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Original Research Paper

Application of Vertical Electrical Sounding and Water Analysis for Study the Contaminated Area at Al Misk Lake, Eastern Jeddah, Saudi Arabia

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ABSTRACT

Waste management, especially dump sites, are the most important problems in developing countries. For Al Misk Lake (Buraiman Lake), there is a threatening environmental problem, as for more than ten years this lake was used for the waste disposable site of Jeddah's sewage. Now it is abandoned, but the leachout of the contaminant is still problem. A concrete dam was constructed to block the migration of contaminants from the lake. The purpose of this research is to use the results of geophysical method integrated with the hydrogeological studies in delineating the contaminant layer emanating from the seepage of sewage water from Al Misk Lake to the end of Wadi after the concrete dam. Vertical electrical sounding was applied to determine the contaminated layer thickness in front and back of the dam. Also, the water samples were collected from some wells to support the results of geophysical method. Results of the vertical electrical sounding show that there is a seepage of contaminated water in front of the dam and the thickness of the contaminated layer at the back of the dam towards lake side is more than that in the front of dam. Whereas, the hydrogeological studies also show the concentration of ions, and TDS are more in back of the dam than in the front.

INTRODUCTION

In most of the industrialized countries, household and industrial wastes are treated before discarding in disposal sites. Al Misk Lake where all the domestic and industrial wastes of Jeddah community were unfortunately dumped without any treatment. The lake is located about 40km on east-side of Jeddah, besides the Wadi Bani Malik area which is one of the biggest Wadi of Jeddah. Jeddah is one of the principal cities in Saudi Arabia; it has more than three hundred thousand inhabitants. The estimated water depletion is 200 litres per capita per day (Ewea 2010). About 70-85% of Jeddah area is not connected to sewerage pipelines; wastewater is collected in an underground septic tank and then transported by truck tankers to the lake for more than 10 years now. It was projected that more than 800 tankers empty 40,000 cubic meters of wastewater into the lake every day (Ewea 2010, News 2013, Zafar 2013) and the amount has extended drastically. The lake is also contaminated with poisonous industrial residues. The seepage from the lake has reportedly infected some of the near wells (Elfeki et al. 2011, Ewea 2010).

Ewea (2010) simulated the flood associated with Al Misk Lake and he proposed the conceptual model to estimate the effects of subsurface flow to the city of Jeddah. In the start of dumping, the earth fill dam was constructed to block the movement of contaminated water to Jeddah city. A concrete dam was constructed, when the water level in the Al Misk Lake reached to the height of earth fill dam. For geological mapping of Jabal Bani Malik area, Bishta (2010) used the multi resolution satellite images and processed images were used in the geological and structural interpretation. The drainage system and geomorphological studies were carried out to delineate the detailed drainage map and geomorphological features (Qari 2009). Many investigations were carried out relating to Al Misk Lake, and most of these investigations were for the safety and stability of the dam. But none of the geophysical study was carried out to delineate the contaminated zones associated with the lake. So to understand the contamination situation in Al Misk lake area, the vertical electrical sounding study was carried out in the precinct of the dam.

The electrical resistivity technique proved to be one of promising tool in groundwater contamination studies. Its major application include waste disposal studies to locate contaminant plume and its movement, to delineate the geological structures of earth (Abdullah et al. 2011, Ekeocha et al. 2012, Soupios et al. 2007a, Soupios et al. 2007b, Storz et al. 2000), to investigate seepage (Buselli & Lu 2001), to study the extent of pollution in aquifer (Srinivasamoorthy et al. 2009), saline water intrusion studies, oil, hydrocarbon contamination (Ayolabi et al. 2010, Choudhury & Saha 2004, Zogala et al. 2009) and mapping the characteristics and areas of contaminated soil and groundwater (Benson et al. 1997, Samouëlian et al. 2005).

LOCATION AND GEOLOGIC SETTING OF THE STUDY AREA

The study area is located in the Makkah quadrangle (Moore & Al-Rehaili 1989) in the west central portion of the Arabian Shield bordered by Red Sea. Makkah quadrangle contains major cities of Makkah, Jeddah and Taif. Several discrete plutons of the Precambrian age and five large composite batholiths consist of 65% land area of the quadrangle. Intermediate rocks range from diorite to tonalite, predominate in Shiwan, Hafnah and Makkah batholiths are assigned to the Kamil suite and the Aqiq batholith consists of granodiorite and monzogranite (Moore & Al-Rehaili 1989). The main formations and rock units recorded in the study area (Fig. 1) are unassigned units of uncertain affinity (metagabbro and gabbro), Madrakah formation, Dighbij complex, Hafnah complex, syenogranite and finally Quaternary deposits and mafic dykes. Fig. 2 shows the main quaternary beds that are repeated in the vicinity walls of wadis in the study area.

