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Spatial Groundwater Quality Assessment Using Geostatistics in Puntland, Somalia

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Abstract
Groundwater is an essential source of drinking and farming in Puntland state of Somalia. Puntland suffers from major water scarcity, the lack of safe drinking water in Puntland is a frequent problem. The objective of this study is to assess the groundwater quality using geostatistical algorithm based on Geographic Information System (GIS). In this research, we utilized ordinary kriging interpolation technique for generating the spatial distribution of groundwater parameters. Experimental semivariogram were tested for different models to identify the best fitted semivariogram model for each parameter and best fitted semivariogram models was chosen based on the lowest value of root mean square error (RMSE) value. The final map indicates that the majority groundwater quality in the study area are not suitable for drinking purposes in according to WHO water quality standards. The results of the research shows that it is vital to develop monitoring tools and management strategies for the groundwater in the region.

Keywords: Groundwater, Geostatisctis, GIS, Puntland, Somalia

1. Introduction

Groundwater is one of the major sources of drinking water all over the world (Bear 1979). In Somalia, groundwater is the major source of water for the majority of the people. With the exception for the people living along the rivers a Shabelle and Juba, who met their water demand from surface water. Groundwater is utilized by the rural and urban population to satisfy their water needs of domestic and livestock as well as irrigation purposes. Recently year's country face water crisis. Puntland suffers from major water scarcity, the lack of safe drinking water in Puntland is a frequent problem, according to a recent Puntland State Agency for Water Energy and Natural Resources (PSAWEN) study, 71% of rural people do not have access to safe drinking water (MoPIC 2016). So a main issue is become to find optimum locations for high quality groundwater for both domestic and livestock water demands. Spatial behavior of groundwater is essential for monitoring and management decisions of the groundwater to meet the increasing demand for water.

Geostatistics is technique to handle spatially distributed data. The techniques are based on a set of theoretical concepts known as the "Theory of Regionalized Variable" and involve a study of the spatial relationships between sample values, thickness, or any geological phenomena showing intrinsic dispersion (Matheron, 1971). Geographic information system (GIS) has an important role in the management of natural resource, therefore offer a suitable method for integrating physicochemical groundwater data analysis (El Omran et al. 2014). However, there many authors who investigated the role of GIS in the evaluation of the groundwater quality spatial distribution (Srivastava et al. 2011 Delbari et al. 2014 Zehtabian et al. 2013). Istok and Cooper (1988) used the kriging method to estimate the concentration of heavy metals in groundwater and concluded that kriging method was the best estimator for lead prediction. Shamsudduha (2007) used various interpolation techniques to evaluate the most suitable prediction method for estimating arsenic levels in a shallow aquifer in Bangladesh.

This study has been conducted (1) to map groundwater quality spatial distribution using Ordinary kriging in Puntland state of Somalia; (2) to evaluate the suitability of groundwater for drinking purposes.

2. Materials and Methods

2.1 Study area

Puntland state is located in the northeastern of Somalia with the Gulf of Aden in the north and the Indian Ocean in the southeast, Puntland consists nine administrative regions it extends between longitudes 46° E – 51° E and latitudes 6° N – 12° N (figure 1). One third of the population of Somalia lives in Puntland approximately 4 million, which contains about one third of the geographical area of the nation about 212,500 km^2. The climate of state are can be classified as semi-arid with a warm climate. The are two rain seasons, the first is Gu season which start March to late May and the Dayr season from October to early December with poor rainfall distribution pattern 27 – 250 mm annually. The entire population depend groundwater as a main source of drinking and irrigation water, since there is no surface water.

