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Application of Resistivity Sounding In Environmental Studies: A Case Study of Kazai Crude-Oil Spillage Niger State, Nigeria

Abubakar Yusuf Ismail* and Umar Adamu Danbatta
Department of Geology, Ahmadu Bello University, Zaria. Kaduna State, Nigeria
*E-mail of Correponding Author: ismi_asma@yahoo.com, ismazee2003@gmail.com.

Abstract
A pipeline conveying crude oil from Escravos via Izom ruptured in the year 2000 and polluted the Kazai area, although the ruptured pipe was replaced and the site cleaned up, an examination of the point of spillage two years later gave the impression that the pipeline might be still leaking. The present work presents the use of Vertical Electrical Soundings (VES) techniques, and systematic trenching, to determine the source of this environmental problem. A total number of eight soundings along two profiles were carried out around the point of spillage, and data analysis revealed that the area is predominantly clayey in nature, and that the pipes are no longer leaking. Due to the plasticity of the clay when wet, it expands when in contact with rainwater and, as it does so, it entrapped any oil existing around it. However, when not in contact with water in the dry season, the clay shrinks and cracks, thereby releasing the trapped oils. This mechanism continued seasonally, and the oil released during the dry season, is the one responsible for the apparent leakage of the pipeline. Geoelectric models in the form of Vertical Isoresistivity Sections (VIS) and Isoresistiviy Maps were plotted. These were used to delineate the polluted zones, which were recommended for excavation and refilling.
Keywords: Vertical Electrical sounding, Geoelectric Models, Isopach map, Isoresistivity Map.

1. Introduction

In the Izom area of Niger State Nigeria, an underground high pressure pipeline that is conveying crude oil from Escravos to the Kaduna Nigerian National Petroleum Cooperation (N.N.P.C) refinery got ruptured at Kazai (km 198) in the year 2000. This caused severe environmental pollution and considerable ecological damage, in the form of water pollution and loss of access to farmlands, which was immediately arrested. The Kazai area of Izom lies within the Basement Complex region of northern Nigeria (Fig. 1), and is about 30 km south of Sarkin Pawa, and about 20km East of Gwada. Danbatta et al. (2002) discussed the different basement rock types found in the study area, which include migmatites, gneisses, metasediments (schists, quartzites), and Older Granites. The dominant rock types are the migmatitic-gneisses, with subordinate amount of the Older Granites, one of which outcropped near the point of spillage (Fig. 2).The crude oil pipeline is trending at 010° around the point of spillage, and the spillage occurred along a tributary of River Dinya, which is sometimes called River Dapulo (Fig. 2). Although the ruptured pipe was replaced and the site cleaned up, oil kept appearing on the surface polluting the water resources in the area particularly during the wet season. The present work illustrate the application electrical resistivity survey to environmental studies, with the sole aim of investigating the source of the persistent appearance of oil on the surface and to point out areas where urgent intervention is needed for the rational use and protection of the water resources of the area

1.1 Materials and methods

A reconnaissance survey was first undertaken in order to study the location and nature of the oil spillage, and used to delimit the study area. Literature review, fieldwork, and laboratory analysis were undertaken during the investigations. Eight (8) surface Vertical Electrical Soundings (VES) geophysical data were acquired using an ABEM Terrameter SAS 300, and a Schlumberger electrode array with a maximum electrode spacing of 100 m. The 8 VES stations were established on two profiles, trending N-S and E-W (Fig. 3). Moreover two large pits were dug to physically observe the soil profile in the study area.

The data obtained were then reduced and were subjected to both qualitative and quantitatively interpretation using different analytical methods.

1.1.1 Results and discussion

The data acquired from the eight soundings are presented in Table 1, and the field curves are predominantly three-layer A and H-types. The thickness of the most conducting layers in the study area varied from 12 to 117m with resistivities in the range of 4 to 115 ohm-m. Geoelectric models for the spillage site in the form of Vertical Iso-ohms Section (VIS) and Iso-ohms Map (Resistivity contours) at different depths were plotted. These were used to delineate the polluted zones around the west and central areas of the point of spillage.

The acquired VES field curves were initially interpreted using the conventional partial curve matching technique and the Petrowski's method (Telford et al., 1976). Initial estimates of the resistivities and thickness of the various geoelectric layers were deduced from this preliminary interpretation. The deduced parameters were later used as starting models in a "Zohdy" computer program. This computer assisted resistivity interpretation is based on the calculation of theoretical VES curves, and gave the 'best fit' for the data obtained.

