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The examination of the spread of the leachates coming out of a solid waste disposal area on the ground with geophysical and geochemical methods (Sivas, Turkey)

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ABSTRACT

This study has been conducted in the irregular solid waste disposal area in the city of Sivas. The pollution spread formed by the leachates coming out of the disposal area has been examined with geophysical and geochemical works in this study. For this reason, the spread of the leachate pollution expanding in different geological units at both sides of a creek on the ground has been examined. For this purpose, the pollution spread has been examined with the methods of Direct Current Resistivity (DCR) and Electromagnetic Conductivity (EMC) and soil analyses. In the DCR method, 2D inversion of each sounding-profile datum measured alongside the lines parallel to each other and 3D inversion of the data measured in all the lines have been used in the interpretations. Apparent conductivity map has been attained from EMC measurements. The results of heavy metal analyses in the soil samples taken alongside the Haçin Creek have been assessed with the Spider diagram method. It has been determined that the flow of the leachate from geophysical models is in a SE direction and towards Kızılırmak and it continues vertically deeper than 4 m. In addition, it has been understood that the flow direction of the leachate is inspected by the geological structures. It has been understood from the geochemical results that the pollution in the soil stems from the leachate. In this way, it has been observed that the underground and surface water resources in the territory are under the threat of the pollution occurring due to the leachate.

1. Introduction

The waste waters and rain waters coming out of irregular disposal areas distill the chemicals in the wastes and bear the polluters further. These waters that include chemical minerals pollute wide areas when they mix with surface or groundwaters. Therefore, these leachates stemming from the irregular disposal areas form an important environmental problem today. The studies of environment geophysics have an important place in the determination of these problems. The spread of the leachate on the ground is also examined with geophysical methods. Electrical methods are at first place and electromagnetic methods are at second place among these methods. The DCR method is a method that is sensible in determining the conductive zones in which there is the entrance of leachate to the groundwater or soil from the disposal areas; this is because, the ion concentration in the soil and groundwater on the soil grounds increases with the impact of the leachate. For this reason, the DCR method and EMC method are frequently used in the determination of the pollution spread in the shallow studies especially with the purpose of environmental monitoring (Nobes et al., 2000; Rucker and Sweeney, 2004; Rucker and Fink, 2007). One of the most important studies in the issue of leachate monitoring techniques belongs to Frangos (1994). Frangos has used the DCR method in the determination of leachate places. In this issue, successful studies have been conducted especially in open (irregular) solid waste disposal areas (Laine, 1991; Frohlich et al., 1994; Frangos, 1997; Petrovsky et al., 2001; Charlesworth and Lees, 2001; Rucker and Fink, 2007; Frohlich et al., 2008; Lopes et al., 2012). Afterwards, Aaltonen (1998), Aaltonen and Olofsson (2001) and Olofsson et al. (2006) have developed the monitoring systems for the leachates occurring in the disposal areas. In addition, Dahlin (1996) has attained very successful results in the determination of the old filling areas and possible leakage ways via the DCR method. Binley and Beven (2003) and Rubin and Hubbard (2005) have revealed the models regarding the monitoring of the hydrogeophysical properties in vadose zone, pollution or water flow. Karlık and Kaya (2001) and Kaya et al. (2007) have conducted studies regarding the mapping of the groundwater pollution by using the electrical-electromagnetic methods together in the open disposal areas and close surroundings. Rucker and Fink (2007) using these two methods together have examined the distribution of the liquid inorganic wastes via DCR and EMC methods. Rucker et al. (2009a, 2009b, 2009c, 2012) also have many similar 2D-3D studies regarding the distribution of different pollution types in disposal areas, leachate monitoring and displaying. It

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has been shown with the use of different algorithms conducted by Neyamadpour et al. (2009) and with the technique developed by Dahlin et al. (2002) that 3D inversion is very beneficial in the environmental applications. In addition, according to Rucker et al. (2009c), pole-pole, pole-dipole and dipole-dipole arrays are more convenient in attaining a 3D model.

2D inversion of DCR data has been made and the results of the horizontal and vertical spread of leachate pollution have been discussed in most of these aforementioned studies. 3D studies are in majority of the studies in which DCR and EMC methods have been used together.

The examination area subjected to this study is the irregular solid waste disposal area and close surroundings in the city of Sivas taking place 15 km south of the Sivas-Erzincan highway (Fig. 1). The geophysical study area takes place in the north-western section of the creek drainage area. The disposal area in the city of Sivas in which unconscious (random) storage was made was used for 16 years. The majority of the rock types taking place in this area are aquifers or at least they have a limited quality of aquifers (Atmaca, 2004; Yılmaz and Atmaca, 2006). Groundwater level is 4 m in some places and it is close to the surface by as much as 2–3 m in the south of the waste area (EIA, 2005; Yılmaz and Atmaca, 2006). For this reason, the region is under a serious pollution threat continuing for years due to the leachates. The leachates get mixed with the creek in the waste area. This creek is connected to a bigger river, the Kizilirmak River, and it pollutes a wide area. Prior studies have been conducted for the purpose of examining this problem in the issues of environmental geology and environmental geotechnics (Atmaca, 2004; Yılmaz and Atmaca, 2004; Yılmaz and Atmaca, 2006). However, this study conducted with the use of DCR and EMC methods in the area is the first geophysical study. Such a study is also necessary in terms of monitoring the disposal area EIA (Environmental Impact Assessment) operation process and inspecting the occurring pollution on time.

2. Geology of study area

The disposal area and the dominant geological units in its surroundings are the Selimiye Formation (Ts), Hafik Formation (Th) and Quaternary (Qa) aged formations (Fig. 2).

The Selimiye Formation is the lowest level outcrop in the disposal area and it is predominantly represented with Oligocene-Miocene aged terrestrial fractured rocks (Kurtman, 1973; Yılmaz and Yılmaz, 2005). This unit generally consisting of violaceus, red or sometimes speckled gray pebble stone, sand stone, silt stone and mudstone intercalation (Ts, SW-ML) has been separated into various levels (Atmaca, 2004; Yılmaz and Atmaca, 2006). Tsa-e taking place at the bottom level consists of a level clay stone and sand stone intercalation and e level main pebble stone, sand stone, clay stone, mudstone and shale intercalation. Tsf consists of the intercalation of f level layered gypsum and fine grained fractured levels. Tsg being the g level taking place at the top consists of pebble stone and graveled sand stone. Sedimentary structures such as gradation and cross bedding are seen in the fractured levels. The rock types are mostly fractured and jointed and they reflect a porous and permeable structure. The disposal area dominantly takes place on e and f levels (Atmaca, 2004; Yılmaz and Atmaca, 2006).

