

GEOPHYSICAL AND HYDROGEOCHEMICAL EVALUATION OF A SPRING IN ADO-EKITI, SOUTH-WESTERN NIGERIA

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ABSTRACT

Very Low Frequency Electromagnetic (VLF-EM), Electrical Resistivity (ER) hydrogeological, hydrochemical and hydrobiological methods were used to evaluate a spring with a view to determine its feasibility for development in Ado Ekiti, South-western, Nigeria. Three-200 m long traverses and one 120 m long traverse cutting through the three traverses were established with stations at 5 m intervals. Components of the VLF-EM and ER were measurements were conducted. The ER utilized pole-pole and Schlumberger electrode arrays for profiling and Vertical Electrical Soundings (VES) respectively. A hand-dug well was sited at higher elevation and ten meters away from the spring. Microbial and physicochemical analyses were conducted on water samples from the spring and the well. The yield of the spring was determined using the "below-ground" method. The VLF-EM results indicated the relatively conductive zones suspected to be faults/fracture zones while the VES interpretation results delineated three main lithologic layers which include the topsoil, weathered layer and the basement bedrock. The resistivities and thicknesses of the topsoil and weathered layer varied from 116 m to 1710 m, 69 m to 96 m and 0.51 m to 1.19 m and 3.95 m to 9.17 m respectively. The fresh basement bedrock had resistivity > 1000 m. The Total Heterotrophic Bacteria count was 1.8×10^5 CFU/ml and fungal and Coli counts were 1.0 CFU/ml each in the spring. The TDS and pH were 60 mg/l and 8.00 respectively while the cationic concentrations of the metals were 0.014, 1.758, 0.020, 0.013, 0.0773, 0.808, 3.558, 8.79, 0.0651, 0.237, 0.001, and 0.007 mg/l for Cr^{2+} , Fe^{2+} , Cd^{2+} , Zn^{2+} , Ni^{2+} , Mg^{2+} , K^+ , Na^+ , Pb^{2+} , Ca^{2+} , Mn^{2+} and Cu^{2+} respectively in the spring. The yield was 0.021 L/s. The study concluded that though the yield of the spring was relatively low, its quality is good enough and its development was feasible.

Keywords: Spring, Measurements, Analyses, Yield, Feasibility, Development.

INTRODUCTION

Water is one of the most important substances on earth. All plants and animals must have water to survive. Accessing pure, clean and safe or potable water is of primary concern to individuals, organizations and governments alike. Water can occur on the earth's surface as streams, lakes, glaciers, seas and oceans all of which are referred to as surface water or as ground or subsurface water (Fetter, 2001). About 94% of the world's water is found in the oceans, both as liquid water and as glaciers and about 4% of the earth's water is present in the subsurface as groundwater (Hamill and Bell, 1986).

In the last 50 years there have been unprecedented developments of groundwater resource. At a regional level, groundwater is of huge importance in Africa, Asia and Central and South America. An estimated 2 billion people worldwide rely on aquifers for their drinking water supply (Hamill and Bell, 1986). Groundwater is less susceptible to bacterial pollution than surface water. This is because the soil and rocks through which it flows

screen out most of the bacteria. Generally, microbial load of groundwater is significantly low and very rarely exceeds the tolerable level (Davis and Dewiest, 1996).

Groundwater exist in pores between sedimentary particles and in the fissures of crystalline rocks and can occur as springs when the water table intersects the earth surface or the fissure is exposed to the earth surface. A spring (also known as a rising, seep or resurgence) is a component of the hydrosphere. Specifically, it is any natural situation where water flows to the surface of the earth from the subsurface. Springs have always been used as a water supply and catching a spring is an age old long skill requiring a high degree of expertise and experience. The spring is captured at the point it emerges at the surface and the water is collected into a specially prepared surface or sealed collection chamber to prevent contamination from surface run-off and vermin. The water quality is usually good, but less dependable than a borehole as it can come in contact with contaminants and surface water. To

ensure the quality is fit for consumption and other domestic activities, physico-chemical and microbiological analyses of the water is necessary. The evaluation of groundwater resource in terms of quantity and quality are of equal importance (Hamill and Bell, 1986). In other words, the physical, chemical and biological characteristics of the water are of major importance in determining whether or not water is suitable for domestic, industrial or agriculture uses.

Spring source characterization and accurate delineation of capture zone is critical to the design of an effective water exploitation and management strategy. Geophysical exploration techniques provide the means of gaining an insight to the nature of subsurface water bearing layers. In this study, geo-electric and electromagnetic methods and hydrogeochemical

analyses were used to investigate a perennial spring site in Ado Ekiti, Ekiti State, South-western Nigeria in order to determine the feasibility of its development to augment the existing water supply schemes, in the area.

Location, Geology, Geomorphology, Climate and Hydrogeology of Site

The investigated site is located in Ado Ekiti, Nigeria (Fig.1). It lies between Latitudes 738'42"N and 738'47"N and Longitudes 513'05"E and 513'10"E. Geological investigations in the site revealed that the area is underlain mainly by charnockitic rocks (Fig. 2) which were cut by relatively thin roughly parallel bands of quartzite. The superficial materials which are mainly sand, clay and quartz rumbles covered the structural elements on the site except the quartzitic veins which were exposed in some places by erosion.

