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Geospatial Analysis of Groundwater Quality Using GIS: A Case Study of Ahafo Kenyasi, Ghana

Ankomah Ernest, Dadzie Isaac
Department of Geomatic Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

ernestankomah@gmail.com

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Abstract

The exploitation and sustainable use of groundwater has received much attention with the sudden decline in quantity and quality of surface water. Knowledge on the current status of the physico-chemical parameters of groundwater becomes important in ensuring the sustainable use of the resource. This study used Geographic Information System (GIS) to assess groundwater quality in Ahafo-Kenyasi with particular focus on determining the spatial distribution of groundwater quality parameters and also produce groundwater quality map of the area. Physico-chemical analyses of groundwater quality parameters were made after collection of water samples from 24 community boreholes. The results of analysis carried out showed the following concentration ranges: pH (5.12-6.54), EC (71.6-952µS/cm), TDS (35.08-465.59mg/l), Turbidity (0-6.25NTU), Ammonia (0.01-0.61mg/l), Nitrate (0.1-4.12mg/l), Sulphate (1-65.5mg/l). All the samples analysed were above the guidelines set by World Health Organization (WHO, 2011) except for pH and Turbidity. Spatial distribution maps of the individual water quality parameters were developed using kriging interpolation technique and accepted based on the prediction performances of Stable, Exponential, K-Bessel semivariogram models. Overall water quality of the study area was assessed using Water Quality Index (WQI). The results showed that groundwater quality in the area decreases from north-western to south-eastern. However, groundwater from Ahafo-Kenyasi is good for domestic purposes.

Keywords: *GIS, Water quality Index, groundwater quality, Kriging*

1. Introduction

Groundwater is an essential resource for sustainable development all over the world. Due to its enormous benefits to societies, maintaining the quality of groundwater is of great interest. Globally, it is the most sought-after resource which is said to be in the range of 982km^3/year (Margat, 2013). Out of this, the percentage abstracted for agricultural use worldwide is 60%; the remaining 40% is divided between domestic and industrial uses (Margat, 2013). India for instance is reported to be the largest ground water user in the world, using 66.3 trillion gallons in a year (Margat, 2013).

In Sub Saharan Africa, majority of the rural population use groundwater from boreholes and hand dug wells for domestic and agricultural purposes (Adelana and MacDonald, 2008). There has also been success story of groundwater development in arid parts of western, eastern and southern parts of Africa where annual rainfall is less than 1000mm/yr. This is no different from Ghana where groundwater has proven to be very important source of water for both small towns and rural communities (Anornu *et al*., 2012). It contributes about 95% of water used by small towns and rural communities for domestic purposes (Anornu *et al*., 2012). Notwithstanding the numerous contributions of groundwater resources in these communities, issues such as high levels of minerals including metal compounds have been identified as a major problem limiting the degree to which groundwater is being used.

In order to acquire in-depth knowledge on hydrochemical properties of groundwater in an area before mass exploitation can be done, techniques such as descriptive statistics, Piper trilinear diagrams, semi-logarithmic graphs and stiff pattern diagrams have been used to evaluate the hydrochemical properties of water samples (Serio *et al*., 2018, Miglietta *et al*., 2017, Agoubi *et al*., 2013). These methods, by comparing the measured with the recommended standards, are able to determine their suitability for different parameters purposes but failed to determine the spatial distribution of the water quality parameters and also, they lack the predictive functions to be able to interpolate values between sample points.

Geographic Information System on the other hand is a vital tool which is capable of integrating data from different sources and also has the predictive capabilities to be able to determine and give accurate predictions which will help in making decisions. Yammani in 2007 was able to determine zone of groundwater quality that can be used for different purposes like irrigation and domestic use with the help of GIS. Babiker *et al*. (2007) also used water quality index and GIS to assess the suitability and sustainability of groundwater for different purposes in Japan. Yidana and Yidana (2010), used water quality index, GIS and multivariate statistics to assess groundwater quality in the southern voltaian formation in Ghana.

To this end, using GIS to assess groundwater quality in Ahafo Kenyasi becomes essential. The focus of the study is to know the state of the current groundwater quality in the area, the spatial distribution of hydrochemical properties of groundwater and also produce groundwater quality map of the area. This is to serve as a firsthand information as to which locations need further field investigations for the provision of boreholes for community water supply.

2. Materials and Methods

2.1. The Study Area

Ahafo-Kenyasi is the capital of Asutifi North District which is located in the Brong Ahafo region of Ghana. The district has latitudes 6°40' and 7°15' north and longitudes 2°15' and 2°45' west as its geographical coordinates (Figure 3.1). The district is surrounded by districts such as Sunyani Municipal, Tano South District, Dormaa East District, Asutifi South District, Asunafo North and South Districts and Ahafo Ano South and North Districts. It is one of the smallest districts in the Brong Ahafo region with approximately a total land surface area of 1,500 square kilometers. The District falls within the Wet Semi-Equatorial Zone of Ghana which is characterized by double rainfall maxima and has an annual mean rainfall ranging from 125cm to 200cm. The district has May to July as its main rainy season which peaks in the month of June whiles September to October experiences its minor rainy season.

