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RESEARCH ARTICLE

A NEW WAY OF USING THE SPIDER DIAGRAM METHOD IN HEAVY METAL POLLUTION STUDIES FOR NEAR-SURFACE GEOPHYSICS AND THE OTHER EARTH SCIENCES

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ABSTRACT

In this study, a new way of using the Spider Diagram (SD) method has been shown in the investigation of the pollution spread and pollutant species caused by heavy metal-containing leachate in soil ground. Thus, it has been shown that this method can be used in conjunction with the results of earth science studies and its contribution to interpretation was emphasized. Because today, heavy metals in leachate water are an important environmental problem. It was determined that SD and geophysical methods could be used together in studies investigating this pollution. The heavy metal-containing leachate may contaminate the agricultural/non-agricultural soils/grounds or underground/surface waters by spreading in the permeable geological unit. This pollution spread and pollutant species can be analyzed by geochemistry (soil samples) studies. In addition, the horizontal-vertical boundaries of this pollution and the direction of pollution can be determined by geophysical methods. The results of soil analysis can also be interpreted using the SD method. However, it has been determined that this method can be used to interpret with geophysical results. This comparison has been found to contribute to the geophysical results in interpretation and it has been observed that it strengthens the geological interpretations. As a result, it is shown that SD method is a method that allows evaluating a large number of data in a short time and it can be used together with earth science methods. If these methods are used together in heavy metal pollution investigations, it has been shown whether the pollution in the soil is caused by the leachate or the bedrock unit, and in addition, whether the underground and surface water resources in the region are under the threat of pollution caused by leachate. It was thought that such a study would also be useful in Environmental Impact Assessment (EIA) studies.

Keywords: Spider Diagram, Geophysics, Heavy metal, Leachate, Soil pollution

1. INTRODUCTION

In this study, a new way of using the Spider Diagram (SD) method in earth science studies will be presented in the investigation of the spread of pollution caused by leachates containing heavy metals in soil grounds and the types of pollutants. Thus, it will be demonstrated that this method can be used together with the results of earth science studies and its contribution to interpretation will be highlighted. Heavy metal pollution in leachate constitutes a major environmental problem nowadays. Leachates containing heavy metals may contaminate agricultural/non-agricultural soils/grounds or underground waters/surface waters by spreading in a permeable geologic unit. In the studies examining this type of pollution, it has been observed that the SD and geophysical methods can be used together. Accordingly, this spread of pollution and the types of pollutants can be analyzed by taking soil samples with geochemical studies. The dimensions of the horizontal and vertical spread of pollution and the direction of progress of pollution can also be determined by analyzing the spread of pollution in the soil by geophysical methods. The results of soil analyses can also be interpreted using the SD method. The graphs prepared by this method can also be interpreted alone. However, it has been determined that it can be used together with geophysical results in interpretation.It has been determined that this comparison makes significant contributions to geophysical results in interpretation and also strengthens geological interpretations.

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There are [1] and [2] studies in this subject. [1] is determined a new way of using the Spider Diagram (SD) method in the heavy metal pollutions for earth sciences. She has used together with the SD method and geophysical methods (electromagnetic-EM conductivity, electrical resistivity tomography-ERT). She has arranged the conductivity maps and the resistivity level maps for the depths and 2D (two-dimension)-3D (three-dimension) resistivity sections and the geophysical results were interpreted with SD results (drawn from the soil analysis results) in these studies. Similarly, the study of [3] can be also examined for the same geophysical methods. [3] were demonstrated the ability of the two geophysical (EM and ERT) methods to map contamination plume by delineating the lateral distribution and vertical extent of the leachate derived contaminants within the subsurface. [4] carried out 2D-electrical resistivity imaging (ERI) surveys and physical-chemical analysis (the water samples from the leachate pond and boreholes in the edge of the landfill) on a solid waste landfill to assess the impact of leachate pollution on groundwater quality. [5] tested electromagnetic conductivity and electrical resistivity and other geophysical methods for inorganics pollutions in disposal sites and they compared with soil samples the geophysical results. [6] tested together ERI and soil sampling in a subsurface. [7-10] studied similarly in these methods. [11] correlated geophysical and geochemical analysis (analysis of geochemical substances in the water samples taken from wells and boreholes in the dumpsite) results of the leachate originating from open refuse dumpsite systems. Therefore, it was thought that the SD method will be developed to use with these geophysical methods in the future. In this case, if the scientists know the new way of using the SD method and there may occur other innovations related to the method in the future. This article was written for this purpose and also it can be also important for the hydrogeophysical surveys.