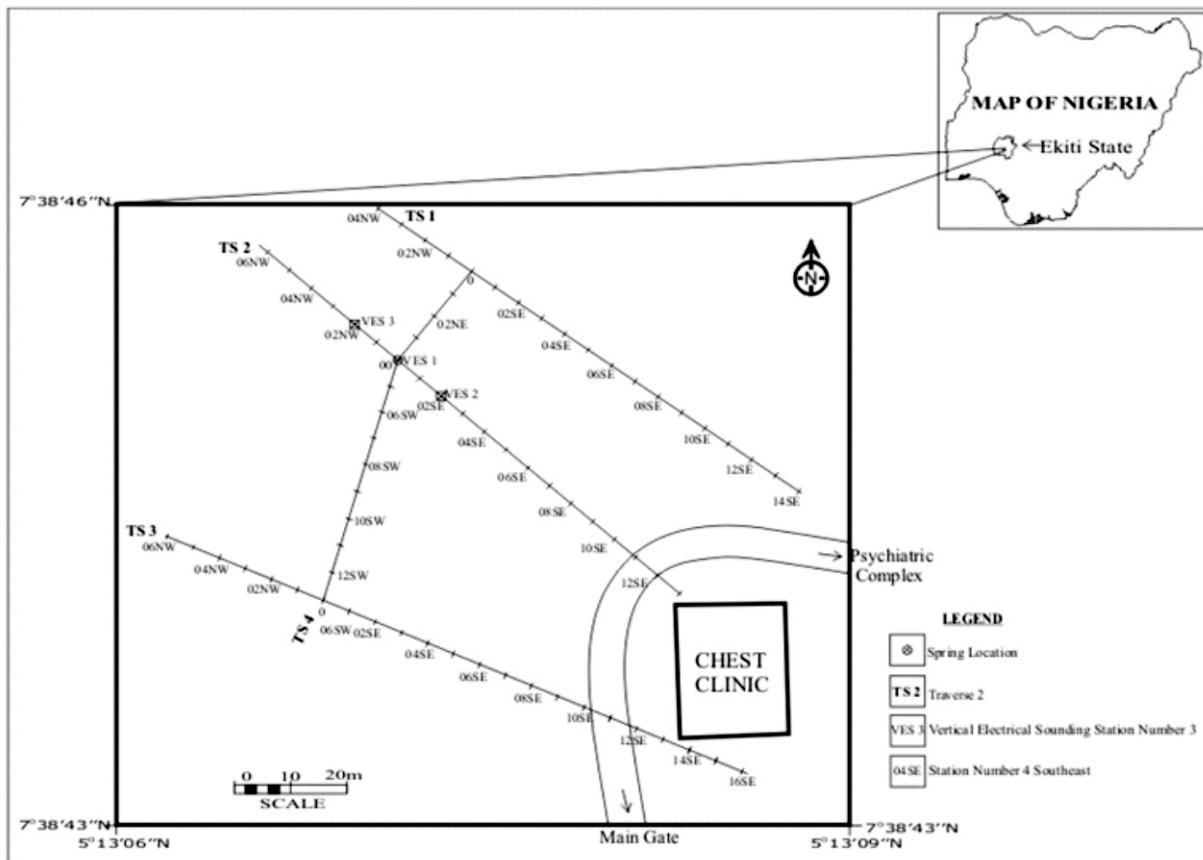


Figure 1: Sketch Map of the of Study Area Showing the Traverses and Stations (Inset: Map of Nigeria)