The Hafik Formation (Th) is an Oligo-Miocene aged unit presenting a wide spread in the Sivas basin and mostly consisting of massive gypsums (Yılmaz, 1984; Yılmaz and Yılmaz, 2005; Aktimur et al., 1988). This unit mainly consisting of massive gypsum and gypsum interfingered fractured rocks (Th, ZK-OSK) is in a structure that is easily dissolved with the impact of the atmospheric processes. Anhydride ($CaSO_4$) and rock salt (NaCl) also take place as well as gypsum ($CaSO_4 2H_2O$) among the evaporate group minerals in the composite of the Hafik formation. These evaporate group minerals are easily dissolved when they come in contact with water. When water leaves the medium, these minerals could get crystallized again or new minerals may occur if the ions change their places or the minerals may transform into each other. Therefore, the water quality in the basins in which the rock types formed by these

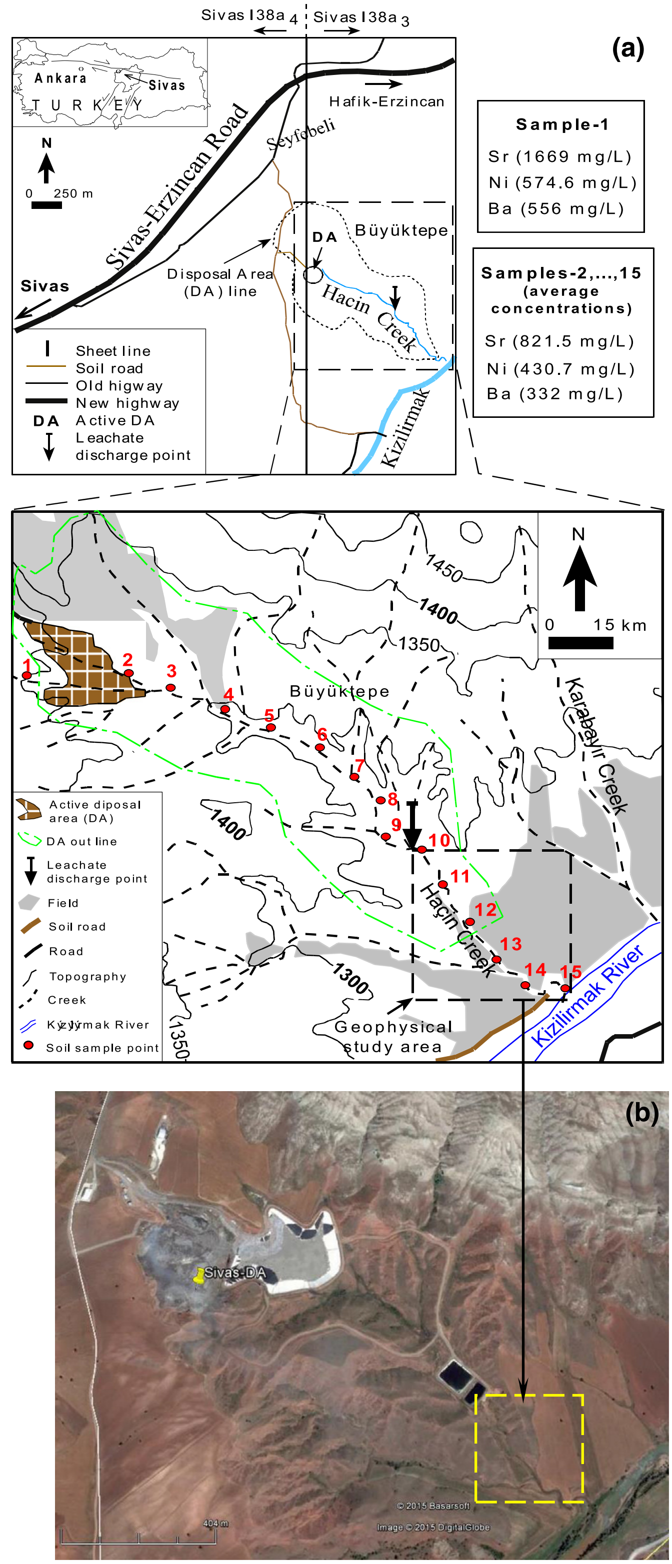

Fig. 1. a) The study area and the soil sample points on the topographic maps. b) The satellite photo of the study area. (www.googleearth, 15.04.2015).

minerals are dominant in the medium gets distorted easily and the surface and groundwaters in which the evaporate group minerals dissolve are naturally polluted (Atmaca, 2004; Yılmaz and Atmaca, 2006).

Quaternary aged alluviums and soil cover are observed in the river valleys and in some plains as a thicker level (Qa, CL-ML-GW-SW). The

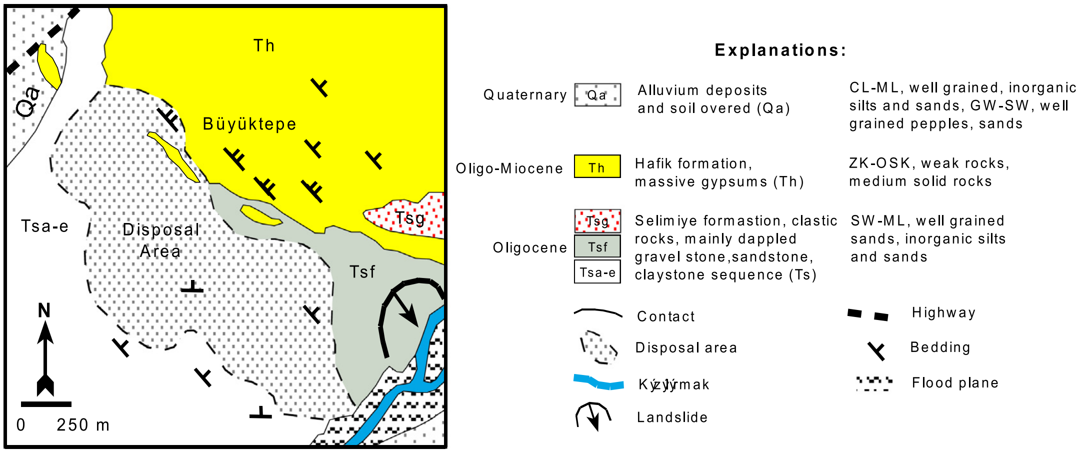

Fig. 2. Geological map of the study area.
(After Yılmaz and Atmaca (2004, 2006) and new organization)

alluviums are generally represented with the fractured rock types in pebble, sand and mud dimensions which have not been bonded, loosely bonded or had a bearing stage. The soil cover is the assemblage of a rather fine grained rock type formed in fine grains and in situ. In addition, travertine and hillside rubble or alluvium cones are locally observed in the surroundings of the disposal area. In-situ formed soil is the ground of the disposal area on especially quaternary aged alluvium and the Oligocene-Miocene aged Selimiye Formation. The alluvium and soil taking place alongside Kizilirmak River valley and in the valleys reaching Kizilirmak River or on the hillsides form the levels on which surface waters flow (Atmaca, 2004; Yılmaz and Atmaca, 2006). The disposal area is not under the threat of natural risks such as landslide or flood and overflow.