Methodology: Vertical electrical sounding (VES) is used to study the horizontal or near horizontal interfaces, defines the difference of electrical properties with depth at a single location and it is also called electrical drilling. In VES, the whole spread expanded about a fixed central point where current and potential electrodes are maintained at relative spacing. VES is widely used to define the overburden thickness in geotechnical surveys and to delineate horizontal zones of porous strata in hydrogeology (Kearey et al. 2009, Rubin & Hubbard 2005). The number of layers, their thickness and resistivities are derived from vertical electrical sounding in favourable conditions. The method centres on the principle of four electrodes, which consist of two current and two potential electrodes. Depth of penetration increased with the increase of distance between current electrodes that is AB spacing. In this way deep seated layer influenced the apparent resistivity values and these apparent resistivity values plotted against the current electrode spacing on log-log scale and interpolated to a continuous curve called sounding curve. Common configurations used in the vertical electrical sounding are Wenner, Schlumberger and dipole-dipole arrays. Due to the systematic and practical advantage, Schlumberger configuration is mostly used for vertical electrical sounding where current electrodes A, B move outward and potential electrodes M, N remain closely spaced and fixed to centre of array. The geometric factor for Schlumberger configuration is given as (Kirsch 2007, Pozdnyakova 1999).

$$K = \frac{\pi}{MN} \times (AB/2)^2$$

Where, K is a geometric factor, AB is spacing between the current electrodes and MN is spacing between potential electrodes. The apparent resistivity value measured at each step is plotted as a function of AB/2.

VES data were collected at six sites by using a Schlumberger electrode configuration with Elrec-T plus instrument that can measure the resistivity and time domain induced polarization measurements by using a generator as a source. The VES specifications were selected as spacing (AB/2) ranges from 3m to 400 m that permitted considerable penetration depth at each sounding site. These conditions allow significant depth penetration beneath each sounding site. Six of VES were conducted in the precinct of the dam; three at the back of the dam and three in front of dam (Fig. 3).

Hydrogeological studies were carried out in the field and the groundwater chemical ion analysis was performed in the laboratory. Three water samples were collected from the study area. *In situ* field studies included the measurement of depth to water table, total dissolved solids, electrical conductivity (EC), pH and laboratory studies include the analysis of major cations (Table 1).

RESULTS AND DISCUSSION

VES 1: The total depth investigated beneath VES No.1 site is 16.2m (Fig. 4). The interpreted resistivity curve shows four distinctive layers. The first layer has a thickness that reaches to 0.5 m with very high resistivity value 3749.7 Ω.m, and it is generally referred to as the fragment of basement. The second layer is to a depth of 4.5 m with resistivity 9.4 Ω.m, which indicate that it is a sandy layer filled with saline water. Third layer is at a depth of 16.2m with a very low resistivity 3.8 Ω.m, that also indicates the sandy layer with contaminated water. The last zone is characterized by increasing resistivity with increasing depth, to 444.8 Ω.m. This zone indicates the accumulation of alluvium and basement boulders with clay.

VES 2: The total depth investigated beneath VES No.2 site is 13.5m with varying resistivity of 4.1 to 1462.4 Ω.m (Fig. 5). Interpreted curve in Fig. 5 shows four distinctive layers with varying thickness and resistivity values. The upper most layer with thickness of about 0.8m has relatively higher resistivity values than the second and third layers. Uppermost

Table 1: Chemical analysis of water samples (Units are in mg/L).

Well. No	Water depth(m)	E.C (mS/cm)	pH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	TDS
1	1.15	66.3	7.88	2484.9	680.9	12220	48.9	40799
2	0.805	45.9	7.74	1763.5	632.3	8960	37.4	30880
3	3.05	25.4	8.03	721.4	291.8	6540	35.3	21300