2. LEACHATES AND HEAVY METAL POLLUTION IN THE SOIL

Leachate is contaminated water that emerges and spreads in enterprises such as irregular landfill / disposal area, mining site, refinery or industrial zone where it is randomly deposited in an uncontrolled manner. These leachates cause pollution problems of soil, underground and surface water, one of the most important environmental problems. These leachates, which contain organic and inorganic pollutants, are also likely to interact with other materials. Therefore, attention should be paid to the damages of such water as a pollutant source. Thus, leachates threaten underground water, surface water, soil quality, plant, animal and human life in places where they are present. Most importantly, they lead to various environmental problems (e.g., water, soil, noise, visual and air pollution).

As it is known, the soil is a geologic unit at the top in the vadose zone (or a thin layer covering the earth's surface, a final storage area for pollutants and a natural treatment plant in nature). The vadose zone consists of permeable geologic units, and its pores are not completely filled with water. If the soil and vadose zone thicknesses are not sufficient or if there is too much intrusion of leachate into the soil or vadose zone, a natural treatment event cannot occur. In this case, the amount of pollutants is above the treatment capacity of the soil and this zone. Thus, the risk of underground water and soil pollution increases.

In other words, high concentrations of heavy metals in the soil can be explained by the pollutant retention and filtration properties of the soil and/or its ability to accumulate these substances over time. The resulting pollution may affect both soil and underground/surface water resources. Especially in rainy periods, rainwater is likely to be transported in the form of surface and sub-surface flow or to distances from a permeable unit to underground water. The level of underground water rises with precipitation, and these pollutants may contaminate the soil, underground water, and surface water by being transported to further distances and deeper levels. This pollution may threaten plants and the life of living beings in a wider area. Similarly, since agricultural lands are also affected, product quality, range, and yield of agriculture may also be low. All of the issues mentioned above are important to ensure a sustainable life and environmental conditions.

2.1. Soil Samples Collection-Analysis for Spider Diagram Method

The soil is a geologic unit which is the sum of the zones separated by various characteristics within themselves. Each of these layers is given a zone name. For geochemical analyses, soil samples are taken from the top zone of the soil. The top zone of the soil is called the "O" zone. This zone is also open to exposure to all kinds of atmospheric events and pollutant effects. Therefore, it may usually be eroded or lose its characteristics. If this zone has lost its natural structure, soil samples can also be taken from the next zone where pollutants are transported. There is systematics of collecting soil samples. Furthermore, attention is paid to whether the geometry of the contamination area has a linear or spatial distribution. In other words, to take just a few samples randomly from several areas does not represent the line or area correctly, and the SD cannot be drawn.

The Spider Diagram (SD) method is simply a method of graphically evaluating a group of sampling data. It is a graph calculation application in Excel Software. In earth science studies, these samples are usually soil, water, and rock samples. Then, the results obtained from the analysis of these samples are used to prepare the SD. The appropriate number of data is required to make an evaluation with the SD method. The number of samples which is not less than 8-10 will be sufficient. However, while studying large areas/longer lines, it is possible to take more sufficient numbers of samples that will represent the area/line. The elevations and coordinates of sampling locations are also recorded. These are required for the combination use of geological and geophysical results in interpretation. Therefore, it is important to perform accurate sampling in this method. There are two types of sampling (Figure 1) and the samples consisting of one raw sample from a clean area and other samples from a contaminated area are taken. Therefore, it is important to perform accurate sampling in this method.

