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Geophysical Investigation of Impact of Geologic Structures on Preferred Percolating Paths of an Oil-based Leachate within a Migmatite-Gneiss Environment: A Case study of Federal University of Technology, Akure Campus (Nigeria)

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Abstract

The study was aimed at determining the lateral and vertical flow of an oil-based leachate within the Migmatite-Gneiss environment with time and to delineate the presence of possible bedrock structures that can enhance the leachate movement. The method of study adopted combines the use of VLF-EM profiling, Electrical Resistivity Tomography survey (Dipole-dipole) and Vertical Electrical Sounding (VES). The surveys were carried out at four times with regular interval of four-week. A particular point along a feeder road within the Federal University of Technology, Akure campus was polluted with used black engine oil. The location was left to settle for two weeks before the first round of survey involving the above mentioned methods was carried out. The results show that the oil-based leachate percolated towards the south which is an uphill direction. Each successive results showed a gradual progression of the leachate in different directions; laterally and vertically. At the fourteenth week, which is the fourth round of survey the leachate was observed to have percolated down to the depth of about 10-15 m, which is rather too fast for a leachate moving according to normal gravity flow. This indicated that probably geologic structures; perhaps faults, fracture and void could be present at the subsurface beneath the polluted point. The VES result presented as geoelectric section confirms this speculation as the bedrock layer beneath VES 1, 2 and 3 have resistivity values that range between 230 and 347 ohm-m.

The integrated geophysical method adopted for this study successfully helps in delineating the oil-based leachate flow direction, extent and preferred paths.

Keywords: Electrical resistivity tomography, vertical electrical sounding, oil-based leachate, bedrock structures and bedrock fracture.

1. Introduction

Groundwater resources are important natural resources that sustain life on earth. In the last one century, the enormous expansion of industrial and agricultural activities has led to an increased environmental pressure on groundwater systems. Groundwater is very important because it accounts for much of our freshwater water resources. In many developing countries such as Nigeria where there is little or no public potable water production schemes, citizens must make personal effort to provide potable water for their domestics and industrial use. However other human activities, such as agricultural and industrial activities, and open space disposal of both industrial and domestic wastes can expose this invaluable groundwater resources to pollution and contamination (Longe and Balogun, 2010). Notable among such industrial waste that is often released to the ground are hydrocarbon-oil, such as Diesel oil, Petrol and used engine oil (Weaver et al., 1999).

The ease at which such pollutants will get to the groundwater table often depends on the geology of an area and its weathering products. The type of weathering product (comprising the topsoil and the weathered layer) in an area determines the rate at which it allows fluid to move through it and this includes pollutants. It is an axiom that fluids transmit fast in a sandy soil than in a clayey soil because of the difference in there permeability. Therefore, the rate at which fluids such as water, leachates, oil and so on percolate through a geologic Formation differs. Bedrock structures such as fractures and joints have also been identified as possible control factors that determine flow of leachate within the subsurface (Bayode et al., 2011a). Different authors have used electrical resistivity method in mapping leachate plume in the Crystalline Basement Complex environment of Nigeria (Olayinka et al., 2001; Adepelumi et al., 2005; Bayode, et al., 2011b).

The study area is within the Federal University of Technology, Akure, Nigeria campus and it is underlain by the rocks of Precambrian Basement Complex of Southwestern Nigeria. The local geology of the study area is Migmatite-Gneiss (Figures 1 and 2). An area of about 1 m^2 is polluted with used black engine oil. Geophysical investigations were subsequently carried out in the area repeatedly at four-week interval in order to delineate the rate and direction of movement of the generated leachate. This research is expected to provide an insight into the rate of movement and direction of an oil-based leachate within the geologic environment of the study area.

2. Methodology

The study area (Figure 2) was artificially polluted by injecting about 200 liters of black engine oil in a shallow hole. The hole was subsequently covered with soil and allowed to rest for about two weeks before the geophysical survey was deployed to investigate the possible leachate paths. An integrated geophysical method involving Very Low Frequency Electromagnetic method (VLF-EM) and Electrical resistivity method which comprised two techniques; Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) was adopted for this work. The VLF-EM and Electrical resistivity tomography surveys were carried out on four occasions at four weeks interval; two weeks, six weeks, ten weeks and fourteen weeks after the pollution. ABEM WADI VLF-EM measuring tools was used to measure the VLF-EM responses; both the Raw real and Filtered Real components. PASI 16Gl earth resistivity meter and its accessories were used to collect both the Electrical Resistivity Tomography (Dipole-dipole) and Vertical Electrical Sounding (VES) data. The VLF-EM station interval and Dipole-dipole spacing (a) is 5 m (Figure 3), while the Vertical Electrical Sounding that was only carried on the fourteenth week was done at 20 m interval across the traverse. The VLF-EM profiling results were presented as plots of raw real and filtered real against distances. The raw real values were also inverted using the inversion programme developed by Karous and Hjelt (1983). The dipole-dipole data were interpreted using Dipro^{TM} inverse modeling software. The VES field obtained data were first interpreted, using manual curve matching technique and the resulting geoelectric parameters were subsequently refined using WinRESIST Version 1.0 (Vander Velpen, 2004).

