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HYDROCHEMICAL EXAMINATION OF UNDERGROUND LEAKAGE WATER SPREAD FROM OPEN LANDFILL IN AKSARAY CITY IN TURKEY AND DETERMINATION OF ITS LOCATION. CASE STUDY

Uncontrolled dumping of open landfills has been becoming a significant threat to developing countries. The areas where solid wastes are stored increase the risk of groundwater and environmental pollution. Groundwater pollution causes poisoning and even death in terms of public health. This study investigated the impact area of pollutants that pose environmental risks in the Hamamboğazı (Aksaray Turkey) landfill area. Six vertical electrical sounding (VES) measurements were made in the study area. The direction of the leakage water is southwest, and the penetration depth is 15 m. The electrical conductivity reaching high values such as 4160–7900 $\mu\text{S}/\text{cm}$ shows the polluting effect of the leachate. Heavy metals detected in leachate were Cu (0.183 mg/dm^3), Pb (0.234 mg/dm^3), Zn (0.33 mg/dm^3), and Fe (3.179 mg/dm^3).

1. INTRODUCTION

Worldwide, 1.4 billion tons of municipal solid waste (MSW) are generated yearly (1.25 kg per capita per day) expected to rise to roughly 2.20 billion tons by 2025 [1]. According to Turkish Statistical Institute data, approximately 32 million tons of domestic waste was collected in Turkey by 2020. 70% of this waste was dispensed of into landfills, 13% into recycling facilities, and 17% into open areas. Uncontrolled dumping of 5,495,160.24 tons of domestic waste, corresponding to 17% of total waste, into empty

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areas is a serious health problem. Solid wastes and toxic chemicals are the main contributors, which influence the environment and quality of life [2]. Environmental pollution from dumpsites constituted a challenge to environmental scientists and people living around the waste disposal sites. These sites are routinely known to let out a substantial amount of concentrated toxic chemicals to air, soil, groundwater, and surface water through leachate plumes, which present threats to the environment and could pose a high risk to public health [3].

Waste deposits are significant sources of groundwater pollution since they generate highly contaminated leachates that percolate through the subsoil, reaching the aquifers and altering them for decades or centuries after the end of the disposal activities, independently of the deposit size [4]. The open dumpsite is an unfavorable global phenomenon causing pollution of the groundwater system due to the dumpsite leachate percolation into groundwater [5]. Geophysical methods are effective tools for determining changes in physical parameters of the geological environment, such as soil or groundwater in the presence of contamination [6]. Geophysical techniques have been widely used for geo-environmental impact investigation due to their least harmful effects on the environment [7]. The direct current (DC) resistivity method is favored for such applications as the inorganic pollutants, present in most leachates, on entering the fluid pathways increase the fluid conductivity due to an increase of the number of ions in the solution [8]. The electrical resistivity method is based on a system, where current and potential electrodes are coupled to the ground and connected to a resistivity meter through conducting wires. The farther apart the current electrodes, the deeper the depth of penetration is [9]. The electrical resistivity of the soil can be considered a proxy for the spatial and temporal variability of many other soil physical properties (i.e., structure, water content, or fluid composition). Because the method is non-destructive and very sensitive, it offers a very attractive tool for describing the subsurface properties without digging [10].

Integrated application of geophysical methods offers a vital tool to describe and evaluate contaminants generated by indiscriminate disposal of wastes. Electrical methods have been found very suitable for such kind of environmental study, owing to the conductive nature of most contaminants [11]. While the geophysical analysis indicates a high leachates infiltrating index in the subsoil, which invariably affects the groundwater resources, the physicochemical analysis indicates a high concentration of heavy metals, chemical oxygen demand (COD), biological oxygen demand (BOD), total dissolved solids (TDS) and high electrical conductivity (EC), supporting the geophysical results [12]. The degradation of the organic fraction of waste in combination with percolating rainwater leads to the generation of leachate. It constitutes a highly contaminated liquid due to the presence of toxic compounds such as organic constituents, heavy metals, ammonium, and phthalates. Therefore, leachate is considered a source of pollution for ground surface water resources [13].

Major potential environmental threats posed by municipal landfills are pollution of groundwater and surface water, mainly due to the contact of these environments with landfill leachate. Since this leachate contains pollutants from various groups in high concentrations, i.e., dissolved organic matter, inorganic macrocomponents, and heavy metals, the resultant impacts can be extensive and very harmful to the aquatic habitat [14]. Municipal landfill leachates are highly concentrated complex effluents that contain dissolved organic matter, inorganic compounds such as ammonium, calcium, magnesium, sodium, potassium, iron, sulfates, chlorides, and heavy metals such as cadmium, chromium, copper, lead, nickel, zinc among others [15]. A particularly onerous and dangerous pollution in the leachate could be heavy metals. Their toxic nature disturbs the natural biological balance and inhibits self-purification processes. The composition of heavy metals in the leachate varies during the landfill activity depending on the waste composition, waste age, landfill technology, and the quality of water percolating through the waste body. The evaluation of the metal release potential from a landfill needs information on the amount of deposited refuse, its composition, and historical records of the leachate quality and quantity at a given time [16]. The purpose of this study was to investigate the effect of the solid waste storage area around Hamamboğazı Stream in Aksaray on groundwater pollution by geophysical (resistivity) and hydrochemical methods. It is also to interpret the polluted part of the aquifer with the results to be obtained and to contribute to preventing an environmental problem before it grows.

2. MATERIALS AND METHODS

Study area, hydrogeology, and geology. The working area is located in Aksaray, a Central Anatolian Region in Turkey, at a point that can be considered the heart of Anatolia (Fig. 1). The average altitude of Aksaray is 965 m, and its surface area is 7626 km².