1. Linear sampling: If the contamination zone is observed along a line, sampling locations should be selected along this line, in a number to adequately represent this line and at equal intervals.

2. Spatial sampling: If the contamination zone shows a spatial spread, sampling locations can be selected in a way to create parallel or other lines. The distances between sampling locations are selected at equal distances upon the line. The distance between the lines can be decided according to the size of the sampling area (distances between parallel lines have no effect on the SD). In a spatial study, it is easier and preferable to study with line data.

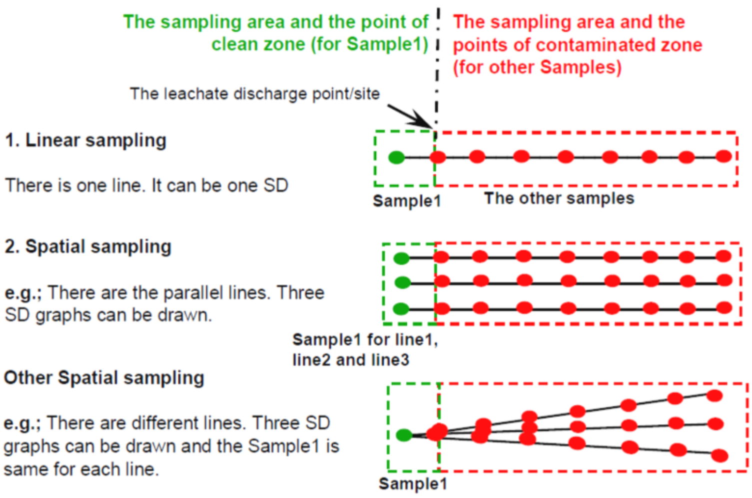

Figure 1. The types of soil sampling for geochemical studies.

The process of taking samples begins after sampling planning is performed. In the soil analysis, raw sample/samples and contaminated samples are brought to the laboratory as soon as possible. Heavy metal analyses are performed/completed without waiting in the laboratory. In taking samples, samples are taken from the levels (from the soil section where stone, plant and plant residues are removed) after approximately a 5-10 cm section on top of the soil is skimmed and thrown. Approximately a 250 g sample is taken from each sampling point for laboratory analyses. Samples are separately placed in plastic bags. Sample bags are numbered and named. The samples consisting of one raw sample from a clean area and other samples from a contaminated area are taken (Figure 1, Figure 2). There are two types of sample in Figure 1 and Figure 2.

a. The 1st type of sample is the raw sample: It represents the raw sample from the clean geological unit. This first sample is also taken at an equal sampling interval behind the line representing the contaminated area.

b. The 2nd type of sample is the contaminated samples (the other samples): These samples are numerous samples representing the contaminated area, and the sampling intervals are also equal.

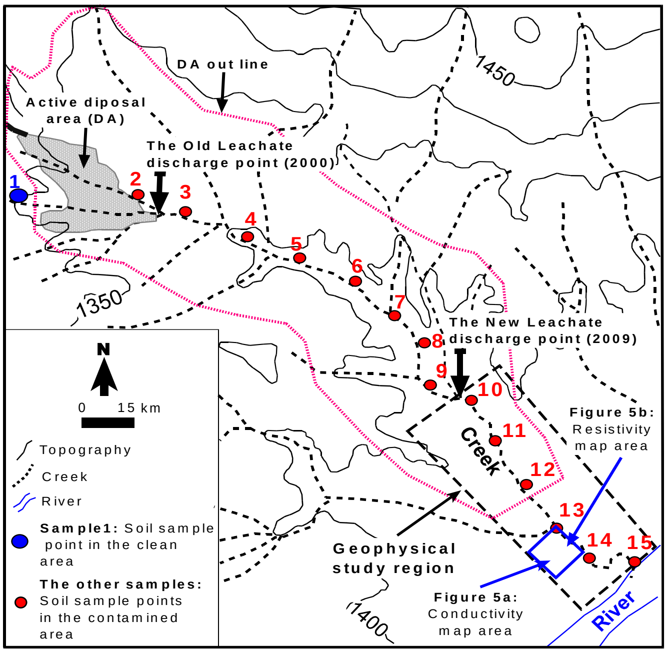

Figure 2. Linear sampling of an example area from Turkey. The sample points of soil analysis and geophysical study region (rearranged from [1] and [2]).