Various structural elements are also observed in the surroundings of the examination area. The disposal area takes place on the northwestern wing of an anticline with the flow of NW-SE and in which the layers become steep. The layering of the Oligocene aged fractured units has the flow of approximately NW-SE. The slope of the layers in the main axis of this curve is approximately 10–15° and it is around 35–45° towards the wings (Atmaca, 2004; Yılmaz and Atmaca, 2006). This structure inspects the flow alongside the creek with a NW-SE flow of the leachates.

3. Geochemical studies

Irregular solid waste storage (garbage) areas are the areas in which all kinds of wastes are randomly left in an uninspected way. One of the most important problems in these areas is the problem of the pollution of the soil with the impact of the leachate occurring during the storage of the wastes. Because the leachates are the waters containing organic and inorganic polluters, they have the probability of interacting with other agents. For this reason, they have great importance in terms of the damages they may cause. Therefore, irregular garbage areas threaten the groundwaters, surface waters, soil quality and the lives of plants, animals and humans and they form various problems of environmental pollution (water, soil, noise, visual and air pollution). In this way, the polluters mixed in the soil as a result of human acts affect the living beings in the soil, plants grown/growing in soil or the living beings fed by these plants. These impacts occur especially due to the fact that the wastes are not removed in a convenient way in correct areas and with legal regulations and the waste waters (especially the waste waters including hazardous substances) are given to the soil without any refinement. At the same time, the soil also works as a natural refinement facility. For this reason, the quality and fertility of the soil decrease when the polluter concentration is above the levels exceeding the refinement capacity of the soil if the vadose zone is not thick enough or there is so much entrance of leachate to the soil.

The soil has been separated into various layers within itself. In this study, the section in which soil samples have been taken is the top layer of the soil called the "O" zone, rich in organic agents and including so much air. However, because this layer has lost its natural structure in the places in which the samples have been taken, it has the property of a layer in which polluters are born. Firstly the sampling places have been determined alongside the valley through which the water flows for the purpose of taking a soil sample. Samples have been taken from the sublevels remaining after a 5–10 cm section of the soil on the top has been removed. An approximately 250 g sample has been taken in each sample point for the lab analyses. The samples have been taken as 1 sample (Sample-1) starting approximately 50 m before the disposal area and other samples below the garbage (Sample-2) and again once per approximately 50 m alongside the creek in which leachate flows in the section continuing from the garbage area to Kizilirmak River (Fig. 1). Sample no. 1 with an elevation of approximately 1395 m is a sample belonging to an original (natural) rock type and it has not been polluted with leachate. The other 14 samples taken in varying elevations around 1300 m on average are the samples polluted with leachate. The heavy metal analyses of these 15 samples have been conducted in the lab. It has been examined whether the polluters of the soil samples stem from the leachate or from the rock types dominant in the region via the heavy metal analyses. For this purpose, firstly, the heavy metal types and concentrations have been determined in the lab and their histograms have been drawn (Fig. 3a). In this way, it has been examined whether the heavy metals exceed the limit values. Afterwards, the Spider diagram method was used for the purpose of determining the resource of the polluters. In this method, the sample belonging to the rock type has been kept constant and all heavy metal concentrations have been divided into the concentration of the sample belonging to the rock type. A Spider diagram has been drawn from the attained ratios (Fig. 3b).

When Fig. 3a is examined, the heavy metals with the highest concentration determined from the soil samples are respectively Sr, Ni, and Ba (244–1669, 286.8–574.6, 217–556 mg/L). The Sr element is the heavy metal with the highest concentration according to the histogram results. The reason for this is the gypsums taking place in the Oligo-Miocene aged Hafik Formation that is dominant in the region in terms of geological age (Yılmaz and Atmaca, 2006; Ozel, 2010). Sample 1 is taken from basement rock and it is not polluted. Sr concentration of this sample is measured at 1699 mg/L (Fig. 3a). The other samples (from Samples 2 to 15) were taken from polluted soils and their average Sr concentration is 821.5 mg/L. The average of the total concentrations of the other most common elements (Cu, Co, Zr, Zn, Ce, Rb, Pb, La, Al, As, Ga, Y, Br, Ta, Nb, W, Ca, Mo, Cs, Hf, I, U, Fe and Mg) varies between 2.7 and 97.5 mg/L. The average of the total concentrations of the