The study area is rich in drainage networks (Fig. 2). Hamamboğazı Stream is constantly fed by hot and mineral water sources. The Hamamboğazı Stream flows in the northeast and southwest directions. At the same level as the solid waste site, it is unaffected by leachate. The Boduroğlu Stream stretches in the east-west direction on the land. There is an irregularly stored Aksaray landfill on the stream showing seasonal flow. The groundwater flow direction is estimated to be from north to south towards Aksaray and from Gazi Hill to the west. There are several seasonal springs and boreholes with depths ranging between 35 and 80 m in the study area. The most essential elevations of the study area are Hamamüstü Hill and Gazi Hill.

In the area's geological structure, the Mezgit Formation covers a large area (Fig. 3). This formation is generally characterized by yellow and brown and consists of terrestrial red-colored conglomerates, sandstone, mudstone, and claystone. Gabbro, ophiolite, granite, diabase, basalt, and Lutetian-aged limestone pebbles belong to the older units at the

bottom of the conglomerate. Gravels should be loosely attached and be better sorted. The team was formed in a Stream and lake environment.

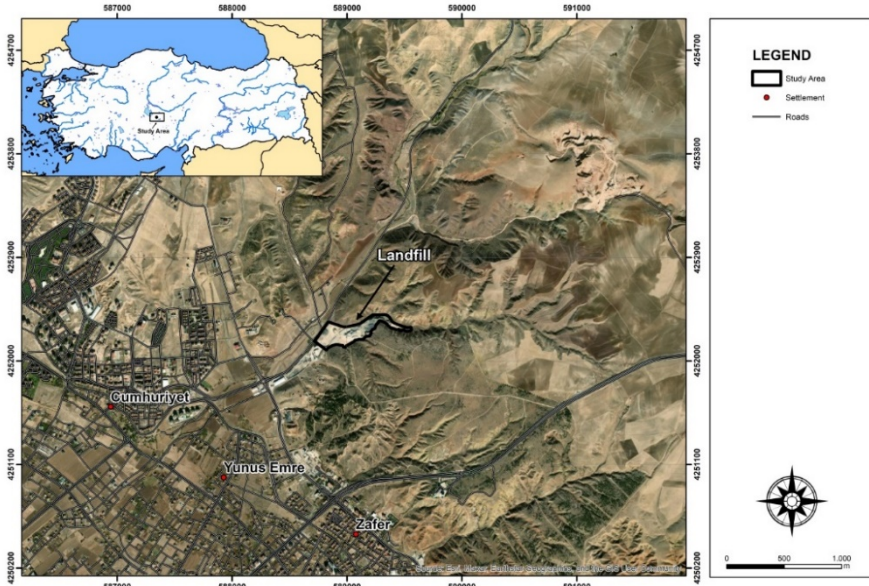


Fig. 1. Site location

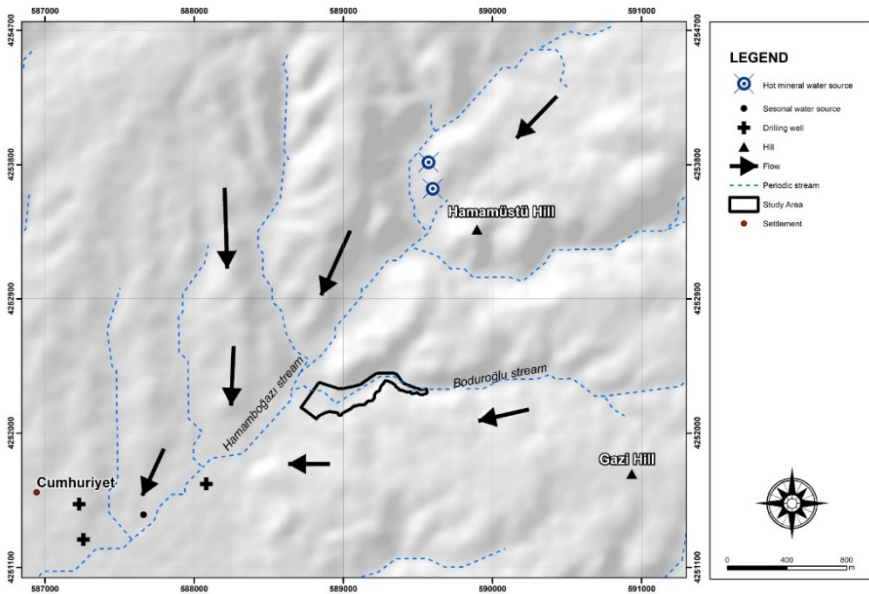


Fig. 2. Site hydrogeology

Since the Göstük tuffite is best seen in the Göstük region, it was first named Göstük tuffite by Beekman (1996). It unconformably overlies the tuffite Mezgit formation in the study area. The unit starts with andesite, granite, and diorite pebbles at the bottom and continues with volcanic rock clastic, medium-thick bedded sandstone, loosely cemented clay, and sand (Fig. 3). Travertines are whitish-yellow and have a hollow structure; their thickness varies between 1 and 30 m. In the study area, travertines are observed around the Hamamüstü Hill and Tuzlusu hot and mineral springs (Fig. 3).

