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Spatial Variability Analysis of Some Groundwater Physico-Chemical Parameters in Parts of Akwa-Ibom State, Nigeria

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ABSTRACT

The groundwater physico-chemical parameters of Parts of Akwa Ibom state and their spatial distribution have been examined in this study. The physico-chemical parameters analysed are Ph, total dissolved solids, electrical conductivity and water hardness. The average pH, electrical conductivity, water hardness and total dissolved solids obtained are 6.4, 163.4242 μS/cm, 83.81 mg/l and 90.5 mg/l respectively. The computed values are within the permissible limit set by World Health Organisation (WHO). Semi-variogram and ordinary kriging were used for the spatial distribution analysis. The semi variogram of the pH, total dissolved solids, electrical conductivity and water hardness were model with Gaussian, spherical, linear functions respectively. The pH map is dominated with values ranging from 6.2 to 6.6 while the total dissolved solids map is associated mainly with values ranging from 90 to 95 mg/l. The water hardness and electrical conductivity values increases from central part toward the west and eastern regions. The geostatical modelling has been used to estimate the values of the parameters at unsampled points.

***Keywords*:** Water analysis; Akwa Ibom; Physico-chemical parameters; Semi-variogram; Kriging

1. INTRODUCTION

Water is essential for sustenance of life and groundwater is one of the major sources. The quality of groundwater is as importance as the quantity available in any groundwater resource evaluation. The physical, chemical, and biological characteristics of water are very essential in determining its suitability for domestic, industrial and agricultural application. Groundwater quality can be used to infer the interconnectivity between surface water and aquifers, groundwater movement and storage.

Groundwater can be contaminated from natural sources or different forms of human activities such as changes in the use of land, urbanization, intensive irrigated agriculture, disposal of untreated sewage in river (Voudouris, 2009; Amadi et al., 2010). Large quantities of human and industries waste disposals pose serious challenges to groundwater quality. Studies have shown that groundwater contamination may cause different kinds of diseases and other health related issues (Fetter 1993). It is imperative to regulate and monitor the quality of groundwater because once it is contaminated, its quality cannot be restored by stopping the contaminant from the source (Mufid, 2012).

Evaluation of the physical, chemical and biological nature of groundwater in relation to its effect on human beings, natural quality, and intended uses is known as groundwater quality assessment involves (Balakrishnan et. al., 2011). Even though regular monitoring of groundwater quality is very crucial, it is not always feasible to take the measurement every location because of its cost and time implication (Gorai and Kumar, 2013). The physico-chemical properties of ground water can be described in terms of spatial distribution. Modeling the spatial distribution is very important in groundwater management. Geostatistics provides different techniques for the spatial interpolation or simulation. Geostatistics is one of the methods which has been used for determining spatial distribution of groundwater quality parameters. Geostatistics analyses assumed that the properties of earth have some spatial continuity up to a certain lag distance. The main geostatistical tools include semivariogram analysis which characterise the space structure and kriging analysis that is spatially interpolating scattered measurements to create spatially exhaustive layers of measured parameters (Goovaerts, 2000; Isaaks and Srivastava, 1989).

Geostatistical estimation of spacial variation of groundwater physico-chemical parameters adopted in this work involves Variogram analysis and estimation of parameter at unsample location. Variogram analysis is the identification and modelling of spatial structure and it characterizes the spatial continuity or roughness of studied parameters. Normally, one-dimensional statistics for two data sets may be nearly identical, but the spatial continuity may be quite different. The geostatistical techniques is aimed at estimating the physico-chemical parameters at unsampled locations and mapping them. Variogram analysis is made up of the experimental variogram calculated from the data and the variogram model fitted to the data. The second techniques is the estimation of the parameters by using kriging methods. The kriging methods depends on the variogram model. The objective of this study is to analyses the groundwater quality and its spatial distribution with respect to different physico-chemical parameters such as: pH, total hardness, total dissolved solid and electrical conductivity in parts of Akwa- Ibom state, Nigeria.

2. MATERIALS AND METHODS

The study involves the determination of some physico-chemical properties of groundwater and their spatial variation in the study area.