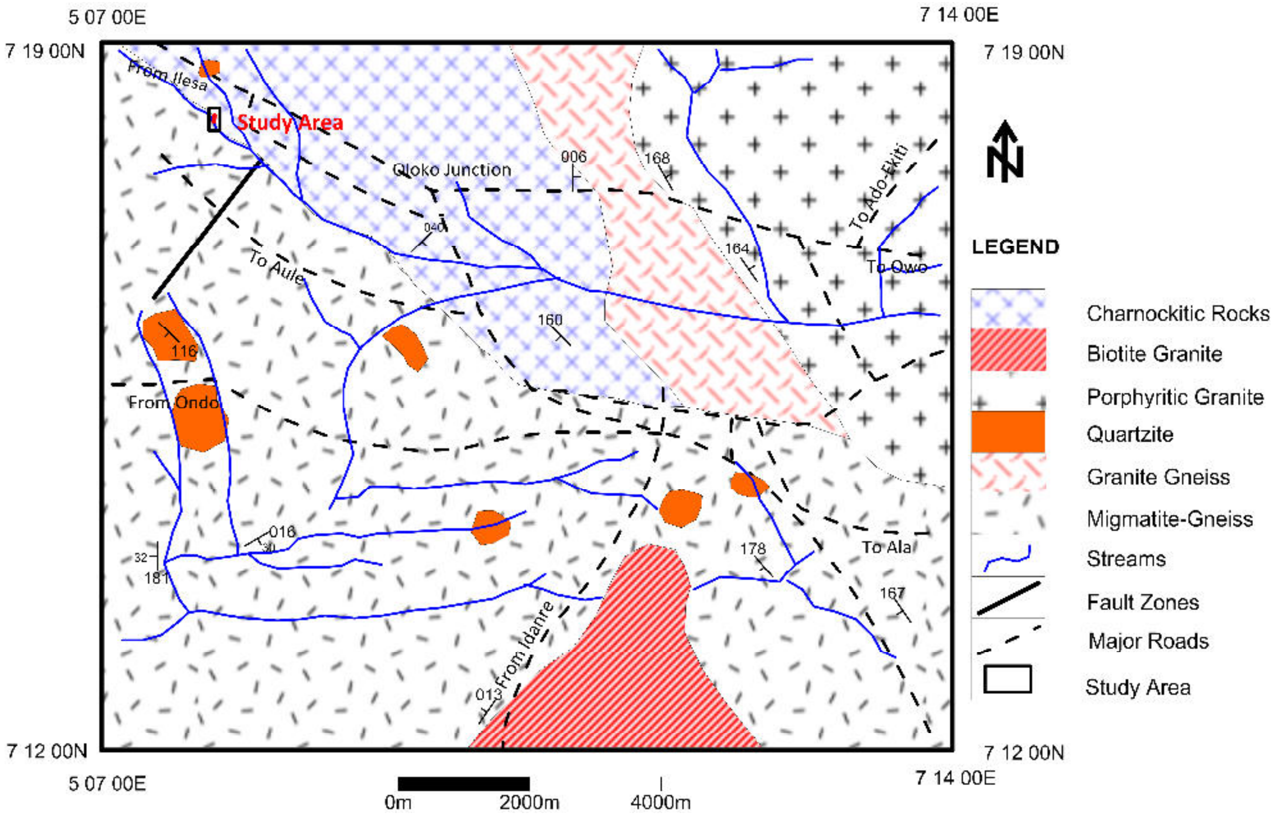

Figure 1: Simplified geological map of Akure showing the study area (Modified after Owoyemi, 1996)

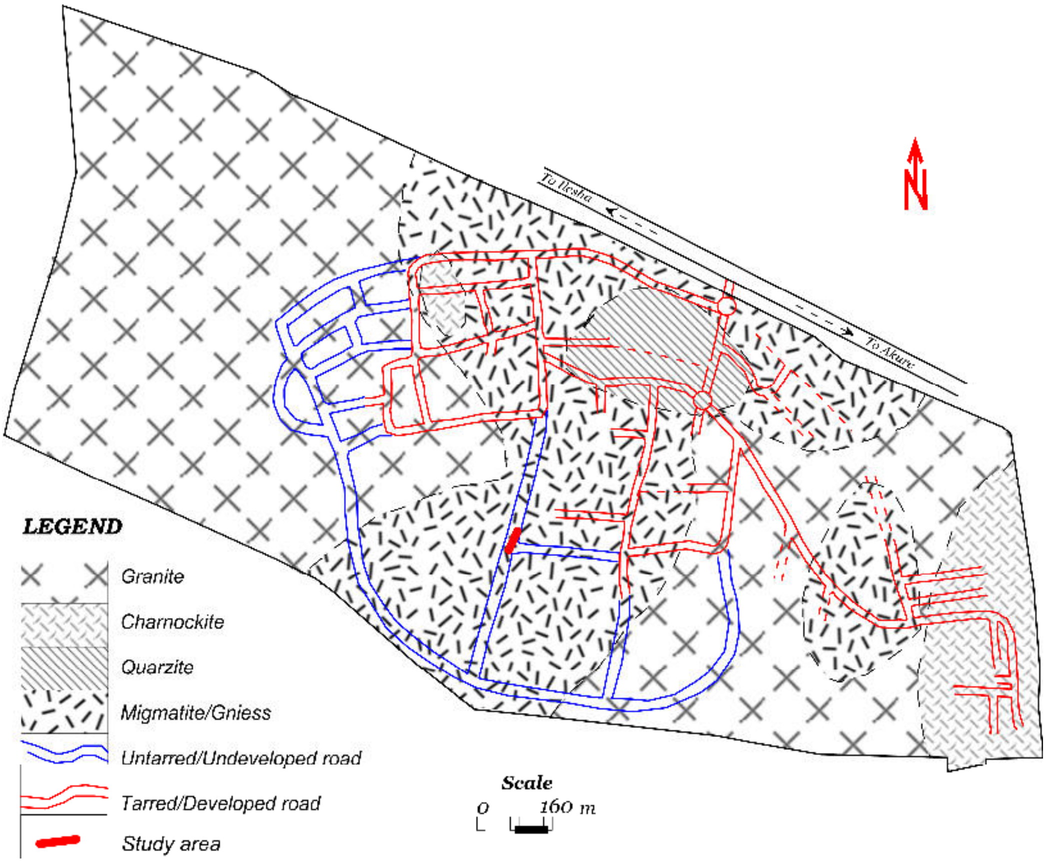

Figure 2. Simplified geological map of Federal University of Technology, Akure showing the layout map of the study area (After Adegoke, 2008)