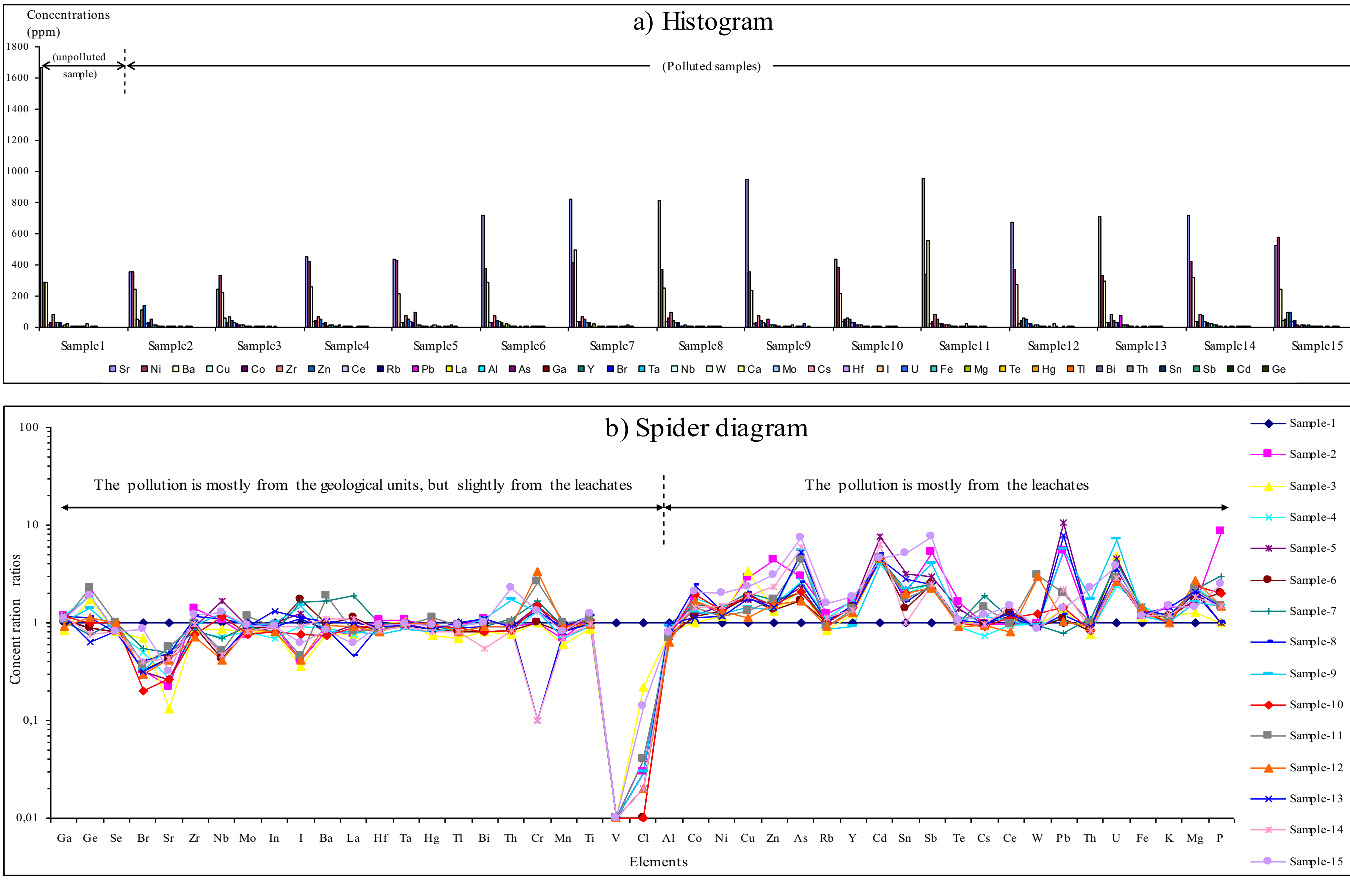

Fig. 3. The results of soil analysis. a) Histogram evaluation, b) Spider diagram.

remaining elements (Te, Hg, Tl, Bi, Th, Sn, Sb, Cd, Ge, In, K, Mn, Se, Ti, Cl, P, Cr and V) varies between 0 and 2.7 mg/L (Ozel, 2010).

When Fig. 3b is examined, the heavy metals that are above the sample belonging to the rock type in the Spider diagram show the polluters stemming from the garbage and the heavy metals below the sample show the polluters stemming from the original rock type. According to the Spider diagram, mostly Co, Ni, Zn, Cu, Ga, Ge, As, Rb, Y, Mo, Cd, In, Sn, Sb, Ta, Te, Cs, Ce, W, Pb, Th, U, Fe, K, Cr, Mg, I, Zr, Nb, Ba, La, Hf, Tl, Bi, Ti, V and P elements cause the pollution stemming from garbage in the soil. Sr, Br, Nb, Zr, I, Ba, La, Hf, Ta, Hg, Tl, Bi, Th, Mn, Ti, Ta, Ga, V, Ge, Se, In, Mo, Cl and Al elements cause the pollution stemming from the rock types. In addition, all these determined heavy metals mix with Kizilirmak River.

The reason for the heavy metal concentrations to be very high in the soil could be explained by the fact that the soil could accumulate these substances in time due to its properties of keeping the polluters and filtration. The occurring pollution both affects the soil and underground/aboveground water resources. It is possible for the rain waters to be carried to the distances up to the groundwater from the permeable unit or due to surface and sub-surface flow especially in rainy periods, because the groundwater table is at a distance of a few meters to the polluted zone according to the conducted soundings (EIA, 2005). Because the groundwater table shall also rise together with the rains, they may be carried to further and deeper zones and may pollute underground and surface waters. Therefore, garbage-based polluters shall threaten the lives of the plants and living beings in a wider scope. The agricultural fields in the surroundings of Hacin Creek are affected by the occurring pollution. When the impacts of this pollution on the environment are considered, it has been detected that the plants do not sufficiently grow in the places close to the river and bold stains occur on the plants densely. However, agriculture is still conducted in the region. Because the agricultural fields are affected from the occurring soil pollution, the product quality, variability and productivity of the conducted agriculture also get insufficient.

4. Geophysical studies

The kinesis of the current given to the ground in DCR method within the ground is dependent on the conductivity properties of the medium. Conductivity in soil is provided with the electrolytes in the pores. Electrical resistivity of the ground, temperature in the medium, compression, porosity, permeability and saturation of the medium with water and the distribution of the water inside the ground are efficient in increasing or decreasing the conductivity in soil. In addition, the mobility, concentrations and dissolution degrees of the ions in the medium are also efficient. For this reason, the DCR method is frequently preferred in the examination of the pollution spread of the leachates especially in disposal areas in the studies of environmental geophysics, because, the leachates coming out of the disposal areas contain dissolved ions (substance-mineral) in very high concentrations. These ions pollute these resources if they pass through the groundwater and soil at more than a certain ratio. Some of these polluters are the heavy metals and these metals change the composition of the medium. These polluters in the groundwater and soil increase the ion concentration and conductivity of the medium. In this situation, because the electricity current is carried with ions, the electrical conductivity of the medium also increases. In contrast, the resistivity decreases when compared to the situation in which these polluters have not entered the medium (Kelly, 1977; Frohlich and Kelly, 1985; Mazac et al., 1990; Frohlich, 1994).

Therefore, these waters leave the minerals they carry to the rock types they pass through and they expand within the unit out of their path. Canals and/or areas with low resistivity may occur within the unit in this spread (expansion). As a result, the resistivity of the rock unit decreases with the leachates mixing with the soil in shallow depths of the ground or on the surface. In addition, as it is known, resistivity is reversely proportional to the conductivity. For this reason, the places with low resistivity have been examined with DCR and the places with high conductivity have been examined with the EMC method. In this way, the places with low resistivity to which there is a leachate intake in horizontal and vertical directions and with high conductivity in correspondence to this could be determined with these two methods in the places in which measurements have been taken. In addition, leachate proceeding direction could also be determined in 2D-3D models.

4.1. Direct current resistivity (DCR) method

Today, the measurements could be taken very quickly thanks to the multi-electrode and multi-channel measurement systems developed in the Direct Current Resistivity (DCR) method. In contrast to the classical vertical electrical sounding measurement, sounding-profiling data are collected along a line and this data set can be used to get a 2D ground electrical resistivity model.