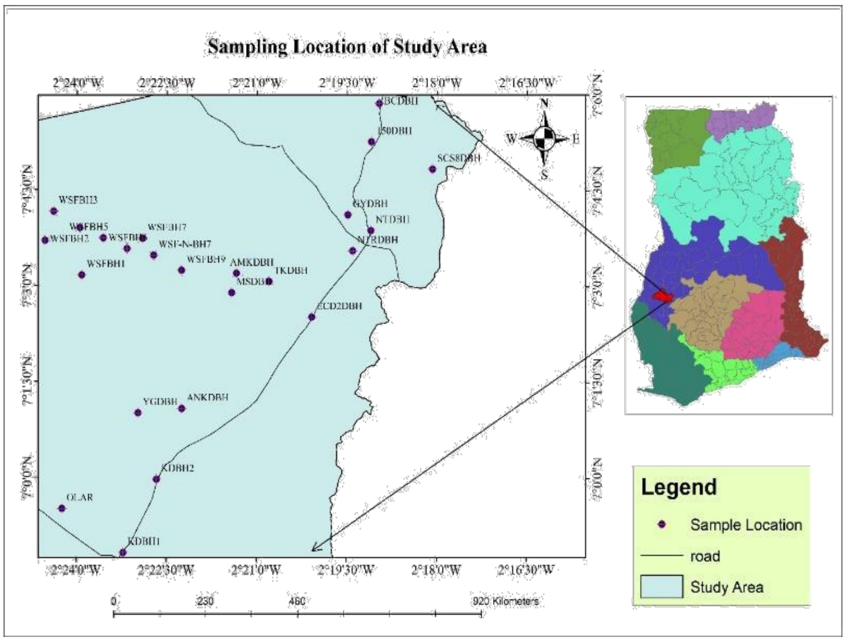


Figure 1. Map showing locations of boreholes

2.2. Sample Collection

Groundwater samples were taken directly from 24 community boreholes from 17th to 21st December 2018, from morning to afternoon each day. Samples were taken from Kenyasi, Ola resettlement, Ntotroso, Ntotroso resettlement, Gyedu, Tawia Kurom, Amankona Kurom, Anane Kurom, Manu shed, Beposo and water storage facility. Clean 125ml bottles were used to collect water samples for chemical (sulphate, nitrate and ammonia) analysis from each of the sample locations. First, these bottles were washed thoroughly three times with some of the samples being taken before samples were taken from each of the sample locations. Stickers were placed and labelled for easy identification of samples before they were transported to the laboratory for analyses.

Water samples were analysed for parameters like pH, electrical conductivity (EC) and total dissolved solids (TDS) in the field using YSI Pro 1030 water quality instrument. Turbidity was also analysed using Hach portable turbidimeter 2100P. These parameters were measured in-situ to prevent changes in their chemical composition as a result of changes in temperature during transportation. Ammonia, nitrate and sulphate were analysed at the laboratory using Hach DR5000 spectrophotometer. Locations of sampling points were obtained using Garmin eTrex 30x handheld GPS. The GPS coordinates were then exported into ArcGIS to create point features to show the positions of the sampling points.

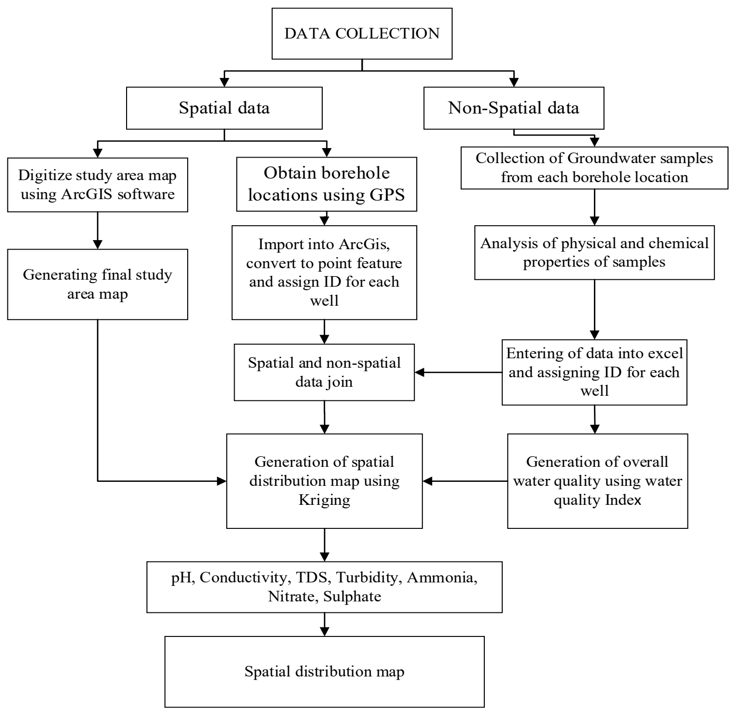


Figure 2. Flow chart of methodology used in the study

2.3. Data Analysis

The types of data acquired for this research comprised of spatial and nonspatial data. The water quality data made up the nonspatial database. The nonspatial data was entered in Microsoft Excel and was joined with the spatial data in ArcGIS environment. The joined spatial and nonspatial data was used in the preparation of water quality spatial distribution maps of the parameters. Geostatistical technique (Kriging) was employed in the study to determine the spatial spread of physico-chemical properties of groundwater showing potable and non-potable areas. The data was explored using histograms, normal QQplots and semivariogram clouds to determine the normality and spread of the data. Prediction performances of the semivariogram clouds were assessed through cross-validation before accepting the final map. The overall water quality map of the study area was generated using Water Quality Index (WQI). The WQI was calculated using Weighted Arithmetic Index which was initially proposed by Horton in 1965 and later developed by Brown et al. 1972. This was calculated in four steps; Assigning of weights to each of the seven parameters, computing of relative weights for the seven parameter, computing of a quality rating scale for each parameter and lastly, the computing of the sub-index of ith quality parameter.