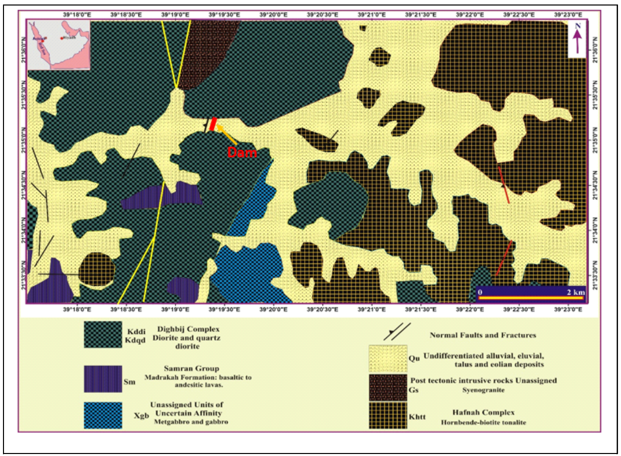

Fig. 1: Geological map of Al Misk Lake study area, Eastern Jeddah, Saudi Arabia: (Modified after (Morre & Al-Rehaili 1989).

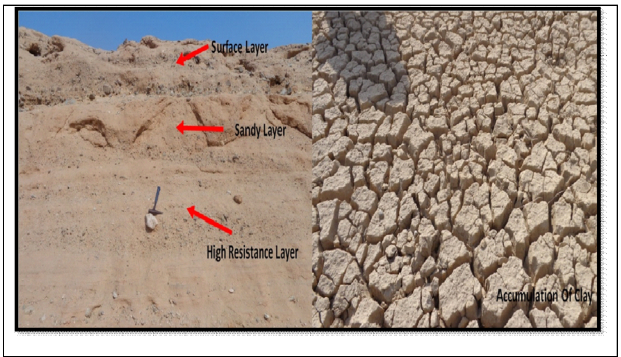

Fig. 2: The main beds which are repeated in the study area, Al Misk Lake area, Eastern Jeddah, Saudi Arabia

Fig. 3: Location of vertical electrical sounding and wells on both sides of the dam.

layer is interpreted as a dry surface layer with resistivity 403.6 Ω.m, below surface layer i.e., second layer is interpreted as a sandy layer with saline water having a very low resistivity of 4.1 Ω.m and extend up to 11.3m depth. Third layer reaches

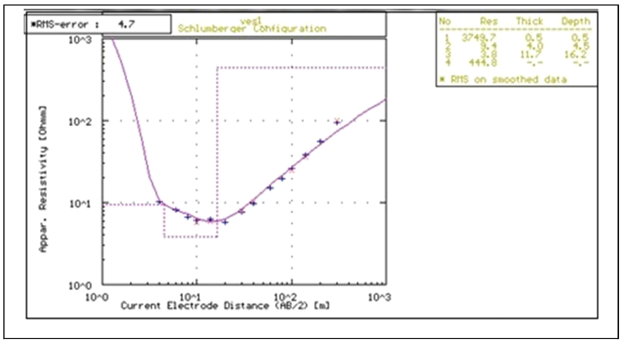

Fig. 4: Layering model for VES 1, Al Misk Lake area, Eastern Jeddah, Saudi Arabia.

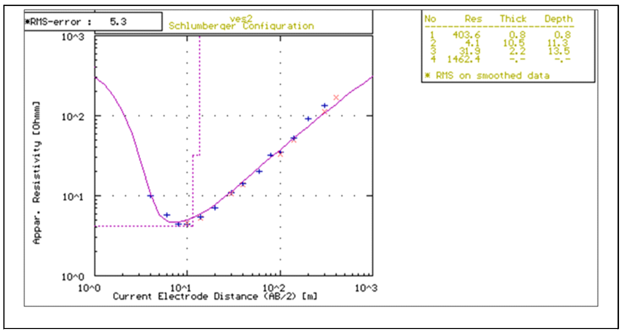

Fig. 5: Layering model for VES 2, Al Misk Lake area, Eastern Jeddah, Saudi Arabia.

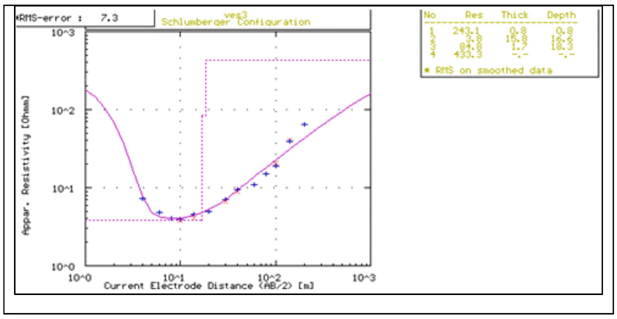

Fig. 6: Layering model for VES 3, Almisk area, Eastern Jeddah, Saudi Arabia.

to 13.5m depth with a very low resistivity of 31.9 Ω.m that indicates a sandy layer with alluvium accumulation and clay. The last zone is characterized by increasing resistivity with increasing depth, to reach up to 1462.2 Ω.m, this zone indicates accumulation of alluvium with basement boulders.