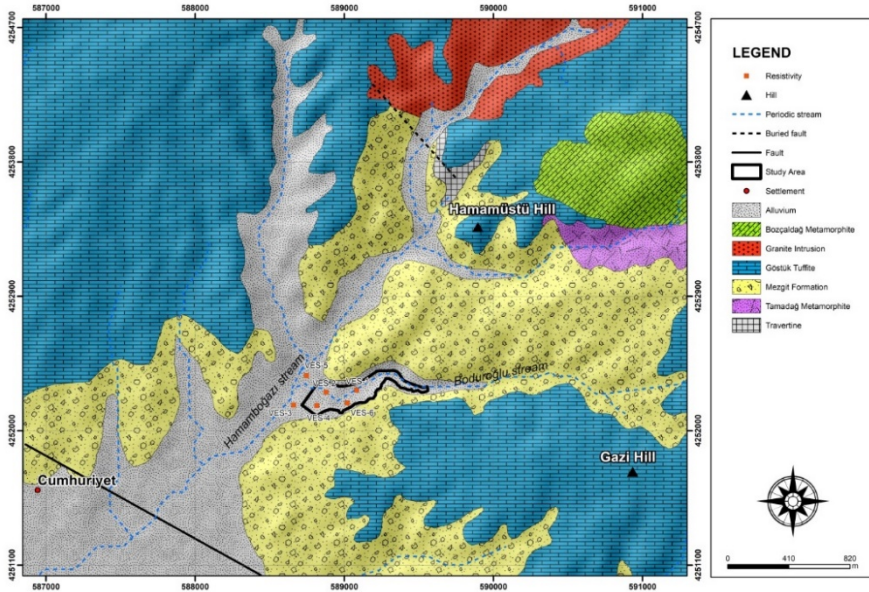


Fig. 3. Site geology

Alluvial material filling the bottom of Boduroğlu Stream and Hamamboğazı Stream and its surroundings, where wastes are stored in the study area, is like a free aquifer. According to the particle size distribution of the clastic material, the alluvium is permeable in some places and semi-permeable in others. The Mezgit formation under the alluvial unit is permeable. It is thought that the fractures and cracks of the Göstük ignimbrites and granite formations in the area where the groundwater in the study area is not limited to the alluvial and Mezgit formations also contain groundwater and are hydraulically related to the aquifer above it (Fig. 3).

Landfill site. The solid waste site is spread over approximately 16.5 hectares on the Boduroğlu Stream southeast of the Hamamboğazı Stream (Figs. 2, 3). There are settlements 1 km west of the site (Figs. 1, 4a). The accumulation in the landfill, which has been in use for 20 years, reaches 15 m at its deepest point and 2 m at its thinning end. The length of the solid waste site is approximately 1 km, and the width starts from 300 m

and tapers towards the east. The solid wastes pushed down the slope by the bulldozer create unstable slopes, and the slope of the hill rises to 35–40°. The annual substantial waste amount of the city, where 155 000 people live, is 49 662 tons.

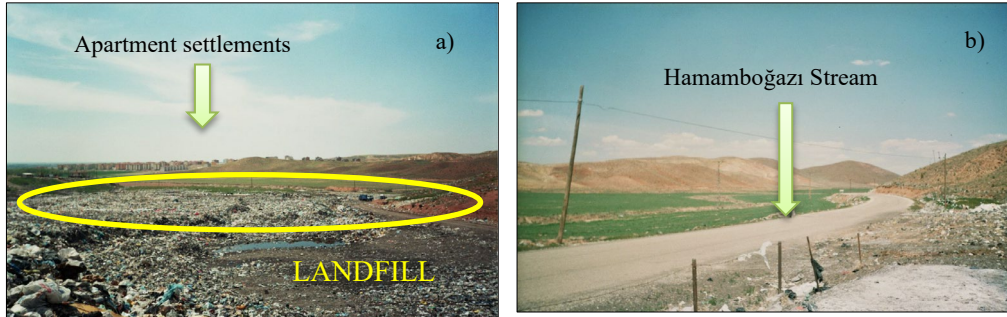


Fig. 4. Landfill and settlements (a), and landfill and Hamamboğazi Stream (b)

Geophysical study. Electrical resistivity tomography (ERT) is a multi-electrode method that effectively measures resistivity at shallow depths. The number of electrodes between 20 and 72 is commonly used. The 24-electrode and 48-electrode methods are mostly applied. ERT can create 2D and 3D three-dimensional underground models. The method is based on measuring the potential distribution of the electric field occurring in the ground. The technique aims to determine the resistivity-conductivity values arising from the physical differences between the rocks.

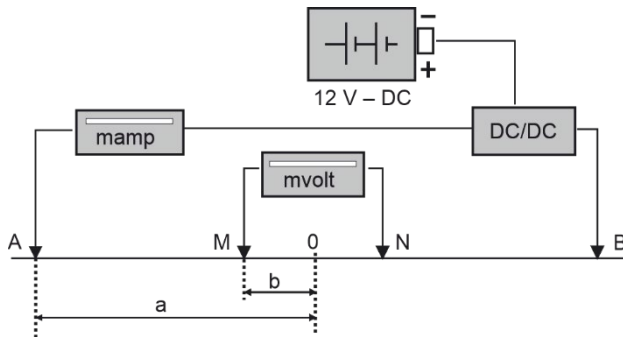


Fig. 5. Schlumberger electrode geometric array

In geothermal reservoir research, deciding on the boundaries of the vertical and lateral directions of different geological structures as the primary method is preferable. In this application, the Schlumberger-oriented resistivity method was used for the objective. The general application of the resistivity method must produce a high voltage (450–600 V) for the current to penetrate deeper ground layers. For this purpose, it is applied using

a DC-DC converter source (Fig. 5). The current density is at a point far away from a medium (r) having a resistivity (ρ) in a homogeneous and isotropic state.