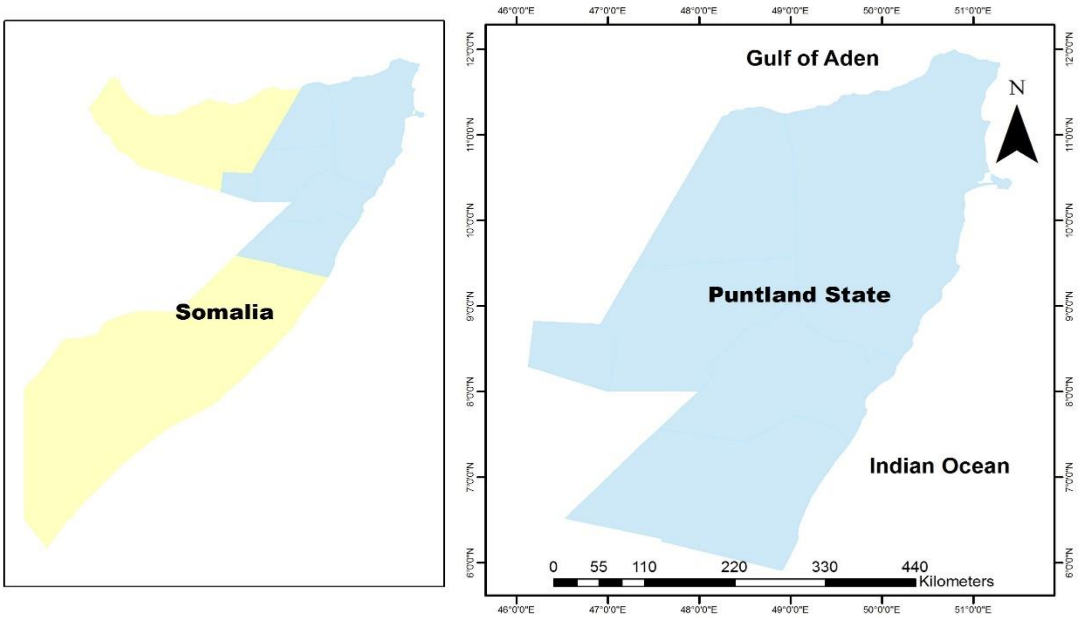


Figure 1 location map of study area

2.2 Data

Groundwater data was obtained by Somalia Water and land Information Management (SWALIM) and were collected in 2008. Obtain data consist only pH and electrical conductivity (EC) parameters. Total dissolved solids (TDS) is important parameter in water quality and used to describe the inorganic and organic material present in water. The relationship between conductivity and TDS is not directly linear; however, according to (Walton 1989), the relationship between TDS (mg l^{-1}) and EC (µS/cm) can be expressed as;

$$TDS = 0.67\, X \times EC \qquad (1)$$

The equation (1) has been used to calculate TDS in the study area.

2.3 Geostatistical analysis and modeling

Geostatistics is a spatial statistical procedure used to measure and characterize concentration distribution over time and space. Ordinary Kriging (OK) technique was employed in this study to Specifying spatial distribution of groundwater quality. Kriging is a linear, optimal and unbiased interpolation method with a minimum interpolation error. One of the main advantages of kriging is that it presents the interpolation error of the regionalized variable values where initial measurements are not available. This feature provides a measure of the accuracy and reliability of the spatial distribution of the variable (Theodossiou and Latinopoulos 2006).The procedure for ordinary kriging application is shown in Figure 2.

