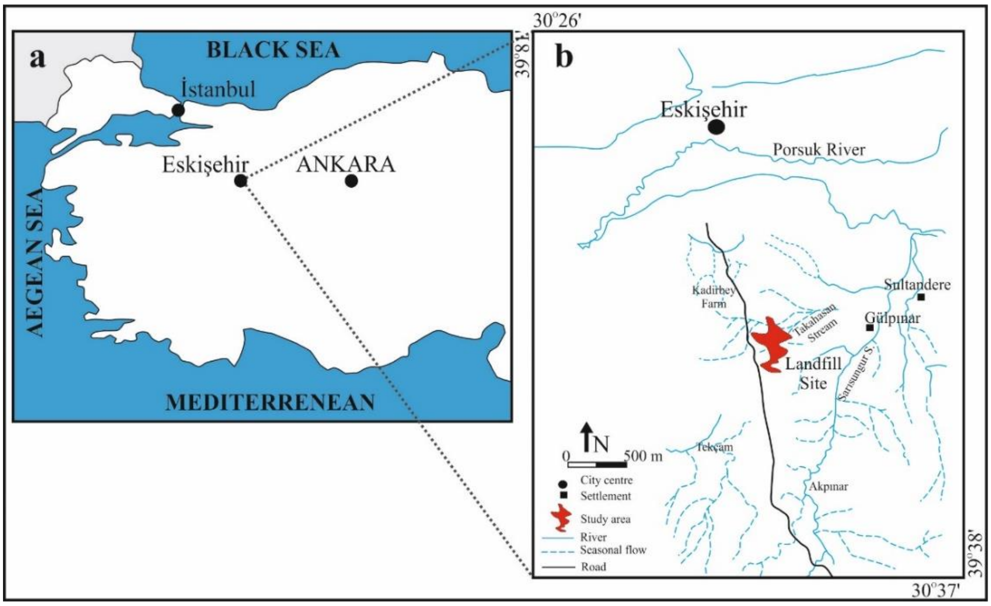

Figure 1. Location map of Eskişehir landfill site.

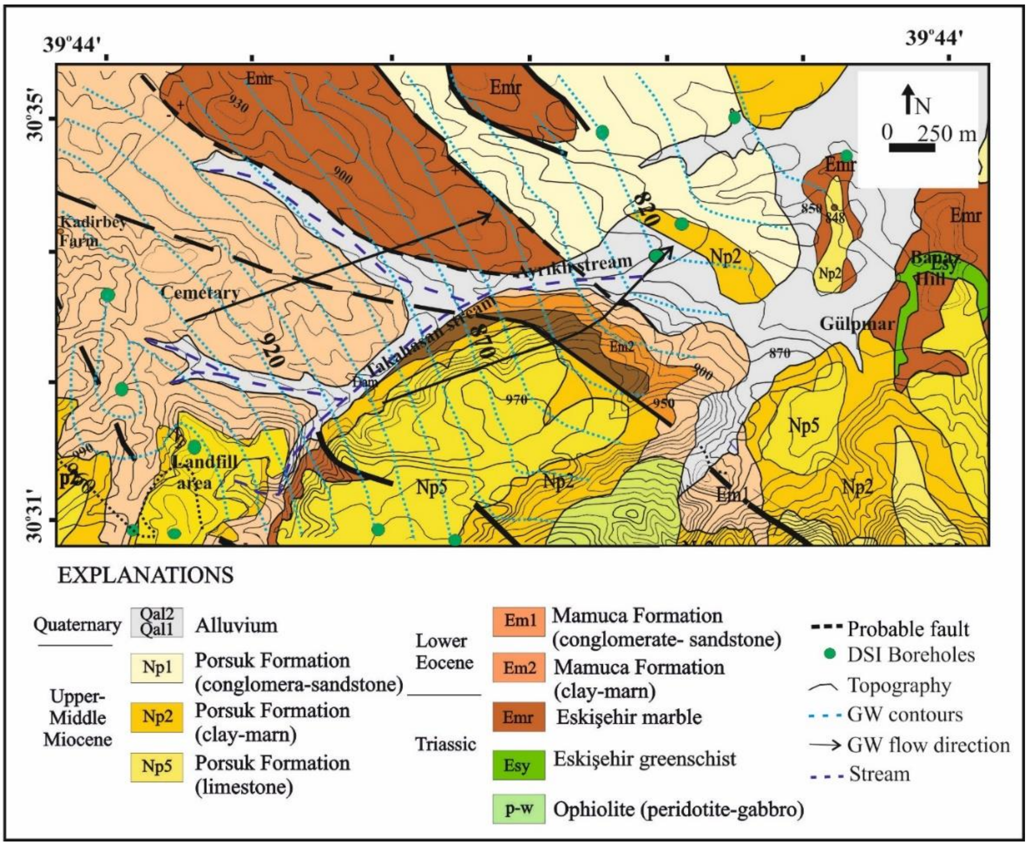

Figure 2. Study area geology, topography, and groundwater flow map vicinity (geology map modified from Gözler et al., 1985).