In multi-channeled and multi-electrode arrays, the electrodes placed on all the corner points alongside a line or by making a grid (for instance; 24, 48, …, 300 …, ea. electrodes) are connected to the receiver and transmitter system via a single cable and the measurements could be taken by using the desired current and potential electrode couple automatically. However, DCR measurements are generally taken by using a sounding-profile measurement technique in the electrodes arrayed alongside a direction and these are assessed with 2D inversion algorithms (Candansayar, 2008). Again, these sounding-profiling data collected alongside the parallel lines are used together and 3D inversion of these data could be made (Papadopoulos et al., 2007).

In the study area, measurements have been taken alongside the lines parallel to each other with the interval of 2 m. Electrode interval has been selected as a = 1 m and measurement has been taken at $n = 1, 2, \ldots, 6$ level by using Wenner-Schlumberger array (Fig. 4). The data were collected by using GF-instrument ARES multi-electrode resistivity equipment with 24 electrodes. We have collected sounding profiling data along 29 profiles. Fig. 5 shows the sequence of profiles and their measurement directions.

DCR data have been assessed with the Res2DInv program of Loke (1994) conducting a 2D inversion process. Therefore, interpretations have been made upon 2D resistivity models attained as a result of 2D inversions of DCR data for the purpose of examining the leachate limits and pollution. In addition, sounding-profile data measured alongside the lines parallel to each other in both areas have been used together and 3D inversion of the data has been conducted by using the DC3DInvRes program (Günther, 2004). 2D and 3D inversion results

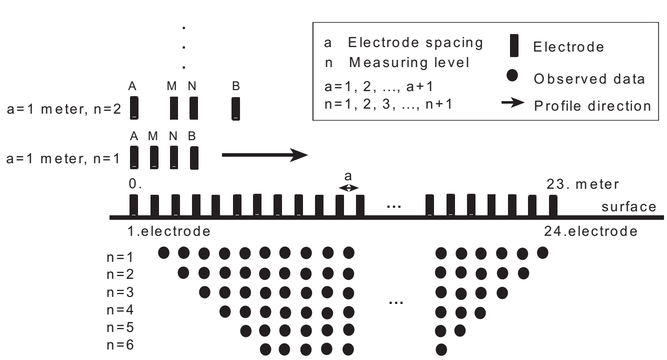

Fig. 4. Wenner-Schlumberger array.

have generally been attained with 5% RMS (Root Mean Square) error (Figs. 7 and 8c). RMS error values have been presented upon each model.

4.2. Electromagnetic conductivity (EMC) method

The conductivity of the ground is directly measured by the electromagnetic conductivity method. EM-CMD4 model measurement equipment of the company of GF Instrument has been used in the electromagnetic measurements. This equipment produces a signal at the frequency of 9.76 kHz and it gives information about the earth conductivity distribution up to approximately 1.5 m depth. The EM equipment gives apparent conductivity value as the measurement value. EMC measurements have been taken by walking at a constant speed alongside the profiles parallel to each other. EMC values have been taken upon the DCR profiles and an apparent conductivity map has been attained from these measurements. The assessment of the data could be easily made with the Surfer program and results could be taken in a very short time.

In this study, the profile lengths have been selected as 25 m and the distances between the profiles have been selected as 3 m. The apparent conductivity attained for the purpose of mapping the leachate spread in the shallow section of the ground has been used for the purpose of comparing the results of two methods and interpreting them together. EMC results only contain the data close to the surface due to the high frequency used for EMC work. For this reason, the apparent conductivity map attained as a result of the study has been compared for the first 1.5 m depth with 2D and 3D resistivity models belonging to the same place (Fig. 8).

5. Geochemical and geophysical interpretation

It has been observed that the places to which the leachate is discharged for approximately 16 years have changed (Fig. 5). After the middle of 2009, a part of the leachate has been carried alongside the sides of the basins in the construction zone in an irregular way and another part has been carried with the pipes passing through the construction zone (the section in which the construction of basins with recycling, composting and waste water refinement purposes and the road and operation building continues) and they mix with Hacin Creek in the new discharge place (Fig. 6a and b). After this point, the leachate reaches Hacin Creek and Kizilirmak River (Fig. 6c). In addition, the geologically examined depth consists of the Quaternary aged alluvium units (Fig. 2).

All the measurements in the study area have been taken in the irregular disposal area and its close surroundings (Fig. 5). Geophysical methods have been applied at both sides of the Haçin Creek in which only the leachate flows in a rainless period. All of the geophysical measurements have been taken from the zone remaining between Kizilirmak River and the new first discharge point in G of the disposal area (Fig. 8). The soil samples have been taken alongside the valley for geochemical studies (Fig. 1). Profile directions and profile numbers have been determined by taking the topographical conditions, geological layering condition and the flow direction of the leachate creek into consideration for the geophysical measurements. All the profiles cut the creek approximately vertically. Profile numbers change due to the topographical properties in each measurement zone. The distance between the profiles is 5 m or 10 m for DCR measurements. Because the selected measurement areas are plain, the measurements have been assessed without taking topographical impact into consideration. DCR measurements taken as sounding profiling data have been assessed with 2D inversion and 2D electricity resistivity sections have been obtained (Fig. 7). In addition, assessment has also been conducted with 3D inversion for the G-H zone (Fig. 8). At the same time, the G zone is the zone in which EMC measurements have been taken (Fig. 8). An apparent conductivity map has been attained from EMC measurements