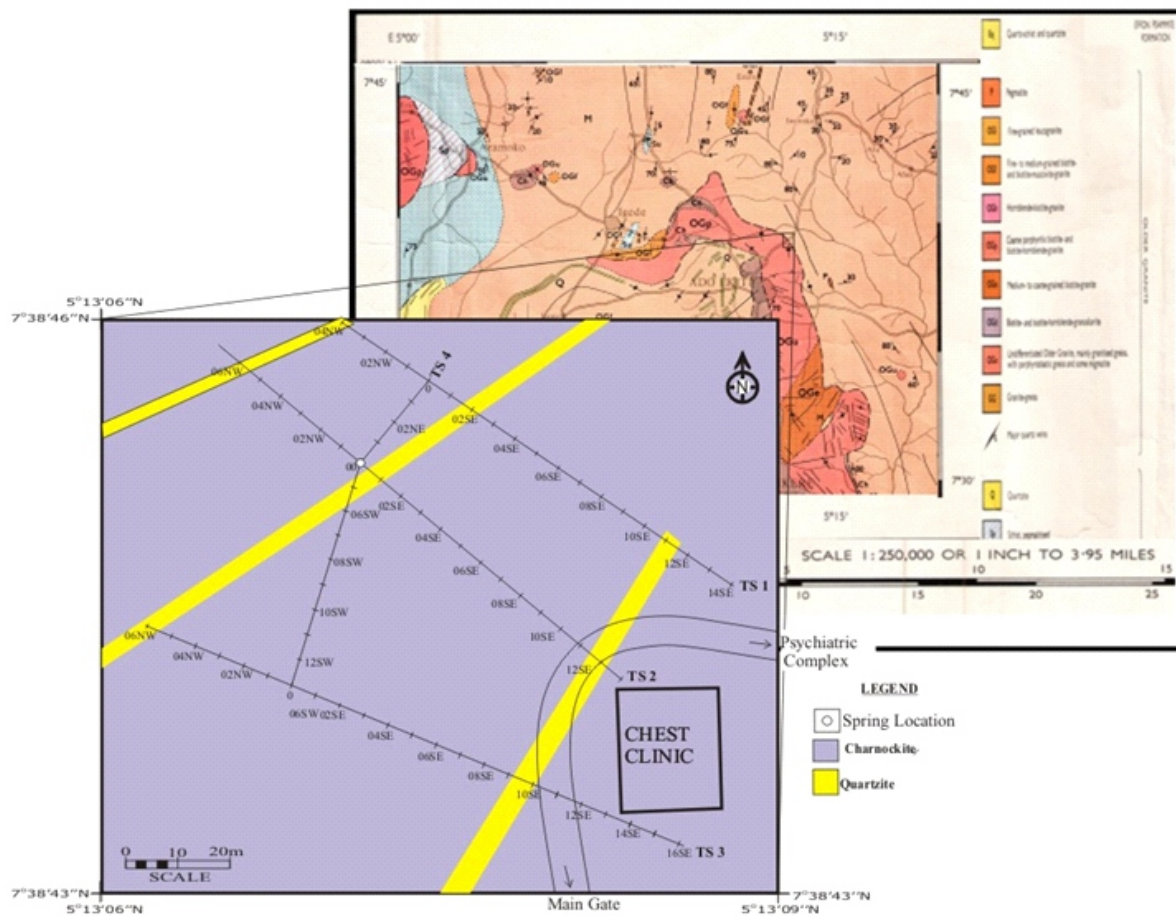


Figure 2: Geologic Map of the Area of Study Showing the Main Rock Types, (Inset: Geological Map of Ado Ekiti and Environs., Modified from Ogundana and Talabi, 2014)

Ado Ekiti lies on a low-land surrounded several hills and inselbergs. The area of study is characterized by rugged topography arising from the charnockite and quartzite ridges which rise abruptly above the surrounding country rocks. Ado Ekiti has a humid tropical climate with two distinct seasons; the rainy and dry seasons. The rainfall ranges between 50.8 mm during the driest months to 2413.3 mm in the wettest period with a mean annual rainfall of about 1500 mm (Babatunde *et al.*, 2007). The amount of rainfall is moderately high while the rate of transpiration is average. The area is drained by River Ireje, Elemi, and Oisanjana and Awedele stream. They flow into River Ose and River Owena which empty into the Atlantic Ocean. The main source of input is atmospheric precipitation and they are seasonal in terms of volume discharge. The availability of groundwater is also affected by factors such as topography, climate, geology, hydraulic properties of rocks (porosity and permeability), geologic structures (faults and joints) and proximity to large

water bodies. It has been shown by several studies (Olayinka & Barker, 1990; Badmus & Olatinsu, 2012; Omosuyi and Oyemola, 2012, Ariyo & Adeyemi, 2009 and Olorunfemi, 1990) that deep weathering is the most important single factor in the hydrogeology of the basement complex with the development of thick regolith providing high storage and the presence of underlying fractured basement providing high transmissivity.

METHOD OF STUDY

The study involved the electrical resistivity and Very Low Frequency Electromagnetic geophysical methods, physico-chemical and microbiological analyses. Geophysical data acquisition was conducted along four traverses out of which three run NE-SW and spaced 50 m apart. The fourth cut across the three and runs through the 'eye' of the spring. Measurement stations were spaced at 5 m apart along all the four traverses. The length of the traverses varied from 130 m to 220 m. Electrical resistivity

measurements were conducted using ABEM SAS 300C Terrameter. The techniques of the electrical resistivity method were horizontal profiling (HP) and Vertical Electrical Sounding (VES). The Pole-pole electrode array and the Schlumberger array were utilized for the HP and VES respectively. The electrode spacing (a) was 10 m in the HP while $AB/2$ was varied from 1 m to 100 m in the VES data acquisition. The HP data were interpreted qualitatively while the VES data interpretation involved the partial curve matching and computer assisted 1-D forward modelling with the Winglink version 1.62.08 software.

The Scintrex ENVI VLF Receiver was used to acquire the in-phase (real) and out-of-phase (quadrature) components as percentage of the total field at each station. The real components of the VLF - EM data were filtered using the Frazer (1969) filter. The real and quadrature data as well as the filtered data are presented as profiles and interpreted qualitatively by visual inspection of the profiles and quantitatively by 2-D inversion using the Hfilt software developed from the Karous Hjelt (1983).

Water samples were collected at the spring and from a hand dug well located 10 m away from the spring and at a higher elevation. The microbiological parameters determined were Total Heterotrophic Bacteria (THB) at 37°C, Total Fungal Count (TFC) at 30°C and coli at 37°C. The physico-chemical parameters determined are pH, Total Dissolved Solids (TDS) and cations concentrations which included those of calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}), potassium (K^+), zinc (Zn^{2+}), cadmium (Cd^{2+}), lead (Pb^{2+}), iron (Fe^{2+}), manganese (Mn^{2+}) and chromium (Cr^{2+}).