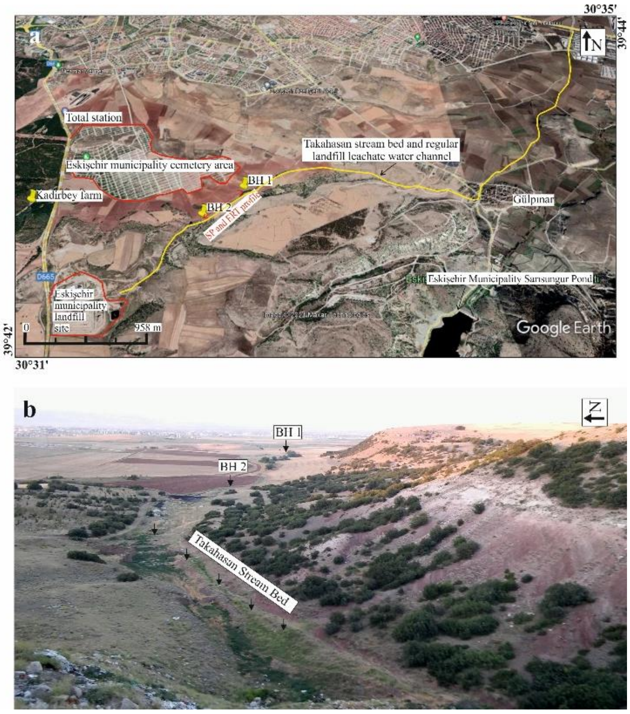

Figure 3 a) Google Earth view of the study area, b) a review of the Takahasan stream bed

Table 1. Soil samples information

Location	Coordinates	Soil samples	Sampling date	pH
KFS	288289.49E 4399119,59 N	SS1M	May 2021	8.00
		SS1S	September 2021	8.71
BH1	290027,29E 4398950,41 N	SS3M	May 2021	8.19
		SS3S	September 2021	8.71
BH2	290357,54E 4399321,73 N	SS2M	May 2021	8.54
		SS2S	September 2021	8.71

In this study, various indices were calculated to assess the effects of heavy metals on soil. The Pollution Factor (CF) is determined by dividing the concentration of each metal in the sediment by its corresponding natural background value (concentration of elements in the Earth's crust; Eq 1) (Pekey, Karakaş, Ayberk, Tolun and Bakoğlu, 2004; Savvides, Papadopoulos, Haralambous and Loizidou, 1995).

$$CF = \frac{C(metal\ content\ of\ soil)}{c\ (background)} \tag{1}$$

CF values were interpreted as follows: low contamination (LC) for CF<1, moderate contamination (MC) for 1<CF<3, considerable contamination (CC) for 3<CF<6, and very high contamination (VHC) at CF>6, according to Hakanson (1980).