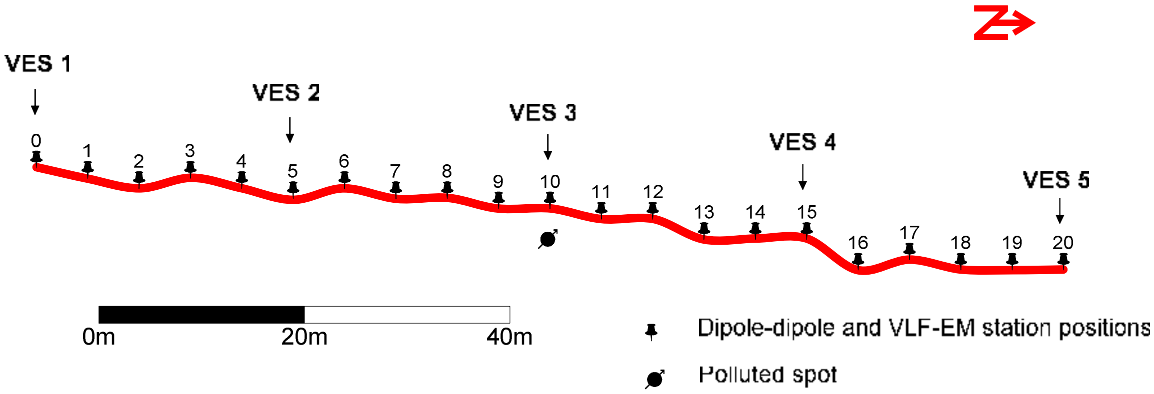

Figure 3. Geophysical survey traverse showing the VLF-EM, Dipole-dipole and VES station positions

3. Results and Discussion

Figure 4 shows the VLF-EM profile and its inverted 2-D model and 2-D inverted model of the resistivity structure of the Dipole-dipole after two weeks from the day of pollution. The VLF-EM plots show response values from -12 to 7% and -14 to 4 % for the raw real and filtered real respectively. This is indicative of presence of several weakly conductive zones along the traverse at distances 20, 35 - 45 and 90 - 100 m which correlates with the VLF-EM 2-D inversion model of beneath it. The polluted area (at 50 m point or station 10 along the traverse) shows approximately low positive peak value (less than 5% in the filtered real curve and above 5% in the raw real curve). The anomaly on the profile is typical of a clayey topsoil and weathered layer. The 2-D resistivity model of the dipole-dipole shows a resistive body towards with a shift towards the left hand side of the polluted point. This could be indicative of the presence of the oil-polluted zone or presence of the basement rock.

Figures 5 shows the results obtained after six weeks in the study area. It shows the VLF-EM profile and its inverted 2-D model and 2-D inverted model of the resistivity structure of the Dipole-dipole six weeks after pollution.

The VLF-EM profile and the 2-D inverted model show a major positive anomaly peak at distance 45 m along the traverse. The response is however low (less than 10%in the filtered real curve and less than 5% in the raw real curve). The 2-D inverted model of the dipole-dipole shows longer resistive body that spans from distance 30 to 65 m along the traverse. This probably due to the effect of lateral movement of the oil-based leachate and this obviously occurred at shallow depth.

Figure 6 shows the VLF-EM profile and its inverted 2-D model and 2-D inverted model of the Dipole-dipole ten weeks after pollution. The VLF-EM profiles and its 2-D inverted model revealed three zones of relative higher filtered real response peaks along the traverse; at distance 10, 35 - 45 and 85 - 100 m. Based on the low response values, these zones are probably indicative of clayey topsoil and clay-rich weathered materials. The 2-D inverted model of the Dipole-dipole of the dipole-dipole shows that elongated resistive zones observed in Figure 5 (at the ten weeks after pollution) have not spread farther, it is still within distances 30 - 65 m. this resistive body is probably the percolating and laterally spread oil-based leachate, while the two extreme of the spread which has higher resistivity values based on the deeper red color signature are probably indicative of basement rock.

Figure 7 shows the VLF-EM profile and its inverted 2-D model and 2-D inverted model of the Dipole-dipole fourteen weeks after pollution. The VLF-EM profile and its inverted 2-D model shows only one significant anomaly at distance 80 m, with a very unusual high value, which could be an noise judging from the previous VLF-EM profile obtained from the same study area in the earlier date. The 2-D inverted model of the dipole-dipole shows a major shrink in the lateral extent of the assumed oil-based leachate. This 2-D model shows that the oil-based leachate has percolated deeper compared to earlier times (2, 6, and 10 weeks after pollution).

