Geoelectric sounding for predicting shallow aquifer properties using modified Archie equations

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Abstract

Intermittent water supply shortages resulting from increasing demand by the burgeoning populace and problems of water resources contamination are major problems of the inhabitants of the Enugu area, Nigeria. Addressing these problems of sustainable management of water resources requires improved hydrogeological knowledge, new groundwater exploration and data processing techniques. As few boreholes may be available and carrying out pumping test can be expensive and time-consuming, relationships between aquifer characteristics and electrical properties exist. 19 geoelectrical data (13 of these selected for evaluation) were recorded in the Schlumberger electrode configuration in the area around Okpara coal mine site, Enugu, Nigeria. The data were interpreted by computer iterative modelling with curve matching for calibration purposes. Driller's log and water-table depth information in existing shallow water wells were used to constrain the inversion of the resistivity data. In situ water conductivity measurements and knowledge of the aquifer thickness were used to make accurate estimation of the formation factor as well as for the extraction valuable hydraulic properties. Geoelectric cross-sections along a number of lines were prepared to ascertain the overall distribution of the resistivity response of the subsurface geology. Identified probable shallow aquifer resisitivity, thickness and depth values are in the range of 28 – 527 Ωm, 2.1 – 22.5 m and 3.1 – 28.3 m respectively. Aquifer system observed consists of fine-grained, clay-silty sand materials. A modification of the Archie equations (Waxman-Smits model) was adopted to determine the true formation factor using the relationship between the apparent formation factor and the pore water resistivity ($F_a = F_t(1+BQ_v\rho_w)^{-1}$) as shown in Figure 1 in order to estimate porosity values. The average hydraulic conductivity of 8.96 x 10^{-2} cm/s and transmissivity ranging from 5.93 x 10^{-4} to 6.37 x10^{-4} m^2/year estimated from surface resistivity measurements correlated well with available field data. The closeness of these values is a good indication of the reliability of the applied geoelectrical method. Results also showed a direct relationship between aquifer transmissivity and modified transverse resistance (R^2=0.84). This positive statistical correlation indicating a progressive increase is attributed to the influence of hydraulic and electric anisotropies as well as the variations in lithology, mineralogy, grain size, size and shape of pore channels.

Keywords: geoelectric sounding, aquifer properties, hydraulic conductivity, transmissivity.

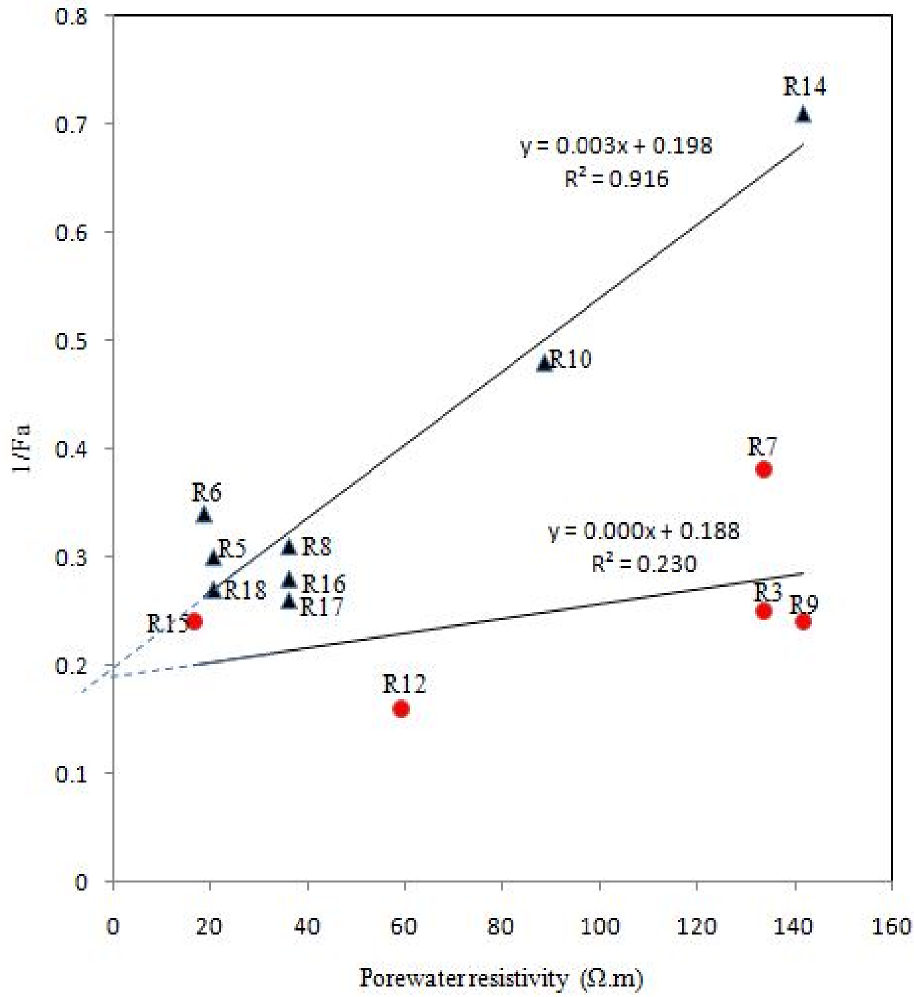

Fig.1. Determination of the true formation factor, F_t, by plotting the reciprocal of formation factor ($1/F_a$) against the pore water resistivity, ρ_w for estimation of porosity ($\phi = e^{\frac{1}{m}\ln(a)+\frac{1}{m}\ln(\frac{1}{F_t})}$)