ISSN: 2771-7763

Research Article

Journal of Economic Research & Reviews

Groundwater Potential Mapping Using Geophysical Techniques: a Case Study in Hosanna Area, Western Margin of The Central Main Ethiopian Rift, Ethiopia

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Submitted: 2023, June 10; **Accepted:** 2023, July 12; **Published:** 2023, July 27

Citation: Yehualaw, E., Haile, T., Nigusse, W. (2023). Groundwater Potential Mapping Using Geophysical Techniques: a Case Study in Hosanna Area, Western Margin of The Central Main Ethiopian Rift, Ethiopia. *J Eco Res & Rev, 3*(3), 192-195.

Abstract

In this study, Vertical Electrical Sounding (VES) and magnetic methods are applied for mapping the groundwater potential and aquifer system in the Gode area, the western margin of Central Main Ethiopian Rift. The VES is used to map the depth to potential aquifer zone of the groundwater and its distribution over the area, whereas, the magnetic survey is applied to delineate contact between lithologic units and geological structures. A total of 12 VES data points and more than 400 magnetic data points at about 10m station intervals along seven profiles are collected, processed and analyzed. Our results from interpretation of the VES data, geoelectric sections, and 2D magnetic modeling results respectively revealed the vertical stratification of the subsurface geoelectric layers and the presence of subsurface weak zones, which control the groundwater flow and storage system where the potential aquifer in the area obtained at a depth range from 45m to 92m. Overall, areas in the neighborhood of four VES points, i.e.VES-2, -3, -10, and -11, show good water-bearing zones in the study area associated with the highly weathered/fractured ignimbrite and pumice layers.

Keywords: Vertical Electrical Sounding, Magnetic survey, Aquifer, Groundwater Potential, Ethiopia

1. Introduction

Ethiopia is blessed with a comparatively large resource of groundwater which provides more than 90% of the freshwater used for domestic and industrial supply. The occurrence and distribution of groundwater aquifers in Ethiopia depend on various environmental and geological factors and the groundwater potential varies from place to place, sometimes within a few meters and even within the same geological formation [1,2]. Many authors have conducted surveys and implemented mapping techniques to investigate the groundwater potential in different zones [3,4,5]. In these studies, the increased advantage provided by the application of geophysics for groundwater resource mapping and water quality evaluations has increased dramatically over the last few decades [6]. In the most southern regions of Ethiopia, especially in Hadiya Zone, groundwater has paramount importance for primary domestic supply, agriculture, and industrial use. However, the exploration for groundwater done so far is not adequate to solve the problem in relation to the demand for clean water that is continuously raised in the society owing to the continuous increase in population. Moreover, some of the existing boreholes are currently non-functional due to a mixiture of logistical and community empowerment problems making the water scarcity even more acute. In this regard, identifying the potential of the aquifer system in the Gode area, which is the main target of this study, is expected to provide a vital role to satisfy the demand for clean water as well as to minimize the risk of sinking dry boreholes at inappropriate locations in Hosanna town and its surrounding rural areas. This was achieved by using combined Vertical Electrical Sounding (VES) and magnetic prospecting geophysical techniques as these enable one to obtain information on subsurface distribution and extent of the aquifer zones.

Hosanna town is a part of the Southern Nation Nationalities and People's Regional State (SNNPRS) of Ethiopia, situated in the Hadiya Zone; and is located 230 km away from Addis Ababa in the Central Main Ethiopian Rift (CMER). It is geographically located at 833500 North and 372100 East with an elevation of 2,177 meters above sea level. Geologically the study area is dominated by ignimbrite, pyroclastic ash tuff, volcanic ash, and residual soils.