Table 1. Relative weight for each parameter

	WHO 2011	Weight (wi)	Relative weight (Wi)
pH	6.5-8.5	4	0.1429
Conductivity	1500	4	0.1429
TDS	1000	4	0.1429
Turbidity	5	3	0.1071
Ammonia	0.5	4	0.1429
Nitrate	50	5	0.1786
Sulphate	250	4	0.1429
		∑wi = 28	∑Wi = 1

$$\mathbf{Wi} = \frac{\boldsymbol{wi}}{\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{wi}} \quad [1]$$

where: (**Wi**) is the relative weight, (**wi**) is the weight for each parameter and (n) is the number of parameters The third step, a quality rating scale (**qi**) for each parameter was determined by dividing its concentration in each water sample by its respective standard (WHO standard) and the result was multiplied by 100 to express it in percentage as shown in equation (2)

$$\mathbf{qi} = \frac{Ci}{Si} \times 100 \quad [2]$$

where: (**qi**) is the quality rating, (**Ci**) is the concentration of each pollutant in water sample in mg\L, (**Si**) WHO standard concentration. For the computation of WQI, the SI was determined for each chemical parameter. The sub-index of ith quality parameter can be determined by:

$$\mathbf{SI_i} = (\boldsymbol{Wi} \times \boldsymbol{qi}) \quad [3]$$

$$\mathbf{GWQI} = \sum_{\boldsymbol{i=1}}^{n} SI_{\mathrm{I}} \quad [4]$$

Where $\mathbf{SI_i}$ = the sub index for each parameter. The final GWQI values were classified into five categories.

Table 2. Results of water quality Analysis obtained from laboratory.

LOCATION	LAT	LONG	pH	EC µS/cm	TDS mg/l	TURBIDITY (NTU)	AMMONIA mg/l	NITRATE mg/l	SULPHATE mg/l
NTOTROSO	7.064583	-2.31833	6.34	358.90	189.14	0	0.10	1.79	13
GYEDU	7.068639	-2.32472	5.87	274.70	134.75	1.83	0.01	0.587	8
NTOTROSO RESETLEMENT	7.059278	-2.32336	5.81	282.30	138.18	2.46	0.16	0.508	4
ENVIRONMENTAL CONTROL DAM 2	7.041972	-2.33467	6.46	575	284.2	2.07	0.21	0.70	45
TAWIA KUROM BH	7.051222	-2.34656	6.44	211.10	102.9	2.08	0.31	0.80	20
AMANKONA KUROM BH	7.053361	-2.35558	5.72	255.90	125.44	4.79	0.50	0.589	10
MANU SHED BH	7.048278	-2.35692	5.70	256.40	125.44	2.71	0.55	0.10	8
KENYASI BH 2	6.999611	-2.37772	6.01	219.60	107.80	5.47	0.07	0.30	1
KENYASI BH 1	6.980472	-2.38694	5.70	826	406.70	1.28	0.61	0.67	65.50
OLA RESETTLEMENT	6.991917	-2.40394	5.40	71.60	35.08	2.85	0.31	0.24	23
WATER STORAGE FACILITY BH1	7.052806	-2.39858	6.08	118.50	57.82	1.06	0.11	0.64	14
WATER STORAGE FACILITY BH2	7.061778	-2.40881	5.31	81.60	39.69	1.77	0.05	0.28	16.10
WATER STORAGE FACILITY BH3	7.069361	-2.40639	5.44	154.10	75.46	3.87	0.10	0.30	40
WATER STORAGE FACILITY BH4	7.065139	-2.39914	5.25	124.50	60.76	6.25	0.01	0.40	17
WATER STORAGE FACILITY BH5	7.062444	-2.39261	5.26	223.40	109.76	3.44	0.10	4.12	2
WATER STORAGE FACILITY BH6	7.059667	-2.38603	5.12	151.80	74.48	2.18	0.01	0.62	1
WATER STORAGE FACILITY BH7	7.062361	-2.38172	5.50	231.90	113.68	2.38	0.07	0.46	40.50
WATER STORAGE FACILITY BH8	7.057972	-2.37864	5.48	248.30	121.52	2.09	0.06	0.76	33
WATER STORAGE FACILITY BH9	7.054083	-2.37086	6.54	278.50	136.22	2.11	0.09	1.16	3
ANANE KUROM BH	7.018056	-2.37072	6.11	280	137.20	1.48	0.08	0.40	1
BEPOSO CAMP BH	7.097639	-2.31606	6.23	658	323.40	1.90	0.14	0.30	12
BEPOSO CAMP BH2	7.087694	-2.31822	5.31	153.90	75.46	1.80	0.04	0.45	35
YARO GRUMA BH	7.016917	-2.38289	5.17	114.10	55.86	1.85	0.11	0.45	5
SEGMENT CONTROL SYSTEM 8 BH	7.080583	-2.30122	6.51	952	465.59	6.20	0.10	0.80	43
Min			5.12	71.60	35.08	0	0.01	0.10	1
Max			6.54	952	465.59	6.25	0.61	4.12	65.50
Mean			5.78	295.92	145.69	2.66	0.16	0.73	19.17
WHO GUIDELINE			**6.5-8.5**	**1500**	**1000**	**5**	**0.5**	**50**	**250**

3. Results and Discussion

As can be seen from (Table 2) pH values in the samples collected ranged from 5.12 to 6.54 with a mean of 5.78. From the 24 water samples, 8 were discovered to be within the acceptable limit (6-8.5) while the remaining 16 groundwater samples had concentration levels slightly below acceptable limit. This shows that the nature of groundwater in the area is slightly acidic. The low pH values recorded may be attributable to biogeochemical processes (CO_2 generation in the soil zone through root respiration and the effect from leaching of organic acids from the decay of organic matter) as stated by (Knutsson, 1994 and Langenegger, 1994). The finding corroborates that of Kortatsi (2007) where low pH waters are mainly found in the forest zone of Ghana.