2. 1. Study Area

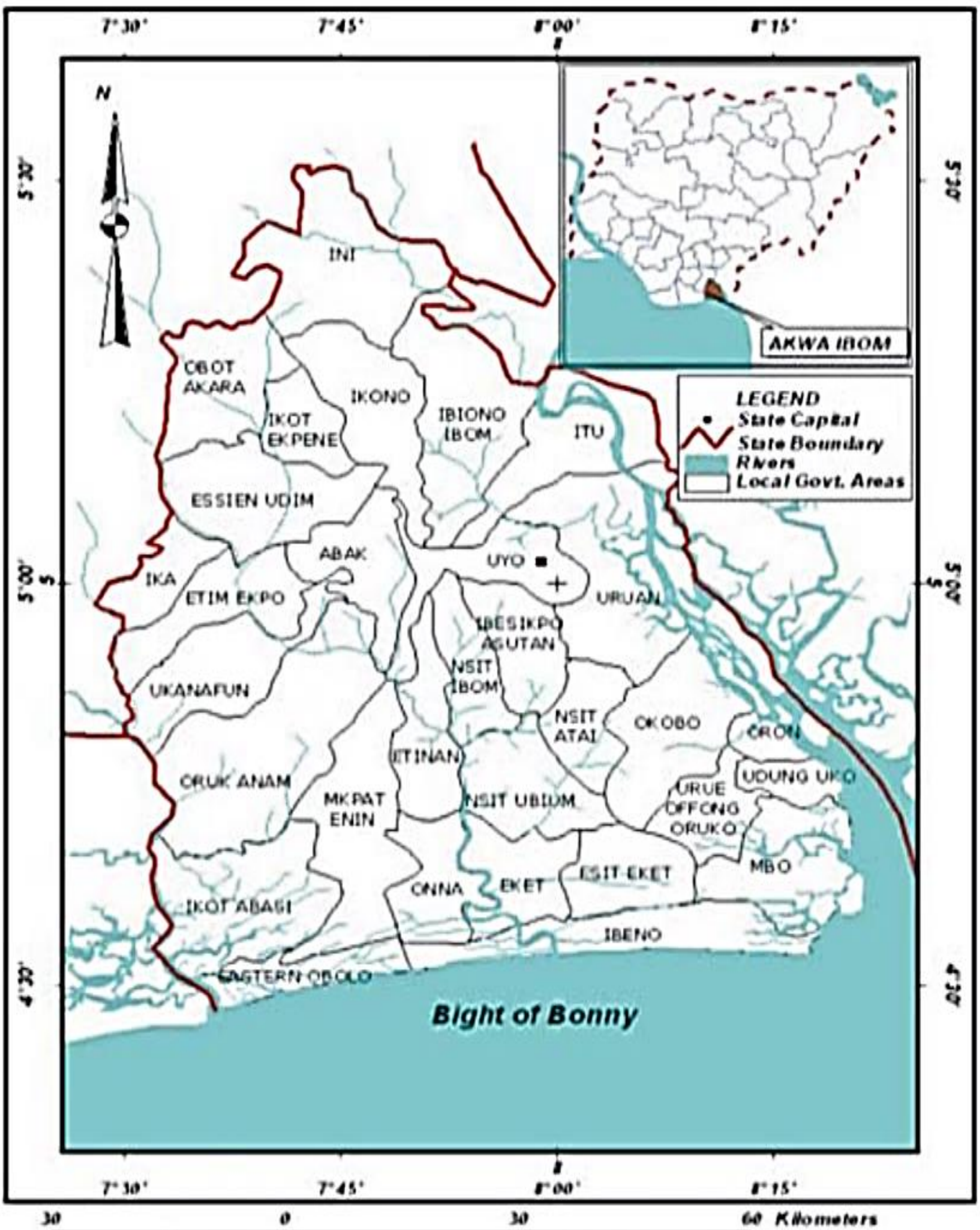


Fig. 1. Map of the Study Area (Akwa Ibom State).

The study area (Akwai Ibom State) is located between latitudes 4°30' N and 5°30' N and longitudes 7°30' and 8°20' E as shown in Figure 1. The geology of the study area is typical of the Niger Delta sedimentary Basin, Nigeria. The area is underlain by the quaternary to tertiary sediments of the Benin Formation. The Benin Formation is the topmost stratigraphy comprising largely of poorly consolidated sands and sandstones. The sands which make up by far the greater part of the deposits, possess several characteristics which make it to act as aquifer. The study area has climate characteristics that could be described as humid to tropical. There are two main seasons — the dry season (November to February) and the raining season which occurs between March and October.

2. 2. The methods of Data Collection

The research methodology involved water sample collection, field and laboratory water sample analysis and geostatistical modelling. Water samples were collected from 25 domestic water bore holes in clean plastic bottles from different locations across the study area (Fig. 2). The plastic bottles were capped immediately after they were filled in order to avoid escape of gases present in the water samples and also to reduce oxygen contamination. The bottles were taken to the laboratory for physico-chemical parameters analysis. Some of the parameters that were measured and used for this research are electrical conductivity, pH, hardness of water and total dissolved solids (TDS).