VES 3: The total depth explored under VES No.3 site is 18.3m with the resistivity ranging between 3.8 to 433.3 Ω.m (Fig. 6). The interpreted resistivity curve shows four distinctive zones. The first zone has a thickness that reaches to 0.8 m with resistivity 243.1Ω.m, this zone interpreted as dry surface layer. The underneath layer is a sandy layer with sa-

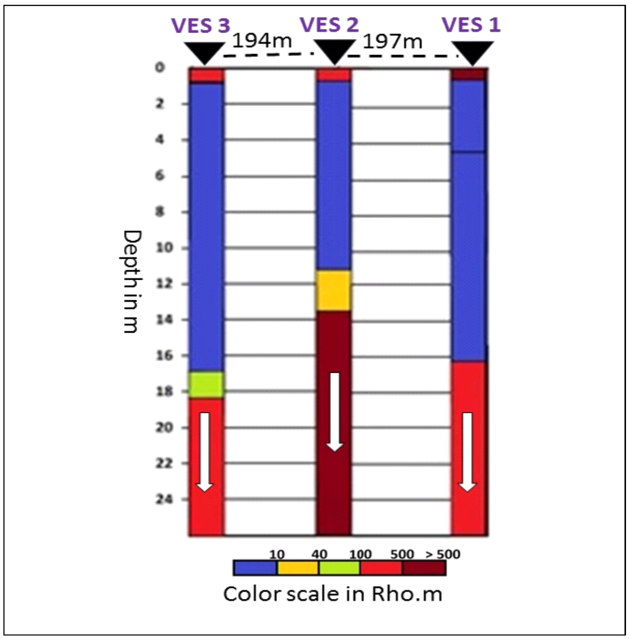

Fig. 7: Interpreted geoelectric correlation diagram of the VES 1, 2 and 3.

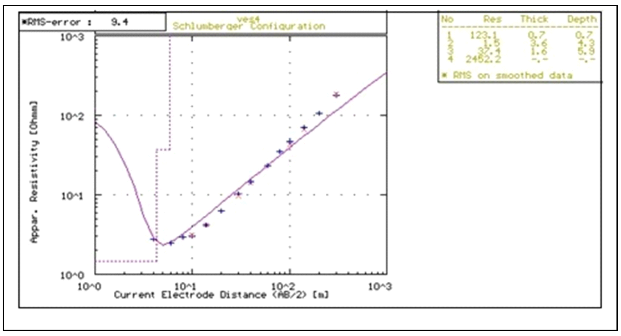

Fig. 8: Layering model for VES 4, Al Misk Lake area, Eastern Jeddah, Saudi Arabia.

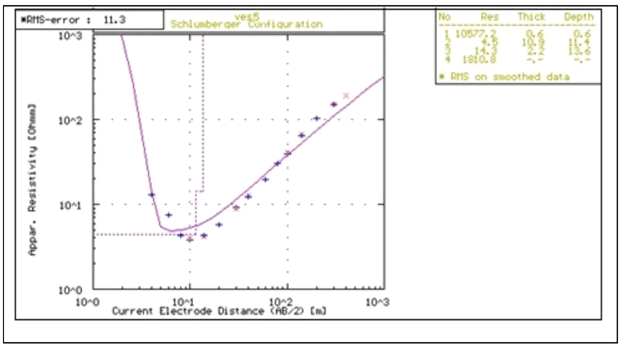

Fig. 9: Layering model for VES 5, Al Misk Lake area, Eastern Jeddah, Saudi Arabia.

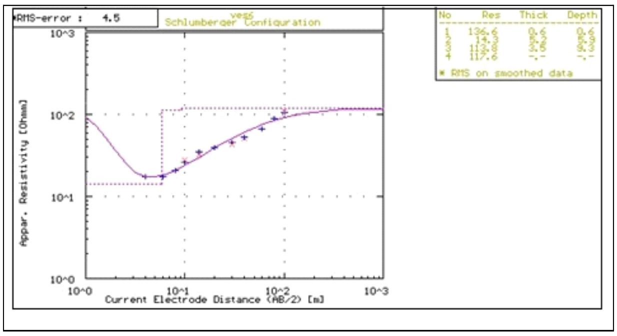

Fig. 10: Layering model for VES 6, Al Misk Lake area, Eastern Jeddah, Saudi Arabia.

