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Geophysical Investigation for Groundwater Potential of an Area in Delhi NCR

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ABSTRACT

This paper deals specifically with the electrical resistivity method, which was applied for the exploration of groundwater potential and water-bearing strata at Jamia Millia Islamia (JMI) campus, so as to deal with the problems of water scarcity in the National Capital Territory of Delhi. Accordingly, four sites were identified at JMI campus for electrical soundings; one for ground truthing, one for estimation of groundwater table and water-bearing strata and the other two to investigate the impact of the injection well located at JMI campus. Moreover, the soundings were carried out by a terrameter using Schlumberger and Wenner configurations. Additionally, the variation of apparent resistivity *versus* electrode spacing as well as the expected lithology for all the sites were also obtained. As a result, the resistivity method indicated that the depth of groundwater table was available at about 18.3 m and goes to a depth of 47.6 m near pumping well (VES2). At the time of installation of the pump, the groundwater table was found at a depth of about 15.5 m. The groundwater table at VES1 was estimated at a depth of 11 m, also possessing sufficient water-bearing strata. The study revealed that sufficient water was available near VES1 and VES2 as compared to other sites. The objective of the study was accomplished with substantial findings which further corroborate the effectiveness of the approach adopted for groundwater exploration.

KEYWORDS: Electrical resistivity, Geophysical investigation, Vertical electrical sounding (VES), Groundwater exploration, Schlumberger array, Wenner array.

INTRODUCTION

Delhi is experiencing increasing pressure to meet the demand for its water resources. Growing urbanization, improvements in living standards and exploding population are just some of the contributing factors. The large-scale extraction of groundwater is a result of this widening gap between the demand and supply of water. And still, serious doubts are being raised about both the quality and quantity of groundwater.

Groundwater is one of the major sources for water supply in many parts of the country. In Delhi, groundwater contributes to a substantial quantity of supply. Especially in new development areas, groundwater is largely being utilized as a drinking water resource, mainly because of the insufficiency of the Yamuna water share for Delhi. In recent days, groundwater has become immensely important for human water supply in urban and rural areas and the

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exploration of groundwater in hard rock terrain is a very challenging and difficult task when the promising groundwater zones are associated with fractured and fissured media (Sunmonu et al., 2012). In this environment, the groundwater potentiality depends mainly on the thickness of the weathered/fractured layer overlying the basement (Al-Garni, 2009).

The groundwater recharge areas need to be identified, so that maximum recharge can be achieved. The recharge areas need to be conserved and preserved for the sustainable management of groundwater and to maintain the potential of groundwater in Delhi. The use of geophysics for both groundwater resource mapping and water quality evaluation has substantially increased over the years. Vertical Electrical Sounding (VES) has proved to be very popular with groundwater studies due to the simplicity of the technique (Sunmonu et al., 2012).

Geophysical methods have recently aroused a considerable amount of interest in view of the work which has been done all over the world with various types of apparatus. These methods are all based on variation measurements in some properties of the Earth, such as its density, elasticity, magnetic permeability and electrical conductivity; some of them have given satisfactory results in the search for soil strata information. These methods may be classified as gravimetric, seismic, magnetic and electrical and the earth resistivity method is one of the simplest of the electrical type.

This paper deals specifically with the electrical method which comprises a multiplicity of separate techniques that employ differing instruments and procedures, have variable exploration depth and lateral resolution and are known by a large lexicon of names and acronyms describing techniques and their variants. Electrical methods can be classified into four classes: (i) direct current resistivity, (ii) electromagnetic, (iii) induced polarization and (iv) self-potential methods. In spite of all the variants, measurements fundamentally are of the Earth's electrical impedance or relate to changes in impedance. Electrical methods have broad applications to mineral and geoenvironmental problems. They may be used to identify sulfide minerals, are directly applicable to hydrologic investigations and can be used to identify structures and lithologies.

The geoelectrical technique has been widely used in groundwater exploration to correlate between the electrical properties of the geologic formations and their fluid content (Ogilvy, 1970; Zohdy, 1969; Zohdy et al., 1974). Many studies have concentrated on the geometry determination of aquifers (Robain et al., 1995).

The electrical resistivity of a formation depends mainly on the salinity of its fluid content, saturation, aquifer lithology and porosity (Shaaban, 2002). This technique has been successfully used in the world to explore groundwater and its condition. The electrical resistivity technique is widely used also to estimate the depth and nature of the alluvium, aquifer boundaries and its location (Young et al., 1998; Lashkaripour et al., 2005; Al-Garni, 2005; Al-Garni et al., 2005; Al-Garni et al., 2006; Hassanein et al., 2007). Moreover, it has been used to delineate the freshwater/saline water interface (Yechieli, 2002; Choudhury et al., 2001); water content (Kesseles et al., 1985); hydraulic conductivity (Yadav and Abolfazli, 1998; Troisi et al., 2000), specific yield (Frohlich and Kelly, 1987) and groundwater contamination (Kaya, 2001). It is worth to mention here that the resistivity method limitation can be expected if the ground is inhomogeneous and anisotropic (Al-Garni, 1996; Matias, 2002).