When a current I , mA, passes through a semi-infinite homogeneous and isotropic structure with a resistivity value of ρ , $\Omega \cdot \text{m}$, the current density J , A/m^2 , occurs at a point r away from the source

$$J = \frac{E}{\rho} = -\frac{1}{\rho} \frac{\partial V}{\partial r} \quad (1)$$

where J is the current density, A/m^2 , ΔV potential difference, mV, E electric field strength, V/m.

For current passing through a sphere surface away from the current source (r), the following equation is given

$$\frac{I}{4\pi r^2} = \frac{E}{\rho} = -\frac{1}{\rho} \frac{\partial V}{\partial r} \quad (2)$$

From Eq. (2), we obtain

$$dV = -\frac{I\rho}{4\pi r^2} dr \quad (3)$$

and after integration, we have

$$\int dV = \int \frac{I\rho}{4\pi r^2} dr = \frac{I\rho}{4\pi r} + C \quad (4)$$

The electric potential away from the source has no finite value and C is zero. Since the Earth is semi-infinite, the potential difference (ΔV) is given by

$$\Delta V = \frac{I\rho}{2\pi r} \quad (5)$$

The generalized resistivity is given by

$$\rho = K \frac{\Delta V}{I}, \quad K = \pi \frac{a^2 - b^2}{2b} \quad (6)$$

where K is a geometric factor for the Schlumberger system, other symbols cf. Fig. 5. The layer thicknesses vs. resistance for six vertical electric sounding (VES) profiles were determined.

Laboratory study. To determine groundwater pollution in the study area, water samples were taken from 7 points in the field in March 2023. Two of these samples were

taken from the landfill (WS6, WS7), one from the hot water source (WS 5), and the other from the cold water sources (WS1–WS4) around the landfill (Fig. 6).

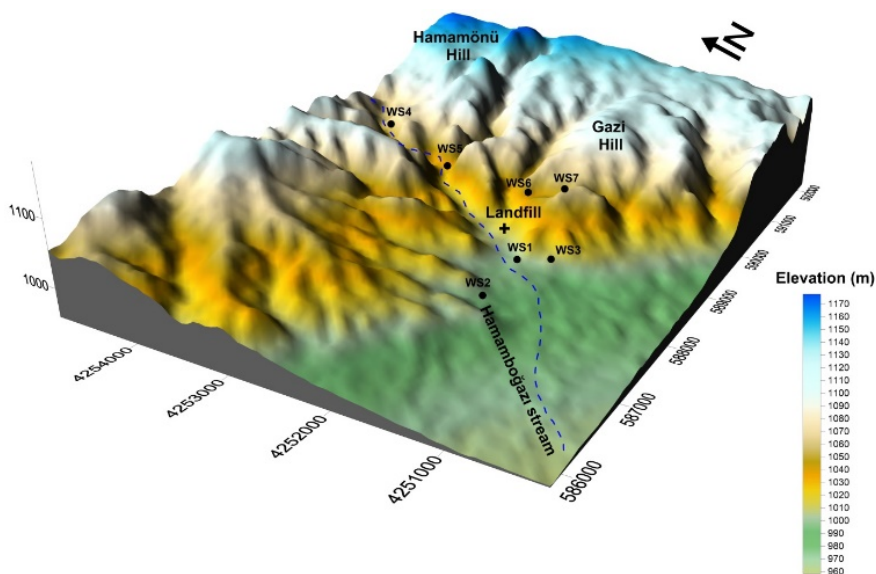


Fig. 6. Study site topography

The samples' temperature, pH, and electrical conductivity were measured on-site in the study area with an Orion 3-star model device. Chemical parameters of the samples taken from the water resources such as total hardness, total dissolved solids (TDS), and heavy metal (Cu, Pb, Cr, Zn, Fe) concentrations were determined in a laboratory environment by applying international standards (US EPA, APHA) methods. The solutions of the sample samples were prepared according to the US EPA 6020B method.

The US EPA 130.1 method and the ethylene diamine tetraacetic acid (EDTA) titrimetric method were applied in the total hardness analysis of water samples [18] using the following equipment: sampler I, conical flask, continuous filter, manifold, proportioning pump, colorimeter equipped with 15 mm tubular flow cell and 520 nm filters, recorder equipped with range expander. 10 cm³ of water sample was diluted to 50 cm³ with pure water in a conical flask. 1 cm³ of NH₃/NH₄Cl (pH = 10) buffer solution was adjusted. Two or three drops of Eriochrome Black T (EBT) indicator were added. The sample was titrated with 0.01 M EDTA. In contrast to Mg²⁺, Ca²⁺ ions form a complex with EDTA. 50 cm³ of pure water and 2 cm³ of 10% NaOH solution were added to the 10 cm³ water sample, and pH was adjusted to 12–13. After adding some murexide with the tip of a spatula, titration with 0.01 N EDTA until the color change from red to blue-purple was performed. Consumption of EDTA solution was noted. The total hardness (*TH*) was calculated according to the equation

$$TH = \frac{1000AB}{V} \text{ mg CaCO}_3/\text{dm}^3 \quad (7)$$

where: A is the volume of EDTA titration solution, cm^3 , B conversion factor of 1 cm^3 of EDTA solution into 1 mg of CaCO_3 .