Vertical Electrical Sounding (VES) was conducted at five VES positions at regular interval of 20 m along the traverse, fourteen (14) weeks after pollution in order to identify the geoelectric characteristics of the subsurface layers underlying the study area. The following four curve types were identified; A, H, HA and KH, with the A type occurring twice (Figure 8). The geoelectric sounding results reveal that the study area is underlain by three to four geoelectric layers which correspond to three geologic layers; the topsoil, weathered layer and partially weathered basement/presumed fresh basement. The resistivity of the four layers varies from 88 - 231 ohm-m, 98 - 525 ohm-m, 97 – 347 and 1035 – 1564. The thickness of the three upper layers varies respectively from 0.8 – 3.3, 3.0 – 13.3 and 25.1 m (Table 1). Geoelectric section was drawn across the traverse along South – North direction (Figure 10). The geoelectric section shows that VES 1, 2 and 3 are underlain by partially fractured bedrock. The presence of fractured bedrock beneath these VES points will enhance the flow of oil-based leachate beneath these VES points. Correlation of the 2-D inverted Dipole-dipole model with geoelectric section of the traverse (Figure 9) shows that the geologic structures associated with the bedrock in the study area have strong impact on the preferred oil-based leachate paths. Naturally the expectation is that the leachate will flow down the slope along South-North direction, but due to the presence of near surface bedrock fracture, the leachate was surprisingly conducted uphill toward the south direction. The presence of bedrock fracture is also responsible for the quick flow of leachate; both laterally and vertically.

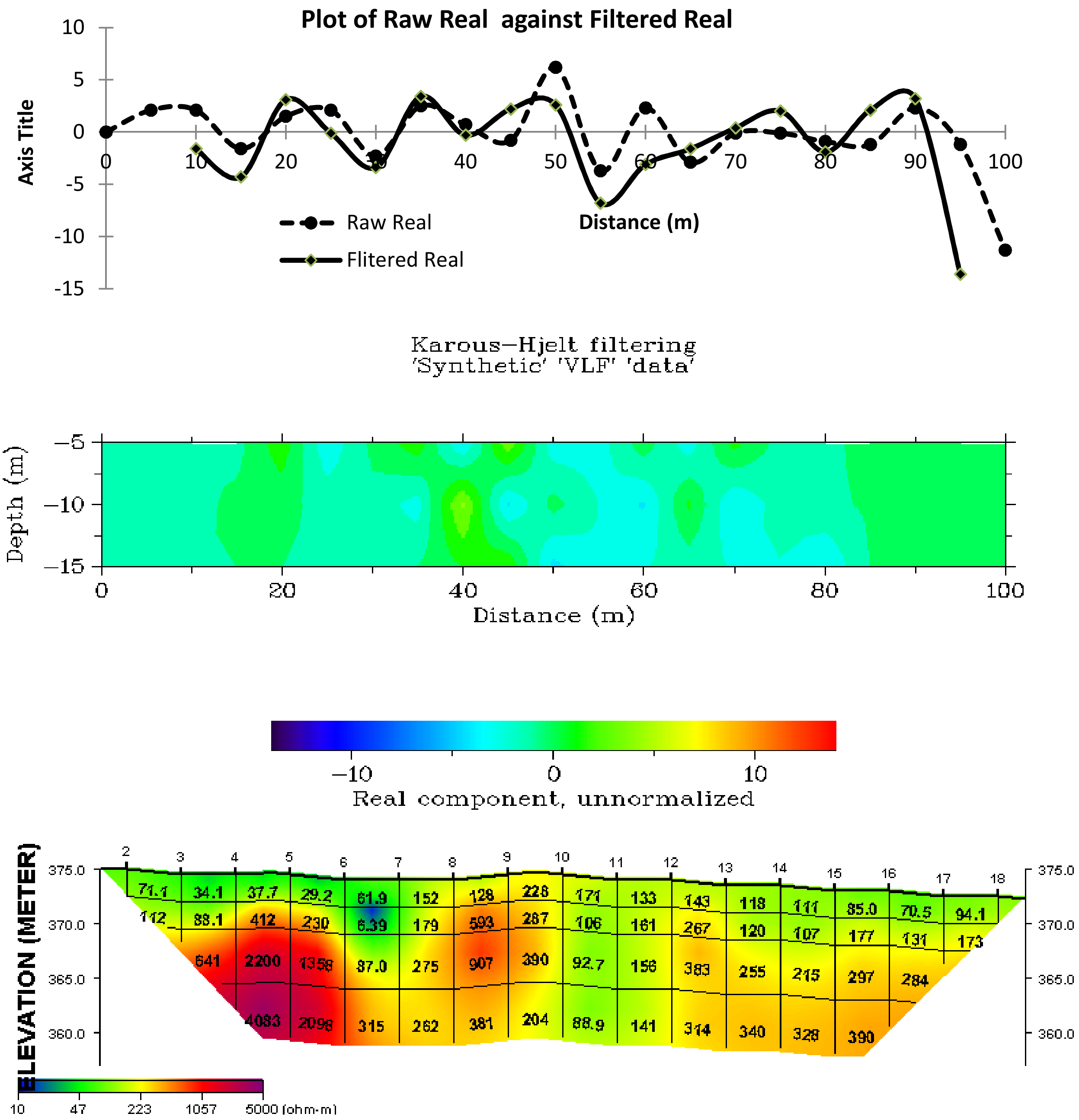

Figure 4. Dipole - dipole Pseudosection and VLE-EM Profile across the polluted area after two weeks