Lateef (2012) performed a geophysical survey involving electrical resistivity methods at Annunciation Grammar School, Ikere- Ekiti, south-western Nigeria with the view to delineate the geo-electric characteristics of the basement complex and evaluate its groundwater potential in the area. A total of 5 vertical electrical sounding stations were established within the site along 5 traverses. The Schlumberger configuration was used for data acquisition. Half-current electrodes ($AB/2$) used ranged from 1 to 100 m. The quantitative interpretation of the VES curves involved the use of partial curve matching and the 1-D computer iteration technique. The depth sounding interpretation results were used to generate geo-electric sections from which the aquifer

was delineated. The geo-electric section drawn from the results of the interpretation reveals five subsurface layers which comprise topsoil, lateritic sand, partially weathered, weathered and fractured basements. The weathered and fractured layers constituted the aquiferous zone in all the stations. Hence, from this research study, it was recommended that boreholes should be sited in high-conductivity zones in VES1, 2, 3 and 4, as they contain probable aquifers. The depth of any borehole should be located between 15 m and 30 m to take advantage of the basement fractures.

Kurien et al. (2013) employed an electrical resistivity method for hydro-geophysical investigation of groundwater. Wenner configuration of electrode arrangement with vertical electrical sounding (VES) was adopted in the study. IGIS signal stacking resistivity meter model SSR-MP-ATS was used to obtain the pattern of aquifer distribution in selected lateritic terrain and to delineate possible sites for locating aquifers. The inverse of the resistance measured 1/R was plotted against Wenner electrode separation on a linear graph.

Venkatarao et al. (2014) pursued a geophysical investigation around Pydibhimavaram industrial area, Srikakulam district, Andhra Pradesh, India using the vertical electrical sounding technique. Vertical Electrical Sounding (VES) using Schlumberger array was conducted at thirteen VES stations. The study was carried out with a view to determine the subsurface layer parameters (resistivities and thicknesses) and use the same to categorize groundwater potential of the study area. The interpretation of results showed that a major portion of the study area consisted of three layer formations. A vast range of resistivities and their corresponding thicknesses were obtained. Pseudo-sections and geo-electric sections were generated using Surfer software.

Aku and Gani (2015) carried out a geophysical investigation of the subsurface condition of the permanent site of Federal University Lokoja, Kogi State using electrical resistivity method with the aim of studying the subsurface geologic layers, in order to determine the aquiferous zones, their depths and the thicknesses of the geologic layers. They performed vertical electrical sounding (VES) using Schlumberger array at twenty VES stations along four profiles. The VES results revealed the heterogeneous nature of the subsurface geological sequence to contain four layers; topsoil (sandy and clayey laterite), weathered layer, partly weathered or fractured basement and fresh basement with two aquiferous zones (weathered basement and fractured basement). The resistivity values of the topsoil layer varied from 20 Ωm to 250 Ωm with thicknesses ranging from 1.0 m to 3.0 m; the weathered basement has resistivity values ranging from 25 Ωm to 300 Ωm and thicknesses between 2.0 m and 41.5 m; the partial/fractured basement has resistivity values ranging from 100 Ωm to 600 Ωm with thicknesses between 5.0 m and 50 m across most part of the area. Lastly, the fresh basement had resistivity values of 900 Ωm and above with infinite depth. However, the depths from the Earth's surface to the aquiferous zone varied from 10 m to 50 m and the overburden in the area was low.

METHODOLOGY

Site Location

The location of all the four sites was selected at Jamia Millia Islamia campus, New Delhi. All the specific sites were identified for vertical electrical sounding (VES) and each site has been designated as VES1 to 4, respectively. The details of each site with their designations are mentioned below:

(i) National Museum for Independence near Academy of Third World Studies (VES1);
(ii) Near Pumping Station at Faculty of Management Studies (VES2);
(iii) Near Centre for Physiotherapy (VES3);
(iv) Behind Construction Yard (VES4).

The National Museum is coming up at Jamia Millia Islamia. The construction has been started. Therefore, it is necessary to know the groundwater level and water-bearing strata at the site, so as to plan for water supply from groundwater. The second site was chosen to do the

ground truthing of the geophysical investigation. The third and fourth sites were identified to know the water level variation and the impact of the injection well located in the neighborhood area. The sites have been depicted in a map shown in Fig. 1.