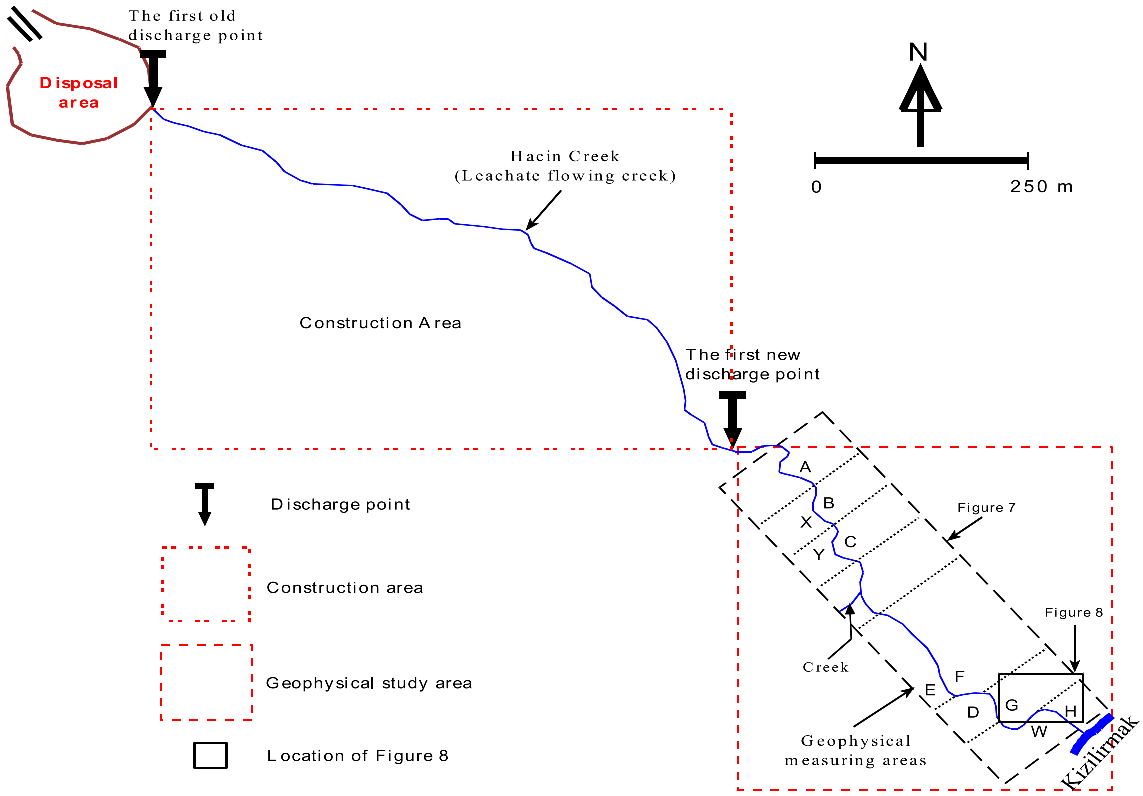

Fig. 5. Study area and geophysical measuring area (see Fig. 1 for location).

(Fig. 8c). All DCR models have been compared for the first 1.5 m depth with EMC models. Geochemical results have separately been assessed for crust and garbage based pollution. Found geophysical and geochemical results are compared in Table 1.

In the survey area, on the surface there is a weathered soil layer with 0.5–1 m depth. Underneath this layer, there is clay mixed with sand and pebbles. At the northern part of the survey area this clay layer is mixed with less sand. At the southern part of the area this clay layer is mixed with less sand and pebbles. In 2D resistivity models, while the leachate shows a spread of up to 5–15 m towards east from the Creek horizontally, this spread continues for much further distances alongside the profile (Fig. 7). Spread of leachate continues for 5 m from the creek to the west. Vertically, the leachate zone is mostly inside the layer after 1 m depth on average and it takes place between the depth of 1–4 m. These effects are

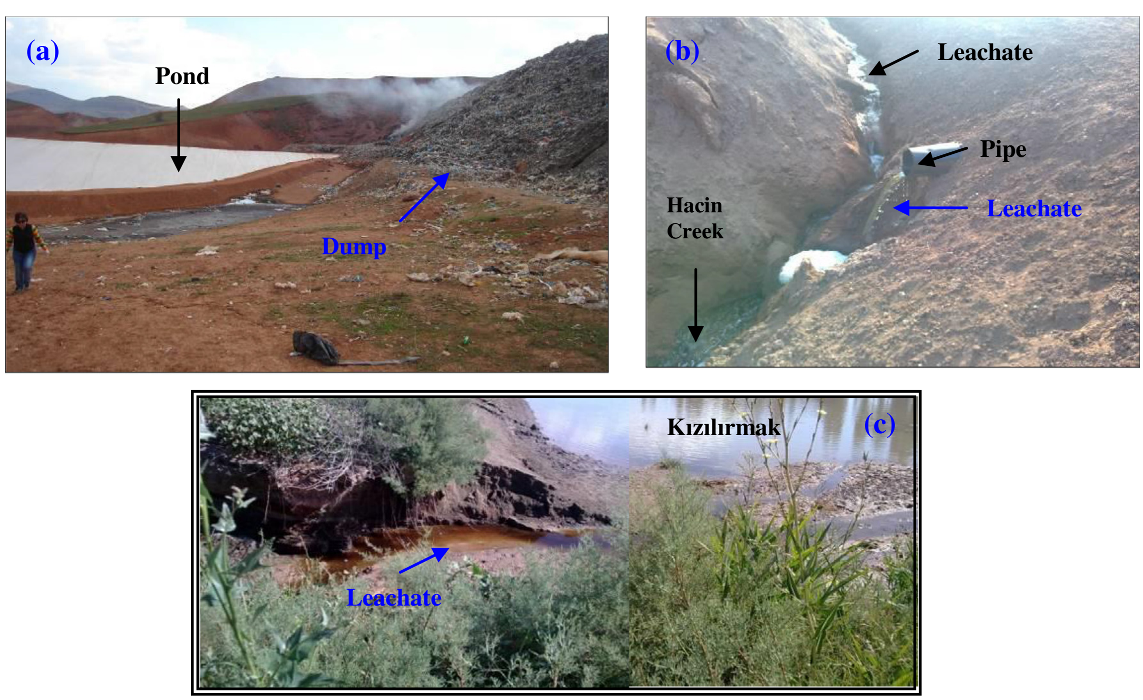

Fig. 6. (a) View from construction and waste disposal area, (b) the new discharge point and (c) point of mixing leachate to Kizilirmak.