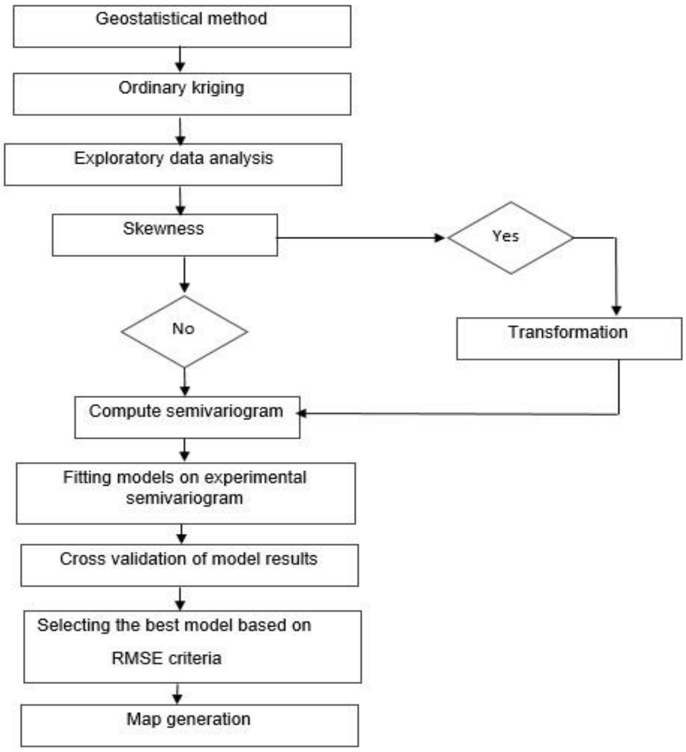


Figure 2 Flow chart of the procedure for Ordinary kriging analaysis

Semi-variogram is a representation of spatial correlation of the data. The experimental semivariogram is a discrete function calculated using a measure of variability between pairs of points at various distances. The exact measure used depends on the semivariogram type selected (Deutsch & Journel 1998). In theory, the following formula is commonly used to calculate the semivariogram:

$$. \gamma(h) = \frac{1}{2N_h} \sum_{i=1}^{N_h} (g_i - g_{i+1})^2 \quad (2)$$

Where $\gamma(h)$ is the intended value of the semi-variogram for the h, N_h is number of pairs location separated by h; g_i *and* g_{i+1} are values of the variable "*g"* at the point x_i and at a point of distance h from the point x_{i+1}.

Cross validation can be used to assess the semi-variogram model, in terms of prediction accuracy. To verify the selected model and its predictive performance the cross-validation was used. The values of mean error (ME), mean square error (MSE), root mean square error (RMSE), average standard error (ASE) and root mean square standardized error (RMMSE) were estimated to test and validate the selected model (ESRI, 2009).RMSE is used to investigate the best model by comparing its value, and the smallest value of RMSE indicates the most suitable model to the data (Marko et al., 2014). The following equations can be used to calculate the goodness-of-fit criteria:

$$\mathrm{ME} = \frac{1}{\mathrm{N}} \sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{g}^*(\mathrm{x_i}) - \mathrm{g}(\mathrm{x_i})) \quad (3)$$

$$MSE = \frac{1}{\mathrm{N} \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{\bar{\mathrm{g}}(\mathrm{x_i}) - \mathrm{g}(\mathrm{x_i})}{\bar{\sigma}(\mathrm{x_i})}} \quad (4)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{n} [\, g^*(x_i) - g(x_i)]} \quad . \quad (5)$$

$$ASE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}[\,\sigma^{*2}\,(x_i)]} \tag{6}$$

$$RMSSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\,[g^{*}(x_i) - \frac{g(x_i)}{\sigma^{*}}]^{2}} \tag{7}$$

Where $\overline{\sigma}(x_i)$ is the Kriging variance for location isx_i, $g(x_i)$ is measured value at pointx_i, $g^{*}(x_i)$ is predicated value at pointx_i.

3. Results and Discussion

Our data consist 95 wells distributed throughout the Puntland, which is approximately 700km in east-west extent and 330km north-south. Statistical data analysis was carried out to explore data and to check normality of data and also to remove outlier. The reason is because the Geostatistical method give best estimation when data are normally distributed. In order to check the normality of data the histogram graphs and the Quantile- Quantile plot (Q-Q plots) were plotted as shown in figure 3,table 1 shows descriptive statistics of groundwater quality. All parameters are found to be normally distributed.

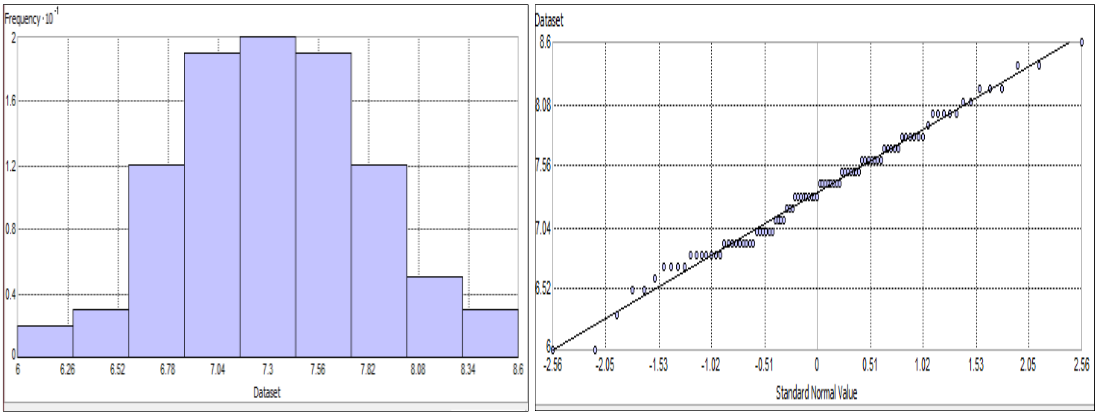
Table 1. Descriptive statistics of groundwater quality parameters