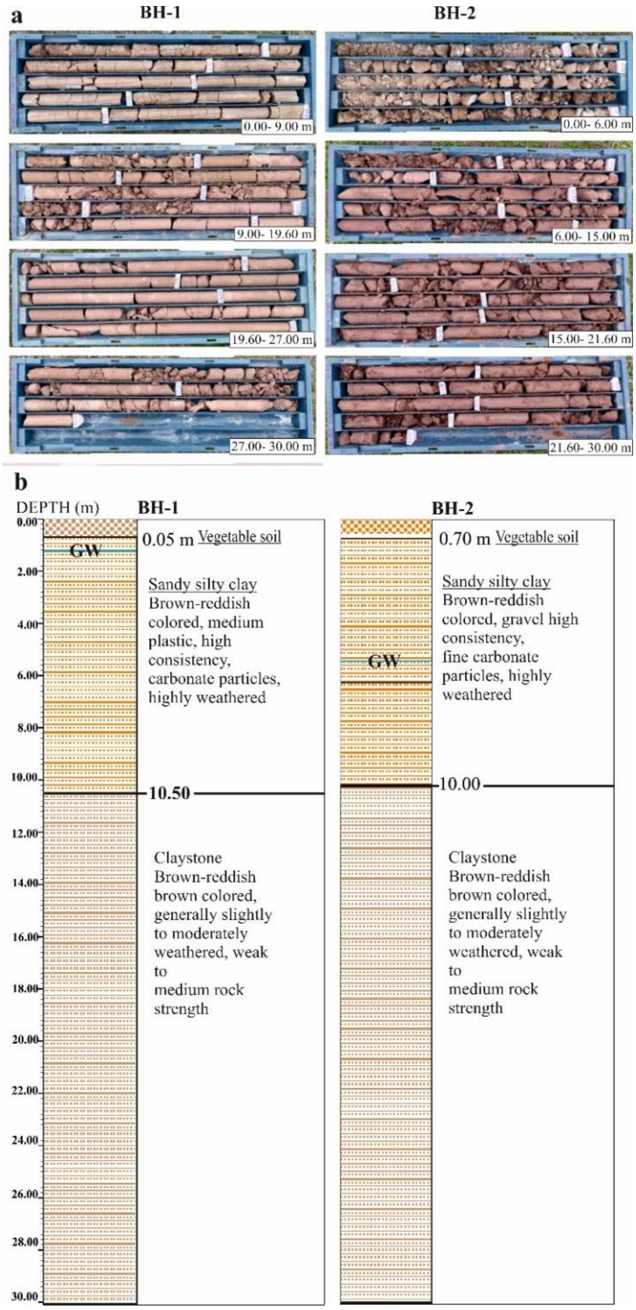

Figure 4 a) Core samples from boreholes BH-1 and BH-2, showing the lithological characteristics at different depths, b) Lithological logs of BH-1 and BH-2, indicating soil and rock types, groundwater levels (GW), and depth intervals.

Pollution load index (PLI), used to assess heavy metal pollution levels and facilitates the comparison of average heavy metal concentrations PLI is calculated by taking the nth root of the product of the pollution factors (CF) determined for n metals (Eq 2). In this context, standard values indicate that PLI<1 represents pollution and PLI>1 indicates the absence of pollution (Tomlinson, Wilson, Harris and Jeffrey, 1980; Bentum, Anang, Boadu, Koranteng-Addo and Antwi, 2011; Rabee, Al-Fatlawy and Nameer, 2011; Maanan et al. 2015).

$$PLI = \sqrt[n]{CF1xCF2xCF3x \ldots\ldots CFn} \quad (2)$$

The geoaccumulation index, first introduced by Muller (1969), is a measure of environmental pollution status, that evaluates metal concentrations by comparing them with background values (Eq. 3).

$$I_{geo} = \frac{\log_2 Cn}{1.5\,(Bn)} \quad (3)$$

Where Cn represents the measured concentration of element n (in milligrams per kilogram), and Bn denotes the element’s content (in milligrams per kilogram) in “average shale” (Turekian and Wedephol 1961) or it is the geochemical background value in the Earth’s crust (Taylor and McLennan, 1995). Soil pollution is classified into six classes based on the Igeo value. When the Igeo value is lower than 0, it indicates an unpolluted soil, , whereas the Igeo value is 5 or higher, which signifies extreme pollution (Table 2).

Table 2. Description of sediment quality (Muller 1969)

Igeo value	Class	Quality of sediment
<0	0	Unpolluted
0-1	1	Unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	Moderately polluted to strongly polluted
3-4	4	Strongly polluted
4-5	5	Strongly to extremely polluted
>5	6	Extremely polluted

3.2. Geophysical Studies

Geophysical methods, in combination with other methodologies, have been demonstrated to be benefical in the investigation of pollution (Karlık and Kaya 2001; Kaya, Özürlan and Şengül, 2007; Kaya, Özürlan and Balkaya, 2015; Boudreault, Dubé, Chouteau, Winiarski and Hardy, 2010; Vaudelet et al. 2011; Haile and Abiye 2012; De Carlo et al. 2013; Ayolabi, Folorunso and Kayode, 2013; Tsourlos, Vargemezis, Fikos and Tsokas, 2014; Wijesekara et al. 2014; Konstantaki, Ghose, Draganov, Diaferia and Heimovaara, 2015; Chira Oliva, Barbalho and Cruz, 2015; Gómez-Puentes et al. 2016; Ganiyu et al. 2016; Çınar, Altundaş, Ersoy, Bak and Bayrak, 2016; Soupios and Ntarlagiannis 2017; Kayode, Okagbue and Achuka, 2018; Meju, 2000; Di Maio, et al. 2018; Akintorinwa and Okoro 2019). The electrical conductivity and resistivity of dissolved waste material have been demonstrated to be directly associated with the presence of ions. Elevated concentrations of these ions have been evidenced to result in diminished electrical resistivity, which is indicative of soil contamination.

A comprehensive geophysical investigation was conducted, encompassing Natural Potential (SP), resistence measurements and Electrical Resistivity Tomography (ERT) measurements. The study spanned the profile between BH1 and BH2, with a total length of 715 meters. The SP and resistence measurements were obtained using a Fluke 179 model voltmeter, while the ERT measurements were facilitated by a Lippmann 4 point light device. The inital geophysical measurement was conducted on April 29, 2021, while the subsequent measurement was conducted on September 22, 2021.