The US EPA 160.1 method was applied to the TDS analysis of water samples. The following equipment was required: porcelain capsule (100 cm^3 in volume), water bath (set at $100 \text{ }^\circ\text{C}$), desiccator, oven, analytical balance (0.1 mg precision), filter papers (circular with $0.45 \text{ }\mu\text{m}$ pore diameter, 4.5 cm diameter). While the vacuum was applied, the filter was washed thrice with 20 cm^3 of distilled water. Vacuum application was continued until no water was left on the filter paper and the washing water was poured out. The filter was dried in the oven at $103\text{--}105 \text{ }^\circ\text{C}$ for one hour and kept in a desiccator to prevent it from being affected by the humidity in the air and to dry completely. The filter paper, which has reached a constant weight, is carefully taken from the desiccator and weighed, and its weight is recorded. The clean capsule was heated at $180 \text{ }^\circ\text{C}$ for one hour and then left in the desiccator for at least half an hour. It is weighed and tared just before use. The sample volume was selected to obtain $2.5\text{--}200 \text{ mg}$ of dried residue. If it took more than 10 minutes to filter the sample, filter paper with a larger pore diameter was used, or less sample was filtered to obtain at least 2.5 mg . The thoroughly mixed sample, whose volume has been measured, was filtered through filter paper. The filter paper was washed three times with 10 cm^3 of distilled water. The water was expected to drain completely. The water under the filter was filled into the porcelain capsule and evaporated in the bath. After evaporation, the capsule was kept in the oven at $180 \text{ }^\circ\text{C}$ for at least one hour and cooled in a desiccator until it reached ambient temperature. The cooled porcelain capsule was weighed on a precision scale. TDS, mg/dm^3 , of the sample was calculated according to the equation

$$TDS = \frac{1000(A - B)}{V} \quad (8)$$

where A is the weight of dried residue together with a capsule tare, mg ; B – the capsule weight, mg , V – the volume of the sample, cm^3 .

Heavy metal analysis of water samples was made with an inductively coupled plasma/mass spectrometry (ICP/MS) device. APHA's method 3125B was used to determine trace metals and metalloids in surface, ground, and drinking water by inductively coupled plasma/mass spectrometry (ICP/MS). The basic working principle of the device is that the sample material is introduced into an argon-based, high-temperature radiofrequency plasma, usually via pneumatic nebulization. Energy transfer from the plasma to the sample stream causes target elements desolvation, atomization, and ionization. Ions generated by these energy-transfer processes are extracted from the plasma through a differential vacuum interface and separated based on their mass-to-charge ratio by a mass spectrometer. The mass spectrometer usually is of the quadrupole or

magnetic sector type. The ions passing through the mass spectrometer are counted, usually by an electron multiplier detector, and the resulting information is processed by a computer-based data-handling system [19, 20].

3. RESULTS

The study area is essential in three respects. First, this area is located in the recharge zone of the free aquifer in terms of groundwater. Secondly, approximately 1 km north-west of this area is the Tuzlusu hot and mineral spring area, which has an essential hot water potential for Aksaray. Third, there is a mass housing settlement area approximately 1 km west of the solid waste site. For these reasons, the storage area in question may adversely affect groundwater and settlements from an environmental point of view.

3.1. PHYSICOCHEMICAL ANALYSIS OF WATER

The average temperature of the waters in the study area was 18.42 °C, and the highest electrical conductivity, hardness, and TDS values were determined in the water source (WS6). Considering the pollution analysis of water resources, five heavy metals (Cu^{2+} , Pb^{2+} , Cr^{3+} , Zn^{2+} , and Fe^{2+}) were chosen (Table 1).

Table 1

Physicochemical analysis results of water resources (March 2023)

Parameter	Water source (WS)						
	WS1	WS2	WS3	WS4	WS5 (hot water)	WS6 (waste leachate)	WS7 (waste leachate)
T, °C	17	14	15	15	27	22	19
pH	7.6	7.2	7.8	7.4	6.4	7.9	7.1
Electrical conductivity, $\mu\text{S}/\text{cm}$	2620	2650	352	670	4160	7900	1607
Hardness, $\text{mgCaCO}_3/\text{dm}^3$	469	576	62.5	224.5	1229	1679	667
TDS, mg/dm^3	4087	4134	549.1	1045.1	6489.6	12324	2506.2
Cu, mg/dm^3	0.183	0.163	0.119	0.056	0.031	0.013	0.03
Pb, mg/dm^3	0.208	0.129	0.120	0.130	0.142	0.234	0.181
Cr, mg/dm^3	0.014	0.019	0.011	0.015	0.012	0.049	0.01
Zn, mg/dm^3	0.33	0.016	0.008	0.008	0.082	0.081	0.184
Fe, mg/dm^3	1.756	0.16	0.031	0.017	0.043	3.179	1.572

The values in the field were close to the values of standard potable water. However, from seven different water samples in the field, the general average concentration of lead was $0.306 \text{ mg}/\text{dm}^3$, and the general average concentration of iron was $0.965 \text{ mg}/\text{dm}^3$. The calculated average concentrations of Pb and Fe were slightly higher than the WHO ($0.05 \text{ mg}/\text{dm}^3$) and US EPA ($0.015 \text{ mg}/\text{dm}^3$) limit values. Average concentrations of Pb

and Fe above standard drinking water posed a significant health risk. Lead is a poisonous and carcinogenic metal and causes many diseases, from respiratory and nervous system enzyme problems to fatal heart and brain damage. According to the WHO, the known effects of lead exposure ranged from subtle changes in body chemistry and nervous system function at low levels of exposure to severe toxic effects and even death at very high levels associated with acute poisoning. High Fe concentration in the water gave the water a sour malodor. Since the lead and iron concentrations in the spring waters are above the potable water standards, the water sources around the solid waste should never be used.

3.2. ELECTRICAL RESISTIVITY TEST RESULTS

This study investigated the groundwater contamination risk of leachate occurring in the Aksaray landfill. 6 vertical electric soundings (VES) were applied in the solid waste site. Schlumberger electrode opening geometry was used in the research area. The maximum electrode opening was taken as $AB/2=150$ m. From these electric soundings, VES-1, VES-2, VES-4 and VES-6 were applied at the landfill site, and VES-3 and VES-5 around Hamamboğazı Stream (Fig. 3). According to the obtained data, depth-resistivity relationships were determined for each VES profile (Table 2). Two-dimensional geological sections were obtained by evaluating the functional curves.