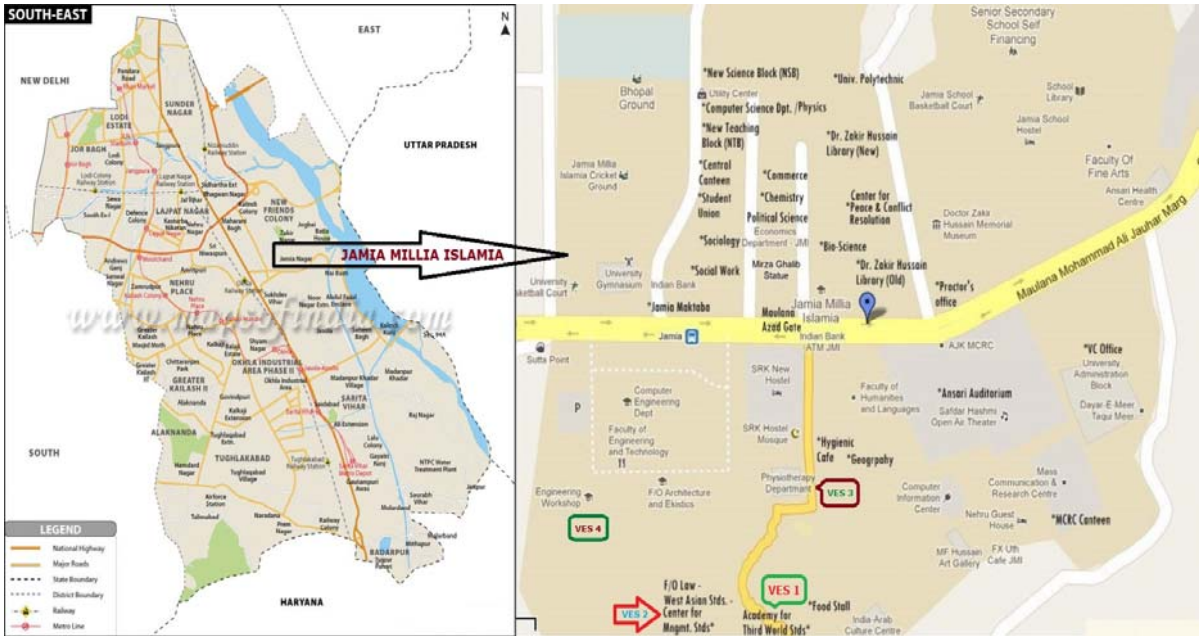

Figure (1): Map of south-east Delhi depicting the study area (various VES sites)

Geology of the Study Area

The study area is located in the south district of Delhi NCR which has an areal extent of 250 sq km and a population of 22.58 lakhs (as per the census, 2001). The district is occupied by diversified geological formations consisting of unconsolidated newer and older alluvium and quartzites of Delhi Supergroup. Quartzite rocks which occupy the maximum part of the south district have limited source of available groundwater confining largely to fracture planes and the weathered zone/mantle. Yield potential of the fracture zones varies from 100 to 200 lpm. The older alluvium in the Chattarpur basin consists of predominantly sand with subordinate silt, clay and kankar. The thickness of alluvium is highly variable because of the presence of subsurface ridges and faults in the district. Except along the river Yamuna, groundwater level in the district is declining with rates varying between 1 and 4m per annum. With a few pockets in the district, the rate of decline has been recorded to be from 3 to 4m *per annum*, which is very alarming. This rapid declination in groundwater levels can be attributed to:

a) The rapid pace of urbanization, leading to a reduction in recharge of aquifers.
b) The increasing demand in agriculture and industrial sectors as well as domestic needs for the ever growing population.
c) A change in cropping patterns in order to raise cash crops in certain areas.
d) The stress laid on groundwater extraction during drought periods when all other sources shrink.
e) Unplanned withdrawal from subsoil aquifer.

Terrameter (Equipment Used for Geophysical Survey)

For field investigation, the TERRAMETER SAS 1000/4000 has been used. SAS stands for Signal

Averaging System; a method whereby consecutive readings are taken automatically and the results are averaged continuously. SAS system results are more reliable than those obtained using single-shot systems. SAS 1000/4000 systems can be used for resistivity surveys, IP surveys,… etc. (See Fig. 2).

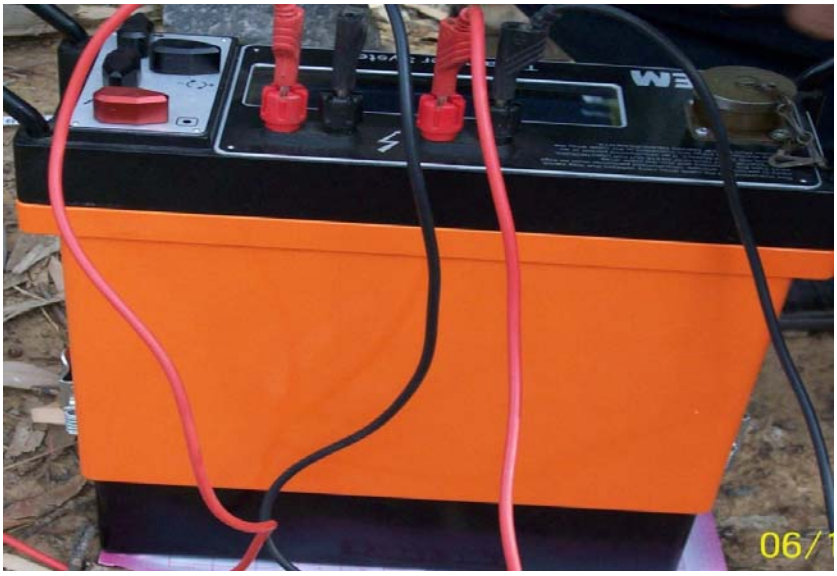

Figure (2): Pictorial representation of terrameter

Electrode Configuration

In the present study, two electrode configurations; namely, Schlumberger and Wenner configurations, were used at all the VES sites except at VES site 2. The spacing of electrodes, as well as the ratio of the spacing between current electrodes and potential electrodes, were kept as recommended in the literature. Data was collected through field investigations during June 2016. The field data collections are demonstrated in Figs. (3-5).