The microbial and chemical analyses were carried out at the Department of Zoology Laboratory and the Central Science Laboratory, Obafemi Awolowo University, Ile-Ife respectively. The method adopted for the yield determination of the spring in the current study is referred to as the “below ground” method.

RESULTS AND DISCUSSION

(a) Electrical Resistivity

The resistivity values varied from 152 to 335 Ωm , 105 to 340 Ωm , 89 to 465 Ωm and 151 to 190 Ωm respectively along Traverses 1 to 4 (Fig. 3). Along Traverse 1, the resistivity varied over a narrow range averaging 280 Ωm and decreased to less than 200 Ωm between 55 m and 70 m SE with a minimum at 65 SE. Along Traverse 2, the resistivity gradually decreased from 470 Ωm , first sharply at around 5 m SE to 270 Ωm and then gradually to 130 Ωm on the south-eastern end. Traverse 4 presented a relatively flat profile or resistivities averaging 160 Ωm . The variation in resistivity seem to mirror the topography.

The VES curves obtained along Traverse 2 are H and KH types (Fig. 4). The interpretation results (Table 1) were used to produce a 2-D image of the subsurface in the area (Fig. 5). Three main layers were delineated. The first layer has thicknesses varying from 0.5 m to 1.2 m and resistivity values varying from 116 Ωm to 1710 Ωm . This is the topsoil. The weathered layer has thickness varying from 4.0 m to 9.2 m and resistivity values varying from 69 Ωm to 96 Ωm . The third fresh bedrock layer has resistivity greater than 1000 Ωm .



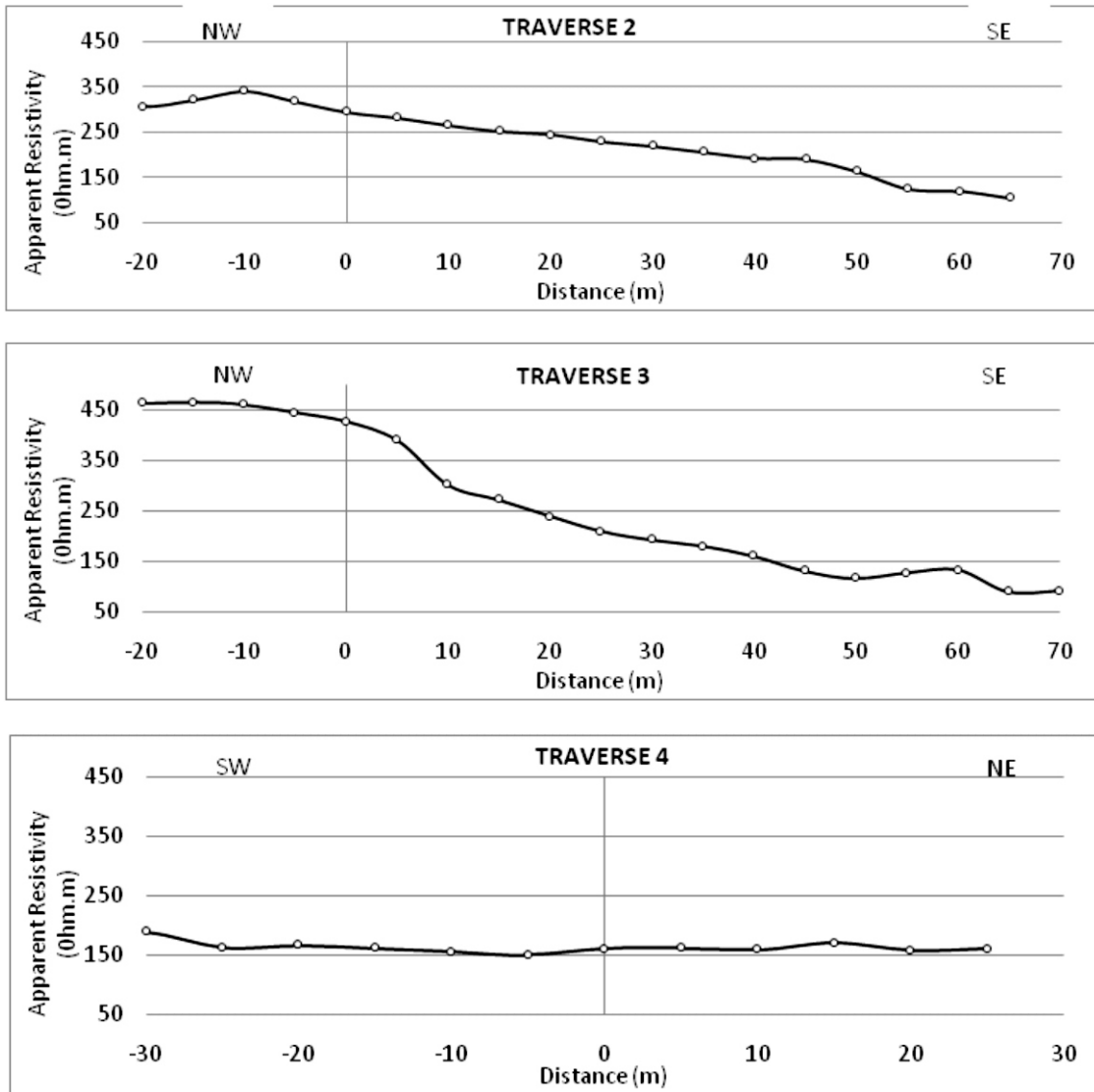
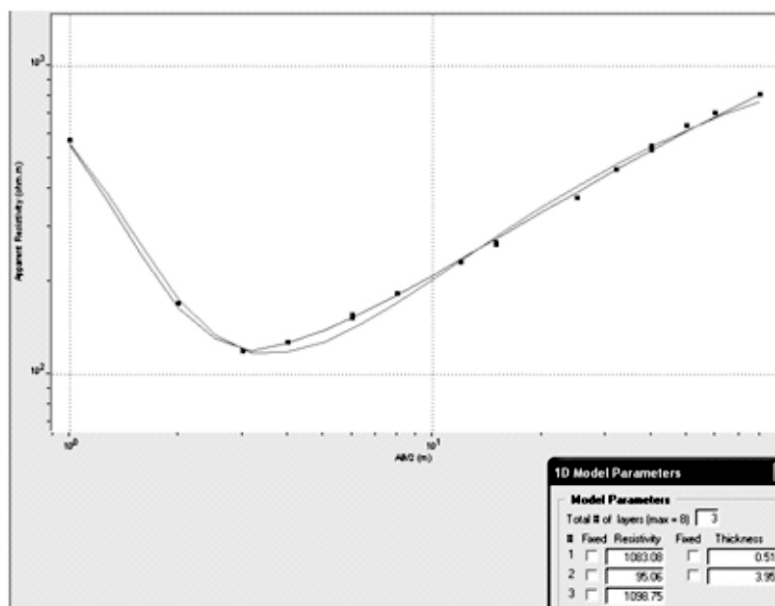