Electrical Resistivity Tomography (ERT) is a well-established geophysical method that has been utilized for numerous years (Adepelumi, Ako, Afolabi and Arubayi, 2005; Falebita, Bayowa, Olorunfemi and Adepelumi, 2012) and in the context of solid waste (Warner, 1969; Donaldson, 1984; Ayolabi and Daniel 2005). However, when determining anomalies, the characteristics of the electrode arrays utilized are of paramount importance. Consequently, the calculated apparent resistivity values for any ground model will yield different results depending on the electrode array employed. Therefore, the selection of an appropriate electrode array is crucial for the success of the research. Electrode spacing of 5 meters, employing the dipole-dipole measurement technique across six stages. The apparent resistivity (AP) data, as measured by the dipole-dipole electrode array, is situated at the intersection point of the lines descending at an angle of 45o from the A-B current and M-N voltage electrode pairs. While the distance between the current and voltage electrodes (AB-MN) remains constant, the ratio of the distance between the b and M electrodes, which are a current and a voltage electrode, to the distance between the two current and two voltage electrodes, that is, "a", is "n" (Fig 5). The disadvantage of this array is that as the n value increases, strong signals cannot be obtained. For instance, when the n value is increased from 1 to 6 while maintaining a constant current, the measured potential value is 56 times greater (Loke 2000).

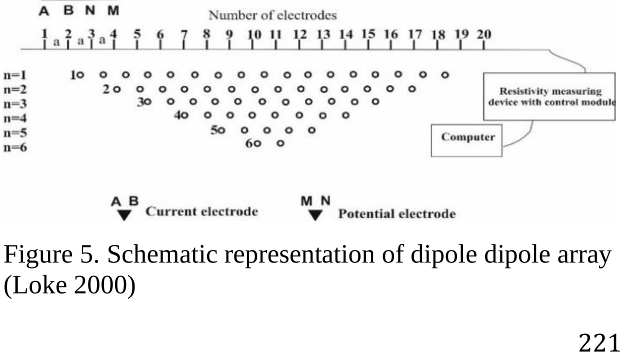

Figure 5. Schematic representation of dipole dipole array (Loke 2000)

4.Results

4.1. Heavy Metals in Soils

Soil samples were collected from Kadirbey Farm (designated SS1), BH1 (designated SS3) and BH2 (designated SS2). The letter S denotes the dry period (September) and M denotes the wet period (May). The SS2 and SS3 samples were obtained from boreholes, while the SS1 samples were collected from a region not affected by landfill pollution due to the location of KF upstream of the landfill.

Following the evaluation of heavy metal concentrations in the soil samples, it was established that the levels of Mn and Fe were, on the whole, elevated; however, these levels did not demonstrate significant disparities between the various samples. This observation suggests that these elements may have a natural origin. Conversely, the presence of elevated concentrations of elements such as Ni, Cu, Zn, Cr, and Pb in the SS2 sample indicates that the landfill site has resulted in substantial metal contamination. Particularly the increase in Zn, Cr, and Pb levels in September, suggesting that heavy metals tend to accumulate more in the soil during the dry period as the washing effect of water decreases. Although Hg and Cd levels were generally low, a significant increase was observed in the SS2 sample (Fig 6a). The evaluation diagram, created by normalising the heavy metal ratios in the soil samples according to the SS1 sample, revealed that elements such as Ni, Zn, Cr, and Hg exhibited significantly higher concentrations in areas proximate to the landfill site. The fact that these metals are especially concentrated in the SS2 sample demonstrates that the most significant effect of landfill pollution is observed in this area. Conversely, a decline in the concentrations of Cu and As was observed. This decline may be attributed to the dissolution and migration of these elements under varying geochemical conditions.

A further analysis, comparing rates across the seasons, reveals that September values are typically higher than those recorded in May. This may be due to the fact that the leaching effect of heavy metals is reduced during the dry period when rainfall is low. Consequently, the accumulation of heavy metals in the soil is increased (Fig 6b). Heavy metals are also found in the lithologic composition in nature. Soil samples taken from the Kadirbey Farm will give the heavy metal concentration in the lithological structure, while the heavy metal analysis results of the SS1 and SS2 soil samples taken from the boreholes will give the heavy metal concentration both litological structure and pollution (Table 3).