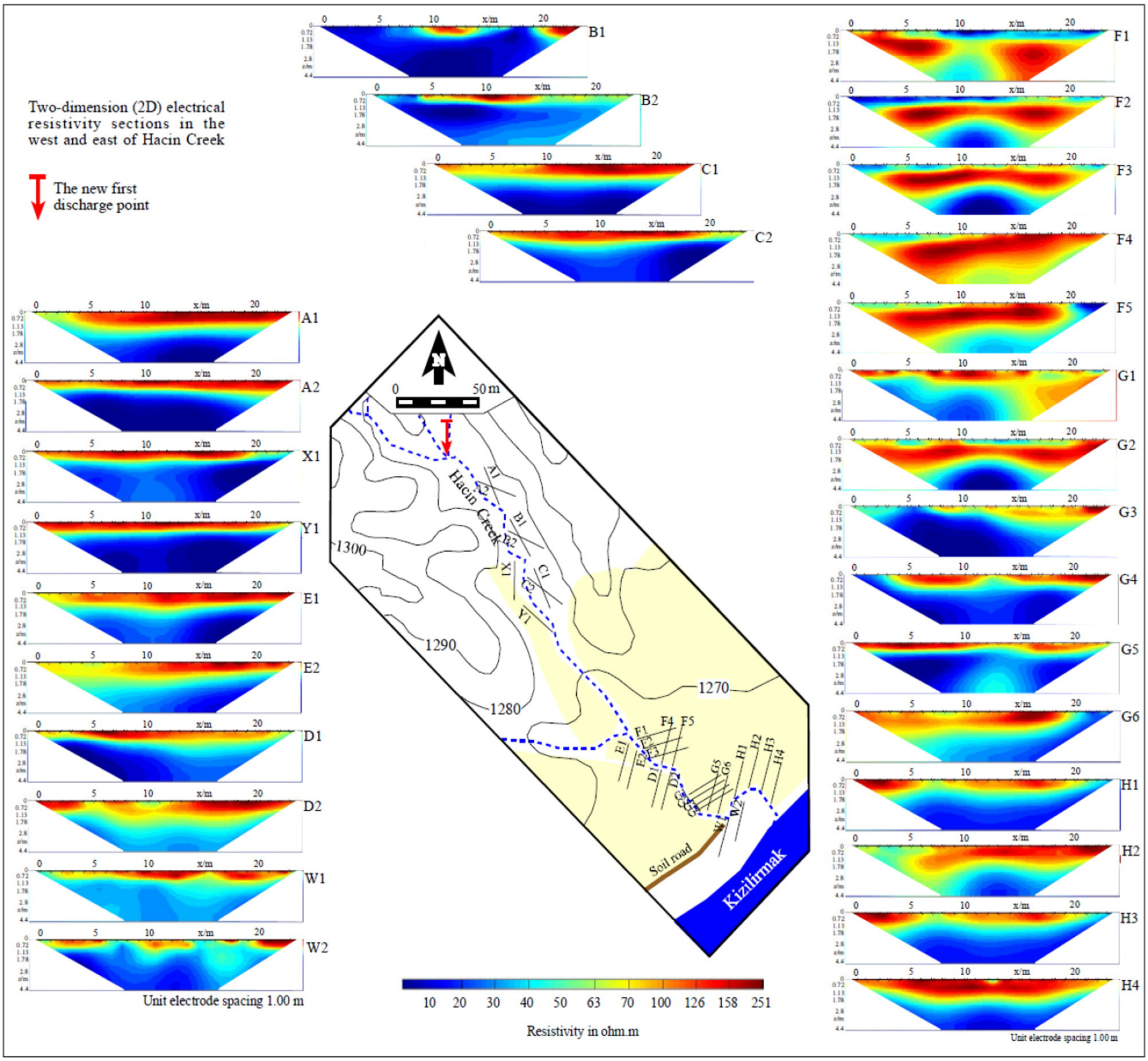

Fig. 7. The location of 2D resistivity sections and their profiles in the topography map (see Fig. 5 for location).

seen as a conductive zone (resistivity is <20 Ω·m) in the resistivity models. However, leachate zones may be deeper than 4 m in the places with lower elevation. However, it cannot be seen in the 2D resistivity model. The slope direction of the layers are oriented to the east and the permeability of the layers may also be efficient in the horizontal and vertical spread of the leachate. Groundwater level measured in the dry period inside the geophysical measurement zone and towards its north is within a less sanded clay unit at 4 m (EIA, 2005) and it is within a less pebbled and less sanded clay unit at 2–3 m (Atmaca, 2004; Yılmaz and Atmaca, 2006). Therefore, leachate water mixes the groundwater in the geophysical measurement zone and it pollutes the groundwater. This has been reducing the resistivity values seen in the 2D resistivity models (Fig. 6).

The resistivity changes of all 2D resistivity models and 3D resistivity models are examined; it could be seen that the resistivities are generally lower than 20–30 Ohm·m on average in the places with low resistivity. The places with low resistivity express the areas polluted with leachates (Fig. 6). The places with high resistivity are higher than 20–30 Ohm·m on average. These areas are the ones in which there is no general pollution or there is less. In addition, when the rock types of the region are taken into consideration, it is seen that the layer with high resistivity takes place on the polluted layer with low resistivity and the northern section consists of the herbal soil and partly sorted underpebbled and less sanded clay units. In the south at the zone near Kizilirmak, there is herbal soil and partly less pebbled and less sanded clay unit.

Data could be taken from the first 1.5 m depth due to the high frequency from the conductivity measurements taken on DCR profiles in the G zone with the electromagnetic (EM) method (Fig. 8a, b). Because this depth contains the data only close to surface, the apparent conductivity map results have been compared to 2D and 3D resistivity models belonging to the same place for the first 1.5 m depth (Figs. 7 and 8). According to this, when Fig. 8 is examined, it could be seen that EM conductivity results are not in accordance with 2D resistivity models, but they are in accordance with the 3D resistivity model. High conductive zones in apparent conductivity maps in Fig. 8b can be correlated with low resistive zones in the 3D resistivity model in Fig. 8c, respectively.

As it is known, the reverse of resistivity is conductivity. Therefore, while the conductivity values reach the values higher than approximately 18–20 mS/m on the polluted zone, the resistivity values are lower than

