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Geoelectrical parameter-based multivariate regression borehole yield model for predicting aquifer yield in managing groundwater resource sustainability

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Abstract

This study developed a GIS-based multivariate regression (MVR) yield rate prediction model of groundwater resource sustainability in the hard-rock geology terrain of southwestern Nigeria. This model can economically manage the aquifer yield rate potential predictions that are often overlooked in groundwater resources development. The proposed model relates the borehole yield rate inventory of the area to geoelectrically derived parameters. Three sets of borehole yield rate conditioning geoelectrically derived parameters—aquifer unit resistivity (ρ), aquifer unit thickness (D) and coefficient of anisotropy (λ)—were determined from the acquired and interpreted geophysical data. The extracted borehole yield rate values and the geoelectrically derived parameter values were regressed to develop the MVR relationship model by applying linear regression and GIS techniques. The sensitivity analysis results of the MVR model evaluated at $P \leqslant 0.05$ for the predictors ρ, D and λ provided values of 2.68×10^{-05}, 2×10^{-02} and 2.09×10^{-06}, respectively. The accuracy and predictive power tests conducted on the MVR model using the Theil inequality coefficient measurement approach, coupled with the sensitivity analysis results, confirmed the model yield rate estimation and prediction capability. The MVR borehole yield prediction model estimates were processed in a GIS environment to model an aquifer yield potential prediction map of the area. The information on the prediction map can serve as a scientific basis for predicting aquifer yield potential rates relevant in groundwater resources sustainability management. The developed MVR borehole yield rate prediction mode provides a good alternative to other methods used for this purpose.

Keywords: Multivariate regression yield model; Groundwater reservoir yield; Geophysical parameters; GIS; Hydrogeological

1. Introduction

The need for successful planning and management of groundwater exploration in the field of groundwater hydrology for both local and regional groundwater productivity potential mapping cannot be underestimated [1,2]. Nonetheless, existing literature has established that the success of area groundwater productivity potential assessment is largely based on the availability of

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well yield rate parameters [3,4]. The uniqueness of this parameter as a good, albeit indirect, indicator of groundwater occurrence in an area has been documented in the studies of [5–7]. A provisional means of assessing borehole yield information either locally or regionally is necessary to prevent the mismanagement of this invaluable but non-renewable natural resource, as this information can safeguard the sustainability of groundwater resources by avoiding saline intrusion, encrustation, borehole failures, and the excess lowering of water tables or piezometric surfaces. Consequently, the modelling of an aquifer yield potential rating through a simple and accurate mathematical technique can complement the conventional borehole pumping test (BPT) approach. This is necessary for enhancing the optimisation of groundwater resources that can provide portable water resources to address the challenges of scarce water supplies that threaten the entire world. The growing reliance on groundwater resources stem from unique attributes such as constant temperature, excellent quality, and low vulnerability to pollution and catastrophic events compared to surface water. Moreover, driving factors in various indispensable areas of human economic activity such as irrigation services and industrial utilisation often provide the basis for a nation to increase the availability of groundwater resources [8,9]. Therefore, the concept of enhancing the sustainability of groundwater resources through regional borehole yield rate assessment is timely and necessary.

The conventional approach of assessing borehole yield rate utilises a borehole pumping test (BPT) technique. This approach also provides information such as transmissivity, storability, aquifer geometry, and hydraulic conductivity properties that is useful when hydrogeologists are required to make accurate decisions concerning aquifers [10]. Ultimately, the evaluation of an aquifer's yield potential rate for the purpose of successful groundwater resource development can be best assessed by the BPT technique. However, the BPT approach is laborious, costly, uneconomical and time consuming [11–14]. In addition, the BPT output application is highly localised, thus limiting any regional evaluation of an area aquifer potential yield rating where there are no boreholes in existence. To gain better insight into regional subsurface aquifer potential yield ratings, which can be particularly useful in hard-rock terrains where the locations of groundwater reservoirs (aquifers) are varied and discontinuous, this study proposes a simpler and regionally compliant aquifer yield potential evaluation technique that can address the deficiencies of the BPT approach.

This study develops a GIS-based multivariate regression borehole yield prediction model. The approach employs empirical modelling that can accommodate the simultaneous integration of multiple factors for estimating an aquifer yield potential rating index. The efficiency of regression-based techniques in determining borehole yields from relevant borehole yield conditioning parameters obtained from different sources was established by [15,16]; these studies found that the well yield parameter was strongly correlated with well yield conditioning factors. Other studies [16–18] identified some of those well yield conditioning factors as hole depth, drawdown, screen length, geoelectrical parameters and geological rock formations. However, the regional applicability of this proposed regression model efficiency was carried out through a GIS technique application. The potential of GIS techniques has been explored in numerous environmental decision-making studies with encouraging results, including the management of natural resources—particularly in groundwater potential prediction domains [3,14,19]. Employing the proposed GIS-based MVR yield prediction model can significantly enhance the prediction of the potential yield of underlying groundwater reservoirs (aquifer units) where drilled holes are lacking. The proposed aquifer yield rating potential model output could optimise the sustainability of underlying groundwater resources.

This paper develops a GIS-based multiple variate regression (MVR) yield prediction model for predicting aquifer yield potential on a regional scale. This study introduces the use of derived parameters from geoelectric surveys obtained from an electrical resistivity (ER) prospecting method and applies linear regression and a GIS technique to develop the MVR yield prediction model. The ER method has widely been used for the quantitative estimation of the water transmitting properties of aquifers, aquifer zone delineation and the evaluation of the geophysical properties of aquifer zones in several locations [20–28]. Moreover, the ER method possesses non-invasive, low-cost attributes and offers quick data acquisition and the ability to map geological layers and determine the nature and composition of unseen subsurface formations [29,30]. The unique attributes of the ER method are well exploited in the proposed GIS-based MVR yield model and enable the model to surpass the conventional BPT technique. Applying the developed GIS-based MVR yield model in an area can provide aquifer yield potential rate prediction on a regional scale. The methodologies are illustrated by using a case study in the Crystalline Basement Complex terrain in southwestern Nigeria to establish a robust