As demonstrated in Table 4, the Contamination Factor (CF) and Pollution Load Index (PLI) are utilised to categorise the concentrations of heavy metals present in the samples. Evaluations based on the pollution factor (CF) reveal that soil samples near the Eskisehir landfill site are affected at different levels in terms of heavy metal pollution. A detailed analysis of the C factor values indicates that Ni and Cr levels are particularly pronounced. In May 2021, the Ni (14.692) and Cr (7.430) concentrations in the SS3 sample were classified as a very high contamination level (VHC). In September 2021, a decline in the concentrations of these metals was revealed, though they continue to be classified as significant contaminants. For Co, significant (CC) pollution was observed at SS2 in May and very high pollution (VHC) at SS3. Despite a decline in the concentration of cobalt in September, the contamination effect persists. The Cu concentration in the SS3 sample reached 20.733 in May, indicating very high contamination. However, a significant decrease in the rate of this metal was observed in September. Mn and Fe levels were measured at moderate pollution levels, suggesting that these metals may have a natural origin or be influenced by the geochemical characteristics of the region. The presence of Pb, Zn, and Cd was detected, but at low levels, indicating that these metals do not pose a significant environmental threat from the landfill. In general, heavy metals were found to have higher concentrations in May, with a partial decrease in September. This is explained by the increased accumulation of metals on the surface or transport by drainage during the rainy season. PLI value being greater than 1 in all soil samples indicates that there is no risky pollution.

The Igeo accumulation index classification of the elements is given in Table 5. Ni concentration is in the moderately to high contamination class, Co and Cr are in the moderately contaminated class, Fe and Cu are in the uncontaminated to moderately contaminated class. Other metal elements are in the uncontaminated class. Representative CF and Igeo calculations for Mn are given in Table 6. In the CF calculations, the C value was based on samples from Kadirbey Farm (Table 6).

Limit values for Pb, Cd, Cr, Cu, Ni, Zn, and Hg in the Turkey Soil Pollution Control Regulation (TSPCR, 2005) are given in Table 7. According to the limit ranges in Table 7 there is no risk for Pb, Cd and Hg, while Ni, Cr, Co, Cu, Fe, and Mn concentrations create environmental pollution and pose a risk to living health.

4.2 Geophysical study

Natural potential and resistivity measurements are given in Figure 7. After every reading, the pots were brought side by side and the tension difference was measured. Resistance measurements was made in parallel with SP measurements. SP values vary between -10 mV and 30 mV at most. SP measurements taken on 29.04.2021 and 22.09.2021 were very close to each other and no obvious anomaly could be detected. When the resistance values measured in parallel with the SP measurements taken into account, in the resistance values measured at 29.04.2021 was in the range of 1.11 kΩ

-1.45kΩ, whereas the SP measurements made on 22.09.2021 was in the range of 1.71 kΩ -2.13 kΩ.

Table 3. Heavy metal analysis test results in soil samples

Heavy metal concentration(ppb)	Wet period (May 2021)			Dry period (September 2021)		
	SS1 (Kadirbey)	SS2 (SK2)	SS3 (SK1)	SS1 (Kadirbey)	SS2 (SK2)	SS3 (SK1)
Mn	3.306	7.330	4.836	4.72	5.716	5.456
Fe	60.620	87.719	134.4	68.43	88.622	116.252
Co	0.067	0.306	0.551	0.137	0.371	0.344
Ni	0.461	4.950	6.773	1.054	6.292	5.1
Cu	0.015	<LOQ	0.311	0.402	0.762	0.406
As	0.024	0.018	0.020	0.066	0.023	0.093
Cd	<LOQ	<LOQ	<LOQ	0.022	0.012	0.022
Pb	0.064	0.010	0.019	0.129	0.022	0.102
Zn	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Cr	0.637	4.086	4.733	0.870	3.249	4.579
Hg	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

0.001≤LOQ (limit of detection)