Figure (3): Field investigation near Academy of Third World Studies (VES1)

Figure (4): Field investigation behind Construction Yard (VES4)

Figure (5): Field investigation near Centre for Physiotherapy (VES3)

RESULTS AND DISCUSSION

Keeping in view the problem of water scarcity in the National Capital Region (NCR) of Delhi, the present study was designed to estimate the groundwater potential at JMI campus based on electrical resistivity method. Four sites were identified at JMI campus for electrical soundings; one for ground truthing, one for

estimation of groundwater table and water-bearing strata and the other two to know the impact of the injection well located at JMI campus. The soundings were carried out with terrameter SAS 100/4000 using Schlumberger and Wenner configurations.

After finishing the field investigation, data stored in the terrameter was transferred to the computer with a serial cable. The terrameter SAS 1000/SAS4000 utility software was used to interface the terrameter and computer. The utility software also converts the file format from binary to other formats such as ASCII that can be read by most utility software. Data was processed and analyzed with 1X1D version 2.13 software. This software allows for forward and inverse modeling of resistivity data from Schlumberger, Wenner, dipole-dipole, pole-dipole and pole-pole arrays. The software also allows data to be imported from generic ASCII or other files. It permits for forward and inverse modeling for layered (1-D) models, equivalence analysis and automatic estimation of layered and smooth models. The variation of apparent resistivity *versus* electrode spacing for all the sites is given in Figs. (6-12). The layered models are shown in Figs. 13 and 14. The expected lithology for all the sites is given in Tables (1-4).

Table 1. Expected lithology at VES 1 (near third world studies site)

Depth (m)		Expected lithology	Water availability
from	to		
0.0	0.7	Silty sand with moisture	Moisture
0.7	3.8	Silty sand	--
3.8	10.5	Fine to medium sand	--
10.5	11.1	Fine to medium sand	Fresh water
11.1	18.5	Medium sand	Fresh water
18.5	onwards	Medium sand with gravel and water	Fresh water

Table 2. Expected lithology at VES 2 (near pumping well site)

Depth (m)		Expected lithology	Water availability
from	to		
0.0	1.4	Silty sand with moisture	Moisture
1.4	18.3	Silty sand	--
18.3	47.6	Fine to medium sand	Fresh water
47.6	onwards	Sand with gravel	Fresh water

Table 3. Expected lithology at VES 3 (near physiotherapy centre site)

Depth (m)		Expected lithology	Water availability
from	to		
0.0	0.4	Silty sand with moisture	Moisture
0.4	4.5	Silty sand	Moisture
4.5	17.5	Silty sand	--
17.5	onwards	Fine to medium sand	Fresh water

Table 4. Expected lithology at VES 4 (behind construction yard site)

Depth (m)		Expected lithology	Water availability
from	to		
0.0	0.5	Silty sand with moisture	Moisture
0.5	1.3	Silty sand with kankar	--
1.3	3.1	Silty sand with clay	--
3.1	4.5	Silty sand with kankar	--
4.5	16.1	Fine sand	--
16.1	50.1	Fine to medium sand	Fresh water
50.1	onwards	Hard strata	--

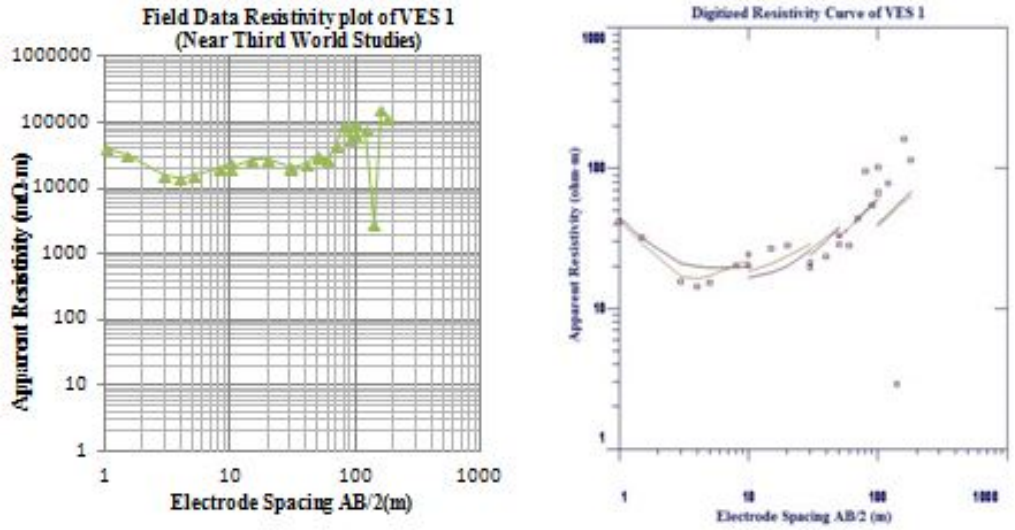

Figure (6): Field and digitized apparent resistivity data curves of VES1 with Schlumberger array