Figure 3. Pole-pole Electrical Resistivity Profiles on Traverses 1 to 4.



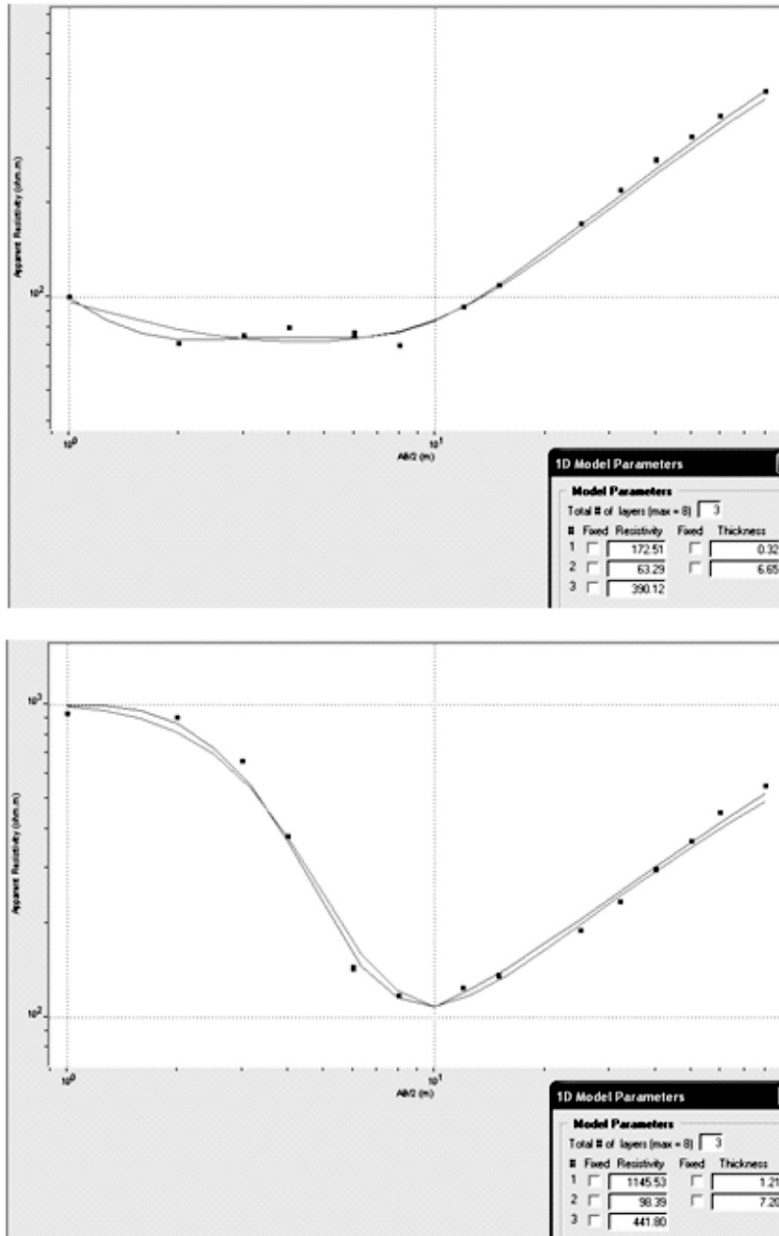


Figure 4. Field VES Curves and Model Parameters of VES 2, VES 1 and VES 3 (from Southeast to Northwest).