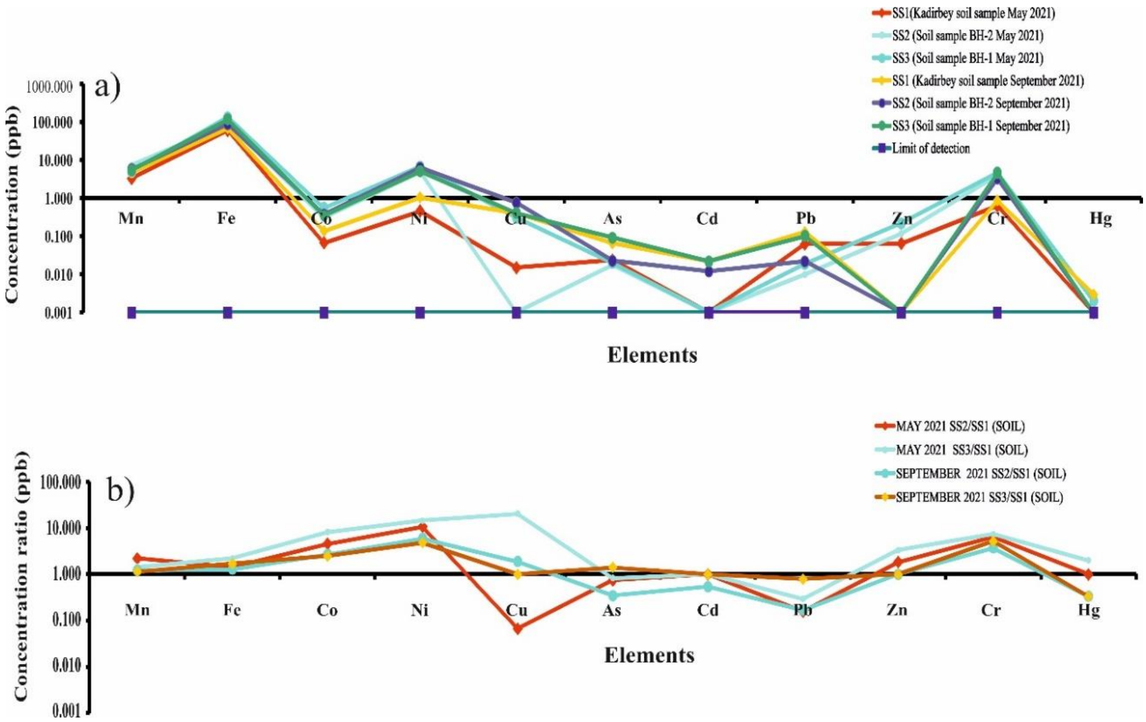

Figure 6. a) The trendline graph of heavy metal concentrations in soil samples, b) The trendline graph of the ratio of heavy metal concentrations determined in soil samples taken from the landfill area and the heavy metal concentrations in soil samples taken fom Kadirbey Farm.

The groundwater level (GWL) measured on 29.04.2021 was 1.50 m in the BH1 and 4.90 m in the BH2. and 6.0 m in the BH2. It is thought that the difference between the GWL measurements made on 22.09.2021 was 3.5 m in BH1 measured resistance vaues may be due to the change in GWL.

Table 4. Contamination factor (CF) and Pollution load index (PLI) classification of heavy metal concentration

Heavy metal	CF May 2021-SS2	CF May 2021-SS3	CF Sep 2021-SS2	CF Sep 2021 SS3
Mn	2.217 (MC)	1.463 (MC)	1.211 (MC)	1.156 (MC)
Fe	1.447 (MC)	2.218 (MC)	1.295 (MC)	1.699 (MC)
Co	4.567 (CC)	8,224 (VHC)	2.708 (MC)	2.511 (MC)
Ni	10.738 (VHC)	14.692 (VHC)	5.970 (CC)	4.839 (CC)
Cu	0.067 (LC)	20.733 (VHC)	1.896 (MC)	1.010 (MC)
As	0.750 (LC)	0.833 (LC)	0.348 (LC)	1.409 (MC)
Cd	1.000 (LC)	1.000 (LC)	0.545 (LC)	1.000 (LC)
Pb	0.156 (LC)	0.297 (LC)	0.171 (LC)	0.791 (LC)
Zn	1.000 (LC)	1.000 (LC)	1.000 (LC)	1.000 (LC)
Cr	6.414 (VHC)	7.430 (VHC)	3.734 (VHC)	5.263 (CC)
PLI	1.21	2.34	1.17	1.57

Table 5. The Igeo accumulation index classification of the elements

Metals	Igeo	Igeo	Geo accumulation index
Mn	-3.26378	0	Uncontaminated
Fe	0.964821	1	Uncontaminated to
Co	-4.27392	2	Moderately contaminated
Ni	-1.45023	3	Moderately contaminated
Cu	-5.68624	1	Uncontaminated to
As	-2.83388	1	Uncontaminated
Cd	-7.97633	0	Uncontaminated
Pb	-12.5228	0	Uncontaminated
Zn	-17.7056	0	Uncontaminated
Cr	-2.69248	2	Moderately contaminated
Hg	-8.23745	0	Uncontaminated

Table 6. Representative CF and Igeo calculations for Mn (for CF calculation, c value is taken by KF samples from Table 3).

Mean SS1 (Bn)	**MS**	**Constant**	**Cons*Bn**	**MS/ Cons*Bn**	**Igeo**
4.013	5.835	1.500	6.020	0.969	-0.045
CF May SS2	**CF** May SS3	**CF** Sep SS2	**CF** Sep SS3		
2.217	1.463	1.211	1.156		

Table 7. Heavy metal concentration limits in the soil in Turkey and Some European Union countries (Kaptan, 2003).