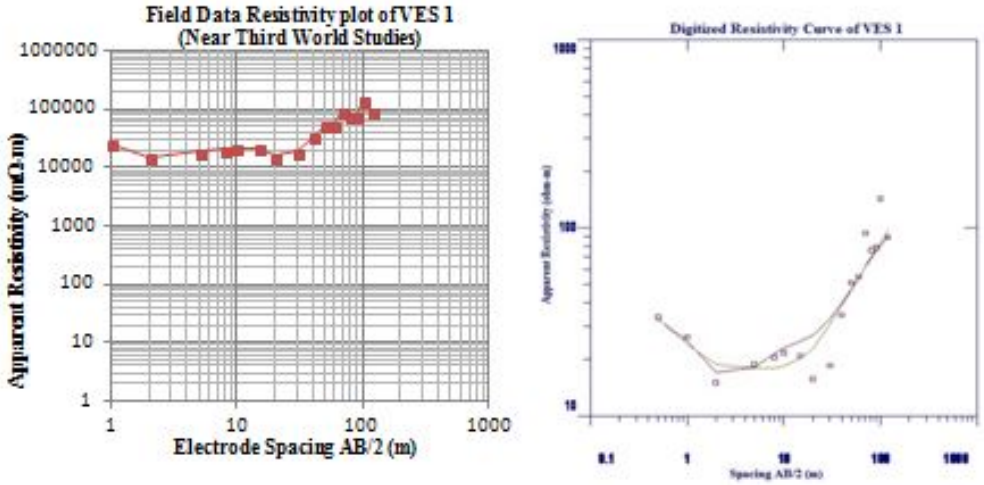

Figure (7): Field and digitized apparent resistivity data curves of VES1 with Wenner array

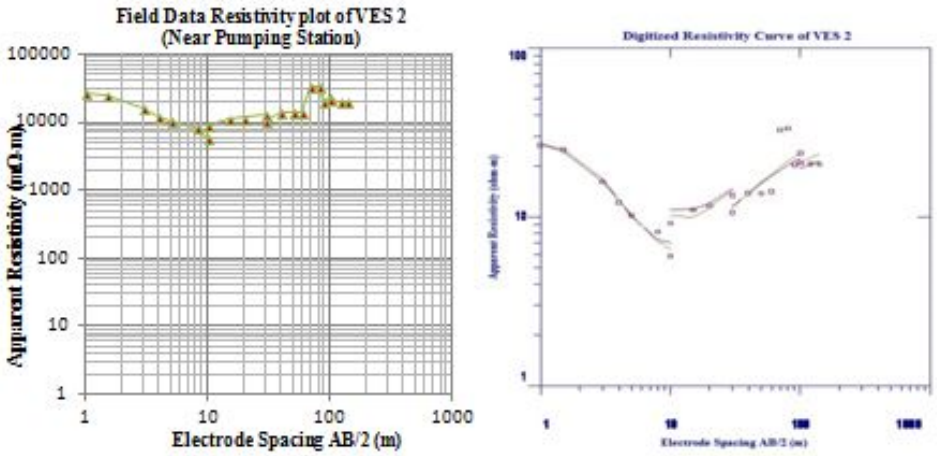

Figure (8): Field and digitized apparent resistivity data curves of VES2 with Schlumberger array

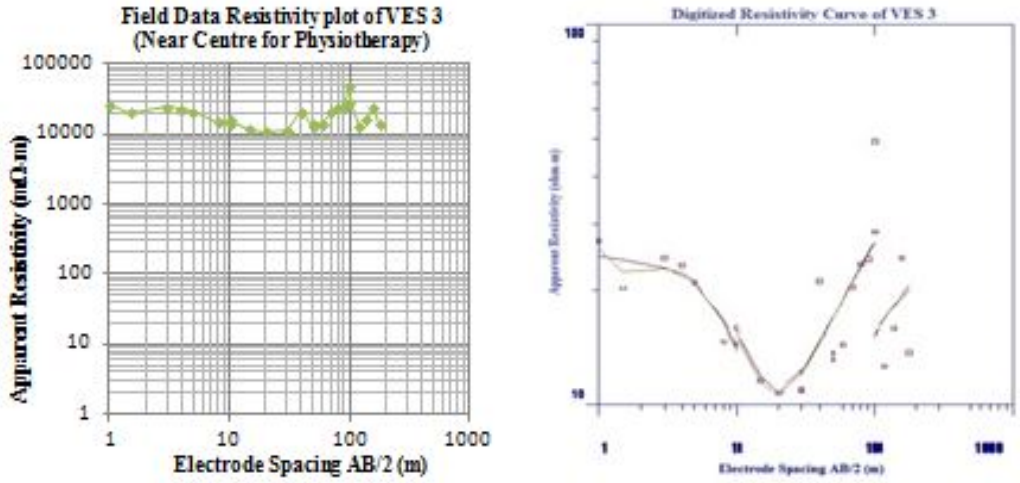

Figure (9): Field and digitized apparent resistivity data curves of VES3 with Schlumberger array

