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Estimation of geohydraulic parameters from fractured shales and sandstone aquifers of Abi (Nigeria) using electrical resistivity and hydrogeologic measurements

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ABSTRACT

Geohydraulic parameters are essential elements in groundwater resource management and conservation. Most of these parameters especially the hydraulic conductivity and transmissivity are usually estimated from pumping test carried out on drilled boreholes. This paper presents a study conducted in Abi area of the Ikom-Mamfe Embayment with the objective of estimating aquifer parameters from 30 evenly distributed vertical electrical soundings using the Schlumberger configuration and hydrogeologic measurements from 28 boreholes within the area as an alternative way of generating an initial data for groundwater characterisation and quality assessment in the area. The results showed low resistivity $\leqslant 45\ \Omega\text{m}$, hydraulic conductivity $\leqslant 2.0 \times 10^{-5}$ m/s ($\leqslant 1.7$ m/day) and transmissivity $\leqslant 5.2 \times 10^{-4}\ \text{m}^2/\text{s}$ ($\leqslant 45\ \text{m}^2$/day) for the water-bearing aquifer horizons in the northeastern and northwestern parts of the study area due to the nature of the aquifer system that were predominantly fractured shale. The sand based aquifers had higher values in the neighbourhood of $\sim$100–800 Ωm, $\sim 4.0 \times 10^{-5}$–1.0×10^{-4} m/s ($\sim$3.46–9.04 m/day) and $\sim 6.94 \times 10^{-4}$–$3.81 \times 10^{-3}\ \text{m}^2/\text{s}$ ($\sim$60–330 m^2/day) for the respective parameters mentioned above. The potability of the groundwater system as observed from hydrogeologic measurements of water samples from most boreholes were relatively poor, having electrical conductivity and total dissolved solids values of $\sim$250–931.0 μS/cm and $\sim$500–623.77 mg/l respectively due to the influence of clay minerals within the aquifer horizon. Some of the vertical electrical sounding points were taken in the vicinity were pumping tests and lithologic data were available for adequate comparison of the results.

1. Introduction

Abi is within the Ikom-Mamfe Embayment (IME) known to have water shortage challenges especially in the dry season when the available surface and groundwater resources dry up in some localities. This problem has led to the prevalence of water borne diseases such as guinea worm, cholera, dysentery and others, since the rural dwellers will have to resort to ponds and a few available streams for their domestic water needs (Akpan et al., 2013). Successive governments and other donor agencies such as the United Nations Children Emergency Fund (UNICEF), European Union (EU), Micro Project Programme in the nine Niger Delta States (MPP9), Niger Delta Development Commission (NDDC) amongst others have been tackling these problems by funding boreholes to be drilled in the area and other social amenities to alleviate the suffering of the people. Many of such boreholes have not been successful due to generalised regional subsurface geologic description and poor understanding of the hydrostratigraphy, inadequate knowledge of the aquifer geometry and characteristics, location of water recharge and discharge areas and their dynamic fluctuations with time (Akpan et al., 2013). Recently, there has been growing interest in understanding, characterising and mapping the spatial distribution of aquifers in the area.

Hydro-research institutions and other water related agencies are currently embarking on intensive site specific investigations that will generate localised information needed by the various donor agencies in siting sustained water yielding boreholes in the area. Besides, this information is also necessary in assessing groundwater quality and aquifer protective capacity since the shallower aquifers are likely susceptible to contamination from

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anthropogenic activities. Geohydraulic parameters are key parameters usually employed in investigating wide range of hydrologic and hydrogeologic problems such as groundwater flow modeling, prediction, aquifer characterisation, protection, management and remediation (Okiongbo and Akpofure, 2012; Mastrocicco et al., 2010). The hydraulic parameters of interest in aquifer investigation and characterisation include the hydraulic conductivity (Gemail et al., 2011), porosity (Aristodemou and Thomas-Betts, 2000), transmissivity and diffusivity (Kirsch and Yaramanci, 2009; Niwas and Singhal, 1985), longitudinal conductance and transverse resistance technically referred to as the Dar-Zarrouk Parameters (DZP) (Egbai, 2011; Ekwe et al., 2006) and storage coefficient. These parameters are useful in estimating the flow of water through a porous medium as well as assessing its response to pumping (Chang et al., 2011). Pumping tests, permeameter experiments (Butler and Dietrich, 2004), slug tests (McCall et al., 2002) and grain size analyses (Alyamani and Sen, 1993) are the standard techniques for determining these parameters. These approaches are invasive, relatively expensive and can generate information to a lesser degree in the adjoining areas. In locations where the boreholes are widely spaced, interpolation of aquifer properties between boreholes will be difficult and often times erroneous, since geologic formations do vary over relatively small distances (Muldoon and Bradbury, 2005; Bogoslovsky and Ogilvy, 1977).