The final computed computer parameters for VES1 are hi = 7.26m, rho ($\rho 1$) = 100 Ωm, h2 -13.26 m, $\rho 2$=289 Ωm, $\rho 3$=401 Ωm. Root mean square(R.m.s) error for the final model was 4.2, and the suggested depth of the third layer (h3) is infinity. A similar procedure as discussed above was followed in the interpretation of all the remaining 7 VES points collected for this work, and the result presented in Table 2. The resulting interpreted models of the various profiles sounded were used to produce geoelectric sections, geologic sections, isopach maps, and isoresistivity (iso-ohms) maps for the surface, overburden and basement.

The composite geoelectric section was obtained for the four VES points established along the N-S profile. It suggests that the subsurface along the profile is made up of 3 layers at VES point 1, while 2-layers underlay VES points 2, 3 and 4. The resistivity of the first layer in all the VES points ranges from 100.7-1605 ohm-m, and the thickness of the layer varies from 2.42 m to 30.54 m . The second layer has a resistivity in the range of 289-62479 Ωm, and the thickness of this second layer varies from 13.26 m –Infinity. The third layer is the deepest and has resistivity values in the range of 400 Ωm.

The geoelectric section derived from the interpreted VES data was converted to geologic section based on available borehole data and dug pit in the area. The geologic section derived along the N-S profile suggests that the first layer likely consists of two different types of soils. The high resistivity zone (5071 ohm-m) of the layer occurring around VES point 2 is considered to be fresh crystalline rock. The second soil type occurred at zones with relatively medium resistivity values (100-198 ohm-m), which occurred at VES points 1, 2 and 4, and is considered to be dry clay.

The data also suggests that the second layer likely consists of two types of soils. The first type occurred at around VES point 1, with a resistivity value of 289 ohm-m, probably suggesting a sandy loam soil. The second type occurred at VES points 2, 3 and 4, and is likely considered to be composed of fresh crystalline basement, but at VES point 2 it is the oil pipeline which runs N-S across the VES profile. The third and final layer along the N-S profile is composed of one soil type, which occurred at VES point 1, and is also considered a region of fractured basement predominantly composed of gravelly sand.

The interpreted resistivity data for the final models of each of the remaining four VES points along the E-W profile in the study area were also interpreted in a similar way. Geologic section of some selected VES points are shown in fig.4.

In order to investigate other hydrogeophysical aspects of the study area, two isoresistivity maps and isopach map were also prepared from the interpreted VES data, through contouring. These maps include the isoresistivity map of the top layer (fig.5), the isoresistivity map at 5m depth (fig.6) and the isopach map of aquifer (over burden and fractured basement) fig.7. The isoresistivity map of the top layer was primarily produced to show the variation of resistivity of the topmost layer, which would be a function of the surface geology of the study area. It could also suggest the possible existence of spilled oil saturated zones in the top layer.

Table 2 shows that the resistivity values of the upper layer range from 54-714,683 ohm-m at around VES 5 and 6, respectively. The figure further shows the zone with lowest resistivity values (>100 ohm-m), suggesting that the soil formations within the zone consists of sand, silt and clay. The zone occurs largely in the western part of the study area and some portions of its northern parts. The zone with medium resistivity values in the range of 711 ohm-m occurs around the central portion of the study area VES 7, and consists of fractured basement. The low resistivity zone occurs at the eastern portion of the area, and is occupied by dry sand. These three zones have incidentally coincided with what was obtained in the geologic section earlier derived at the corresponding VES points. Moreover the interpreted categories of soils were physically mapped at the study are during the field data acquisition after the dug pits were logged.

Two high resistivity areas were identify in the topmost layer around VES 3 and 6,this areas might have been polluted by spilled oil which accounts for the high resistivity values. The top layers in this areas were interpreted to be sand,silt and clay. Due to the plastic nature of clay when wet, it usually expands when in contact with rainwater, and as it does so it squeezes out the entrapped in it (Deer, et al., 1963; Bragg and Claringbull, 1965). However, in the dry season when not in contact with water, the clay will shrink and crack, thereby releasing the trapped oils. This mechanism continued in an alternating way following the dry and the wet seasons (Barrer, 1978), and the oil released during the wet season is the one responsible for the impression that the pipeline might still be leaking.