Parameter	Min	Max	Mean	Median	SD	Skewness	Kurtosis	Transformation
pH	6	8.6	7.33	7.3	0.52	-0.02	-0.07	Normal
EC (µS cm^{-1})	497	4812	2795.44	2957	865.26	-0.68	0.42	Normal
TDS (mg l^{-1})	332.99	3224.04	1872.94	1981.19	579.72	-0.68	0.42	Normal

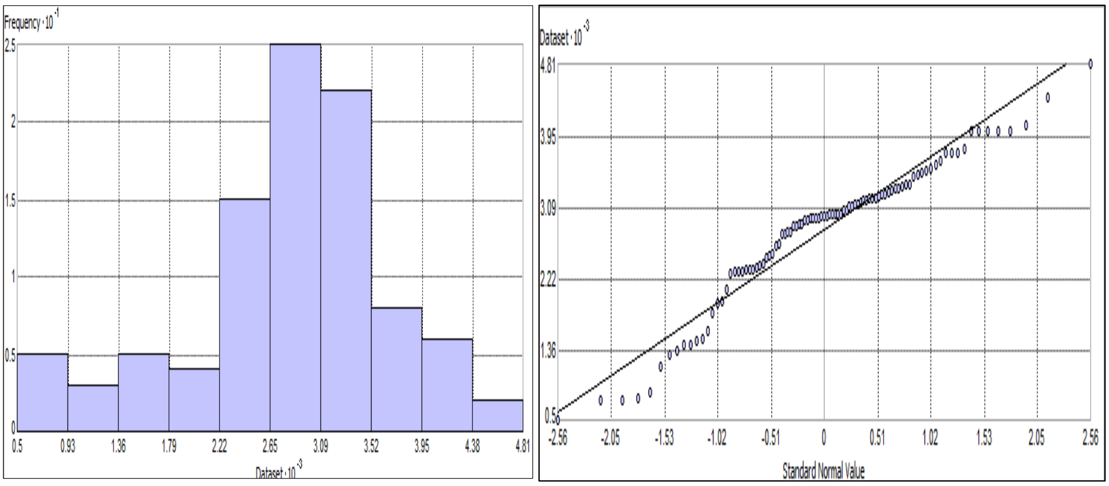
The analysis of semi-variograms was calculated using the Geostatistical Analyst Tool in ArcGIS. Firstly each variable experimental semi-variograms were obtained. Secondly, the semi-variogram modeling were carried because the semi-variogram model parameters are required in order to estimate the OK. In this study, we tested 7 semi-variogram models (Hole effect, Tetraspherical, Pentaspherical, Spherical, Exponential, Gaussian, Circular). For each variable, the best fitted semivariogram model was selected based on the lowest RMSE value. Figure 4 shows best fitted semivariogram models and table 2 shows the best fitted semivariogram models parameters. After the cross validation process, the kriging prediction maps were produced and the spatial distribution of groundwater quality parameters was visually represented.

