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Hydrogeophysical and hydrogeological investigations of groundwater resources in Delta Central, Nigeria

Ochuko Anomohanran *

Physics Department, Delta State University, Abraka, Delta State, Nigeria

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Abstract

An electrical resistivity survey, down-hole logging and pumping test were conducted in Delta Central District of Nigeria to determine the groundwater potential and aquifer characteristics of the study area. Twenty vertical electrical soundings of the Schlumberger configuration were performed with an ABEM SAS 1000 Terrameter. The geoelectric data obtained were interpreted with partial curve matching and computer iteration using RESIST software. The results showed the presence of four geoelectric layers comprising loamy–sandy topsoil, clay, fine sand and coarse sand. The investigation also revealed the presence of a confined aquifer in the area, with resistivity values of 869.1–8704.1 Ωm, while the depth of the aquifer ranged between 20.2 and 25.4 m. The average values of the groundwater characteristics obtained were 0.026 mS/m for electrical conductivity, 25.75 mg/m^3 for total dissolved solids, 0.022 m^2/min for transmissivity and 0.000133 for storativity. Comparison of these values with international standards indicated that the water in the aquifer is of good quality and that the yield could withstand heavy pumping. It is therefore recommended that a good water scheme be established to serve the people of the area, including its surrounding towns.

Keywords: Groundwater; Aquifer; Electrical conductivity; Transmissivity; Storativity

1. Introduction

The need for adequate, good-quality water has increased extensively due to awareness and technology. Thus, many people rely on the exploration and exploitation of groundwater. Exploration for groundwater, which is one of the most valuable natural resources and is vital for the sustenance of life on earth, requires a number of techniques [1–3]. The electrical resistivity method is useful in this regard, as it is an efficient and economical method for determining the presence of groundwater [4]. Geophysicists have also used it to determine the thickness of bedrock, clay aquitards, salt water intrusion, the vertical extent of certain types of soil and the spread of groundwater contamination [5,6].

The electrical resistivity method can be used in a wide range of geophysical investigations, such as exploration for minerals, engineering investigation, geothermal studies, archaeological surveys and geological mapping [5]. The method has been used extensively in Nigeria and other parts of the world to investigate the subsurface. Majumdar and Das [7] used it to estimate the aquifer properties of Sagar Island Region in India, where they observed that the results correlated significantly with borehole data from the area. Sirhan et al. [8] used the method to map electrical resistivity distribution in the Al-Avovb Basin in Palestine, showing the existence of

* Tel.: +234 8039488655.
E-mail address: mrochuko@yahoo.com
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a continuous moderate formation accompanied by an upper clayey layer and a strong correlation with existing wells located in the study area. In Nigeria, the geoelectrical resistivity method has been used to search for potable water and to evaluate formation strata [2,3,9–14].

Vertical electrical sounding (VES) is commonly used in electrical resistivity surveys to determine the vertical variation between the electrical resistivity below the earth's surface and the potential field generated by the current [15,16]. The technique involves inducing an electric current into the ground by means of two implanted electrodes and measuring the difference in potential between two other electrodes, referred to as the potential electrodes. The electric current used is the direct current provided by a dry cell. Therefore, analysis and interpretation of the geoelectric data are on the basis of direct current.

The resistivity computed from the measurement of induced current and the potential difference is referred to as the "apparent resistivity". This measurement is based on the assumption that the ground is uniform. However, in reality, the resistivity of the earth is determined by inhomogeneous lithology and geological structures. Therefore, a graph of apparent resistivity against current electrode spacing is used to determine vertical variation in formation resistivity. Interpretation of this graph gives the true resistivity and depth of the geoelectric layers and is also used to ascertain the presence or otherwise of groundwater aquifers in the area. The parameters that are known to affect the estimation of groundwater resources include aquifer thickness and the size and degree of interconnection of pore spaces within the aquifer material [4]. These properties affect the ability of an aquifer to store and transmit groundwater [4,17].

In order to guarantee good-quality, and sustainable groundwater, it is important to integrate aquifer parameters determined from downhole loggings and pumping tests. Downhole logging is used to evaluate the character and thickness of the different geological materials penetrated by wells and test holes. Pumping test involves pumping water from a test well at a constant rate and measuring the water depth over a given time [18,19]. The difference between the measured depth and the static water level gives the drawdown values used in estimating transmissivity.

Various pumping methods have been used to estimate aquifer parameters. Rajasekhar et al. [18] applied the Sushil K. Singh method to calculate the parameters of confined aquifers and found that the transmissivity of the Kabul basin in Afghanistan was 94.16 m^2/day and the storativity was 0.00258. They reported that the method shows high reliability. Halford et al. [19] determined the reliability of the Jacob method of estimating the transmissivity of various aquifer types by interpreting 628 simulated draw-down records. The results were unambiguous, and the transmissivity estimates varied little among analysts. They reported that the estimates were affected minimally by partial penetration, vertical anisotropy and interpretive technique. Gogoi [20] used the Jacob and Theis methods to evaluate the hydraulic parameters in the district of Cachar, Karimganj and Hailakandi in India. He reported that the aquifer of Barak Valley could yield up to 15 m^3/h of groundwater for 6–7 h/day, which could effectively supplement the domestic, agricultural and industrial needs in the area. He commented that the Jacob method has become the most popular for estimating transmissivity because of its simplicity.

The district under consideration in this study is a major economic hot spot in the Niger Delta area of Nigeria, with a population of 1 239 650 in the 2006 national census [21]. The district has no functional scheme for supplying water, and the people of the district have long relied on hand-dug wells, which in most cases are vulnerable to contamination because they are shallow. Those who could afford to drill boreholes have done so without a geophysical survey. The surface water sources available are either far away from habitations or are polluted by various sources. The aim of this study, therefore, was to determine the groundwater potential and aquifer characteristics of the district to serve as a roadmap to providing good-quality, sustainable water to the people. Hydrogeophysical and hydrogeological methods were used to determine the groundwater potential of the area and to evaluate the characteristics of the groundwater aquifer.

2. Materials and methods

The study was carried out in Delta Central District, Nigeria, at latitude 5.50° and 5.80° N and longitude 5.84° and 5.98° E (Fig. 1). The area is central to most major towns and communities in the district and experiences less oil pollution than most parts of the Niger Delta.

We conducted 20 VESs of the Schlumberger configuration with a maximum current electrode separation of 150 m (Fig. 2). This technique was used because it is considered most appropriate in a sedimentary basin [22] and is simpler and more economical than other geophysical methods [23]. An ABEM SAS 1000 Terrameter was used to obtain the apparent resistivity at each VES point. The data were first interpreted by the conventional partial curve matching technique with two-layer master curves in conjunction with an auxiliary point diagram. This