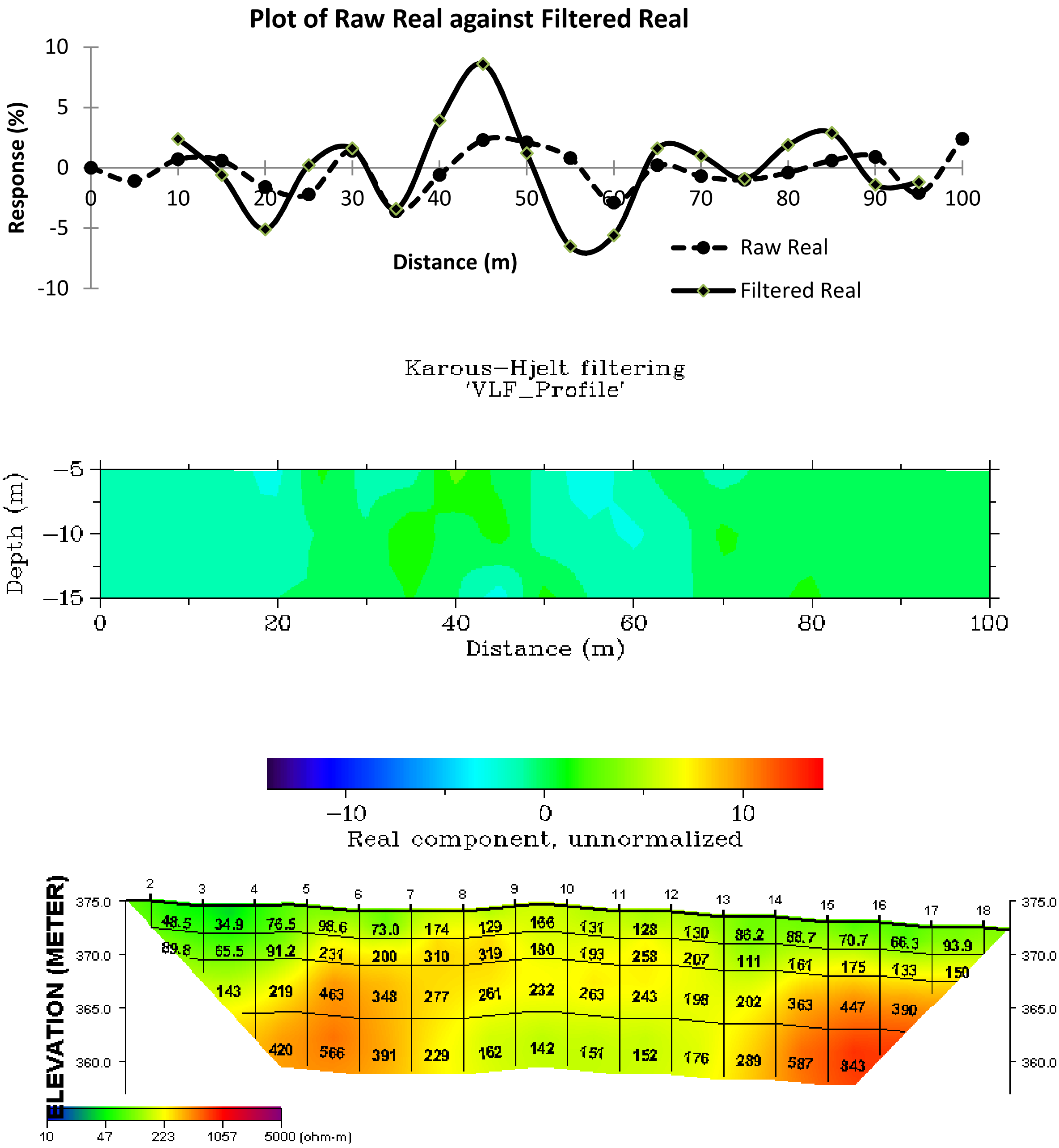

Figure 5. Dipole - dipole Pseudo-section and VLE-EM Profile across the polluted area after six weeks