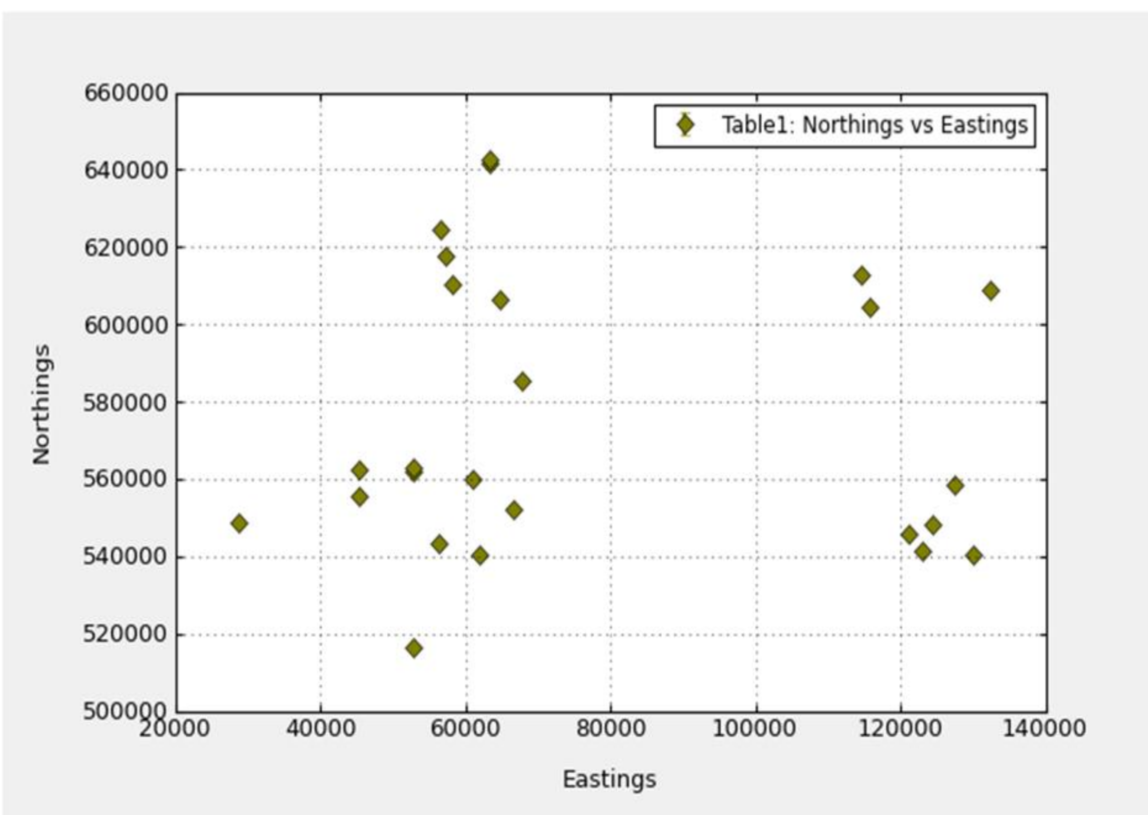


Fig. 2. Distribution of domestic wells in the study area

The water sample pH level was measured in the field with the aid of pH meter (Bromthymol Blue pH kit). Conductivity meter (Mark V Electronics Switchgear) was used for measuring the electrical conductivity of the sampled water in the field. Gravimetric and titration analytical methods were used for the determination of total dissolved solids in the water sample and hardness of the water sample. The gravimetric and titration methods were carried out in the laboratory. These measurements were carried out in accordance with the standard procedures prescribed by American Public Health Association, APHA (2005).

2. 3. Geostatistics techniques

Geostatistics is used for spatial data analysis. Geostatistical analysis involving variogram and ordinary kriging were applied on the measured physico-chemical parameters.