Heavy metal	Turkey (Dry soil	86/28/EEC	Austria	Finland	Holland	Spain
Pb	0.3	0.3	0.1	0.01	0.05	0.04
Cd	0.003	0.00	0.00	0.005	0.008	0.004
Ni	0.75	0.07	0.06	0.006	0.035	0.03
Cr	0.1	-	0.1	0.2	0.1	0.06
Co	0.08	-	-	-	-	-
Cu	0.14	0.14	0.1	0.1	0.036	0.04
Fe	0.004	-	-	-	-	-
Zn	0.3	-	-	-	-	-
M	0.07		-	-	-	-
Hg	0.001	0.01	0.01	0.000	0.000	0.000

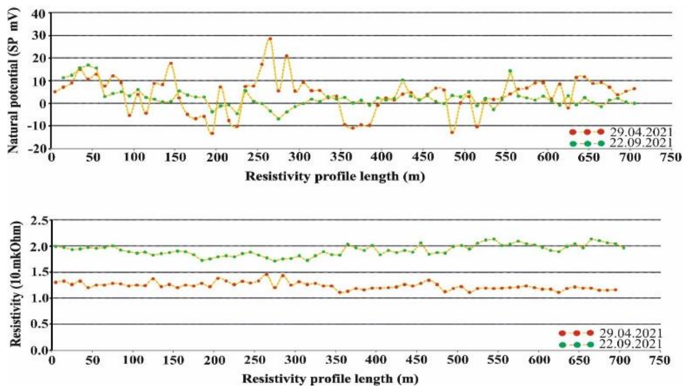

Figure 7. Variation of Natural potential and Resistivity.

The resistivity section showing the right and left ERT measurement data along the Takahasan stream bed is given in Figure 8. There is no surface flow in Takahasan stream during most of the year. However, the groundwater is close to the surface. It is difficult to determine resistivity areas in ERT measurements are due to the water pollution or soil pollution. The low resistivity regions are the blue toned regions close to the BH2 borehole (generally regions with resistivity lower than 5 ohms). Low resistivity means high conductivity. The blue tone areas in the first 140 m where there is high conductivity indicate higher pollution. Small blue dots along the ERT cross-section indicate individual pollution deposits. Red, brown and yellow Levels at a depth of approximately 8 m from the large blue pots show high resistance (>20 Ω). Levels consisting of green tones constitute intermediate pollution region (10 Ω-20 Ω).

It is observed that the resistivity measurements taken on 29.04.2021 are slightly higher than the resistivity measurements taken on 22.09.2021 at the near-surface levels. However, the resistivity values measured on 22.09.2022 are slightly higher than resistivity values measured on 29.04.2022 as the depth increases. The change of the resistivity value with depth may be due to the change of groundwater level and the chemical change of the groundwater or soil composition (Fig 9).

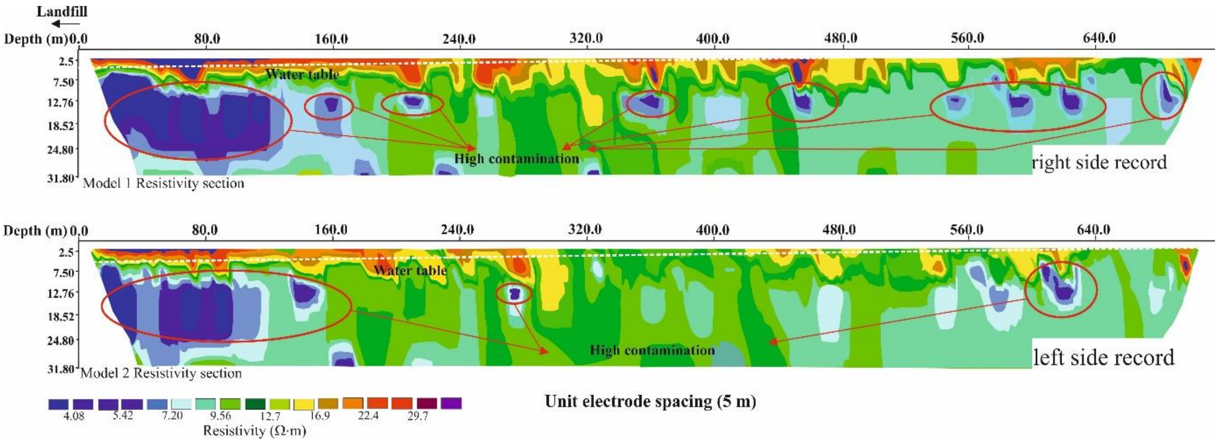

Figure 8. Electrical Resistivity Tomography (ERT) measurements between BH2 and BH