Table 2. Best fitted semivariogram model parameters

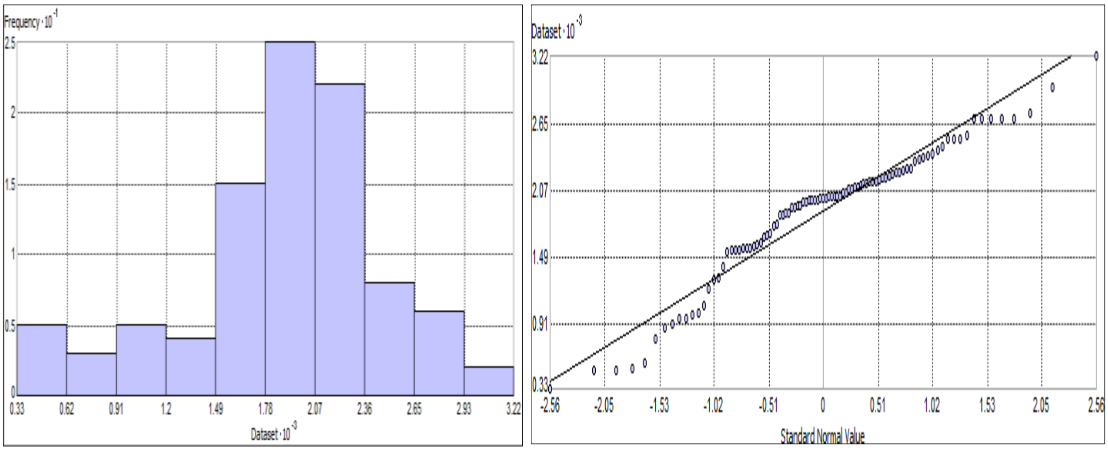
Parameter	Fitted model	Nugget (C0)	Sill (C0 + C)	Range (m)	RMSE
pH	Gaussian	0.1443	0.19002	151437.5	0.4340
EC (µS cm^{-1})	Spherical	49650.1	493035.4	6859.1	616.75
TDS (mg l^{-1})	Spherical	24955.4	212708	6859.1	413.22