Variogram Analysis

A variogram might be thought of as "*dissimilarity* between point values as a function of distance", such that the dissimilarity is greater for points that are farther apart than points that are closer. The variogram is used for describing the structure of variations in a localised or regionalized variable. It explain the variance in variable values due to differences in spatial locations of the analysed parameter. Variogram analysis involves experimental variogram computed from the data and variogram model fitted to the data. The experimental variogram is calculated by averaging one-half the difference squared of the z-values over all pairs of observations with the specified separation distance and direction. It is plotted as a two-dimensional graph. The semi-variogram is a function that provides half the variance of the continuity between all points separated by *h* and is inversely proportional to the distance of points in spatial analysis. The semi-variogram which is half the variogram is commonly used for modeling spatial distribution of data. The semi-variogram can be obtain with the equation (Isaaks & Srivastava, 1989; Journel & Huijbregts, 1978):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i + h) - Z(x_i)]^2 \qquad (1)$$

where:
$Z(x_i)$ = value of data
X_i = locations where measurement were performed
$N(h)$ = number of pairs of points $(x_i, x_i + h)$ separated by distance h

The experimental variogram is not very good for data analysis. Therefore appropriate theoretical models are fitted on the generated variogram. The variogram model is chosen from a set of mathematical models such as gaussian, spherical, linear and exponential, that describe spatial relationships. The best model was chosen by matching the shape of the curve of the experimental variogram to the shape of the curve of the theoretical model. The experimental variogram model was used as an input equation for the geostatistical interpolation (Kriging).

Kriging Analysis

Kriging techniques provides the best linear unbiased estimators of the value of the analyzed regionalized variable. It is a geostatistical method that supports the identification of regularities in spatial distribution of data, and those regularities are used in spatial interpolation. The kriging methods are applied to estimate the value of the analyzed phenomenon in a given location based on measurements (observations) performed at several points with known coordinates. There are different types of Kriging. They includes simple, ordinary, block and others. The ordinary kriging interpolation techniques was adopted for this work. The kriging interpolation was calculated as a linear combination of regionalized random variables as:

$$Z^*(s_0) = \sum_{i=1}^{n} w_i Z(s_i) \qquad 2$$

where:
$Z^*(s_0)$ = estimated value,
$Z(s_i)$ = values observed in known locations,
Wi = weights or importance of the value Z(si).

Kriging account for the distance between data and data estimation locations, their spatial configuration and spatial structure described by a theoretical semi-variogram.

3. RESULTS AND DISCUSSION

Knowledge of the groundwater quality is very important because it determine its suitability for domestic, industrial and agricultural applications. The results of the physico-chemical and spatial analysis of the groundwater sampled are as follows;

3. 1. Physico-chemical analysis

The physico-chemical parameters of the water samples analysed are Ph, total dissolved solid, hardness and electrical conductivity.

pH Analysis

The ph of water is an important water quality and it is the degree of acidity or alkalinity of water. The pH values in the groundwater samples varied from 4.7 to 8.3 with an average value of 6.4. The computed standard deviation of the pH is 1.07. The maximum permissible limit for pH by World Health Organization (WHO) for drinking water is 9.2. The result shows that the groundwater in the study area is slightly acidic to slightly alkaline. The slight acidic nature of the water can lead to corrosion of steel and iron materials.

Total dissolved solids (TDS) Analysis

This is the weight of residue left after water sample has been evaporated to dryness. TDS are compounds of inorganic salts (such as Ca, Mg, K, and Na) and of small quantity of organic matter dissolved in water. The values of TDS obtained ranges from 12.6 mg/l to 147.0 mg/l with a mean value of 90.5 mg/l and standard deviation of 31.93. The computed TDS values are below the permissible limits of 500 mg/l adopted by WHO (1984) and FEPA (1991).

Electrical Conductivity (EC) Analysis

The electrical conductivity of water is cause by the presence of various dissolved salts. The electrical conductivity obtained for the water sampled varies between 20.2 μS/cm and 273.63 μS/cm with an average of 163.42 μS/cm. The computed standard deviation for the electrical conductivity is 58.63. The electrical conductivity is a measure of the salinity of the water. The computed electrical conductivity is below the permissible limit of 500 mS/cm set by WHO.

Total Hardness (TH) Analysis

The total hardness of water is due to the presence of excess of Ca, Mg and Fe salts in water. Total hardness of water is an important parameter of water quality. The values obtained in the water samples vary from 1.04 mg/l to 169.52 mg/l with an average of 83.81 mg/l. The standard deviation is 37.04. The total hardness obtained in the study is less than the permissible limit of 200 mg/l set by WHO (2008).

3. 2. Geostatistical Analysis

Geostatistical analysis is used to revealed different spatial distribution models and spatial dependence levels for physico-chemical parameters. The result of the semi-variogram and kriging analysis of the pH, total dissolved solids, hardness and electrical conductivity are discussed below.

Semi-variogram and Kriging of the pH

The computed semivariogrm and ordinary kriging of the groundwater pH in the study area are shown in Figure 3. The omnidirectional semivariogram was modelled with a gaussian function with a length of 5,000 m, scale of 1.01 and anisotropy of 0.1. The maximum lag distance and number of lags are 54000 m and 25 respectively. The Kriging map was generated with the semi variogram model. Major parts of the ordinary kriging map is dominated with pH values ranging from 6.0 to 6.8.