Conductivity levels in groundwater ranged from 71.6µS/cm (TDS = 35.08mg/L) to 952µS/cm (TDS = 465.59mg/l) with a mean as 2955µS/cm (TDS = 145.69mg/L). The mean EC value is below 1,500 µS/cm, the recommended threshold by the World Health Organization (WHO, 2011). Since the EC and TDS of samples analysed in the area are less than the WHO guideline, groundwater in the area can be considered as fresh water (Davis and De Wiest 1966). The observed low EC and TDS values could be attributed to low mineralized groundwater inflows or perhaps low abstraction of groundwater in the area since most sample locations were in low populated areas.

Analysis of turbidity also showed that turbidity concentrations occurred from 0NTU to 6.25NTU for all 24 samples, having an average of 2.66 and a standard deviation of 1.58. From the 24 samples analysed, 21 samples exhibited compliance with the recommended limit for drinking (5NTU), while 3 sampled areas (Kenyasi Borehole 2, Water Storage Facility Borehole 4 and Segment Control System 8) were slightly above the acceptable limit. The elevated turbid water in these areas is associated with the possibility weathering of rocks or the precipitation of non-soluble reduced iron and other oxides or the disturbance of sediments when the water was being pumped from the wells. According to WHO (2011), turbidity per se is not a threat to health but the possibility of contaminants present in the water would be of health concern, therefore it is recommended that water from these areas be filtered or treated before drinking. However, the mean value of 2.66NTU suggests that the groundwater in the area can be considered good for drinking with respect to its aesthetic properties.

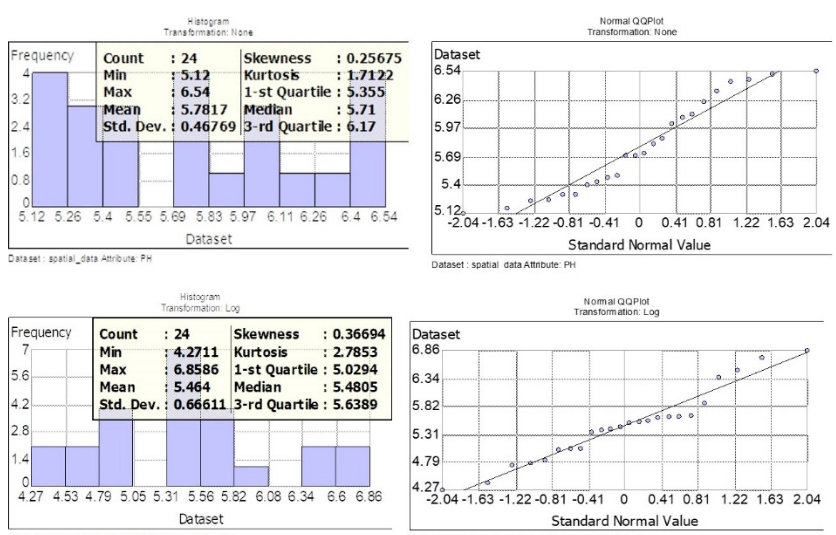
Ammonia had values ranging from 0.01 mg/l to 0.5mg/l with a mean of 0.15mg/l. Ammonia levels from samples analysed showed that concentrations in the area were within recommended limit except two locations (Manu Shed borehole and Kenyasi Borehole 1) which were slightly higher than the recommended limit. According to the International Organization for Standardization (ISO), the presence of ammonia at higher levels than geogenic levels is an indication sewage or industrial contamination. Therefore, the higher levels of ammonia concentration in these two locations suggest the presence of sewage or industrial contamination whiles the remaining locations suggest they occurred naturally through microbiological activities in the soil.

The nitrate levels from the groundwater samples can be seen from the table 4.1 as it ranges from 0.1mg/l to 4.12mg/l having an average of 0.73 and a standard deviation of 0.80. The nitrate levels of all the 24 groundwater samples analysed showed that nitrate levels were below the acceptable threshold (50mg/l). According to Balakrishnan et al. (2011) nitrate concentration in natural water is less than 10mg/l. This is an indication that groundwater in the study area is fresh and natural. The low level of nitrate might be directly linked to leaching from natural vegetation or perhaps through the application of fertilizers and manures since agriculture predominates the entire study area.

Sulphate results showed that concentrations occurred from 1mg/l to 65.5mg/l with an average of 19.17 and a standard deviation of 17.65. The sulphate levels of all 24 samples analysed were below the acceptable threshold (250mg/l) stated by WHO. The low level of sulphate concentration can be linked directly to natural processes without any anthropogenic or industrial influences. Sulphate in drinking water can cause a noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers. However, based on the above results the groundwater in the study area can be considered to pose no physiological or aesthetic problem for drinking or domestic purposes.