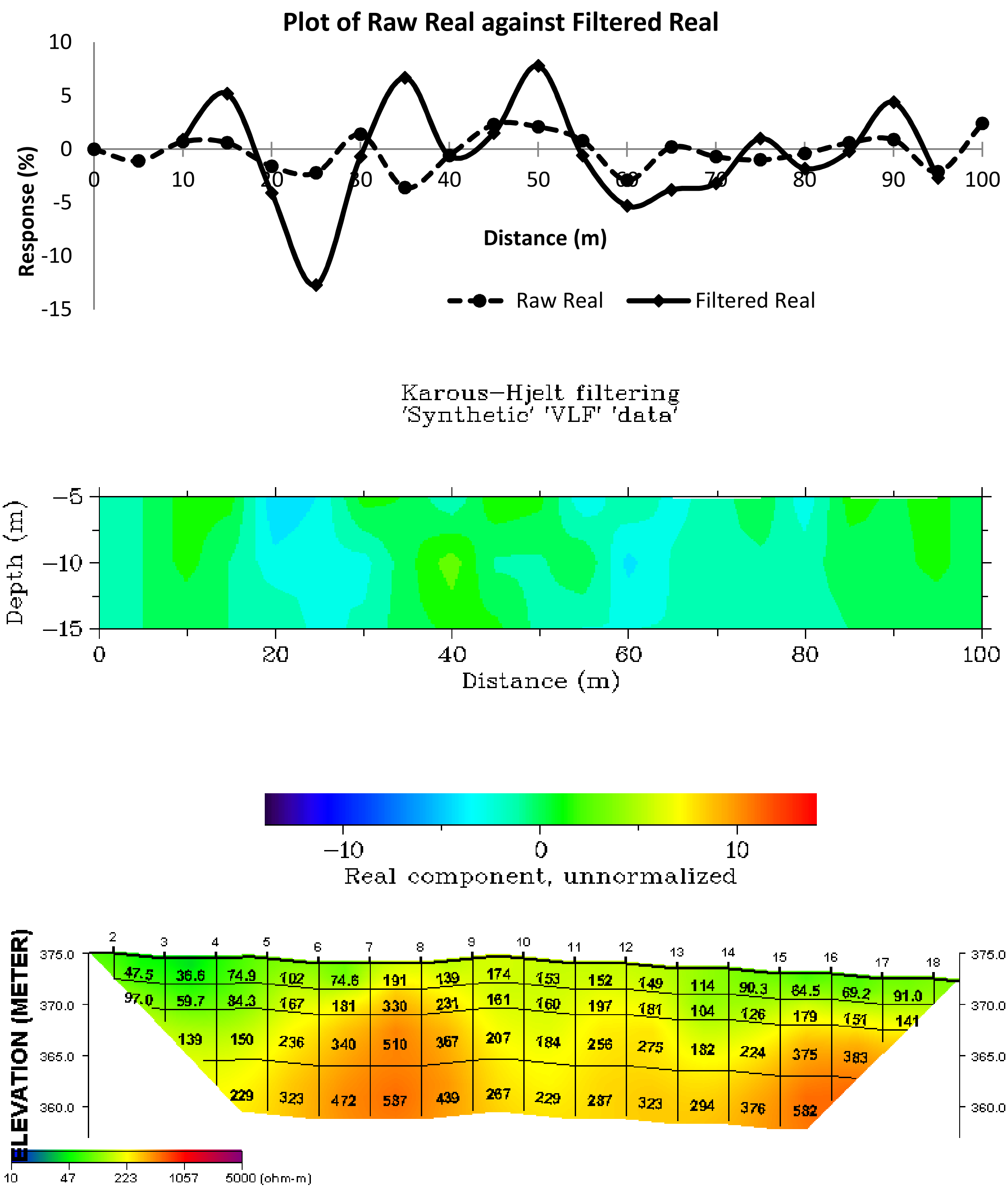

Figure 6. Dipole - dipole Pseudosection and VLE-EM Profile across the polluted area after ten weeks

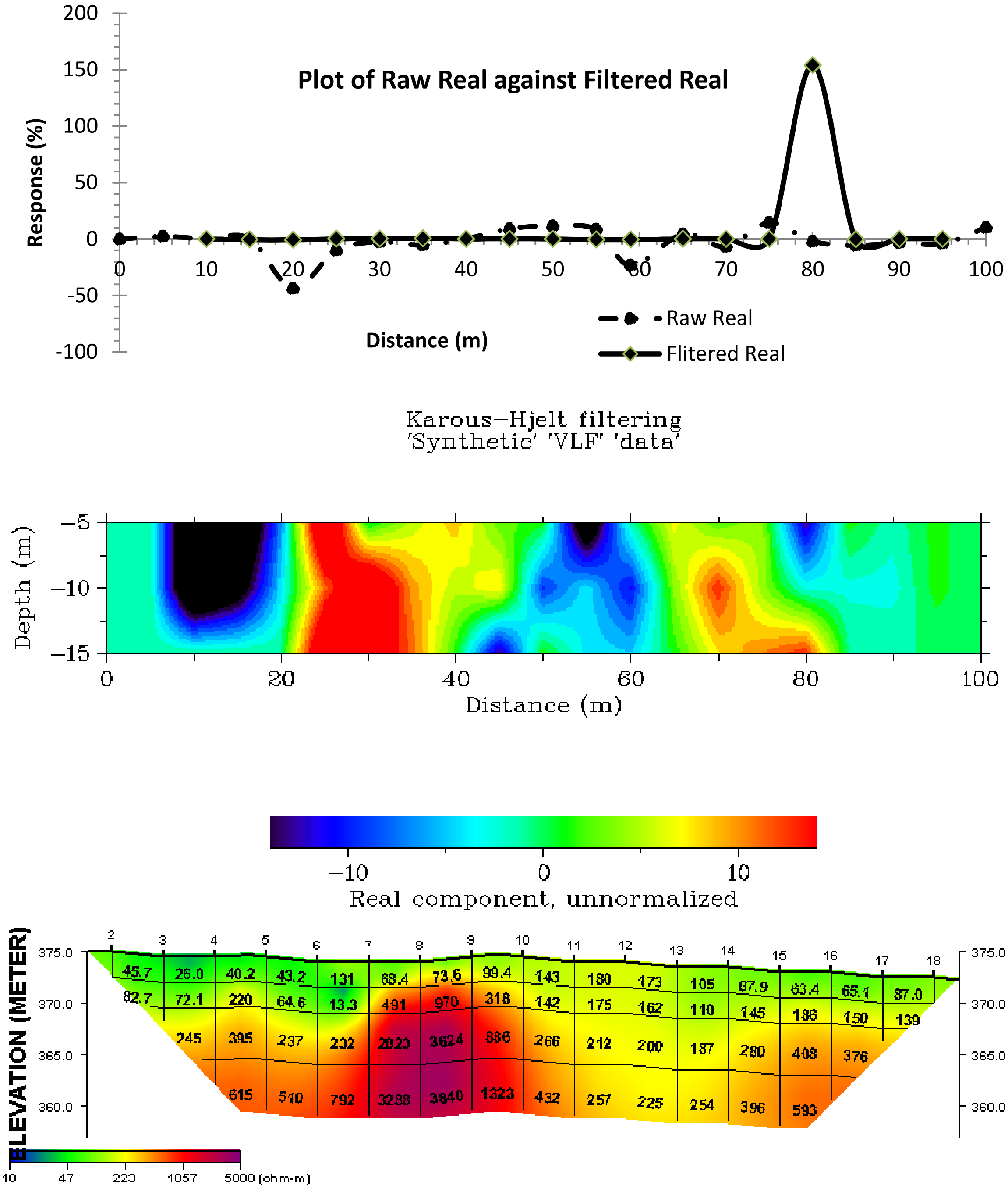

Figure 7. Dipole - dipole Pseudosection and VLE-EM Profile across the polluted area after fourteen weeks

Conclusion

This study have shown that geologic structures such as fracture, joints and voids can facilitates leachate movement within the subsurface and their presence can strongly influence flow direction more than the natural law of gravity.