Values ranging from 6.2 to 6.9 (green colour). Although, there are pockets of high values scattered in the northern and southern portions of the study area. These pockets of high pH values aligned in the north to south direction.

Semi-variogram and kriging of TDS

The computed omnidirectional semivariogram and ordinary kriging map of the groundwater total dissolved solids are shown in Figure 4. The semi-variogram was modelled with a spherical function having a length of 500 m, scale of 500 and anisotropy of 0.1. The maximum lag distance and numbers of lags are 54000 and 25 respectively. The map is dominated with TDS values of 90-95 mg/l (yellow colour). Pockets of low (blue-green colour) and high (red) values occurred in the north and southern parts of the region.

Values ranging from 6.2 to 6.9 (green colour). Although, there are pockets of high values scattered in the northern and southern portions of the study area. These pockets of high pH values aligned in the north to south direction.

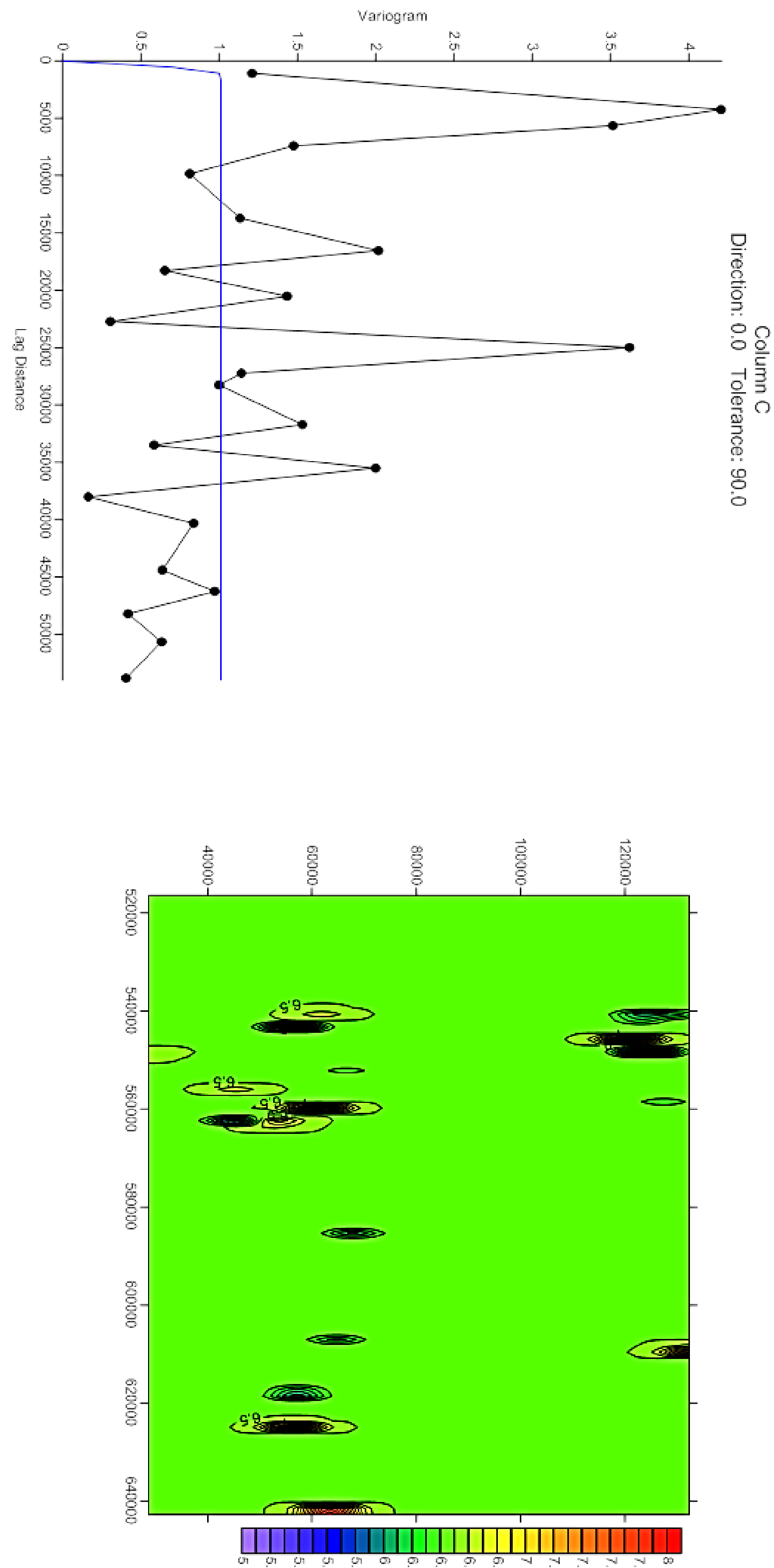


Fig. 3. Semivariogram and ordinary kriging map of the groundwater pH.