3.1. Exploratory Analysis of Data

The data was explored using histogram and normal QQplots to determine the normality and spread of the data. Kriging methods produces accurate results if the data is somewhat close to normality (Nas and Berktay, 2010). Plots of histograms and normal QQplots were used to determine if the data were normally distributed. Histogram plots and QQplot were individually produced for each parameter to help determine their spread and characteristic as shown in (Figure 3) and it was evident that pH, turbidity and ammonia were normally distributed. The rest of the parameters such as Electrical conductivity, TDS, Nitrate and Sulphate were not normally distributed. These parameters had to be log transformed to make the distribution closer to normal.



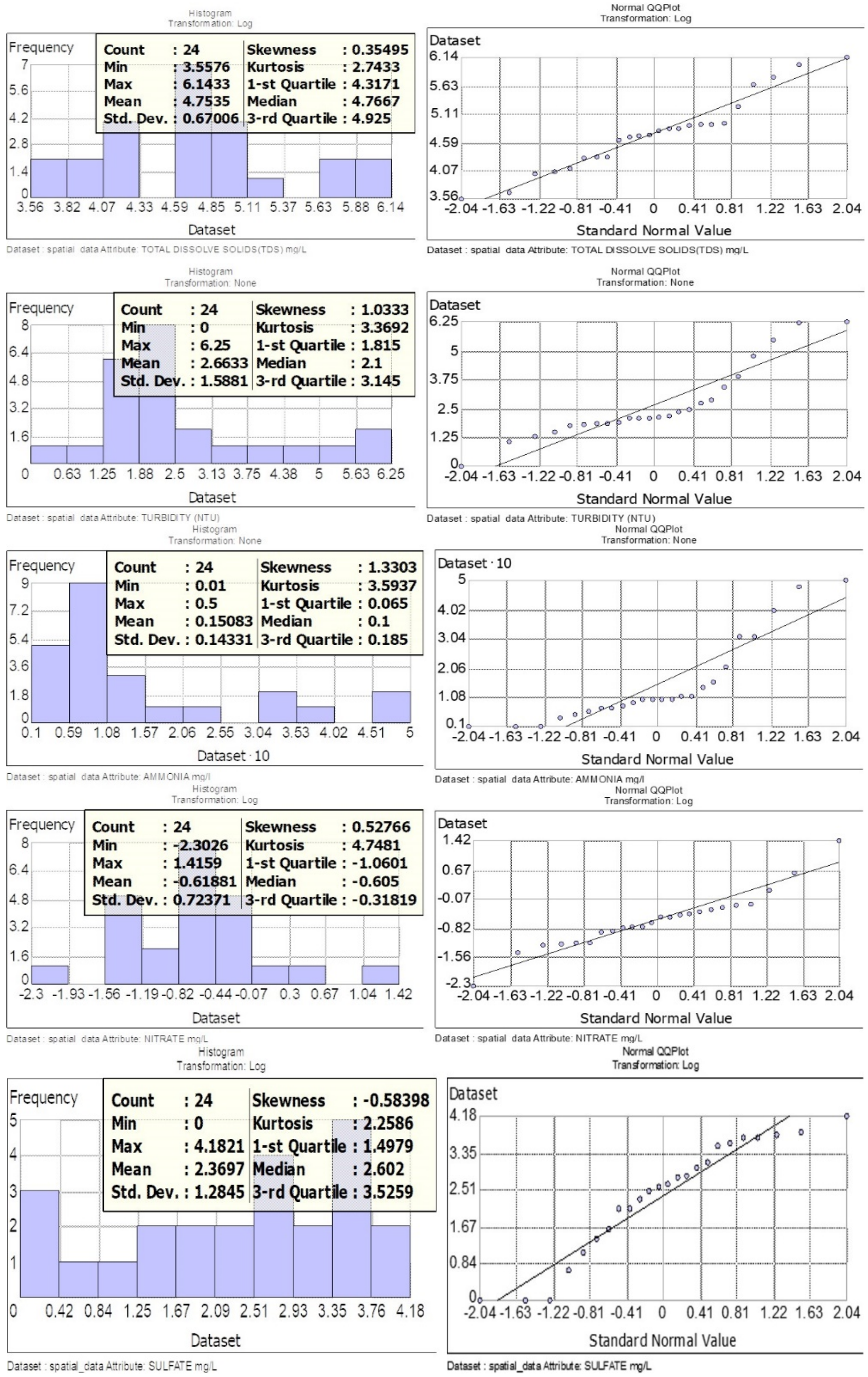


Figure 3. Histogram and Normal QQ plot for water quality parameters

3.2. Semivariogram Models

The semivariogram cloud was used to determine the autocorrelation and spatial dependence in the dataset. Three kinds of semivariogram clouds (K-Bessel, Exponential and stable) were used to test for each parameter (pH, Conductivity, TDS, Turbidity, Ammonia, Nitrate, and sulphate) in order to determine the one that produced accurate predictions. The semivariogram models gives information about the spatial dependencies of the parameters and how they are autocorrelated. Amongst the types of

Kriging techniques, ordinary Kriging (OK) was the preferred method used in this study because of its easiness and accuracy when it comes to predicting surfaces. Figure 4 represents the best-fitted semivariogram models of groundwater quality parameters in Ahafo-Kenyasi. It can be seen that all of groundwater quality parameters have strong spatial dependence except sulphate and nitrate which have moderate to weak spatial dependence respectively.