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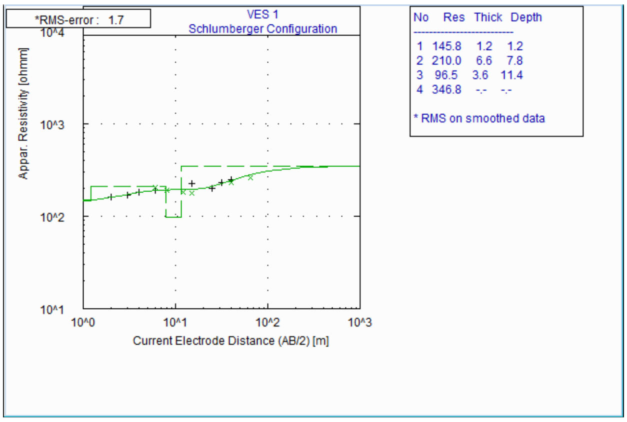
and all the students who participated in the field work are well appreciated.

Table 1. Summary of the VES Interpretation Results

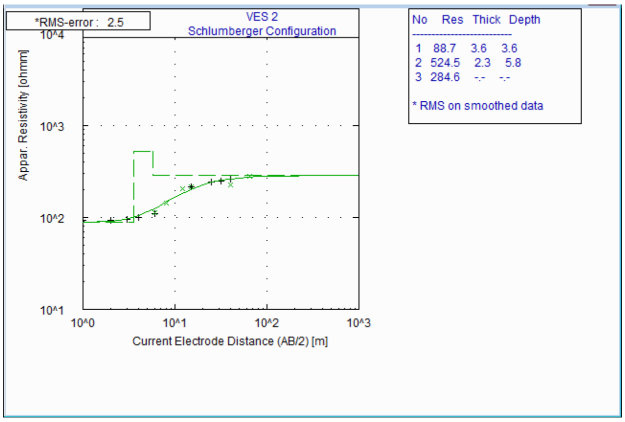
VES Station	Curve Type	No. of Layers	Resistivity Value (Ωm)	Depth (m)	Lithological Characteristics
1	KH	1 2 3 4	146 210 97 347	1.2 7.8 11.4 -	Topsoil Weathered Layer Weathered Layer Partially fractured Bedrock
2	K	1 2 3	89 525 285	3.6 5.8 -	Topsoil Weathered Layer Partially fractured Bedrock
3	HA	1 2 3 4	115 90 230 1035	0.8 3.0 25.1 -	Topsoil Weathered Layer Partially fractured Bedrock Presumed Fresh Bedrock
4	A	1 2 3	88 455 697	3.3 13.3 -	Topsoil Weathered Layer Presumed Fresh Bedrock
5	H	1 2 3	231 98 1564	0.8 4.3 -	Topsoil Weathered Layer Presumed Fresh Bedrock



No	Res	Thick	Depth
1	145.8	1.2	1.2
2	210.0	6.6	7.8
3	96.5	3.6	11.4
4	346.8	-.-	-.-

* RMS on smoothed data

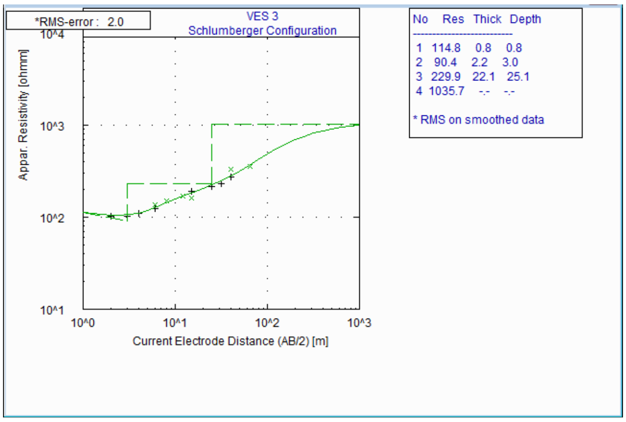
KH curve type



No	Res	Thick	Depth
1	88.7	3.6	3.6
2	524.5	2.3	5.8
3	284.6	-.-	-.-

* RMS on smoothed data

K curve type



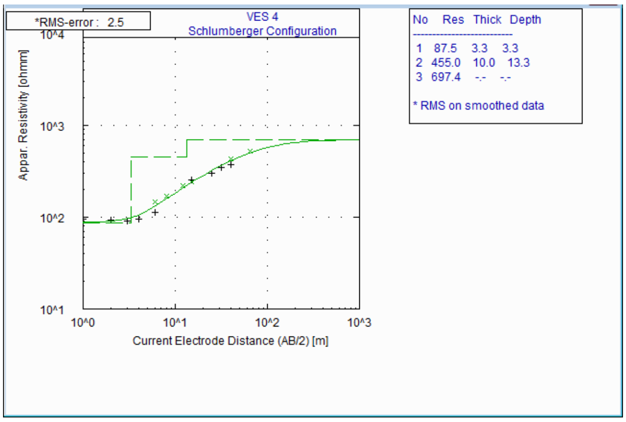
*RMS-error : 2.0

VES 3
Schlumberger Configuration

```
No   Res   Thick  Depth
------------------------
 1  114.8   0.8    0.8
 2   90.4   2.2    3.0
 3  229.9  22.1   25.1
 4 1035.7   -.-    -.-

* RMS on smoothed data
```