Geophysical techniques such as electrical resistivity method offer a more economical and non-invasive alternative for estimating these parameters and extrapolating their spatial spread in locations where little or no information about them exist (Dhakate and Singh, 2005; Christensen and Sorensen, 1998). The spatial distribution of geoelectric and geohydraulic parameters has been used to characterise the heterogeneity of groundwater yielding aquifers and their overlying vadose zones (Börner, 2009). Consequently, results estimated exclusively from geophysical data are traditionally prone to errors incurred in the process of transforming geophysical data into equivalent geological models. These errors are basically due to the indirect mode of information extraction from the data, inversion errors such as geologic constraints and parameters used to generate the starting model and the quality of the data acquired. With recent advances in geophysical technology such as the introduction of microprocessor controlled geophysical data acquisition systems, inversion algorithms and direct information extraction methodologies such as surface nuclear magnetic resonance technique (Günther and Müller-Petke, 2012; Daigle and Dugan, 2011), spectral induced polarization (Ikard et al., 2012; Jouniaux and Ishido, 2012), electrical resistivity tomography and the development of enhanced analytical and interpretational tools for classical geophysical data (Kulessa et al., 2012; Jouniaux et al., 2009), the prospects of solving these problems satisfactorily has improved tremendously (Vereecken et al., 2004).

Presently, a hybrid alternative that involves a joint interpretation of hydrogeological and hydrogeophysical parameters generated from constrained modeling of geophysical data has been found to be an alternative approach for characterising aquifers (Aristodemou and Thomas-Betts, 2000; Khalil and Abd-Alla, 2005). Interest in this option has grown significantly and many practitioners have continued to adopt this approach in estimating aquifer properties (Sultan, 2013; Chandra et al., 2008). Although several geophysical techniques for hydrogeological investigations exist, instrument availability, portability and economic considerations have continued to favour the application of direct current (dc) electrical resistivity method (Okiongbo and Akpofure, 2012; Batte et al., 2010). Also, the existence of a close relationship between aquifer properties and bulk resistivity is another factor that has made the dc resistivity to be preferred over other techniques. The dc electrical resistivity method is also useful in investigating other forms of hydrogeophysical problems including assessment of aquifer vulnerability and depth to water table (Gemail et al., 2011; Yadav et al., 2010), mapping of aquifer salinity and its distribution (Jørgensen et al., 2012; Kirkegaard et al., 2011), determination of aquifer characteristics and distribution (Mele et al., 2010), monitoring of flow and groundwater flow dynamics (Adhikari et al., 2011), monitoring of water quality and contaminant transport (Zarroca et al., 2011; Gemail et al., 2011), groundwater potential studies (Poulsen et al., 2010) and aquifer protective capacity (Okiongbo and Akpofure, 2012; Braga et al., 2006). The spatial distribution of geoelectric and geohydraulic parameters has also been used in mapping aquifer heterogeneities, prediction of contaminants transport, computing their vulnerability index and resource management (Akpan et al., 2013; Börner, 2009).

This study is aimed at employing constrained subsurface models generated from dc resistivity measurements, lithologic and groundwater sample analysis data in estimating geohydraulic parameters in Abi, Nigeria.

2. Site description and geology

Abi is located between Latitudes 5.76°N and 6.02°N of the Equator and Longitudes 7.93°E and 8.17°E of the Greenwich Meridian in Cross River State, Nigeria. It forms part of the Nigerian segment of the Mamfe Embayment referred to as IME that covers ~2016 km^2 extent in western Cameroon (Fig. 1) (Nguimbous-Kouoh et al., 2012). The area has an average annual precipitation of over 2200 mm, while the annual temperature range is between 23 and 27 °C in the rainy season and soars to ~35 °C in the dry season. The average relative humidity for the area is about 88% (Akpan et al., 2013). Towards the end of the dry season, the volume of water in the rivers and streams usually decrease considerably and water flow inside the Cross River is usually restricted to narrow channels within the river bed. At the peak of the rainy season, the water levels in both the groundwater and the rivers usually attain maximum heights while the major drain (Cross River) usually overflows its banks (Ebong, 2012). Seepages from the Owutu-Afikpo-Adadama sandstone ridge system (OAASRS) flows toward the surrounding low-lying areas, as a result the soil within these regions are constantly wet and marshy in the rainy season and dry having deep pressure cracks in the dry season (Egboka and Uma, 1986).

Geologically, the IME that spans between Latitudes 5°15′N and 6°30′N of the Equator and Longitudes 7°45′E and 8°45′E of the Greenwich Meridian, is the NW–SE splay segment of the NE–SW trending Benue Trough and always referred to as a contiguous part of the Lower Benue Trough. The IME is bounded to the west by the Abakiliki Anticlinoriun, to the east and northeast by the Obudu Plateau and the Cameroon Volcanic Line and in the southeastern part by the Oban Massif of Cross River State, Nigeria (Fig. 1B). The IME is characterised by low relief and gently undulating topography (Eseme et al., 2002). It is tectonically believed to have its origin traceable to the regional tectonic and magmatic events during the Cretaceous times that was later affected by the regional Santonian compressional episode (Odigi, 2011). Sedimentation in the IME and its sub-basin such as the Afikpo Basin commenced with the marine Albian Asu River Group (ARG) that was the first lithostratigraphic unit resting unconformably on the Precambrian Crystalline Basement (Fig. 1A and C) (Ekwueme, 2003; Ekwueme et al., 1995). The ARG a non-marine to marginal marine character sediment consists of impervious shale, limestone, sand lenses, sandstone intercalations and ammonites (Odigi and Amajor, 2009; Petters et al., 1987). The Late Albian-Cenomanian thick flaggy impervious calcareous and non-calcareous black shale; siltstone and sandstones of the Eze-Aku Group (EAG) rest on the ARG. The