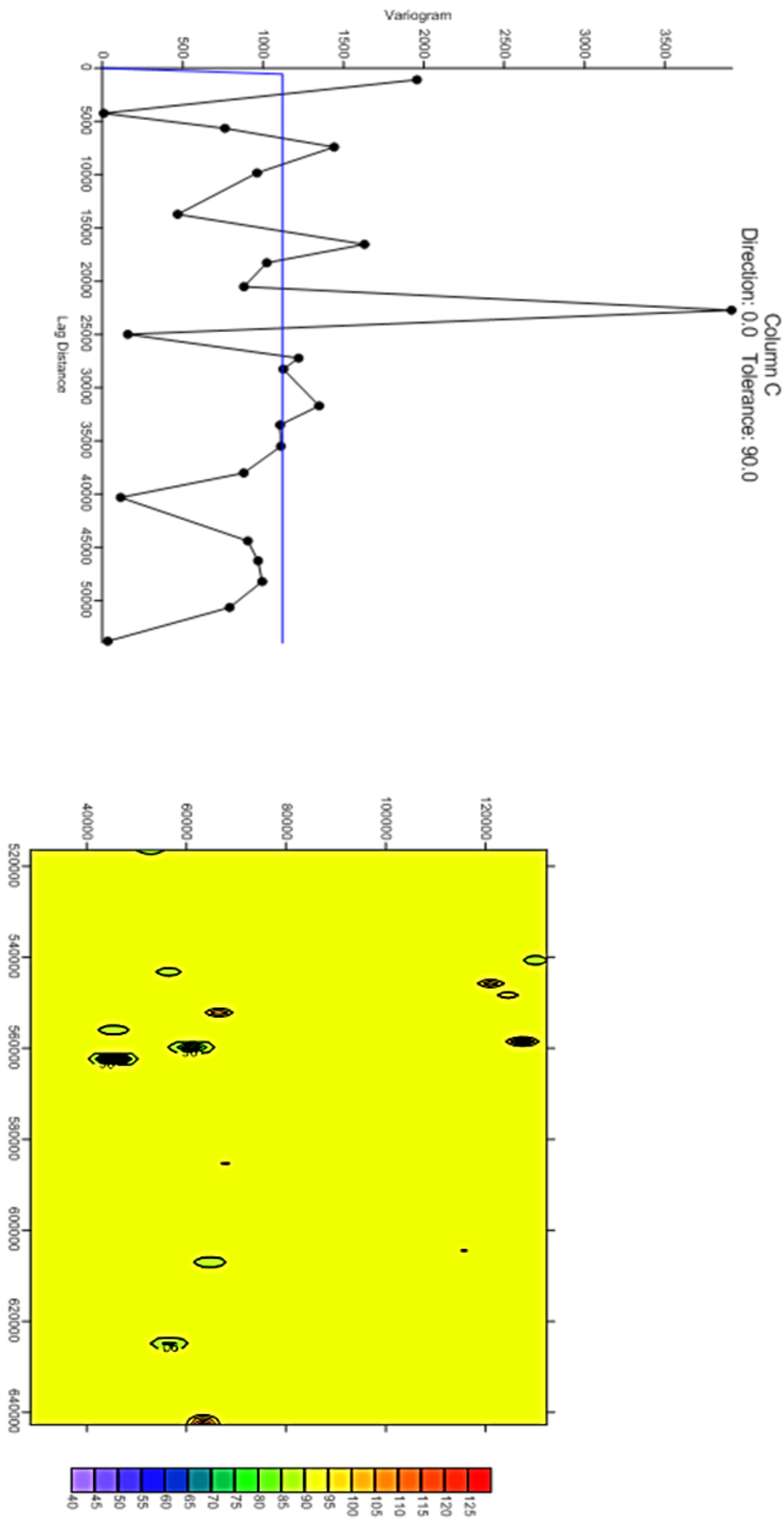


Fig. 4. Semivariogram and ordinary kriging map of the groundwater total dissolved solid