1.1.1.1 Conclusion

The main conclusion reached from the study is that the pipes are no more leaking, and that the usual sources of water in the study area are still contaminated with organic crude oil. For an effective and successful mitigation operation, the cause of the spillage was accurately identified as due to the alternate trapping and releasing of part of the oil that already leaked by plastic clay particles in the rainy and dry seasons. Simple excavation, evacuation and disposal of the contaminated soils, and cleanliness of the polluted surroundings, are some of the methods of improving and safeguarding further apparent leakage of the oil.

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Table 1: Electrode separation and field data of VES points

AB/2 (m)	MN/2 (m)	VES1 (Ωm)	VES1 (Ωm)	VES3 (Ωm)	VES4 (Ωm)	VES5 (Ωm)	VES6 (Ωm)	VES7 (Ωm)	VES8 (Ωm)
1.00	0.5	168	166	204	401	51	528	377	166
1.50	0.5	147	148	1340	315	41	278	646	142
2.50	0.5	104	171	1524	225	108	1038	348	122
3.75	0.5	80	220	1319	203	526	849	248	124
5.00	0.5	66	274	1172	221	425	700	219	148
7.500	0.5	385	700	1414	449	722	978	1511	536
10.00	0.5	149	506	646	576	343	329	261	264
15.00	1.5	284	626	515	420	423	441	357	491
25.00	1.5	3751	1200	787	649	713	803	2706	918
37.50	1.5	7610	1612	20.98	681	1709	2393	1229	1206
50.0	1.5	548	1843	1717	1472	1240	1545	819	1189
75.00	5.0	550	1842	3200	3117	1556	3166	570	978
10.0	5.0	954	2178	4676	2755	1577	4738	369	338

Table 2: Computer Interpretation of VES Data

	DEPTH (m)	RESISTIVITY (m)
VES1	7.26040	100.722
	13.2622	288.920
	INFINITY	400.693
VES2	2.42	146.947
	INFINITY	5071.881
VES3	30.538	1605.148
	INFINITY	62479.000
VES4	1.784	198.174
	INFINITY	4950.040
VES5	0.598	53.784
	16.093	427.222
	31.026	2214.760
	INFINITY	10029.134
VES6	19.461	714683
	33.699	270968.000
	52.414	8568.866
	INFINITY	53.272
VES7	1.23	711.713
	15.05	197.1292
	INFINITY	97.1292
VES8	6.780	113.674
	INFINITY	2414.414