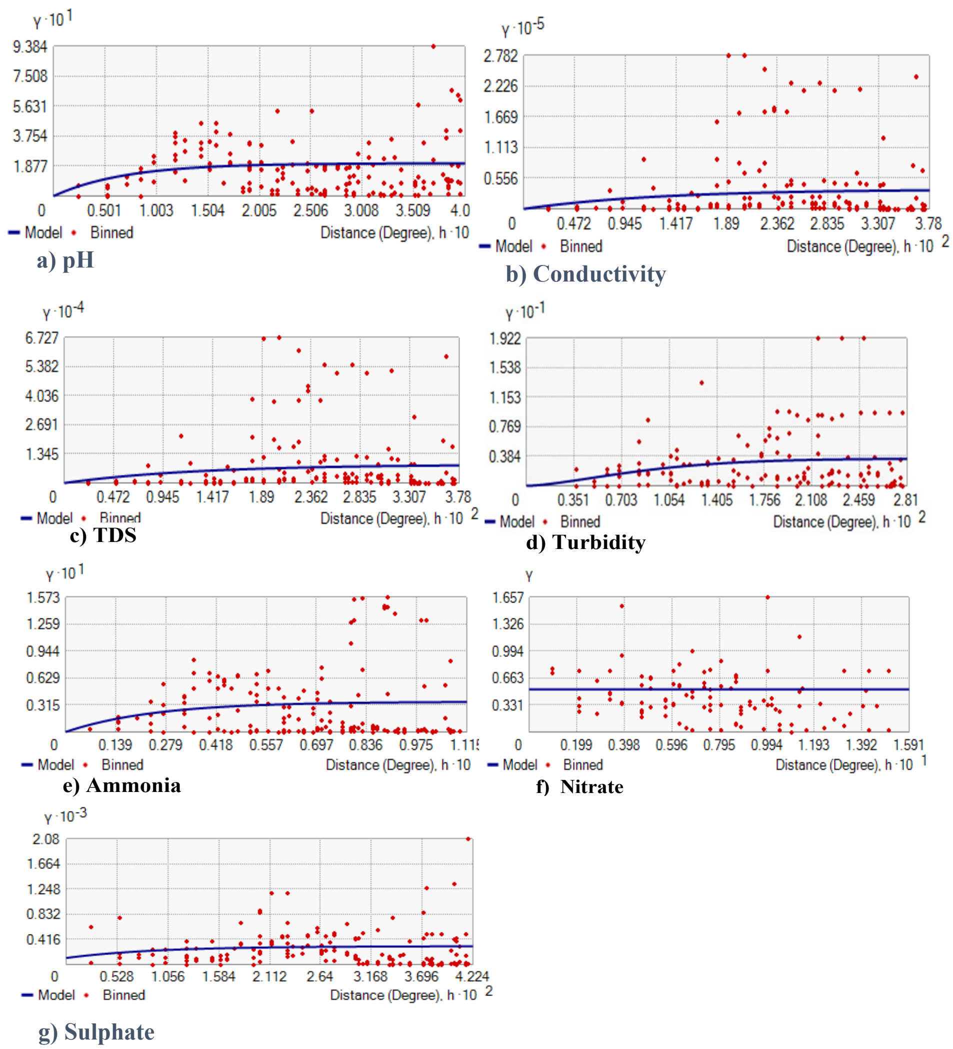


Figure 4. Best-fitted semivariogram models for water quality parameters

3.3. Prediction Performance of semivariogram model

Prediction performances of the semivariogram models were measured through cross-validation to determine the model that produced accurate predictions as seen in (Table 3). Prediction performances were assessed with the assumption that; the standardized mean error must be near 0, the average standard error and root-mean-square error ought to be very small and the root-mean square standardized error must be near 1. When the average standard errors are closer to the root-mean-square prediction errors, then the prediction standard errors can confidently be said to be appropriate (ESRI, 2001).

Table 3. Best-fitted models and prediction errors of groundwater quality parameters

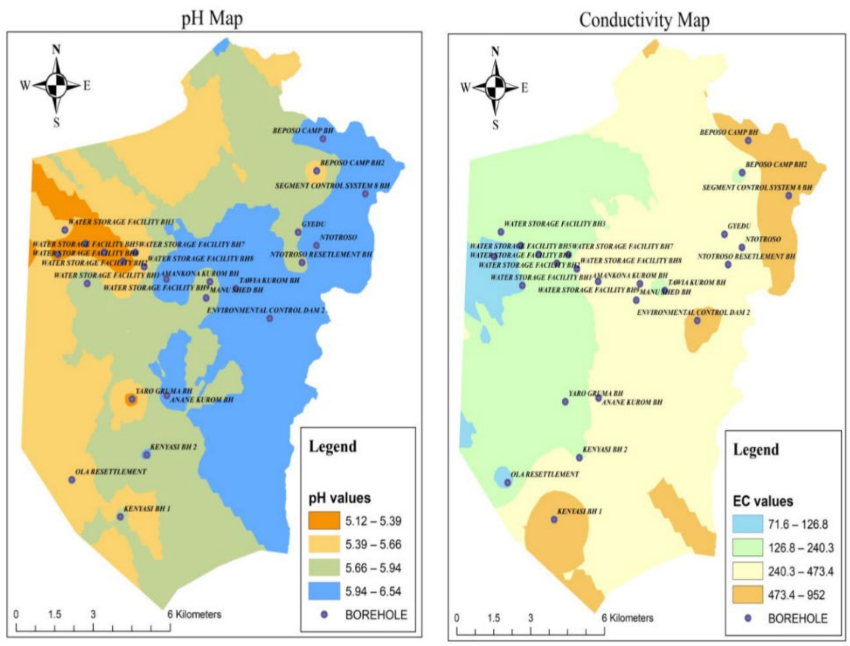
Parameter	**Model**	**Prediction errors**				
		Mean	**Root-mean square**	**Average standard error**	**Mean standardized error**	**Root-mean-square-standardized**
pH	Exponential	-0.1607	0.4631	0.4434	-0.0129	1.0256
Conductivity	Exponential	-22.249	240.424	160.147	-0.0885	1.2959
TDS	Exponential	-10.800	118.118	78.580	-0.087	1.299
Turbidity	Stable	-0.0097	1.6654	1.6919	-0.0079	0.9782
Ammonia	Exponential	-0.0039	0.1224	0.1386	-0.0192	0.8133
Nitrate	K-Bessel	-0.0385	0.8257	0.6366	-0.1538	1.5033
Sulphate	Exponential	-1.4002	19.033	17.247	-0.0638	1.0649