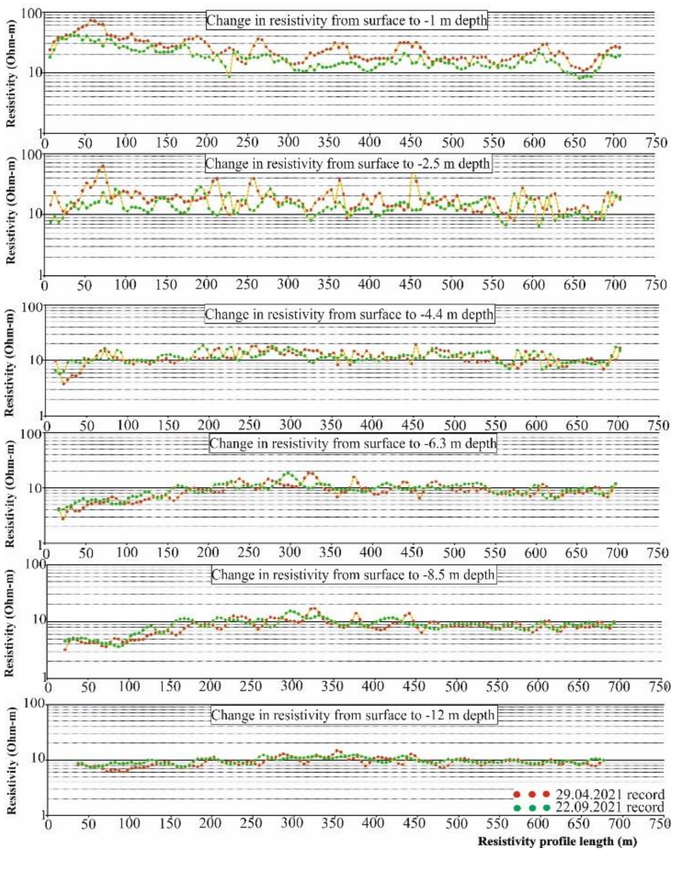

Figure 9. Variation of resistivity with depth by ERT measurements.

5. Conclusions

In this study, possible heavy metal soil pollution was investigated in the regular wastage storage area basin. This area was used as a wild storage area before 2016. After 2016, it was converted into a regular waste storage area, and energy started to be produced after 2018.

Two boreholes at 30 m depth were drilled in the Eskişehir landfill drainage basin. Soil samples were taken in 2021, both during wet and dry periods. In addition, soil samples were taken from the Kadirbey picnic area which is outside of the landfill area drainage basin.

CF reveals that soil samples near the Eskişehir landfill site are affected at different levels in terms of heavy metal pollution. In the rainy season (May 2021) samples, the contamination factor value in Ni, Co, Cu, and Vr samples was determined as “very high contamination” class. In the dry season (September 2021) samples, the Cr contamination factor value was determined as “very high contamination-considerable contamination” class, and the Ni contamination factor value was determined as “considerable contamination” class.

In general, heavy metals were found to have higher concentrations in May, with a partial decrease in September. The PLI value indicates there is no risk of pollution. According to the Igeo accumulation index classification of the elements, Ni concentration is in the “moderately to high contamination” class, Co and Cr are in the “moderately contaminated” class, Fe and Cu are in the “uncontaminated to moderately contaminated” class. Other metal elements are in the “uncontaminated” class.

As a result of this study, Ni, Cr, Cu, Co, Fe, Zn, Mn, and Al concentrations in soil samples were found to be higher according to TSPCR (2005). The sources of the heavy metals determined with high concentration and the diseases they cause are given in Table 8.

Electrical Resistivity Tomography, Self-Potential and Resistance measurements were taken between boreholes. Measurements made with geophysical methods did not give a definite result on the increase of pollution. The change of the resistivity value with depth may be due to the change of the groundwater level and the chemical change of the groundwater. It has not been determined whether the resistivity differences determined by geophysical methods are due to groundwater pollution or soil pollution. For this reason, geophysical measurements alone are not entirely sufficient to assess water and soil pollution. In this regard, the number of boreholes in the waste disposal drainage area should be increased, and soil and water analyses should be conducted more frequently.

It is suggested that the extensive soil and groundwater pollution in the study area should be monitored according to the related soil and water pollution regulation at least one-year periodic intervals.

Table 8. Sources of some heavy metals and diseases they cause (WHO 1996)

Heavy metal	Source	Diseases
Ni	Industry, mining works, welding works	Respiratory system diseases, allergic reactions, cancer of the nose and larynx
Cr	Industry, casting Works, welding works	Respiratory system diseases, allergic reactions, skin cancer.
Cu	Vineyard spraying, Industry, welding Works, bronze work	Respiratory system diseases
Co	Glass-ceramic industry, mining works	Cancer, contact dermatitis
Fe	Industry, mining Works, welding works	Genetic disorder, hemorrhagic necrosis
Zn	Industry, welding works, bronze works	Respiratory system diseases
Al	Industry, mining Works, welding works	Contact dermatitis, Alhzehimer, poisoning, high albumin level

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Author’s Contribution

Author 1: Conceptualization, writing original draft, editing, validation, visualization, and supervision. Author 2: Writing-original draft, validation, visualization, and editing. Author 3: Writing-original draft, validation, visualization, and editing.

Conflict of Interest

The authors have no relevant financial or nonfinancial interests to disclose.

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