Table 2

Apparent resistivity (ρ) and depth (h) for VES

VES-1				VES-2				VES-3			
ρ [$\Omega \cdot m$]		h [m]		ρ [$\Omega \cdot m$]		h [m]		ρ [$\Omega \cdot m$]		h [m]	
ρ_1	28	h_1	3.2	ρ_1	24	h_1	4	ρ_1	13.5	h_1	2.2
ρ_2	12	h_2	54	ρ_2	54	h_2	3.5	ρ_2	42	h_2	7
ρ_3	390	h_3	—	ρ_3	12	h_3	24	ρ_3	11	h_3	44
ρ_4	—	h_4	—	ρ_4	47	h_4	17	ρ_4	36	h_4	—
ρ_5	—	h_5	—	ρ_5	13	h_5	—	ρ_5	—	h_5	—
ρ_6	—	h_6	—	ρ_6	—	h_6	—	ρ_6	—	h_6	—
ρ_7	—	h_7	—	ρ_7	—	h_7	—	ρ_7	—	h_7	—
ρ_8	—	h_8	—	ρ_8	—	h_8	—	ρ_8	—	h_8	—
VES-4				VES-5				VES-6			
ρ [$\Omega \cdot m$]		h [m]		ρ [$\Omega \cdot m$]		h [m]		ρ [$\Omega \cdot m$]		h [m]	
ρ_1	18	h_1	7.6	ρ_1	32	h_1	3.5	ρ_1	18	h_1	4.6
ρ_2	44	h_2	2.5	ρ_2	80	h_2	6	ρ_2	43	h_2	2
ρ_3	11	h_3	17	ρ_3	12	h_3	56	ρ_3	12	h_3	12
ρ_4	53	h_4	7	ρ_4	28	h_4	—	ρ_4	106	h_4	26
ρ_5	9.5	h_5	19	ρ_5	—	h_5	—	ρ_5	12	h_5	52
ρ_6	83	h_6	—	ρ_6	—	h_6	—	ρ_6	92	h_6	—
ρ_7	—	h_7	—	ρ_7	—	h_7	—	ρ_7	—	h_7	—
ρ_8	—	h_8	—	ρ_8	—	h_8	—	ρ_8	—	h_8	—

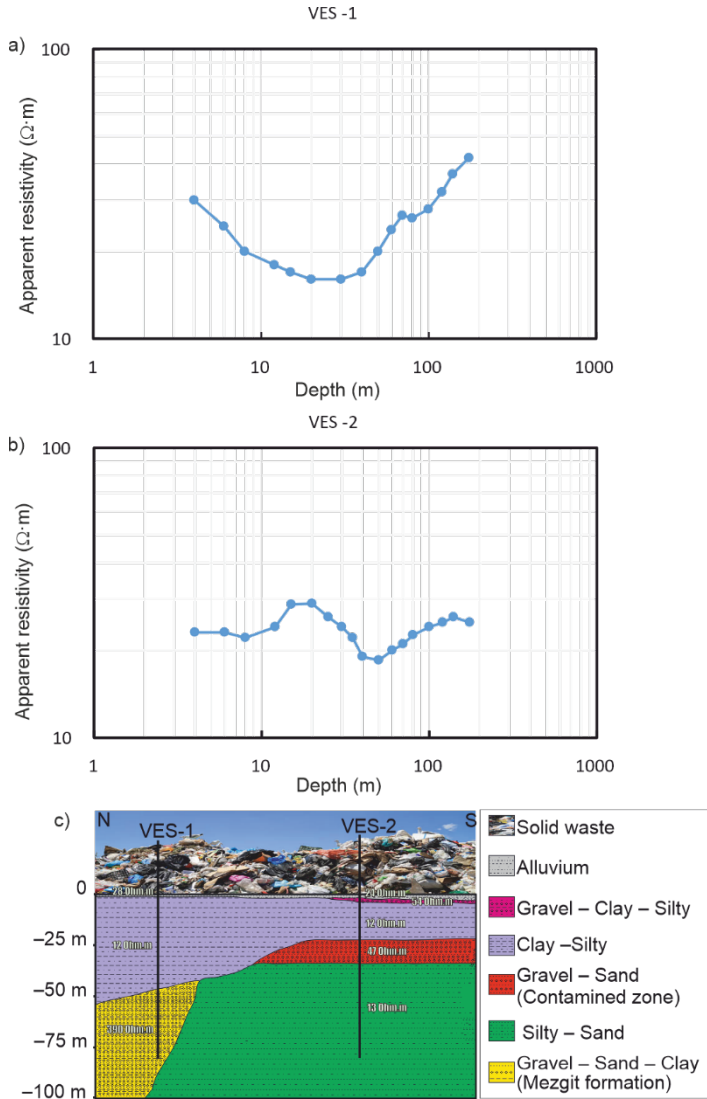


Fig. 7. Apparent resistivities measured in the field vs. depth obtained from VES-1 (a) and VS-2 (b) (+, layer boundary) and geological cross section according to VES-1 and VES-2 (c)

According to the electrical conductivity response of VES-1 with maximum profile length $AB/2 = 145$ m, the first and second layers in the vertical direction contain fine-grained, clayey-silty alluvium. It is also known that the higher the clay-silt ratio, the

higher the electrical conductivity is. This sharp increase is likely due to dirty fluid leaking from the storage area. At the bottom is the Mezgit formation, which has high resistivity (Fig. 7a). VES-2's clay-silt continues under the alluvial cover layer. Gravel-sand and silt-sand alternation was measured under this layer (Fig. 7b). Since clay is an impermeable layer, it is thought that the seepage water in this profile is within the alluvial cover layer on the surface (Fig. 7c).