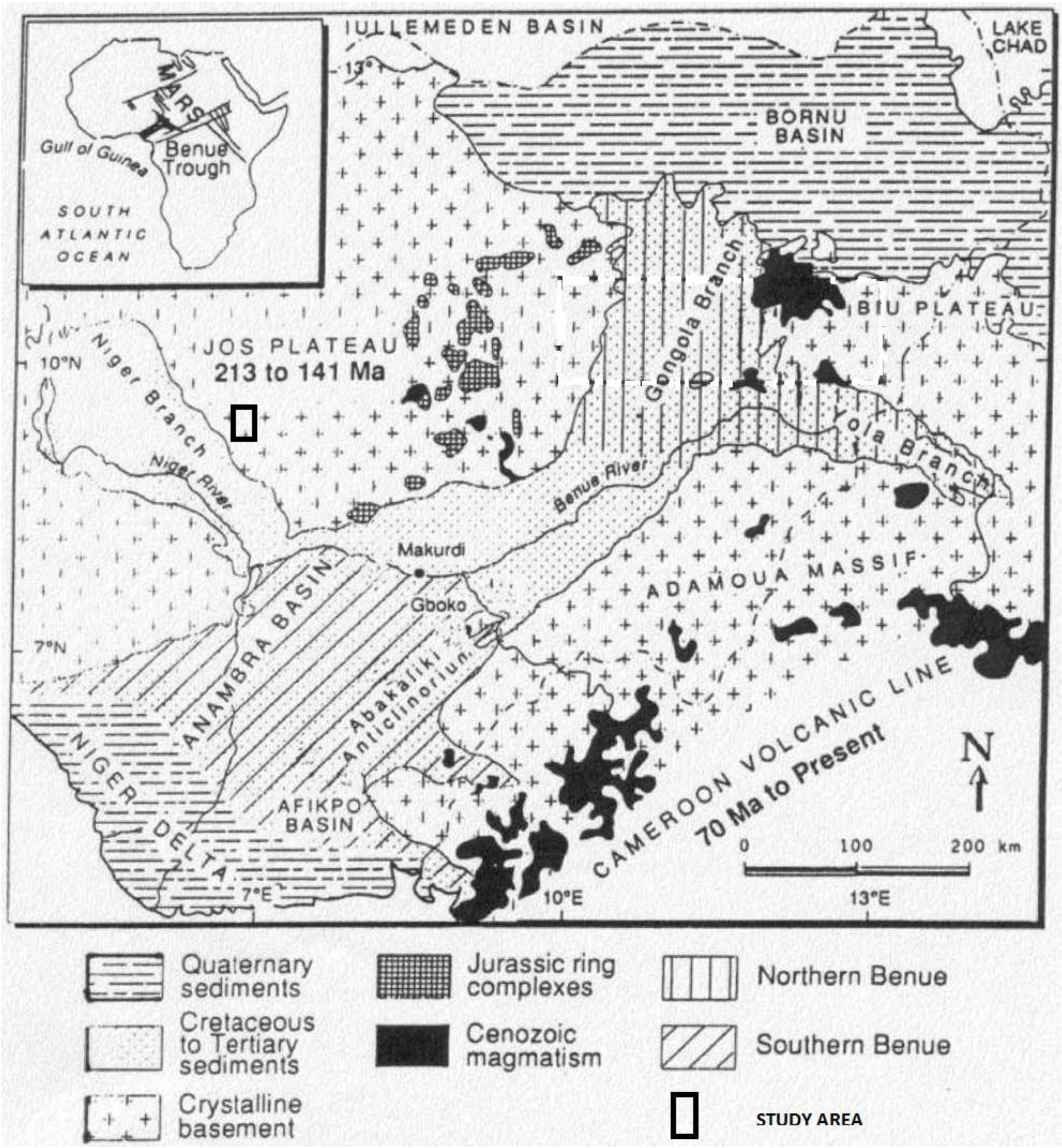

Fig.1: Location map of the study area (adopted from Coulon *et al*.,1996)