2.2. Soil Data Evaluation and Interpretation by the Spider Diagram Method

Whether pollutants originate from leachate or dominant rock types in the region can be determined with the results of soil sample analyses. A program such as Microsoft Excel, Surfer or Matlab is used to evaluate laboratory results. For this reason, take three steps:

First: The concentrations of element types (mg/L) are determined in the laboratory and a histogram is drawn in Excel with the results obtained (Figure 3). For example, it can be drawn a Histogram of soil analysis from the concentrations of all elements in the Table 1 (rearranged from [1]). The concentrations of all elements in the histogram are interpreted. The elements with the highest and lowest concentrations are determined (e.g., Ni, Ba, Co and Cu concentrations in Table 1 are the highest, but Cr and P are the lowest) and whether these elements have exceeded the limit values is checked.

Table 1. The concentrations for the some elements (ppm) of the soil samples (arranged and chosen from [1] and [2].

Elements Samples\ppm	Co ppm	Ni ppm	Cu ppm	Ba ppm	Ga ppm	As ppm	Rb ppm	Mo ppm	Cd ppm	Pb ppm	U ppm	Fe ppm	K ppm	Cr ppm	Mg ppm	P ppm
Sample-1	**26,2**	**286,8**	**17,8**	**292**	**9,3**	**2,3**	**26,7**	**3,7**	**0,2**	**9,1**	**2,9**	**3,2**	**0,75**	**0,03**	**2,7**	**0,02**
Sample-2	43,2	358	52,1	244	10,8	6,8	32,9	2,7	0,9	50,1	8,1	3,8	1,08	0,03	4,1	0,17
Sample-3	26,6	335	59,7	224	7,8	5,1	22,5	3	0,9	12,5	7,2	3,6	0,87	0,03	3,4	0,02
Sample-4	47,9	418,7	34,2	259	11,1	6	29,2	3	0,8	10,1	6,9	4,7	0,81	0,04	6,3	0,03
Sample-5	31,5	426,3	30,3	219	10,1	5,2	26,5	3,4	1,5	97,5	13,1	4,2	0,77	0,045	5,7	0,02
Sample-6	30,3	377,6	32,9	286	9,9	4,3	27	3,3	0,9	10,1	8,2	3,8	0,87	0,03	4,5	0,04
Sample-7	40,5	413,4	35,7	493	9,7	4,6	28,9	3,4	0,9	7,2	12	4,3	0,9	0,05	5,9	0,06
Sample-8	62,4	373,5	35,3	253	11	5,8	27,8	3,6	1	10,9	7,8	4,3	0,89	0,04	5,4	0,03
Sample-9	33	354,2	25,6	234	9,5	12,7	22,9	3,4	0,8	51,4	21	3,7	0,7	0,04	4,4	0,02
Sample-10	50,4	387,2	33,8	217	11	4,8	27	2,8	0,9	13,2	8,2	4,2	0,76	0,045	6,6	0,03
Sample-11	38,2	338,7	23,1	556	10	10,1	24,2	4,3	0,9	18,1	8,4	4,4	0,81	0,08	5,9	0,04
Sample-12	43,7	373,6	20	273	8,6	3,8	24,6	3,2	0,9	9,5	7,7	4,6	0,75	0,1	7,4	0,03
Sample-13	29,4	334,6	31,8	300	10,8	12,1	30,5	3,4	0,9	70,4	10,2	3,9	1,08	<0,01	5,6	0,03
Sample-14	37,3	421,8	33,4	316	10,8	13,8	30	3	1,3	20,1	8,3	3,8	0,89	<0,01	5	0,03
Sample-15	54,2	574,6	42,2	246	10,2	17,1	42,4	3,5	0,9	12,6	11	5	1,11	0,04	3,9	0,05