The mean standardized error for pH, conductivity, TDS, Turbidity, Ammonia, Nitrate and sulphate were -0.0129, -0.0885, -0.087, -0.0079, -0.0192, -0.1538 and -0.0638 respectively. The individual values of RMSSE were 1.0256, 1.2959, 1.299, 0.9782, 0.8133, 1.5033, 1.0649. The MSE values were near 0 whiles the RMSSE values were also near 1 indicating a good prediction model. The values of RMSE and ASE which were also close to each other with respect to the seven parameters shows the prediction of the model can be accepted (ESRI, 2001).

3.4. Spatial Variation of Groundwater Quality Parameters

Spatial distribution maps of the of pH, Conductivity, TDS, Turbidity, Ammonia, Nitrate and sulphate concentration were produced using Geostatistical interpolation technique, an extension in the GIS environment. Figure 5 shows the spatial distribution maps of groundwater quality parameters in the study area. pH map in (Figure 5) shows that pH concentrations in the area increases from the north-western part to south-eastern part of the area. The pH values in the area ranged from 5.12 to 6.54 with a mean value 5.78 (Table 2). This shows that groundwater in the area is slightly acidic. The spatial distribution maps of conductivity and TDS show that concentrations for conductivity and TDS increases from west to east (Figure 5). Knowing that the maximum limit for conductivity and TDS in drinking water are 1500µS/cm and 1000mg/l, the groundwater quality in the area can be considered very good for drinking since conductivity and TDS concentrations are below the maximum limit.

The spatial distribution of turbidity as shown by (Figure 5) indicates that for most part of the study area, turbidity concentrations fall within the acceptable limit of 5NTU set by WHO with the exception of few areas (north-eastern, central, north-western and southern) which were slightly higher than the maximum limit. Water from these areas would have to be filtered or treated properly before use. Ammonia concentration on the other hand increases from north to south (Figure 5) with areas around central and southern having the highest concentration of ammonia. Knowing the maximum concentration limit of ammonia to be 0.5mg/l, the groundwater quality can be interpreted as good for drinking with few areas around the central and southern which were higher than the maximum limit. Nitrate concentration increases from the south to north of the study area (Figure 5). Though concentration of nitrate increases from south to north, concentration in groundwater was below 50mg/l maximum limit set by WHO. This shows that groundwater in the Ahafo Kenyasi is free from nitrate contamination and thus groundwater quality can be considered good for drinking without having any effects. Sulphate had low concentration levels in the central part of the study area but increased towards the southern and some portion of north-eastern area of the study area (Figure 5). Sulphate concentrations limit were below the 250mg/l maximum limit. The low concentrations of sulphate are naturally occurring which will not have any adverse effect on consumer's taste. Thus, making the groundwater in Ahafo Kenyasi is very good for drinking.