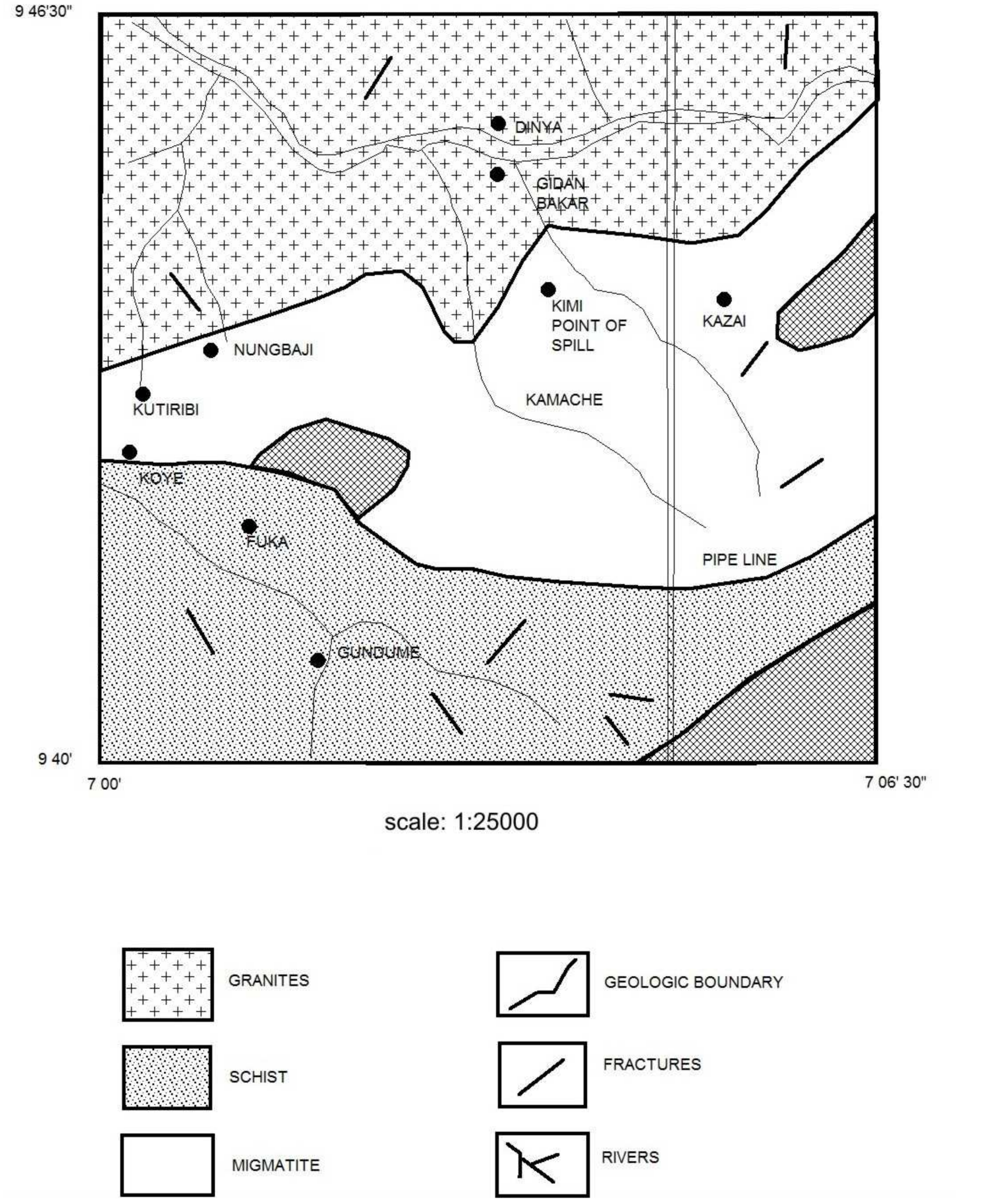

Fig.2: Geologic Map of the study area.

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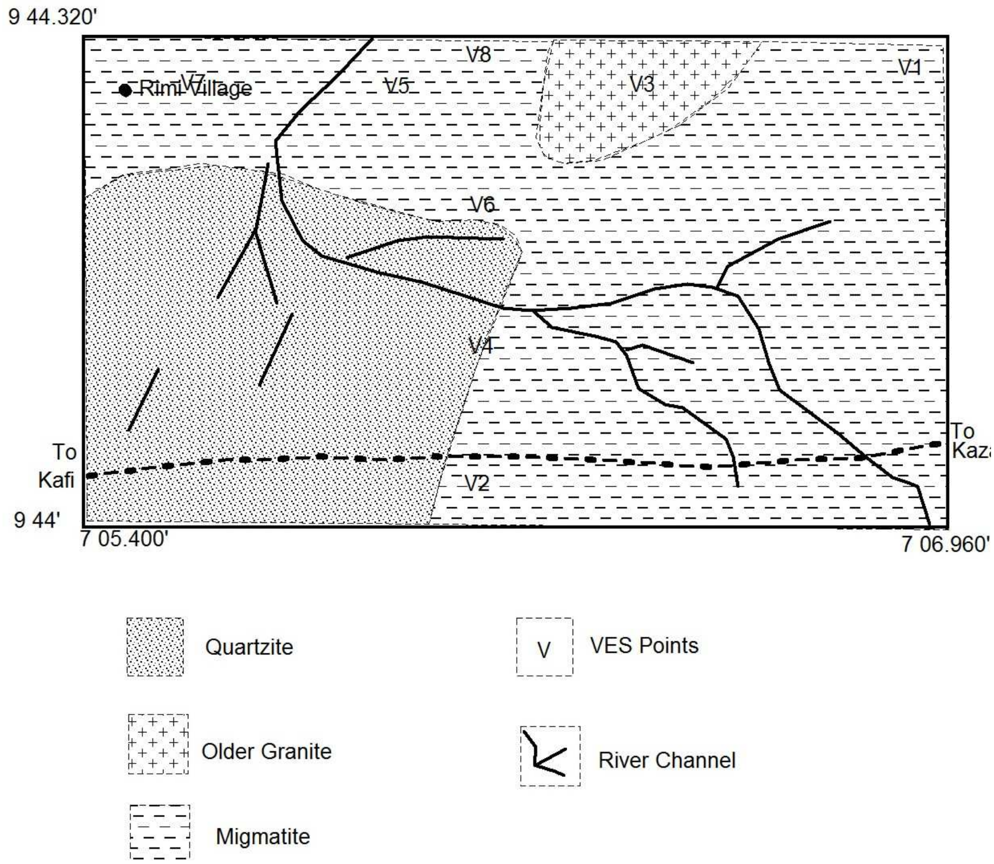