Table 1. VES Interpretation Results

| VES Station Number | Thicknesses (m) $H_1/h_2/h_3/.....h_{n-1}$ | RESISTIVITIES (ohm-m) $\rho_1/\rho_2/\rho_3/.....\rho_n$ | Type Curve |
|--------------------|---|---|------------|
| 1 | 0.51/9.17 | 116/69/1513 | H |
| 2 | 0.41 / 0.78 / 7.59 | 839 / 1710 / 80 / 1057 | KH |
| 3 | 0.51 / 3.95 | 1084 / 96 / 1099 | H |

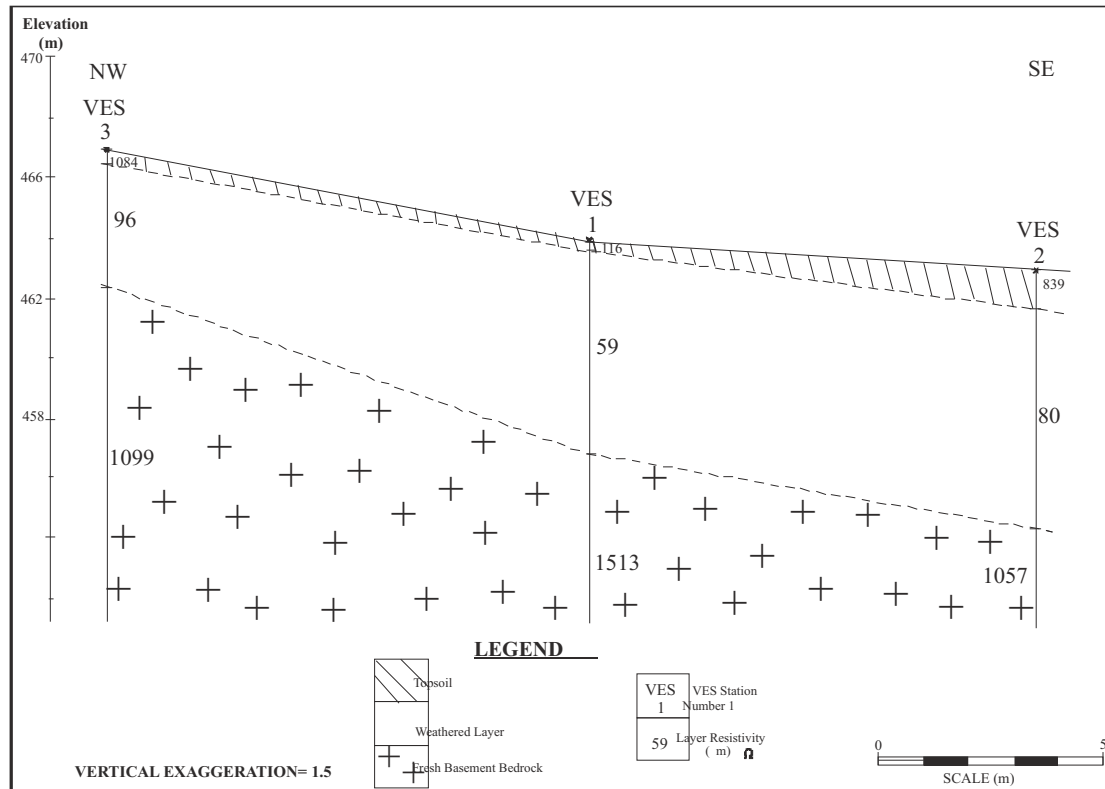


Figure 5: Geoelectric Section Along VES 1 to VES 3 Stations on Traverse 2

(b) Very Low Frequency Electromagnetic (VLF-EM)

Zones with peak positive Fraser-filtered real (Fig. 6) are considered indicative of zones with relatively higher conductivity typical of fractures, faults or rock contacts. These zones are from 20 m to 30 m SE, 10 m to 25 m SE and 20 m to 30 m SE, 22.5 m and 30 m to 25 SW along Traverses 1 to 4 respectively. The filtered real colour map (Fig. 7) shows a major NW–SE and two parallel NE–SW trending peak positive real axes suspected to be fracture zones. One of the NE–SW faults may have acted as a conduit for the water emanating to the surface as spring.

(c) Microbial and Physicochemical Analyses and Yield of the Spring

The THB and TFC value ranged from 1.8×10^5 to 5.0×10^4 CFU/ml and 1.0 to 5.0 CFU/ml in the spring and well respectively (Table 2), while the TFC and Coliform Bacilli ranged between 1.0 and 5.0 CFU/ml in the spring and well. The Total

Dissolved Solids (TDS) varied from 60 to 131mg/l in the spring and well and pH varied from 8.00 to 8.14 in the spring and well. The TDS is below the maximum allowable limits of 600 mg/l and the pH falls within the 6.5 and 9.5 limits (WHO, 2006) for drinking water.