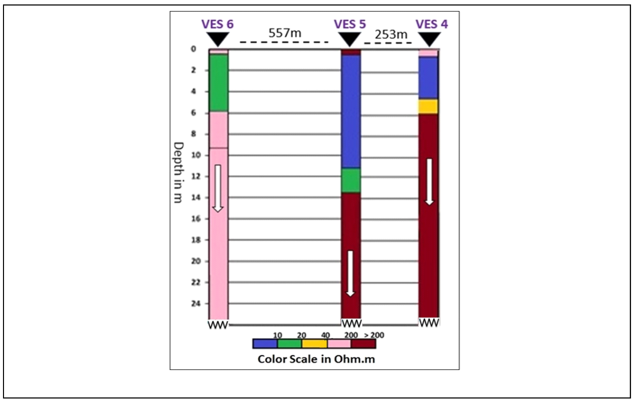

Fig. 11: Interpreted geoelectric correlation diagram of the VES 4, 5 and 6.

line water and has a very low resistivity of 3.8 Ω.m and extend up to 16.6m. Third layer has relatively higher resistivity values than the second layer and it extends up to 18.3m depth with resistivity of 84.4 Ω.m. Last layer indicates the accumulation of alluvium/clay and basement rocks having resistivity of 433.3 Ω.m.

Interpreted geoelectric correlation diagram beneath of the VES 1, 2 and 3 was prepared by using their results as shown in Fig. 7. The diagram shows the surface layer with high resistive values in all vertical electrical sounding, and below the surface layer, a contaminated layer is present. Second layer (with contaminated water) has thickness mainly equal under VES No.1 and VES No.3 and less thickness beneath VES No.2 as a result of the presence of basement below this layer, which may be due to uplifted block of fault in this site.

VES 4: In this VES 4, the depth of the investigation was 5.9m with resistivity ranging from 1.6 to 2452.2 Ω.m (Fig. 8). Four layers were identified by using the interpreted resistivity curve. Uppermost layer is a surface layer with resistivity of 123.1 Ω.m and it extends upto 0.7m. After the surface layer there is a contaminated sandy layer that ex-

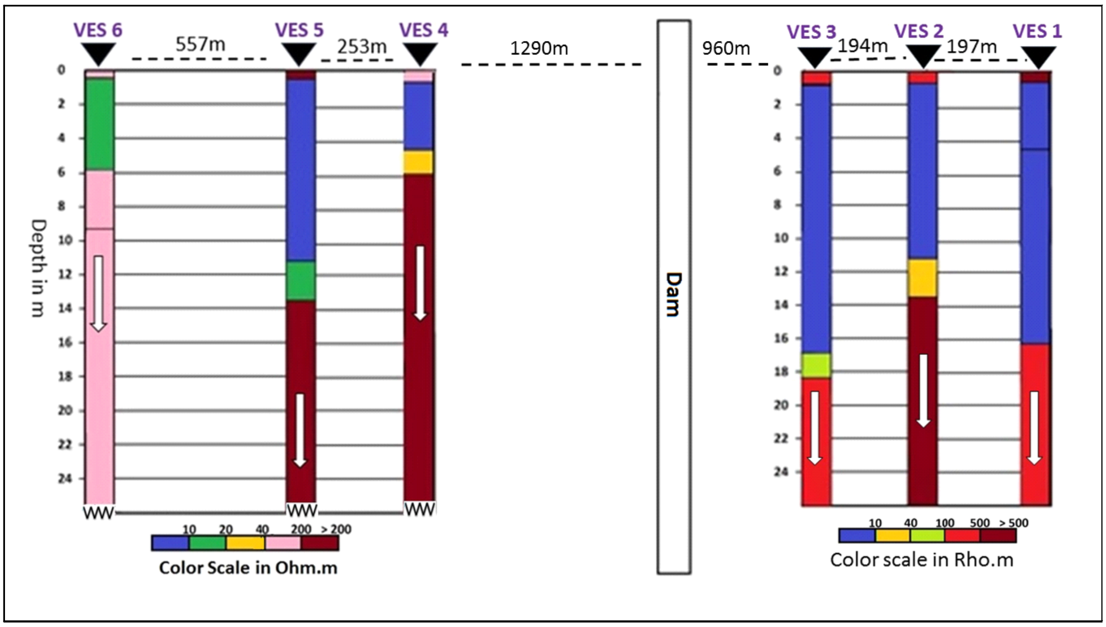

Fig. 12: Interpreted geoelectric correlation diagram of the VES 1, 2, 3, 4, 5 and 6.

tends upto 4.3m depth with very low resistivity of 1.5 Ω.m. After the contaminated layer, a third layer was interpreted as an accumulation of alluvium with resistivity of 37.4 Ω.m and extends upto 5.9m depth. Fourth layer is interpreted as the accumulation of basement boulders having high resistivity values of about 2452.2 Ω.m.