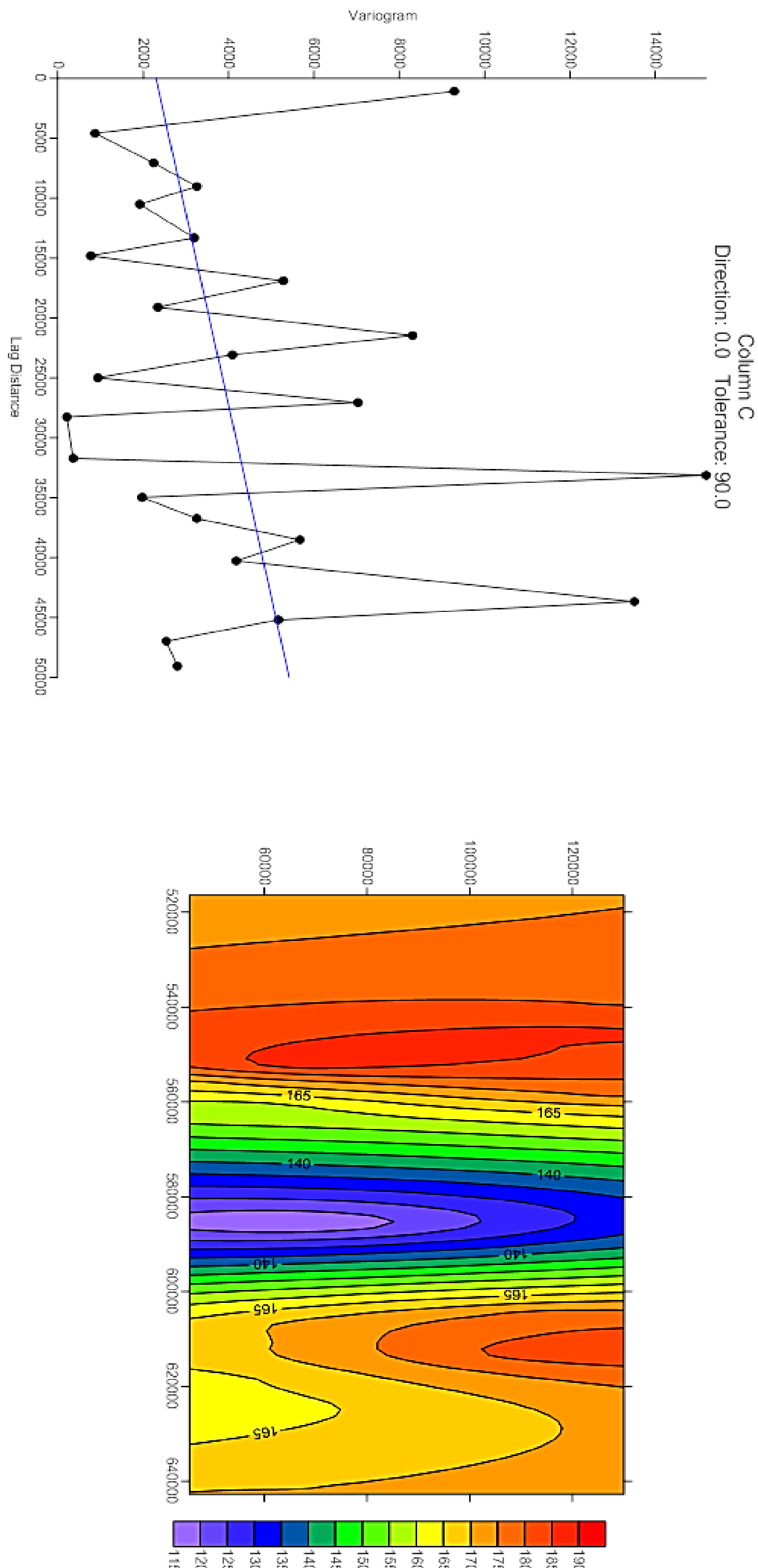
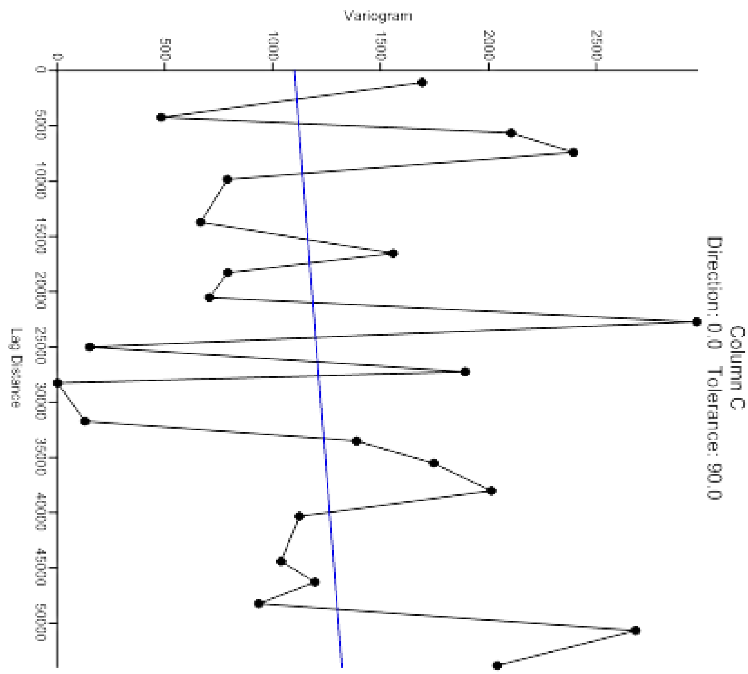