Cationic concentrations of various metals - Cr^{2+} , Fe^{2+} , Cd^{2+} , Zn^{2+} , Ni^{2+} , Mg^{2+} , K^+ , Na^+ , Pb^{2+} , Ca^{2+} , Mn^{2+} and Cu^{2+} were 0.014, 1.758, 0.020, 0.013, 0.0773, 0.808, 3.558, 8.79, 0.0651, 0.237, 0.001, and 0.007 mg/l respectively for the spring water and 0.017, 0.172, 0.021, 0.007, 0.0864, 0.867, 3.634, 10.34, 0.0655, 0.267, 0.001, and 0.003 mg/l respectively for the well water. The concentrations of all the cations in both the well and spring were below the WHO, 2006 maximum allowable limits, except Fe^{2+} whose concentration in the spring was above the maximum. Iron concentration in the spring is higher because it is in a reduced state and is more soluble than that of the well. Iron

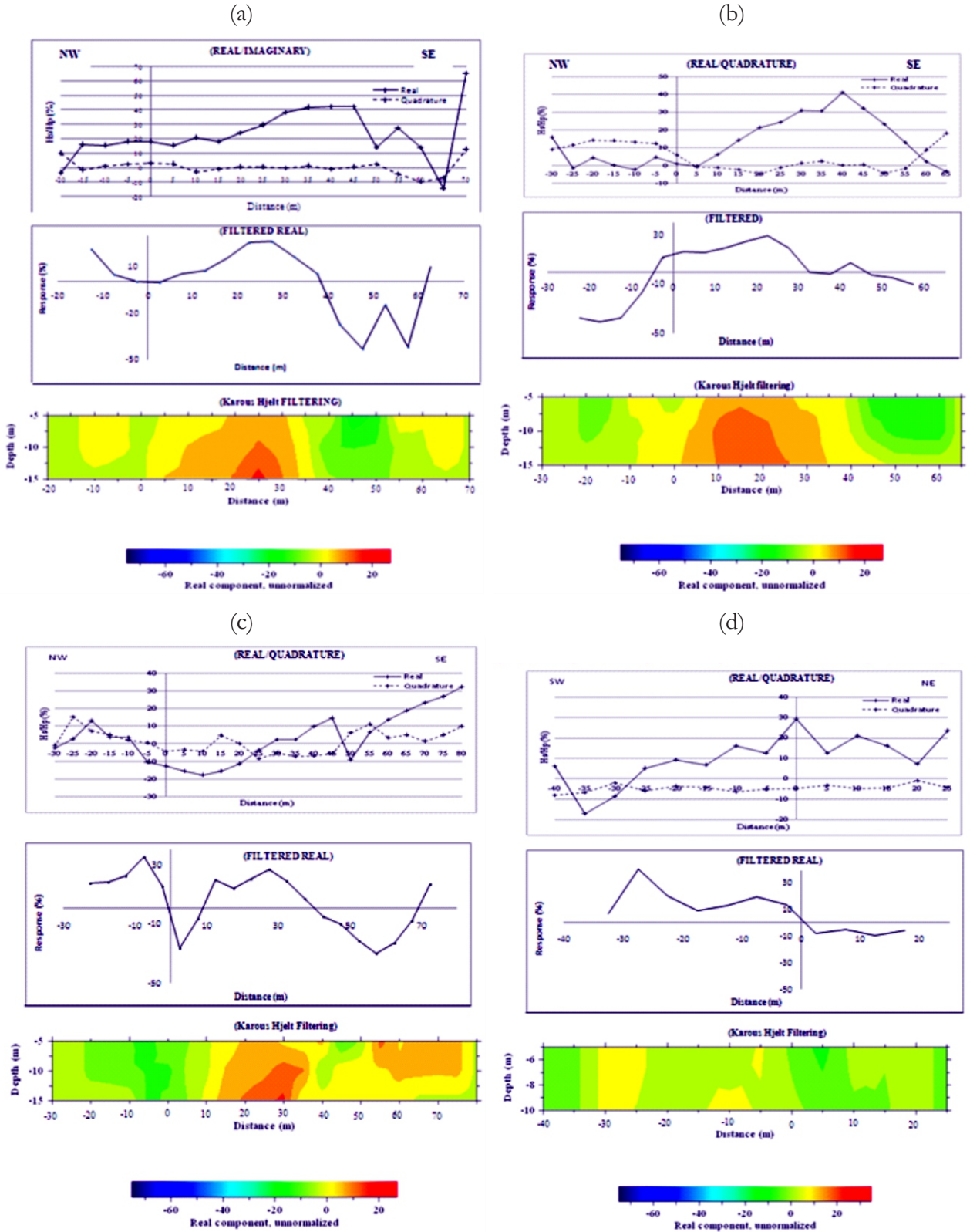


Figure 6. Real/Quadrature, Filtered Real and Karous Hjelt Filtering of (a) Traverse 1 (b) Traverse 2 (c) Traverse 3 and (d) Traverse 4