Fig.3: Geologic map of the study area showing VES locations

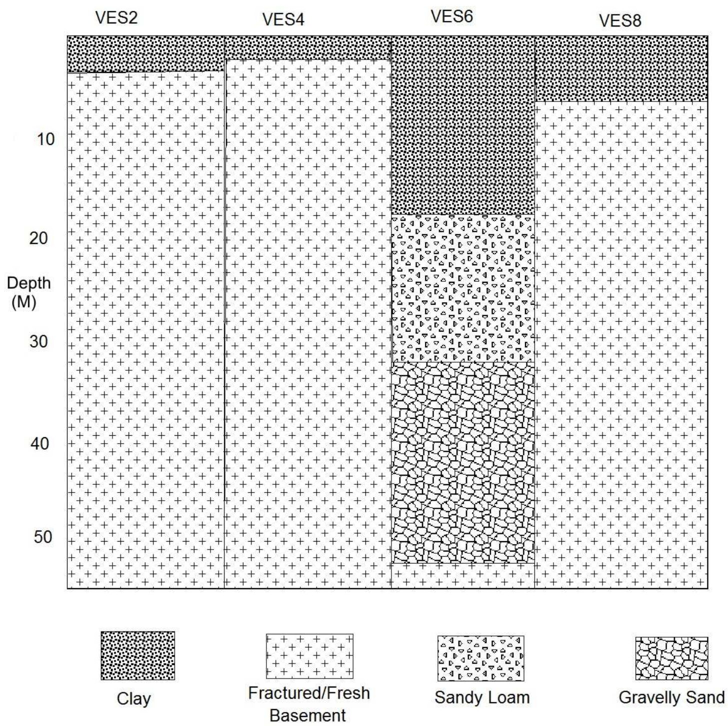

Fig.4: Geologic section of VES 2, 4, 6 and 8

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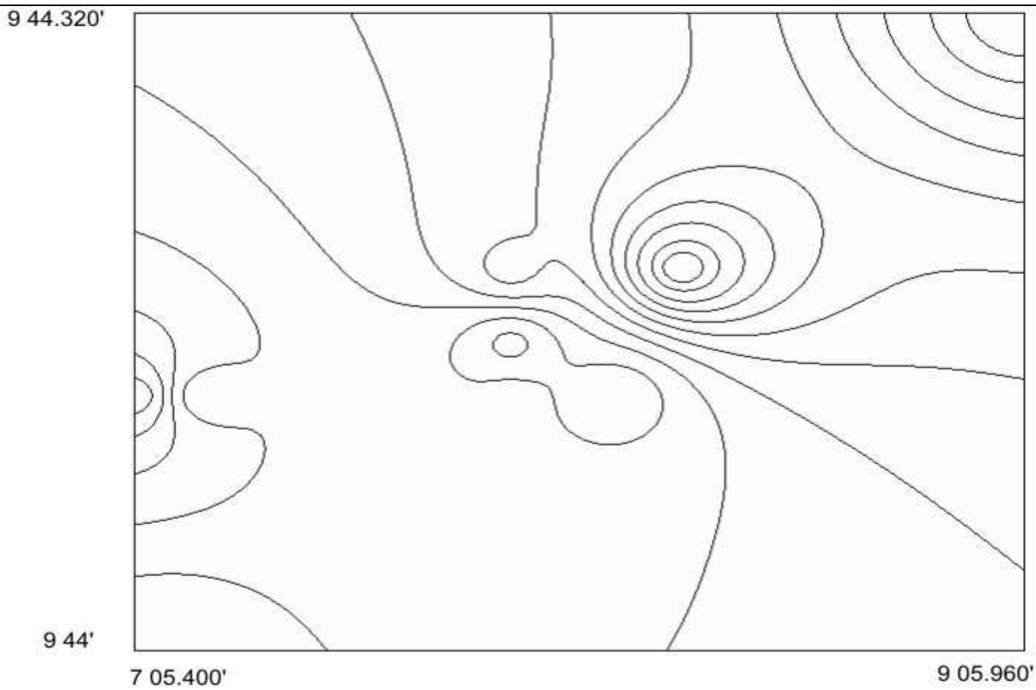