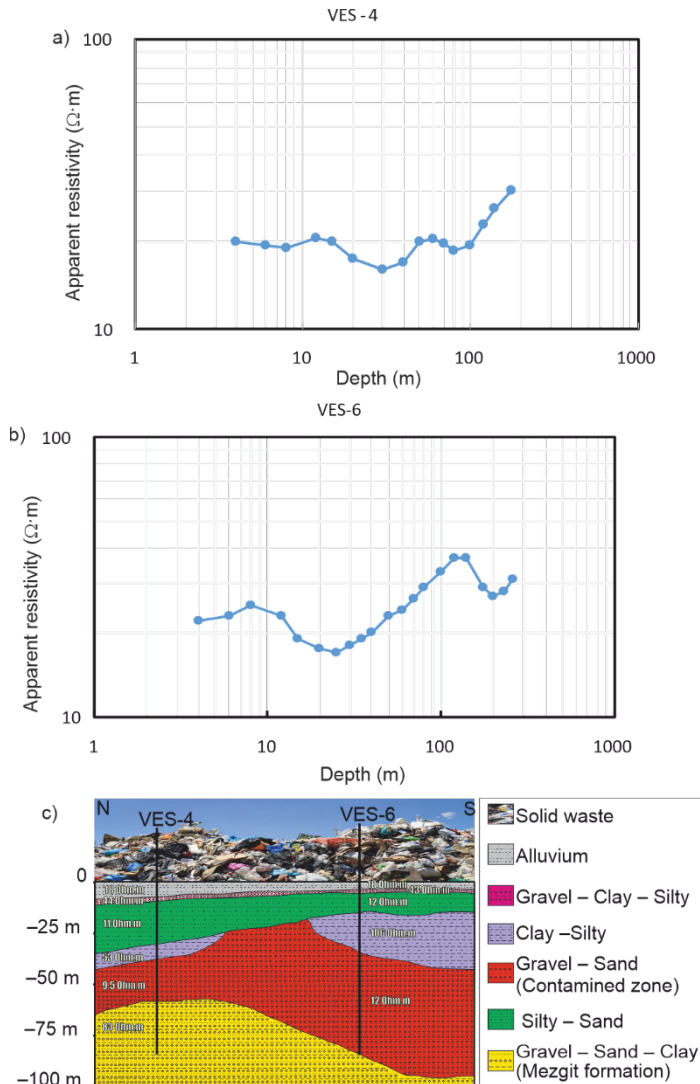


Fig. 8. Apparent resistivities measured in the field vs. depth obtained from VES-4 (a) and VS-6 (b) (+, layer boundary) and geological cross section according to VES-4 and VES-6 (c)

Six different layer transitions were identified in the VES-4 resistivity profile (Fig. 8a). The electrical conductivity of the layers varies with physical parameters such as porosity–permeability, clay ratio, temperature, and fluid content.

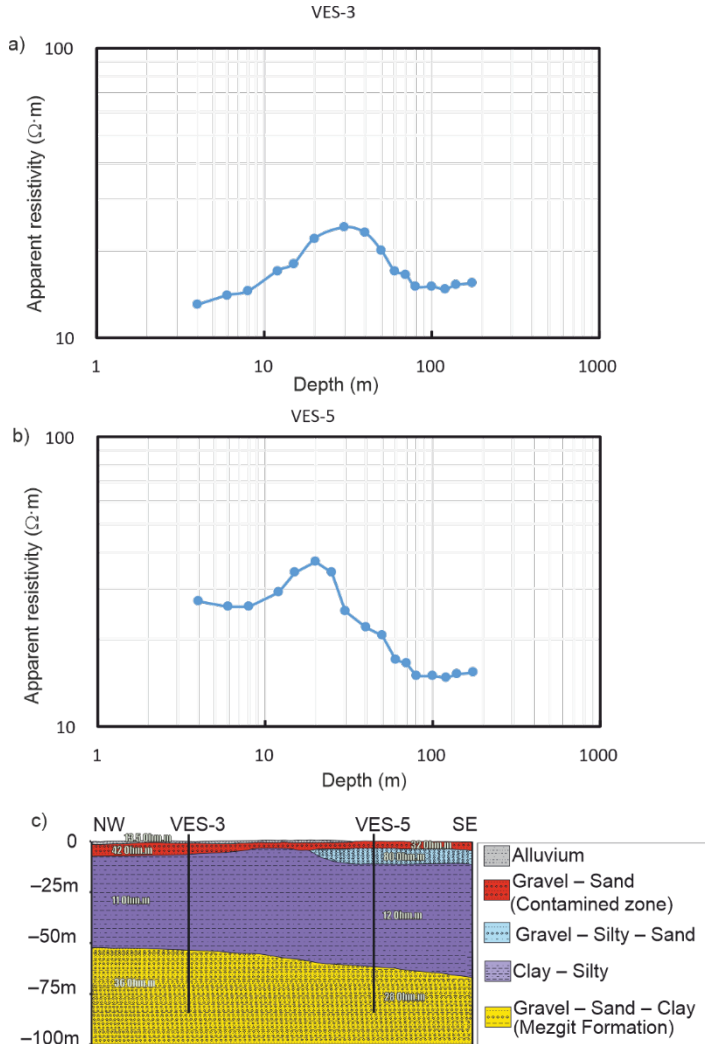


Fig. 9. Apparent resistivities measured in the field vs. depth obtained from VES-3 (a) and VES-5 (b) (+, layer boundary) and geological cross section according to VES-3 and VES-5 (c)

When a porous layer is exposed to salt ion liquid, the electrical conductivity increases and the resistance decreases. The most distinctive feature of the pollution zone is a sudden increase in electrical conductivity due to the concentration of salt ions. This measurement profile showed the effect of the pollution zone in the vertical direction.