Fig. 5. Semivariogram and ordinary kriging map of the groundwater electrical conductivity



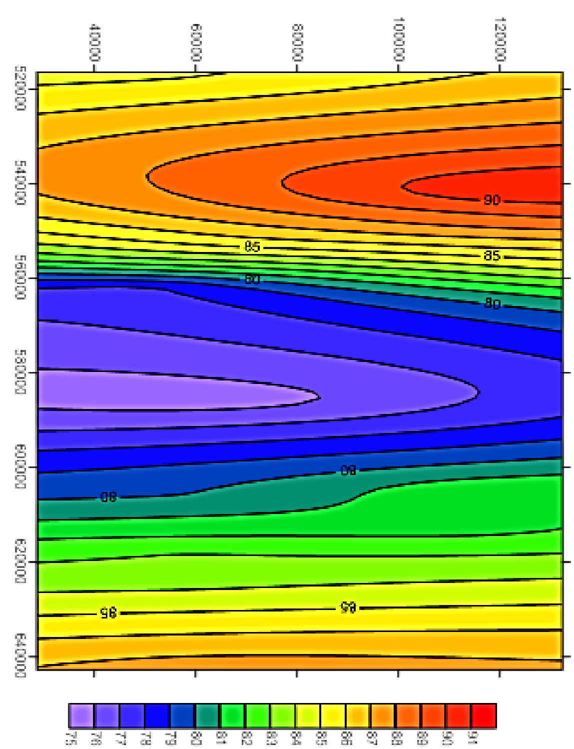


Fig. 6. Semivariogram and ordinary kriging map of the groundwater hardness.

Semi-variogram and Kriging of Electrical Conductivity

The semi-variogram and ordinary kriging map of the electrical conductivity of the groundwater in the study area is shown in Figure 5. The generated omnidirectional semivariogram was modelled with a linear function having a slope of 0.0625, anisotropy of 0.1 and anisotropy angle of zero. Nuggett effect was applied to the model. The central part of the area has low electrical conductivity values (blue-green colours) while western and eastern parts are associated with high values (red colour).

Semi-variogram and kriging of TDS

The computed omnidirectional semivariogram and ordinary kriging map of the groundwater total dissolved solids are shown in Figure 4. The semi-variogram was modelled with a spherical function having a length of 500 m, scale of 500 and anisotropy of 0.1. The maximum lag distance and numbers of lags are 54000 and 25 respectively. The map is dominated with TDS values of 90-95 mg/l (yellow colour). Pockets of low (blue-green colour) and high (red) values occurred in the north and southern parts of the region.

Semi-variogram and kriging of Water Hardness

Figure 6 is a semi-variogram and ordinary kriging map of the water hardness for the study area. The stable omnidirectional semi-variogram was modelled a linear function and nugget effect. The linear function has a slope of 0.0041 and anisotropy of zero. The maximum lag distance and number of lags are 54000 m and 25 respectively. The water hardness increases from the central part toward the west and eastern regions. The water hardness in the central region ranges from 75 to 80 mg/l.

4. CONCLUSION

The groundwater physico-chemical analysis shows that the computed pH, total dissolved solids, water hardness and electrical conductivity in the study area are within the permissible limit approved by the World Health Organisation (WHO). The computed semi variogram for the pH total dissolved solids, water hardness and electrical conductivity were model with Gaussian, linear, spherical and linear functions respectively. The models were used in ordinary kriging to estimate the values of the physico-chemical parameters in unsampled points. The results of the study shows that the geostatistical technique is a cost effective mathematical method for spatial analysis of data and for estimating data in unsample points.

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