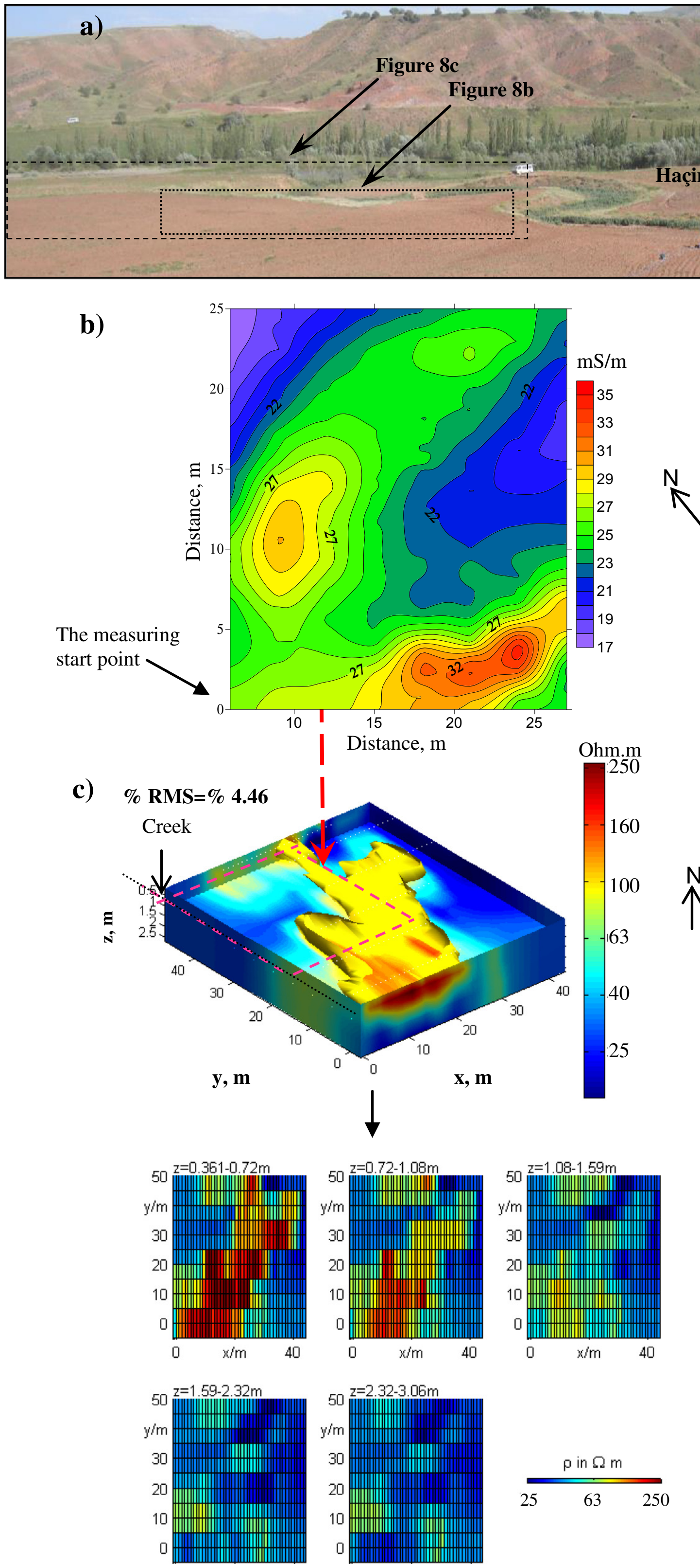

Fig. 8. In the eastern part of the Hacin Creek; a) G and H geophysical measuring areas, b) the apparent conductivity map of the G area and c) 3D resistivity section of the G-H area and its xy-section for different depth range (see Figs. 1 and 5 for location).

20–30 Ohm·m on average (Fig. 7). Consequently, conductivity values shall be high in the places in which resistivity is low. Such places are the areas in which there is pollution. Another result is that the flow direction of the leachate is in a SE direction in the conductivity maps and 2D-3D resistivity models (Fig. 8a, b, c). As expressed above, this flow is inspected with geological structure. According to this, it has been observed in geophysical models that the places with low resistivity in DCR models correspond to the places with high conductivity in EMC models.

Table 1
Geophysical modeling and geochemistry results.

Area	Geophysical results		The ground water levels in dry spell (m)	Geochemistry analysis results	
	Electrical resistivity (Ohm·m)	Apparent conductivity (mS/m)		Heavy metals	
1[a]	> 30	< 25	in N ~ 4 m	Contamination from the crust	Contamination from the waste-water
2[b]	< (20 − 30)	> (18–25)	and in S ~ 2 m	Sr-Br-Nb-Zr-I- Ba-La-Hf-Ta-Hg-Tl-Bi-Th-Mn-Ti-Ta-Ge-Se-Ca-Cl-Al	Co-Ni-Zn-Cu-Ga-Ge-As-Rb-Y-Mo-Cd-In-Sn-Sb-Te-Cs-Ce-W-Pb-U-Fe-K-Cr-Mg-V-P

[a] The less contaminated or uncontaminated area.
[b] The area that has been contaminated by leachate.

6. Conclusions

According to geochemical analysis of soil samples, it has been determined that the pollution occurring in the examination area does not stem from rock type; the actual pollution stems from the leachate of garbage and these garbage based elements are Ni, Co, Zn, Cu, Ga, Ge, As, Rb, Y, Mo, Cd, In, Sn, Sb, Ta, Te, Cs, Ce, W, Pb, Th, U, Fe, K, Cr, Mg, I, Zr, Nb, Ba, La, Hf, Tl, Bi, Ti, V and P. Therefore, it could be said that the soil pollution occurring due to the existence of these heavy metals is harmful to Kizilirmak River.

In the examination area in which groundwater and surface water (Kizilirmak River) have great importance, the thickness and spread of the units possible of bearing water and the horizontal and vertical spreads of the existent pollution have been revealed with DCR measurements in the eastern and western parts of Hacin Creek. Also regarding the eastern slope of the leachate layers and the permeability of the layers, it reaches further distances towards the eastern side of Creek. The places with resistivity generally lower than 20–30 Ohm·m in electricity resistivity models are the areas polluted with leachates and the places with higher resistivity are the areas in which there is no pollution or there is less pollution.

In this study, it has been determined that the horizontal polluted zone has a thickness of at least 3–4 m. This result shows that, leachate mixes with the groundwater and pollutes it in the geophysical measurement zone. According to previous studies, groundwater level measured in the dry period is between 2 and 4 m. These previous studies justify our result. In addition, the conductivity values are high in the places in which resistivity values are low and these places are the areas in which there is pollution. Therefore, the apparent conductivity values in polluted zones are higher than approximately 18–25 mS/m and the resistivity values are lower than 20–30 Ohm·m. It has been determined according to the geophysical and geological results that the direction of the horizontal leak (pollution) is SE and towards Kizilirmak River. The geological structure (namely the slope direction of the layers) and the permeability of the units are efficient determiners for the direction of the pollution.

With these results, it has been revealed that the leachate of disposal areas seriously threatens the rock units on which they flow, groundwater resources and Kizilirmak River that is flowing right in the southeast. The waters leaking from the disposal area follow the creek that is dry in rainless periods and reach Kizilirmak River as surface water and/or subsurface flow. Therefore, the groundwater and Kizilirmak River is under the threat of pollution in the region and the agricultural fields in the region are also affected from the pollution. For this reason, soil fertility and quality is too low in the leachate zone. In addition, it could be said that the dilution possibly occurring in the leachate or waste water in the rainless periods occur mostly after reaching Kizilirmak River.

Because the horizontal and vertical pollution changes observed in geophysical results indicate a pollution that is not too deep except for the regions with low elevations, the pollution is mostly in a slight dimension and the pollution amounts increase in dry periods in the region.

When the facts that the disposal area has a life cycle of 12 years remaining and the basin construction conducted for passing to a regular disposal area has not been completed are taken into consideration, it is clear that the environmental problems in the region shall continue. Water and soil pollution shall continue to threaten the groundwater, Kizilirmak River and the agricultural fields in the region due to the air pollution occurring with the impact of the fires continuing in the garbage and non-refinement of the leachate. For this reason, it is obligatory that a work form with environmental monitoring (EIA) purposes should be prepared in the region, the participation of various disciplines should be provided and a planning work should be conducted.

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