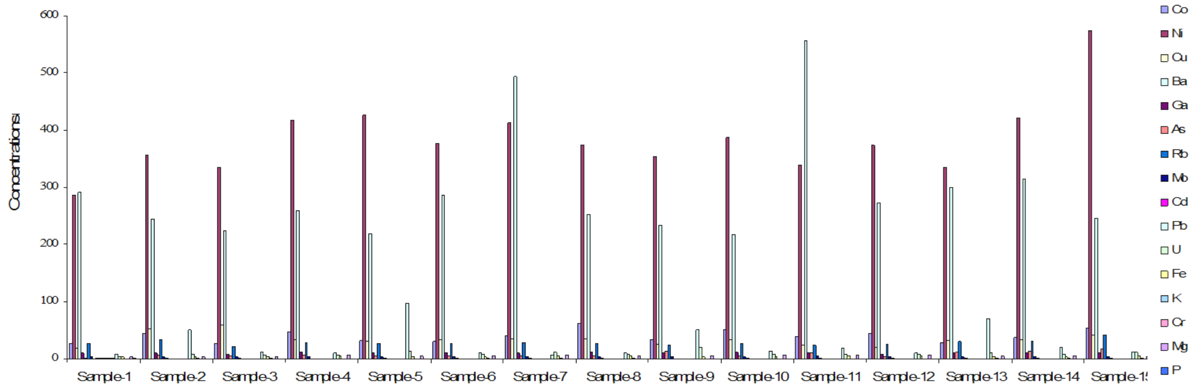

Figure 3. The Histogram of soil analysis results in Table 1.

Later: The Spider Diagram (SD) method is used to determine the source of the pollutant. Therefore, Table 2 is arranged. For this purpose, the element concentrations of the raw sample taken from the sampling point in the uncontaminated area and the samples were taken from the contaminated area are used. In the method, the raw sample (Sample 1) of the uncontaminated area is kept constant. The element concentrations of Sample 1 are divided by the element concentrations of all other samples (Sample 2, Sample 3, …) of the contaminated area (Table 2). Thus, the SD is drawn based on the ratios obtained in Table 2 (Figure 4). This SD in Figure 4 consists of the combination of the results of each sampling point and contains the same number of graphs as the number of samples. All these graphs are also performed in the Excel program and the graph of each Sample is in a different color. In Figure 4, if the concentration ratios of the elements are mostly below the graph of Sample 1 (dark blue and parallel graph to the horizontal axis), the pollution is mostly from geological units of the area and if they are above the graph of Sample 1, the pollution is mostly from leachates of the area.

Table 2. The element concentration ratios of the Spider Diagram calculated from Table 1 (taken from [1] and [2].