(a) pH

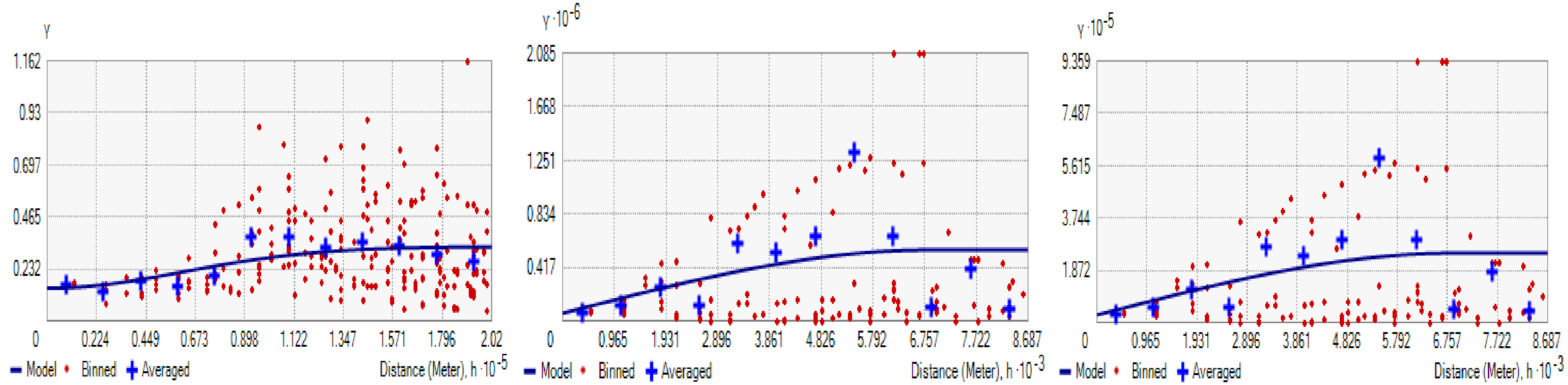


(b) EC



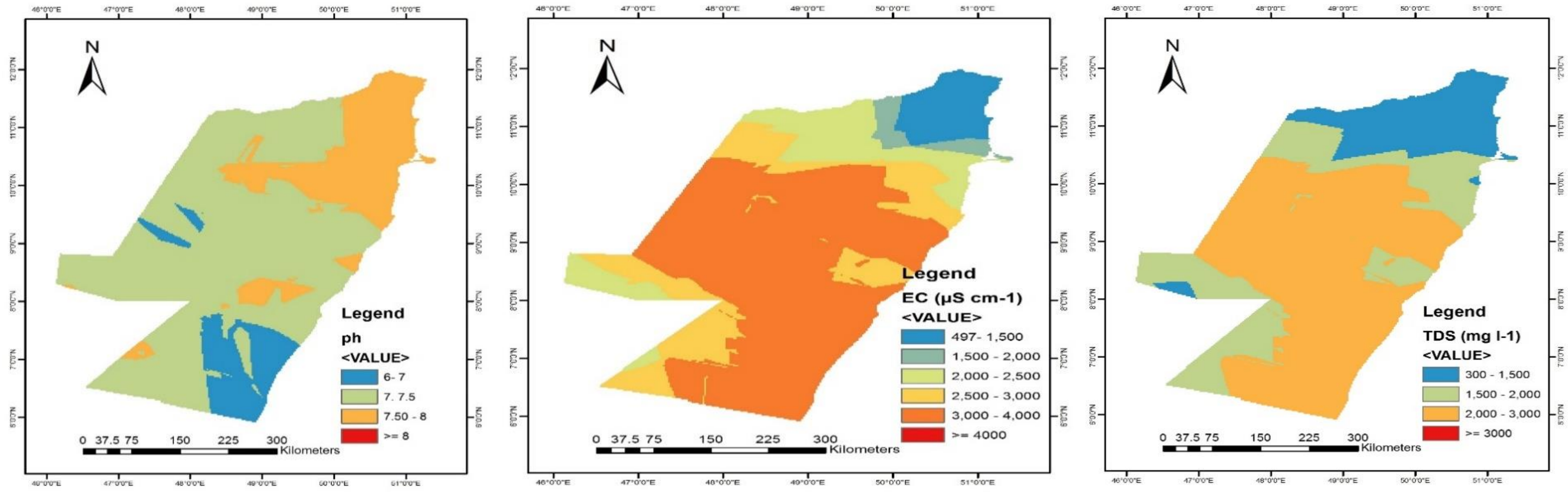
(c) TDS

Figure 3. Histrogram and Q-Q plot for groundwater parameters.



(a) (b) (c)

Figure 4. Best fitted semivariogram models for groundwater parameters, (a) pH, (b) EC, (c) TDS.



(a) (b) (c)

Figure 5. Map of spatial distribution of groundwater parameters (a) pH, (b) EC, (c) TDS.

Quality assessment of groundwater for drinking purposes

pH

pH is a measure of how acidic/basic water is. It was observed that pH value in study area varies 6 to 8.6 (Table 1). Most values are within the limit range 6.5 - 8.5 as prescribed by (WHO 2008), except small value which fall under acidity. Figure 5a shows spatial distribution of pH in the Puntland region.

Electrical conductivity (EC)

Electrical conductivity (EC) is a measure of water capacity to convey electric current, so that the higher EC indicates that high salts in groundwater. EC concentration in study area varies between 497 and 48120 $\mu S\ cm^{-1}$ (Figure 5a). The maximum permissible limit of EC in drinking water is 1500 $\mu S\ cm^{-1}$ according to WHO standards. Most EC concentration in the study area exceeded the maximum permissible limit. Figure 5b shows a decreasing trend in the distribution of EC concentration towards the northeast part of the study area (Bari). It can be concluded that groundwater is not appropriate for drinking water quality except the far eastern of Bari region.

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) usually refer to water mineral content, although dissolved organic material may also be included. The TDS of groundwater in the study area ranged from 332.99 to 3224.04 mg l^{-1}**.** According to WHO specification TDS 1500 mg l^{-1} is maximum permissible limit for drinking water. Figure 5c revealed that most TDS concentration in the groundwater exceeded the maximum permissible limit, therefore the groundwater is not suitable for human consumption.

4. Conclusions

The main objective of this study was to map and assess the groundwater quality of Puntland state. In this study, ordinary kriging has been applied to predict and estimate groundwater qaulity parameters. Before estimating the kriging various semivariogram model were tested and best fitted semivariogram models was chosen based on the lowest RMSE value. Cross-validation was then carried out to verify model predictive performance which shows good prediction model. According to WHO criteria, the majority groundwater of study area is not suitable for drinking water. Further studies considering other hyrdochemical parameters will be necessary to evaluate the concentrations of different ions present in the groundwater. The results of the research shows that it is vital to develop monitoring tools and management strategies for the aquifer system. This study is expected, to help the Puntland State Agency for Water Energy and Natural Resources (PSAWEN) for the monitoring the groundwater qaulity.

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