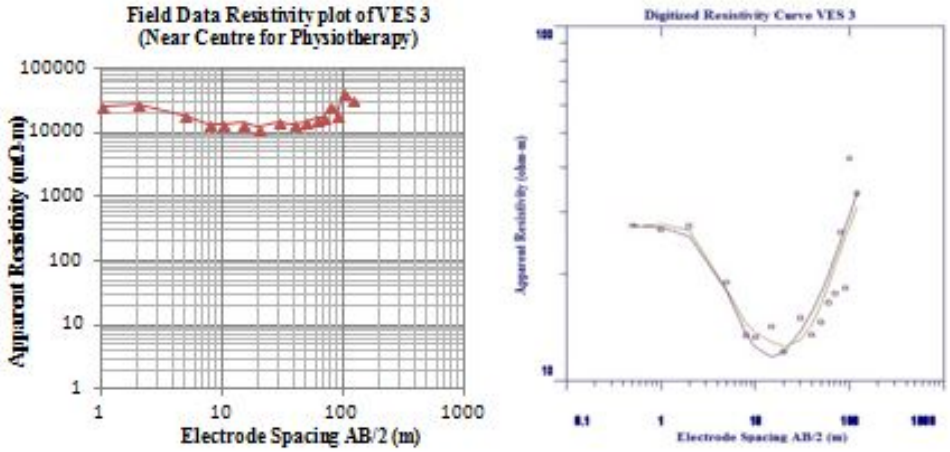

Figure (10): Field and digitized apparent resistivity data curves of VES3 with Wenner array

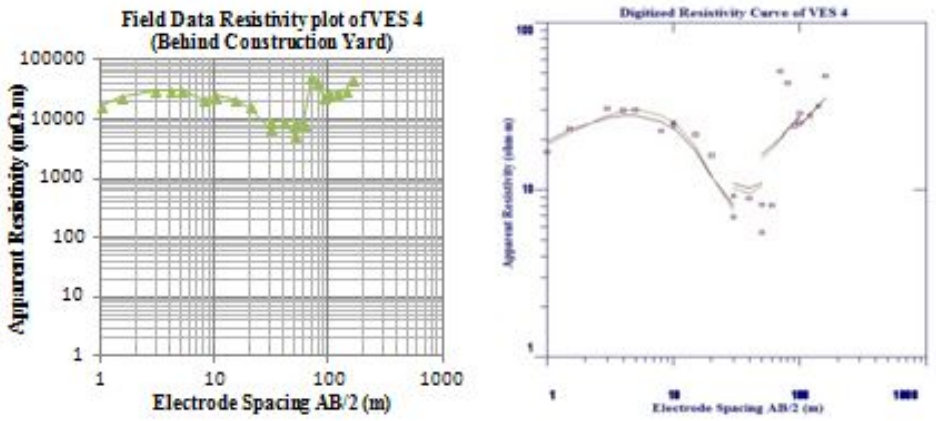

Figure (11): Field and digitized apparent resistivity data curves of VES4 with Schlumberger array

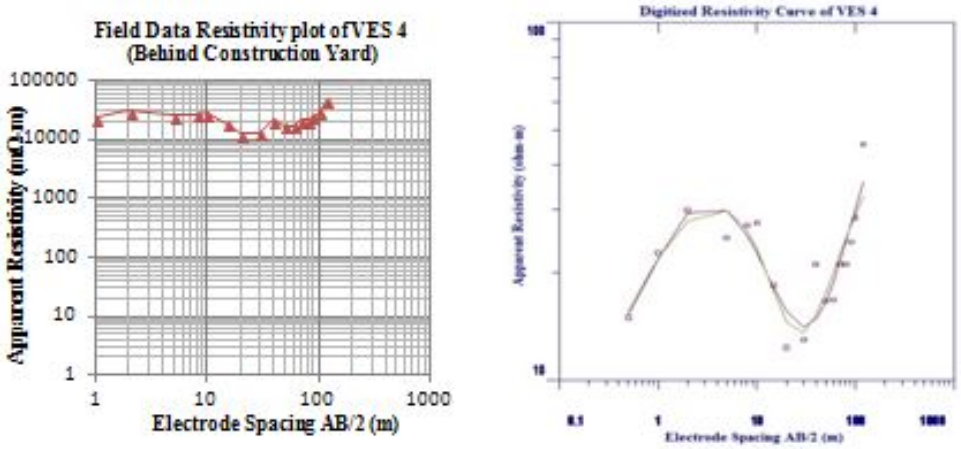

Figure (12): Field and digitized apparent resistivity data curves of VES4 with Wenner array

The VES measurements provided a series of apparent resistivity *(ρ_a)* values as a function of electrode spacing (a resistivity sounding curve) at each site. The variation of apparent resistivity indicates the existence of zones of contrasting resistivities. Accordingly, VES was applied at the 4 sites (VES1, VES2, VES3 and VES4). Field data and digitized data are represented as resistivity curves by log-log graphs (Figs. 6-12) for both Schlumberger and Wenner electrode configurations. The digitized data of the reduced field curve was inverted and interpreted using the inversion technique developed by Zohdy (1989) to obtain the equivalent layered model. The layered model consists of a number of horizontal geoelectric layers comparable with the number of measurements, which describe the sounding curves.