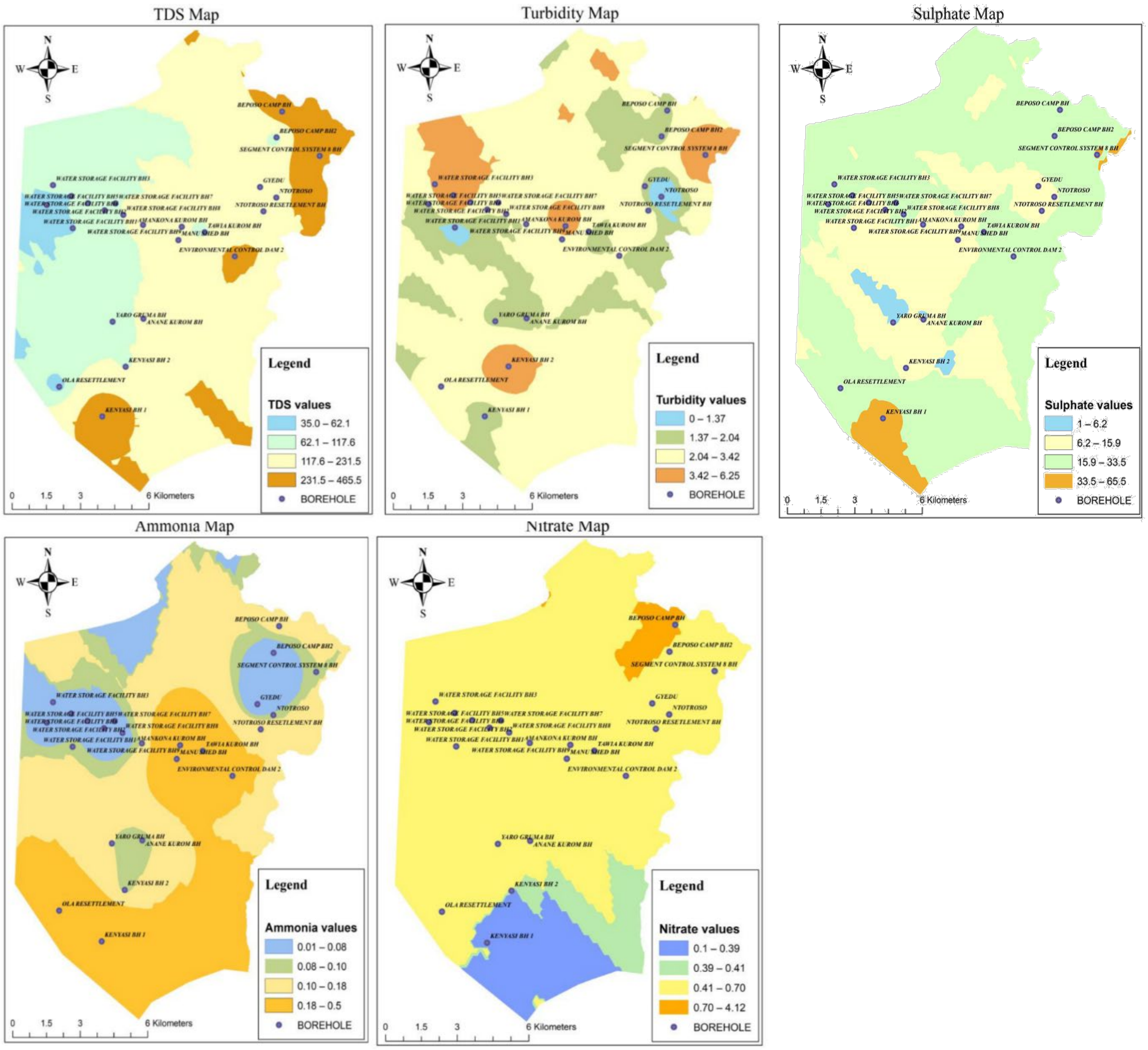


Figure 5. Spatial distribution map of water quality parameters

3.5. Estimation of Groundwater Quality Index

Groundwater quality index map was derived from seven groundwater quality parameters. The groundwater quality index for the seven parameters were processed in GIS environment to get the final groundwater quality index map as shown in (Figure 6). The groundwater quality index map was interpreted with reference to the classification made by Ramakrishnaiah *et al.* (2009) as shown in (Table 4). It is obvious from the classification that, all the samples had water quality index less than 50. This shows that groundwater from the study area is of acceptable quality for human consumption. The spatial distribution map of the groundwater quality index (Figure 6) shows that in general, the groundwater quality decreases from the north-west to south-east of the study area.

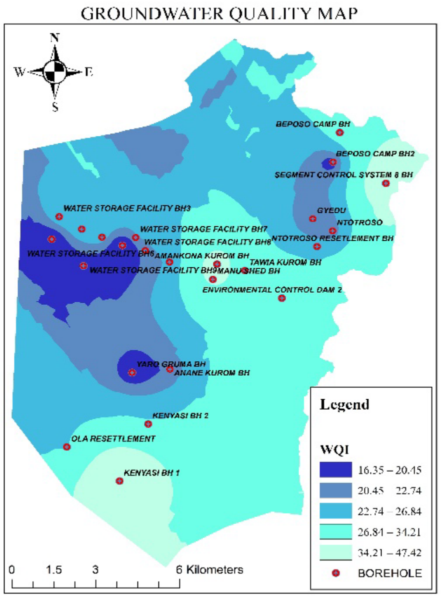


Figure 6. Groundwater Quality Map

Table 4. Groundwater quality index legend

WQI	Status
<50	Excellent
50 - 100	Good
101 – 200	Poor
201 - 300	Very poor
>300	Unsuitable for drinking

(Ramakrishnaiah *et al*., 2009)

4. Conclusion

The study used Geographic Information System (GIS) as a tool to determine the quality of water in Ahafo-Kenyasi. The main focus was to produce a spatial distribution map of groundwater quality parameters and an overall groundwater quality map. The physical and chemical analysis showed that groundwater in the area is fresh with low EC and TDS but slightly acidic in nature. The spatial distribution of groundwater quality parameters assessed also revealed that; low pH values occurred at the north-western part of the area which increases towards the south-eastern part of the area; EC and TDS had low values at western and portions of south-western which increases towards south, south-eastern and north-western part; Turbidity for most part of the study area had low values with the exception of north-eastern, north-western and southern part of the study area; Ammonia concentration also increases from north to south with high values occurring at the central and southern part; Nitrate levels increases from the south to north of the study area. Though concentration of nitrate increases from south to north, concentration in groundwater were very low; Sulphate had low concentration levels in the central part of the study area but increased towards the southern and some portion of north-eastern area of the study area.

The overall water quality analysis derived from the seven parameters using WQI indicates that in general, the quality of groundwater in the area decreases from north-western to south-eastern. However, based on the values obtained from the WQI, the quality of groundwater in Ahafo-Kenyasi can be deemed acceptable for dinking. It is therefore recommended that; further studies be conducted on hydrogeologic properties to determine the depth to aquifers and level of trace elements like mercury, copper and arsenic in the area and also mining activities and other anthropogenic activities in the area be regularized to prevent potential pollution of the resource.

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