HA curve type



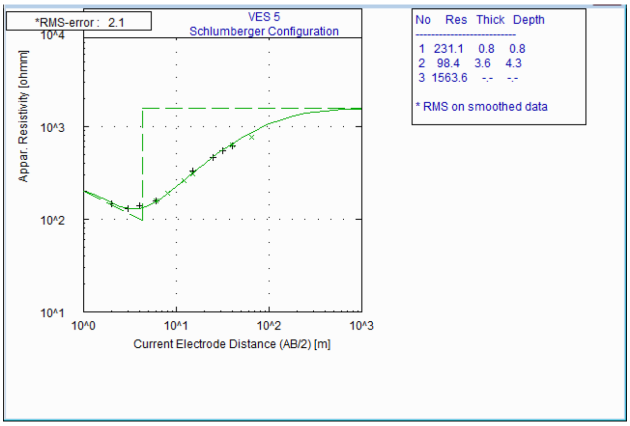
*RMS-error : 2.5

VES 4
Schlumberger Configuration

```
No   Res   Thick  Depth
------------------------
 1   87.5   3.3    3.3
 2  455.0  10.0   13.3
 3  697.4   -.-    -.-

* RMS on smoothed data
```

A curve type



*RMS-error : 2.1

VES 5
Schlumberger Configuration

```
No   Res   Thick  Depth
------------------------
 1  231.1   0.8    0.8
 2   98.4   3.6    4.3
 3 1563.6   -.-    -.-

* RMS on smoothed data
```

H curve type

Figure 8. Iterated curve types obtained from the study area

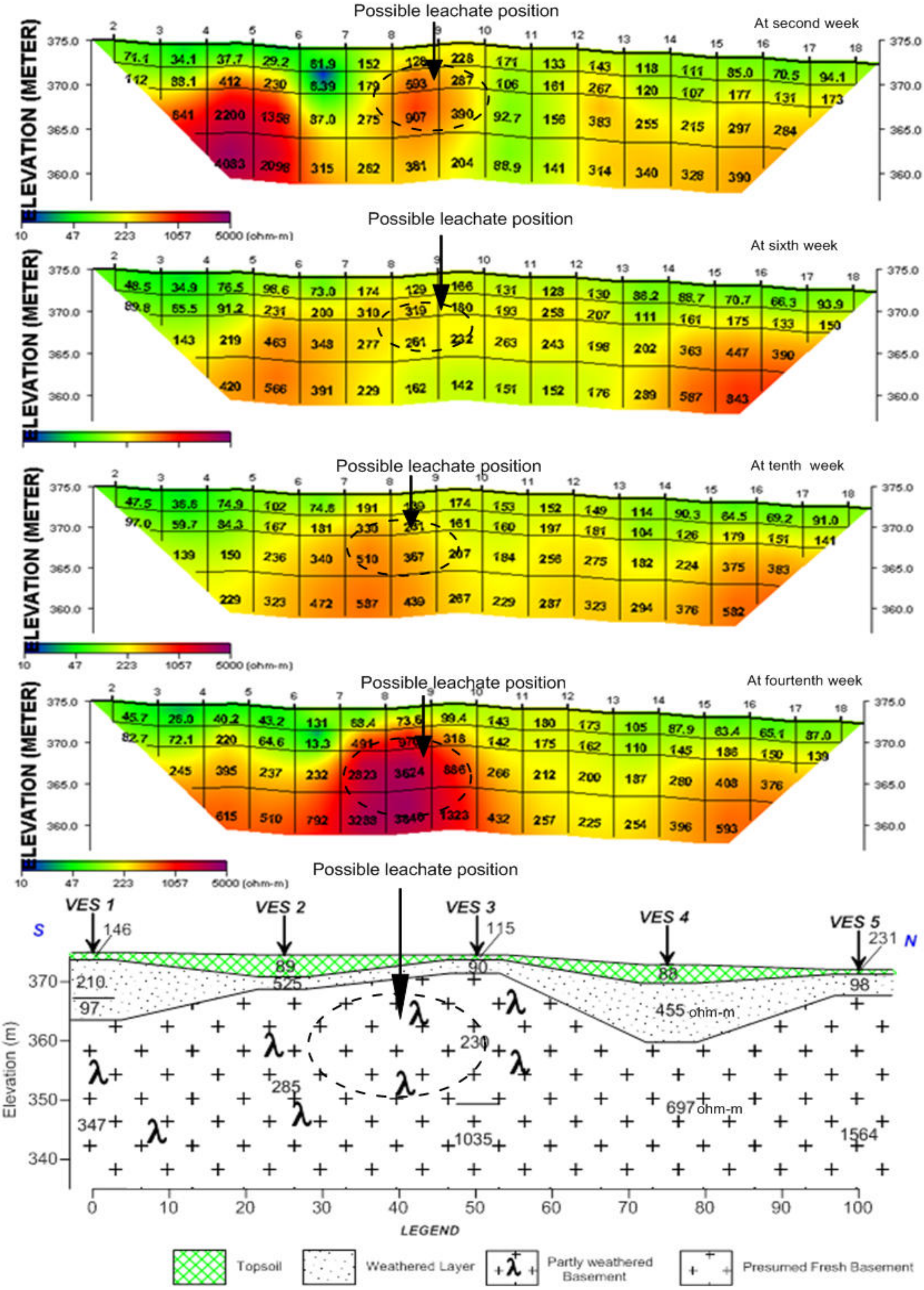


Figure 9. Correlation of dipole-dipole results (weeks 2, 6, 10 and 14 respectively) and Geoelectric section across the polluted area

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