Element	Co	Ni	Cu	Ba	Ga	As	Rb	Mo	Cd	Pb	U	Fe	K	Cr	Mg	P
Sample-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sample-2	1,7	1,25	2,9	0,84	1,16	2,96	1,23	0,73	4,5	5,5	2,79	1,18	1,44	1	1,52	8,5
Sample-3	1	1,17	3,4	0,77	0,84	2,22	0,84	0,81	4,5	1,37	4,82	1,13	1,16	1	1,26	1
Sample-4	1,8	1,46	1,9	0,89	1,19	2,61	1,09	0,81	4	1,11	2,38	1,47	1,08	1,33	2,33	1,5
Sample-5	1,2	1,49	1,7	0,75	1,08	2,26	0,99	0,92	7,5	10,7	4,52	1,31	1,03	1,5	2,11	1
Sample-6	1,2	1,32	1,9	0,98	1,06	1,65	1,01	0,89	4,5	1,11	2,83	1,18	1,16	1	1,67	2
Sample-7	1,6	1,44	2	1,69	1,04	2	1,08	0,92	4,5	0,79	4,14	1,34	1,2	1,67	2,18	3
Sample-8	2,4	1,3	2	0,86	1,18	2,52	1,04	0,97	5	1,19	2,65	1,34	1,19	1,33	2	1
Sample-9	1,3	1,24	1,4	0,8	1,02	5,52	0,86	0,92	4	5,65	7,24	1,16	1,04	1,33	1,63	1,5
Sample-10	1,9	1,35	1,9	0,74	1,18	2,09	1,01	0,76	4,5	1,45	2,83	1,31	1,01	1,5	2,44	2
Sample-11	1,5	1,18	1,3	1,91	1,07	4,4	0,91	1,16	4,5	1,99	2,9	1,38	1,08	2,67	2,18	1,5
Sample-12	1,7	1,3	1,1	0,94	0,92	1,65	0,92	0,86	4,5	1,04	2,66	1,44	1	3,33	2,74	1,5
Sample-13	1,1	1,17	1,8	1,03	1,16	5,26	1,14	0,92	4,5	7,73	3,52	1,22	1,44	0,1	2,07	1,5
Sample-14	1,4	1,47	1,9	1,08	1,16	6	1,12	0,81	6,4	2,21	2,86	1,18	1,19	0,1	1,85	1,5
Sample-15	2,1	2	2,4	0,84	1,1	7,43	1,59	0,95	4,5	1,38	3,8	1,16	1,48	1,33	1,44	2,5

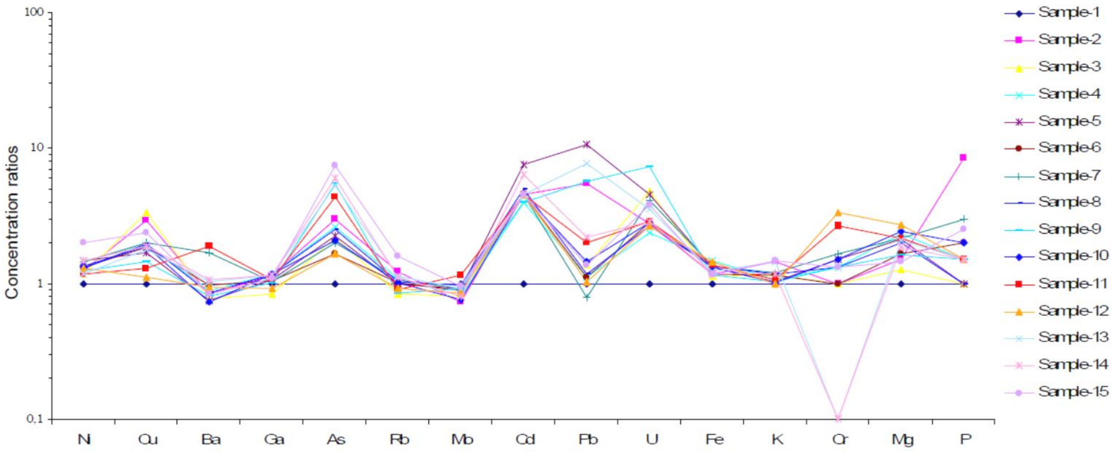

Figure 4. The Spider Diagram of the rations in the Table 2.

Finally: The histogram and Spider Diagram (SD) are mutually examined. The presence of elements with the highest concentration in the main sample and contaminated samples in dominant geologic units in the region is determined. The averages of total concentrations of other most common elements and the remaining elements are calculated separately. These results are compared and interpreted (Figure 3, Figure 4, Figure 5) ([1-2]). These are listed below:

1. In the SD, the elements remaining on top of the sample of the rock type show the pollutants caused by contamination and those under it show the pollutants originating from the original (natural) rock type. Thus, according to the SD, the elements that cause soil pollution in the contaminated area and contamination originating from rock types are distinguished.

2. The geochemical results found are associated with geophysical results (e.g., conductivity map and resistivity section, see Figure 2) (Figure 5). Thus, it is determined that contamination is not caused by the rock type, the main contamination is caused by the leachate in the contaminated area, and the types of these elements are also determined. In Figure 5ab, the electrical resistivity and apparent electromagnetic conductivity the same for 1.5 m depth ([1-2]). These figures are closer to Sample 13 and 14 points in Figure 2.