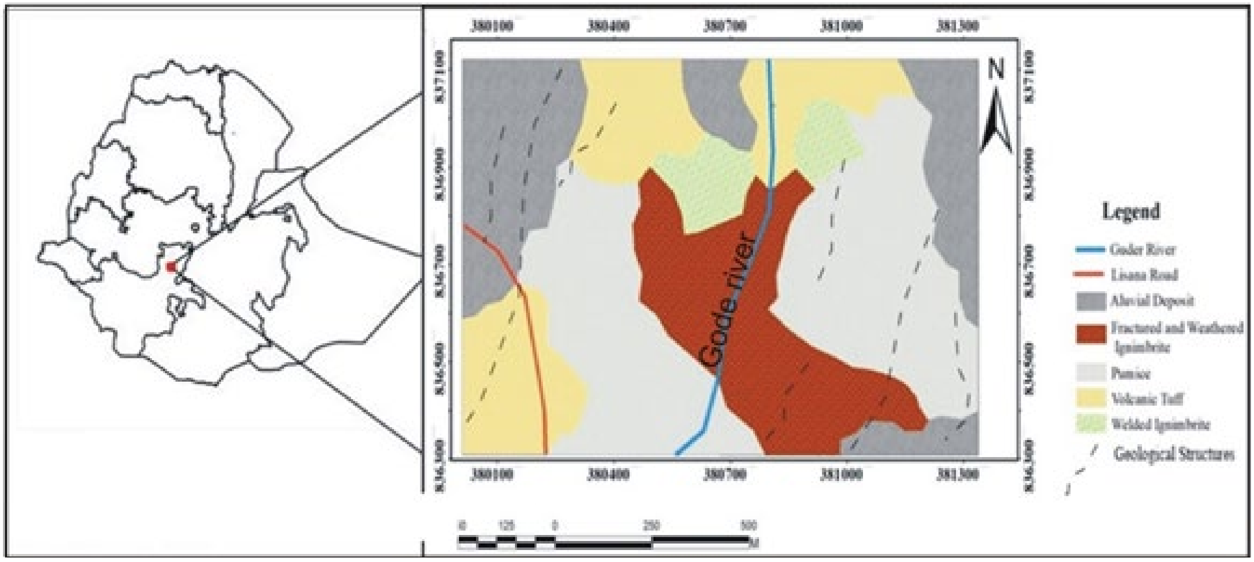

Figure:1 Location map of the study area with the rock units in the study area.

2. Materials and Methods

2.1. The Electrical Method

Electrical methods of geophysical prospecting are the most important methods for groundwater investigation as they are the best method to detect the existence between electrical properties, geologic formations, and their fluid content [7-9]. Out of the various electrode configurations to be possibly deployed, the Schlumberger array, applied in this study- finds wide application where the positions of the electrodes are expanded with respect to a fixed-point (sounding point) for increased depth of investigation. The method is implemented by injecting electrical current (I) into the ground with two current electrodes and measuring the resulting potential difference (ΔV) by another pair of potential electrodes placed close to the center of the array. Knowledge of the geometrical disposition of the four electrodes enables the determination of the apparent resistivity for each measurement which is easily convertible into true resistvity and thickness of the subsurface formations over which the measurements are carried out.

2.2 Magnetic Method

The intention of using magnetic surveys in this study is to accurately demarcate the location of subsurface faults/fractures and weak zones, which govern the flow and movement of groundwater in the area. Proton precession magnetometer (GSM- 19T) has been used and all causes of magnetic variation from the observations other than those arising from subsurface geology are removed by keeping the sensor away from obviously magnetic objects (cars, power lines, metal pipes, etc). Diurnal and IGRF corrections as well as filtering (reducing to pole) are applied in the present study to enhance the data and make it amenable to interpretation.

3. Data Processing

Data over a total of 12 VES points were collected along six survey lines oriented in NW-SE and NE-SW directions. Data processing software (RESIXIP, Surfer, and Win RESIST) are used in the VES curve plotting, pseudo-depth mapping and stacking. The more than 400 magnetic data collected with the base station- located at 380129 Easting and 836873 Northing- reoccupied within one and half hour interval [Fig.2] to do diurnal and main field correction. The magnetic survey lines are oriented generally in an east-west, northwest, and southeast direction so as to detect possible structures that could control groundwater movement. The magnetic data is processed by Geosoft Oasis Montaj software. The layout of the geophysical survey profile lines and observation points are shown in Figure 2.