VES 5: Depth of investigation in the case of VES No.5 was about 13.6m with varying resistivity of 4.5 to 10577.2 Ω.m (Fig. 9). Four layers were interpreted depending upon the result of the interpreted resistivity curve. Uppermost layer is a surface layer with very high resistivity of 10577.2 Ω.m and it extends upto 0.6m. It is the accumulation of basement fragments. After the surface layer there is a sandy layer with contaminated water that extends upto 11.4m depth with a low resistivity of 4.5 Ω.m. After the contaminated layer third layer interpreted as a sandy layer with resistivity of 14.3 Ω.m and extends upto 13.6m depth. Fourth layer is interpreted as the accumulation of alluvium and basement boulders having high resistivity values of about 1810.8 Ω.m.

VES 6: The interpreted resistivity curve shows four distinctive layers up to a depth of 9.3m and resistivity ranges from 14.3 to 136.6 Ω.m (Fig. 10). The first layer has a thickness reaches to 0.6 m with moderate resistivity value of 136.6 Ω.m; this layer is a surface layer. The second layer reaches to 5.9 m depth with resistivity range 14.3 Ω.m, which indicates that it is a sandy layer contaminated with saline water. Third layer reaches to 9.3m depth with resistivity of 113.8 Ω.m that indicates the accumulation of alluvium. The last layer has resistivity value of 117.6 Ω.m, this layer also indicates accumulation of alluvium.

Interpreted geoelectric correlation diagram, beneath the VES 4, 5 and 6, was prepared by using their results as shown in Fig. 11. The diagram shows the first layer as a surface layer with high resistive values in all three vertical sounding but the second layer (with contaminated water) appears under VES No. 4 and VES No.5 with different thickness and disappear under VES No.6 as a result of faulting in these sites. In the VES No.6 the second layer is the less contaminated layer instead of high contaminated layer and this less contaminated layer is also present in VES No.5 under highly contaminated layer. Also two small boulder barriers are present in the field between VES No.5 and VES No.6. May be due to these barriers/dams the thickness of layers varies.

The correlation between six vertical electrical sounding in the front and back of the dam is shown in Fig. 12. It reveals that the contaminated saline water in the sandy layer is still found in the front of the dam but in fewer amounts; it means that the contaminated saline water is seepage under the dam from the back of the dam to the front of the dam towards the city.

Three wells present in the area of wadi flow direction, where, well No.1 is present at the back of the dam towards lake side and well No.2 and 3 are present in the front of the dam towards the city. Results of these wells are compared to understand the concentration of contamination in front and back of the dam. Results of these three wells show that the concentration of ions in the back of the dam towards lake side is more than that in the front of the dam towards city side. The concentration of calcium, magnesium, sodium, potassium, and total dissolved solids is more in the water sample no.1 than the water sample No. 2 and 3.

CONCLUSION

Vertical electrical sounding and groundwater sample analysis were used to find the extent and thickness of contaminated layers in front and back of the dam of Al Misk Lake. Al Misk Lake was a sewage dumping site, where all the domestic and industrial sewage of Jeddah was dumped without any treatment. Result of vertical electrical soundings shows that the contamination exists on both sides of the dam. Geophysical results are supported by the hydrogeological analysis of water samples. The leakage continued beyond the concrete dam due to existence of faults and the possibility of contaminant transport through the alluvium below the dam foundation. Due to seepage from dam, the groundwater in front side of dam is also contaminated. Vertical electrical sounding results show that the thickness of contaminated layer is more in back of dam than the in front of dam, similar results are shown from hydrogeological studies, that the concentration of different ion concentrations is more in lake side than the city side which is in front of dam. From geophysical and water analysis results we can say that the dam helps to block the migration of contamination to some extent, but it is not fully successful, because the concentration of ions and TDS in back of the dam are more than the front of dam. Also the concentration of these ions and TDS concentration in front of dam is much higher when compared with the international standards.

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