It is known that the resistivity of a formation largely depends on the moisture content and on the physical and chemical properties of the saturating water. After the analysis of the field, VES data was recorded at each location and the variations of the resistivity values with depths were correlated with the geological succession of the area under study. It is noted that this area, being part of the Delhi NCR, is composed of gravel or gravel-sand mixtures. Alluvium deposits represent the upper part of the sedimentary cover as a result of weathering.

Therefore, the resistivity of this part of alluvium varies from 10 to slightly more than 100 ohm-m. Beneath this part, there are semi-permeable hard strata with different grain sizes, suitable for water accumulation according to the water table equilibrium. The layers having low resistivity imply less dense or loose strata in the region.

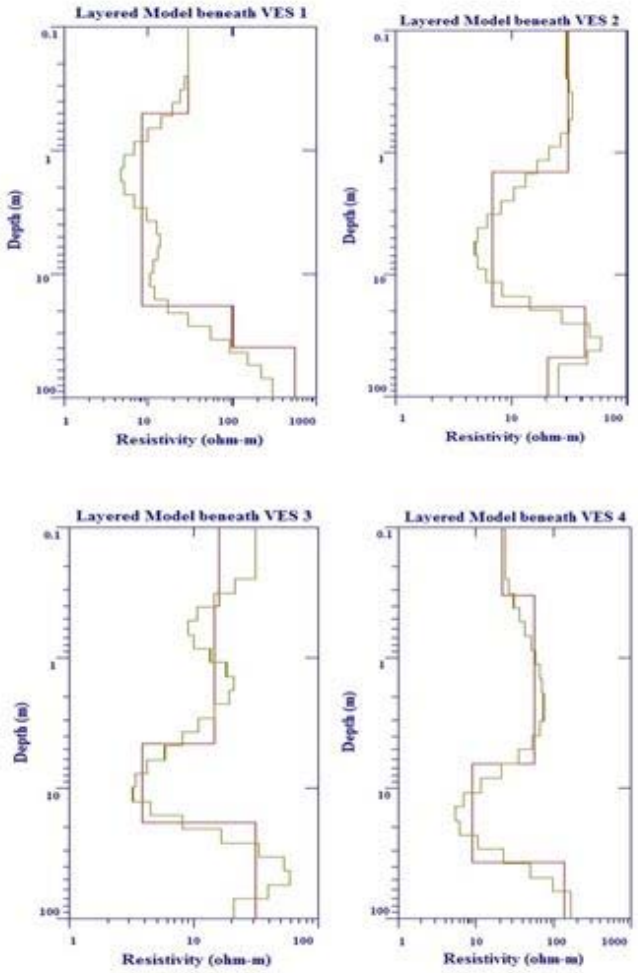

Figure (13): Geoelectric layered model beneath VES1, 2, 3 and 4 (Schlumberger array)