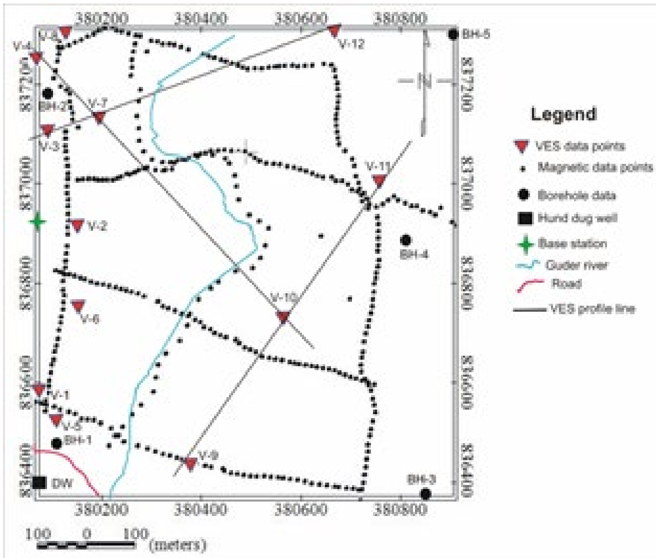

Figure: 2 Distribution of VES points and the magnetic profile lines, Gode area, Hossana, Central Main Ethiopian Rift.

4. Results and Discussion

4.1. VES Analysis

From 12 VES curves, we present here the interpretation of one representative (VES-3) sounding data to elucidate the possible lithologic (Fig. 3a) units consisting of topsoil, silt and clay, ignimbrite and pumice.

4.2. Pseudo-Depth and Geoelectric Section Along the Profile Lines

Our compiled pseudo-depth map over VES-9, 10 11 [Fig.3b] reveals a significant variation in vertical and lateral resistivity values of the subsurface which provides information about the area's geologic and hydrologic situations. It shows low resistivity subsurface at the shallow and deep subsurface beneath VES-10 and 11.

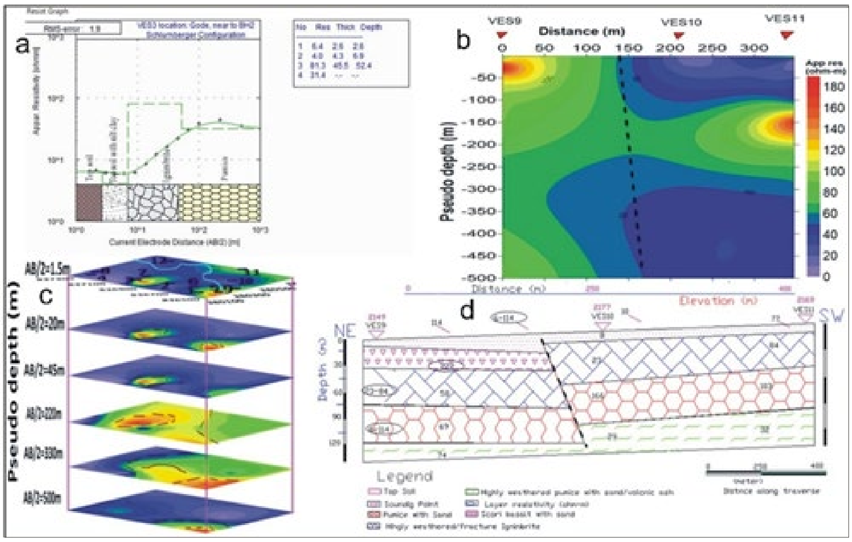

Figure: 3 VES-3 curve (a), pseudo-section (b), stacked maps(c) and geoelectric section (d)

The corresponding geoelectric section in was constructed using the interpreted layer parameters of sounding data from VES constrained by data nearby boreholes. Very thin topsoil with varying resistivity response underlined by a moderately saturated ignimbrite layer which is interpreted to be interrupted by fault zones is observed. A very low resistivity subsurface at the lower section of the pseudo-depth map is interpreted to be caused by the response of highly weathered pumice with sand which is attributed to creating a favorable condition for the occurrence of potential groundwater beneath VES-10 and 11.

4.3. Sliced-Staked and Iso-Resistivity Map

The sliced stacked map shown in is constructed for AB/2=1.5, 20, 45, 220, 330, and 500m. The selection of such a partition depends on the variability in subsurface resistivity distribution in order to show the horizontal and vertical variations of the resistivity in 3D. Figure 3c clearly shows the areas where potential productive boreholes could be proposed as either the northwestern end (unconfined aquifer) or the southeastern part (possibly confined aquifer) of the area.