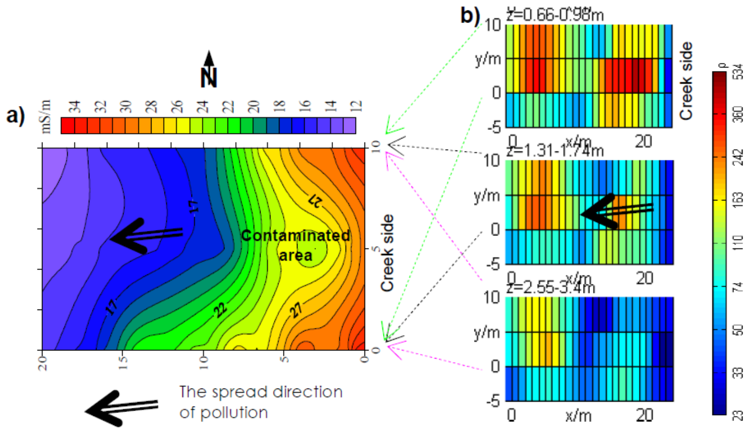

Figure 5. a) The apparent electromagnetic conductivity map and **b)** electrical resistivity depth-level maps of the geophysical results arranged from [1].

In Figure 2, in the study area, the electrical resistivity 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, …, 6 level by using Wenner-Schlumberger array (Fig. 5b). The data were collected by using GF-instrument ARES multi-electrode resistivity equipment with 24 electrodes. The conductivity of the ground is directly measured by the EM-CMD4 model measurement equipment of the company of GF Instrument has been used in the apparent electromagnetic conductivity measurements (Fig. 5a). This instrument produces a signal at the frequency of 9.76 kHz and it gives information about the ground conductivity distribution up to approximately 1.5 m depth. Therefore, the apparent electromagnetic conductivity results only contain the data close to the surface due to the high frequency used. In this study, the profile lengths have been selected as 25 m and the distances between the profiles have been selected as 3 m. Electromagnetic conductivity measurements have been taken by walking at a constant speed alongside the profiles parallel to each other. The apparent conductivity and electrical resistivity 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. 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 level maps belonging to the same place (Fig. 5ab).

3. If there are rivers/lakes representing both the ground cover and underground and surface water in the region, whether soil pollution caused by the presence of heavy metals is threatening for these water resources is interpreted.

4. Another feature of this method is that it allows for the holistic and easy evaluation, visual presentation, and easy interpretation of a large number of data.

Consequently, the results of geophysical and geochemistry studies were compared, and they were observed that these results can be correlated together. Sample-13 and Sample-14 are in the edge of the geophysical study area (Table 1, Figure 2). The high conductivity area in the electromagnetic conductivity map is the low-resistivity areas in resistivity depth-level maps. These areas are contaminated with leachates (Figure 5) and the element concentrations of Sample-13 and Sample-14 and the concentration ratios in the SD showed the presence of pollutant types. Therefore, the pollutant types, the concentration ratios above the graph of Sample 1 in the SD and contaminated areas are the evidences in the geophysical and geochemistry results for the non-nature pollutants.

3. CONCLUSIONS

It has been demonstrated that the SD method allows evaluating a large number of data in a short time and can be used together with earth sciences methods. It has been identified that the following determinations will be obtained if these methods are preferred together in heavy metal pollution investigations "whether pollution in the soil is caused by leachate or the original rock type and whether underground and surface water resources in the region are under the threat of contamination caused by leachate". It has been thought that such a study will also be useful in EIA studies. On the other hand, if the SD method is also tried for similar sampling studies, it may be useful. Furthermore, whether the flow direction of leachate is controlled by geological structures with geophysical results can also be determined.

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This subject was presented as oral presentation in "World Congress on Geology & Earth Science, July 11-13, 2019 at London, UK" [12] and this article were developed after the congress and from Özel [1-2].

CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

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