The leachate in the landfill contained electrolytes. It has the property of holding ions and polarizing against the electric current given. The results of chemical analysis also confirm the pollution effect of this zone. However, at the same time, the contamination had a radial spreading character. The impermeable layer starts at 70–75 m. This depth should be considered in terms of meteoric waters' infiltration. The low resistance of the third layer in this measurement profile showed that it is a fine-grained and absorbent layer. The fact that the second layer is porous and the third layer is fine-grained absorbent increases the possibility of contamination. The concentration of the landfill in a permeable alluvial area such as gravel, sand, or silt is seen as a pollution potential (Fig. 8c).

VES-6 resistivity measurement profile is $AB/2 = 150$ m. In this measurement profile, two gravel and silty sand layers, approximately 15 m thick, are porous and permeable under the cover layer. When the geological section was taken with VES-4, it was determined that the pollutant zone went down to the upper Eocene-Miocene-aged Mezgit formation (Fig. 8b). Both profiles of VES-4 and VES-6 sections show the gravel-sand layer pollution zone effect (Fig. 8c).

In the VES-3 resistivity profile, changes in two layers were measured after the Neogene-Quaternary vegetative cover layer. These are approximately 7 m thick gravel-sand layer and 44 m thick clay-silt layer (Fig. 9a). Leakage from the cover layer contaminated the permeable gravel-sand layer of water.

In the VES-5 resistivity profile, a 6 m thick gravel-sand-silt layer was measured under the gravel-sand layer (Fig. 9b). Leakage from the solid waste area filters through the permeable and porous layers of water and creates a dirty area (Fig. 9c). This waste liquid is electrically conductive because it contains acidic and salt ions.

When we examine VES measurement profiles in general, According to VES-4 and VES-6 measurement results, the gravel-sand layer at a depth of approximately 40 m, which is estimated to be the contaminated area, continues the location of the leachate coming from the porous layers. According to VES-3 and VES-5 measurement results, this contaminated layer is located in gravel-sand one, and the leachate is directed toward the settlements toward the topographic slope at a depth of approximately 15 m.

4. CONCLUSIONS

The electric resistivity tomography (ERT) method has a multi-electrode measurement device. Since it is easy to use, the measurement tool is straightforward and gives effective results; a 2D and 3D tomographic image of the ground can be obtained in shallow geological structures. In our field study, the classical four-electrode application (Schlumberger technique) was preferred due to the high electrical conductivity of the

field and the suitability of the topography. Resistivity measurements were made to determine the depth in the ground. For this reason, the $AB/2$ opening was taken as 145 m, and in return for this opening ratio, the electrical drilling depth was around 80 m.

A total of 6 vertical electrical soundings (VES) were made in the irregular landfill area and its surroundings. Four of them (VES-1, VES-2, VES-4, VES-6) were located in the waste storage area, and the remaining two (VES-3, VES-5) around the Hamamboğazi Stream. Seven water samples were taken for physicochemical analysis from open water sources near the storage area.

The general evaluation of the measurements made is as follows.

- Leakage water in the storage area spreads in a permeable and porous environment. This spreading effect can occur in all directions for absorbent layers. It was determined that the vertical pollution in the study area was at an average depth of 15 m.

- In this unregulated solid waste site, the topographic slope and the layers' physical condition are crucial pollution indicators. The layers' porosity and permeability effects vary depending on the sand, clay, and silt content in its composition.

- The leachate's contamination direction was in the southwest direction. The most obvious evidence is that although the VES-3 and VES-5 measurement locations are outside the waste area, the pollution zone also affects the lateral directions.

- Besides environmental pollution, the most crucial danger are possible effects on underground water aquifers. Therefore, location selection for regular waste areas is essential. Whether the layers in which seepage water containing heavy metals and salt ions spreads is impermeable or not is monitored using hydrogeophysical techniques.

- The alluvial soil in the study area is an unconfined aquifer. In addition, the upper Eocene-Miocene-aged Mezgit formation consists of conglomerate, sandstone, mudstone, and claystone. The gravels are loosely attached and poorly sorted. Therefore, it is estimated that the formation is permeable.

- The results of physicochemical analysis confirm the results of the geophysical method. Although the exact source of heavy metals in the study area is unknown, the combination of medical and household waste has further increased the environmental health hazard of the uncontrolled storage area.

- When choosing the location of uncontrolled open storage areas, the ground type with the most negligible permeability should be selected. Therefore, geophysical (geoelectric) surveys should be applied. However, according to the national solid waste regulation, the distance from solid waste areas to residential areas is at least 1 km. But more is needed from a public health perspective. The distance from solid waste areas to residential areas should be at least 10 km.

- The study area is residential, 1 km from the open landfill. For this reason, the storage area should be surrounded and taken under control.

- Due to the organic structure of waste sites, electricity can be produced from methane gas in landfills. The domestic or foreign private sector should be encouraged to open garbage storage facilities to provide economic gain.

• The values of heavy metals detected, especially lead, are above international standards. Lead in the human body causes abdominal pain, constipation, headache, irritability, memory loss, and tingling in the hands and feet. A more comprehensive physicochemical analysis should be carried out in settlements close to the landfill, and local people should be encouraged to use purified water.

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