5. Magnetic Data Results and Interpretation

5.1. Residual Magnetic Anomaly Map

The study area's residual magnetic anomaly map , where the black dots are the magnetic data distribution, is compiled by plotting all the magnetic data after all appropriate data correction. The northeastern and southwestern part of the surveyed area shows a very low magnetic anomaly relative to the other regions part of the study. These are regions where the subsurface rock units are highly affected by the presence of thick soil cover and/or the presence of weak zones filled with weathered material.

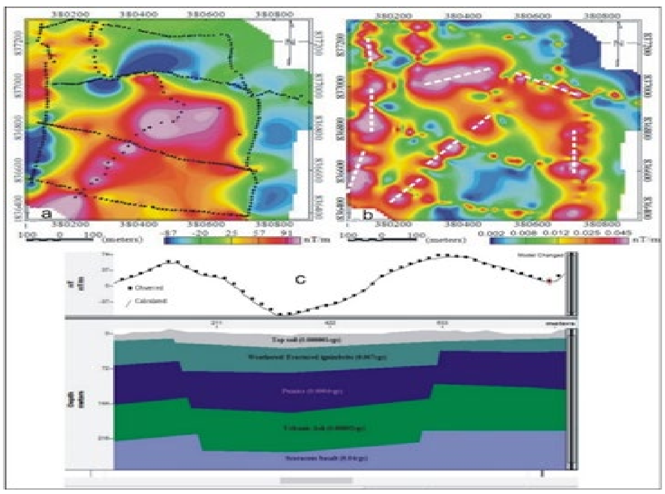

Figure: 4 (a) Total magnetic field anomaly map, (b) analytical signal map and (c) 2D magnetic model.

At the same time, a large portion of the survey area in the northeast direction is characterized by low to intermediate magnetic anomaly response and is due to slightly and moderately weathered/ fractured rock units. The central portion of the map shows high values of magnetic anomalies and depicts regions of very high magnetic anomaly response resulting from the presence of highly magnetized bodies beneath the surface. This could be fresh ignimbrites/ scoriaceous basalt found at a relatively shallower depth, towards the northeast part of Guder River .

6. Magnetic Analytical Signal Map

The analytical signal map shown in was developed from the residual magnetic anomaly map over the causative bodies. The map reveals magnetic anomalies that result from vertical and horizontal variations arising from geological structures / contacts between different rock units. The large area covers analytic signal gradients compared to the surrounding sediments and low magnetic susceptibility rock units like tuff and other pyroclastic volcanic rocks. The maximum values of the analytic signal map are generally coincident with the magnetic anomaly peaks observed in the total magnetic anomaly overall in the northeast and southwest part of the study area

6.1. The 2d Magnetic Model

The 2D magnetic model is constructed using the GM-SYS modeling software, which is essential to estimate the physical properties of the subsurface geological units. It should be noted that the magnetic model is non-unique, with many Earth materials producing the same magnetic response, and several lithologies may be interpreted from a given model block's magnetic susceptibility. The magnetic 2D model is developed from the magnetic anomaly of profile one and reflects the existence of a weak zone (fracture/ fault) below a depth of 25m that extends to 230m depth. Lithologic units that are perceived from the model include; top-soil, ignimbrite, pumice, volcanic ash, and underlying scoriaceous basalt.

7. Conclusions

Vertical electrical sounding (VES) and magnetic survey data are used to investigate groundwater potential along the Guder River in the Gode area, just northeast of Hosanna town. A total of 12 VES data and about 400 magnetic data are collected, analyzed and interpreted in terms of groundwater occurrence, depth to the saturated zone and its distribution. An integrated result from VES curves, 2D magnetic modeling, and geoelectric sections revealed the presence of subsurface weak zones that could control the groundwater flow and storage system. The potential aquifer in the area is obtained at a depth range from 45m to 92m. Overall, areas in the neighborhood of four VES points, i.e. VES-2, -3, -10, and -11 show good water-bearing zones in the study area associated with highly weathered/fractured ignimbrite and pumice layer.

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