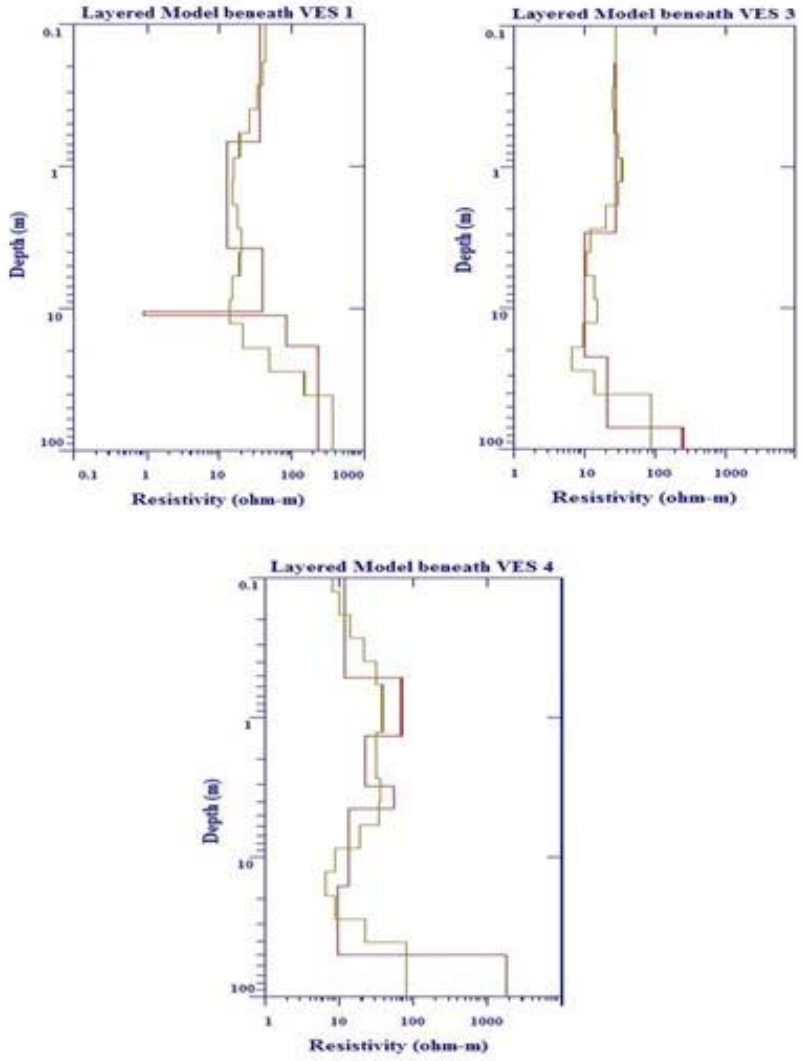

Figure (14): Geoelectric layered model beneath VES1, 3 and 4 (Wenner array)

Figs. (6-12) show the apparent resistivity field and smooth curves of the data obtained at the 4 sites. These curves indicate a decreasing to increasing trend for resistivity with increasing electrode spacing or depth. This shows that the surface of highly resistant basement rocks is still deeper than the maximum depth penetrated by the available system, especially with increasing the silt content of certain alluvium layers. The alluvium cover may be overlying low-resistivity beds, rich in silt or sand content. The alluvium cover can be classified further into different ranges of thickness; the upper part has lower resistivity values which correspond to zones partially or totally saturated with water, while the lower part has higher resistivity values, where the layers are mostly unsaturated. This is shown in Figs. 13 and 14 which illustrate the interpreted subsurface geoelectric layering models considered to be under the VES1, VES2, VES3 and VES4, which were conducted in the Jamia campus. The results determine the depth of the lower resistivity part of alluvium section which

increases in the downstream direction.

The indications of the presence of groundwater saturation zones were observed under all the VES stations, where the depth for groundwater table (GWT) was found as 10.5 m at VES1 which contains sufficient water-bearing strata. Also, the soil layer changes from fine to medium sand with the certain amount of gravel present in the layer when moving deeper. The results at pumping well (VES2) indicated the groundwater table at a depth of about 18.3 m going to a depth of 47.6 m. At the time of installation of the pump, the groundwater table was about 15.5 m. The variation at VES 2 is about 20 percent from the values observed, which may be attributed to the slow but gradual decline of GWT at the site due to pumping. According to Central Groundwater Board Studies in the year 2002, the GWT was usually available at a depth varying from 10 to 20 m in the study area. This also substantiates the findings of GWT in the present study. The GWT values at VES 3 and 4, adjacent to the injection well, are 16 - 17.5 m higher than at the pumping well site (VES2). The higher GWT may be attributed to the injection well, as there was rainfall before the observation day. The lithology at VES4 showed a dissimilar behavior, where the depth for saturated zone starts at 16.1 m and ends at 50.1 m beyond which hard strata have been detected. The quantitative interpretation of the VES shows that the potential occurrence of groundwater is located at VES 1. The interpretation for the expected soil layers (lithology) with the possibility of saturation zones is shown in Tables (1-4) with respect to each VES station.

CONCLUSIONS

In this study, electrical resistivity method using VES survey was carried out at four locations in the study area using the Schlumberger and Wenner electrode arrays with a view to understand the subsurface geologic settings that could guide the successful exploration of groundwater. Among all four locations, one was used for ground truthing, one for estimation of groundwater table and water-bearing strata and the other two to know the impact of injection well located at JMI campus. Analysis of the interpreted results revealed the nature and composition of the subsurface lithologic units. The results of the electrical resistivity method indicate that the groundwater table at the pumping well lies at a depth of about 18.3 m and goes to a depth of 47.6 m. At the time of installation of the pump, the groundwater table was at about 15.5 m. The variation is about 20 percent of the observed values and may be attributed to the slow but gradual decline of GWT at the site due to pumping. According to Central Groundwater Board Studies in the year 2002, the GWT was usually available at a depth varying from 10 to 20 m in the study area. This also substantiates the findings of GWT in the present study. The GWT values at VES3 and 4, adjacent to the injection well, are 16-17.5 m higher than at the pumping well site (VES2). The higher GWT may be attributed to the injection well, as there was rainfall before the observation day. The GWT at the VES1 was estimated at about 11 m and carries sufficient water-bearing strata. The study revealed that sufficient water was available near VES1 and VES2 as compared to other sites and the objective of the study was accomplished with substantial findings which further corroborate the effectiveness of the approach adopted for groundwater exploration.

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