Fig.5: Isoresistivity Map of the top layer

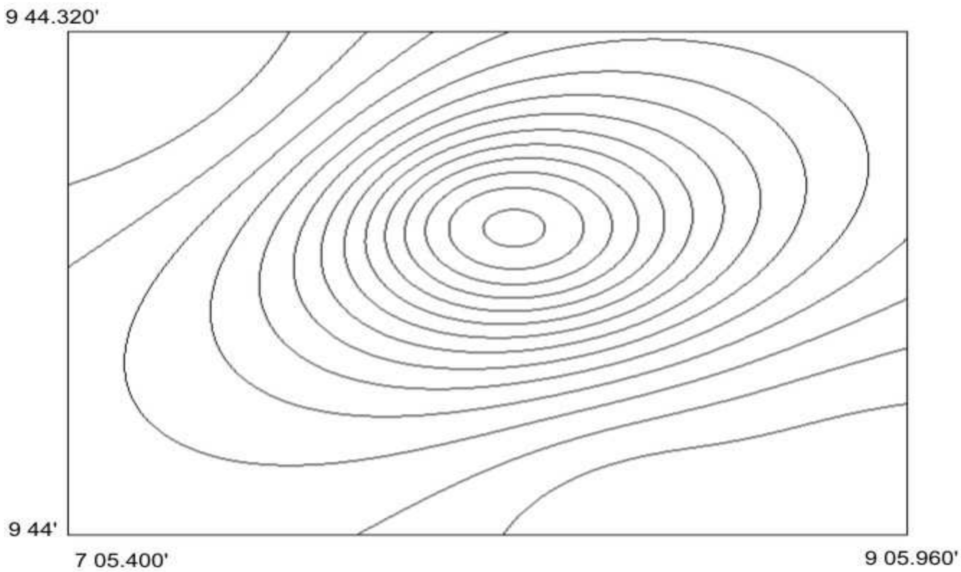

Fig.6: Isoresistivity map at a depth of 5M

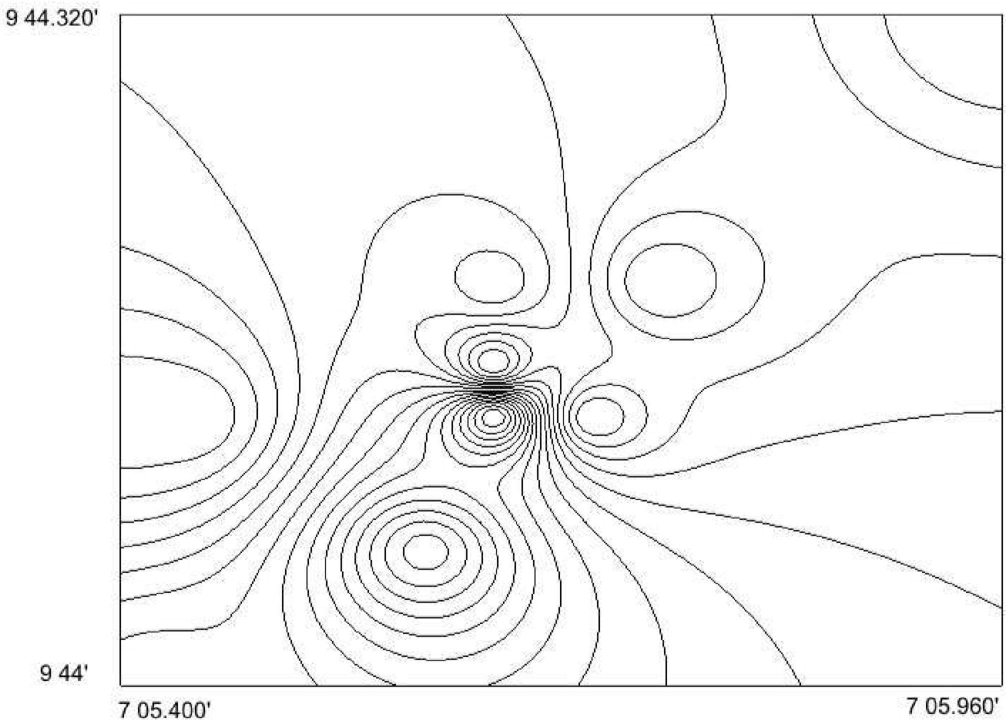

Fig.7: Isopach map of the aquifer in the study area.