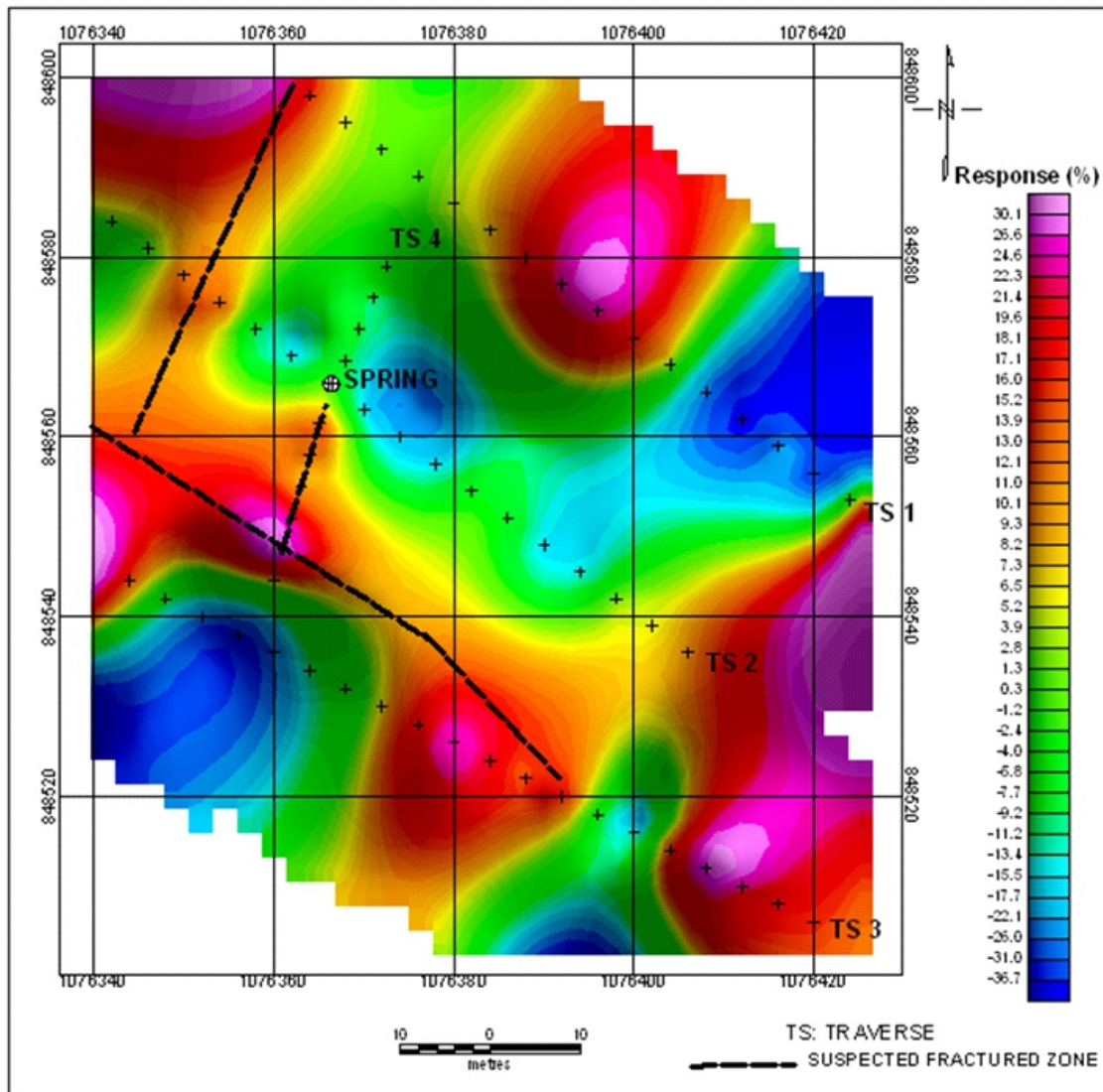


Figure 7. Fraser-filter Response Colour Map.

Table 2: Results of Physical Microbiological Analysis of the Samples

| TEST | SAMPLE A (SPRING) | SAMPLE B (WELL) |
|--|---------------------------------------|---------------------------------------|
| Ph | 8.14 | 8.00 |
| Total Dissolved Solids (TDS) | 60 mg/l | 131 mg/l |
| Total Heterotrophic Bacteria (THB) at 37°C | 1.8 x 10 ⁵ (CFU/ml) | 5.0 x 10 ⁴ (CFU/ml) |
| Total Fungi Count TFC at 30°C | 1.0(CFU/ml) | 5.0(CFU/ml) |
| Coli MPN presumptive at 37 °C | > 1.1 x 10 ³ (Cells/100ml) | > 1.1 x 10 ³ (Cells/100ml) |

makes up 5 % of the earth crust. Rainwater dissolves iron as it infiltrates the soil and underlying geologic formations causing it to seep into aquifers. The yield of the spring was determined to be 0.21 L/s.

CONCLUSIONS

The Electrical Resistivity and Very Low Frequency Electromagnetic methods delineated the geoelectric layers and identified suspected faulted/fractured zones, one of which could have been the conduit for the spring. Although the yield of the spring was relatively low (0.021 L/s) at the time of study, its development was feasible even though the water needed to be disinfected for the removal of pathogenic microbial organism and treated to remove the excessive iron. The yield of the spring could be increased by digging a trench of about 1 m width and 25 m length from the spring southwards along Traverse 4 to depth of about 4 m.

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