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GEOSPATIAL ASSESSMENT OF GROUNDWATER QUALITY IN THE SAVELUGU-NANTON MUNICIPALITY, NORTHERN GHANA.

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ABSTRACT
Water from beneath the earth's surface has been exploited for domestic use, livestock, irrigation and even in some areas for commercial and industrial use. Water quality is affected by a combination of natural processes, most of which relates to chemical compositions underground and human activities. The quality of some sources of groundwater had been found to be unacceptable for domestic use, with negative health implications due to either natural and/or anthropogenic factors that have the potential to adversely affect the health of consumers. There is therefore the need for groundwater quality assessment from groundwater sample results in areas where boreholes exist using geostatistics in order to be able to predict the concentrations of areas where there are no boreholes. The study aimed at using groundwater sample results from areas where boreholes exist in the Savelugu-Nanton Municipality to assess groundwater quality by producing maps of chemical parameters for groundwater quality of the entire municipality using geostatistics. The secondary data used for the study had one hundred and sixty-eight (168) borehole sample results in the Savelugu-Nanton Municipality, Ghana and were obtained from the Community Water and Sanitation Agency (C.W.S.A.). Chemical parameters (sodium, calcium, potassium, fluoride, chloride, nitrates and Sulphates) were mapped using indicator kriging in Geographic Information Systems (GIS). The standards by the World Health Organisation the Ghana Standards Authority were the primary thresholds for the indicator kriging geostatistical analysis. The study showed that Sodium and Fluoride concentration values were mostly above the drinking water standards, with a few values falling below the standard limits. Calcium, Chloride, Fluoride and Sodium concentration values were highest in the south-eastern parts of the Municipality, with their concentrations decreasing towards the central and western portions of the study area.

Keywords: *Borehole, Indicator Kriging, Chemical, Mapping, Geostatistics*.

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1.0 INTRODUCTION

Water from beneath the earth's surface has been exploited for domestic use, livestock, irrigation and even in some areas for commercial and industrial use since the earliest times (W.H.O., 1996). The exact nature of its occurrence was not widely understood, successful methods of bringing the water to the surface have been developed and groundwater use has increased consistently ever since (W.H.O., 1996). Having a basic understanding about groundwater quality will help ensure that a well is supplying potable water for domestic use. Along with human activities, water quality is affected by a combination of natural processes, most of which relates to chemical compositions underground. However, other factors such as biological and physical conditions can cause the processes to occur as well (National Groundwater Association, 2016). Groundwater quality comprises the physical, chemical, and biological qualities of groundwater (Harter, 2003).

In the Northern Region of Ghana, there are 4,657 hand pump boreholes which serve the people (C.W.S.A., 2015). The preference for groundwater stems from the fact that groundwater is generally of better quality, less polluted and requires little or no bacteriological treatment prior to consumption (Anim-Gyampo *et al*., 2014). In addition, groundwater sources are more reliable for utilization in rural areas than surface water sources such as rivers, streams and dams in water-stressed semi-arid regions like northern Ghana (Anim-Gyampo *et al.*, 2012). Groundwater is the most appropriate portable and widely used source of drinking water for many rural communities in the world and its quality has special health significance and needs great attention of all concerned (Wright et al. 2004; Furi et al. 2011; Kanyerere et al. 2012; Sunkari and Danladi 2016; Raj and Shaji 2017; Rashed and Niyazi 2017).The quality of some sources of groundwater had been found to be unacceptable for domestic use, with negative health implications due to either natural and/or anthropogenic factors that have the potential to adversely affect the health of consumers (W.H.O., 1996).

There is therefore the need for groundwater quality assessment from groundwater sample results in areas where boreholes exist using geostatistics in order to be able to predict the concentrations of areas where there are no boreholes.

Figure 1 is a summary of the workflow for this paper.

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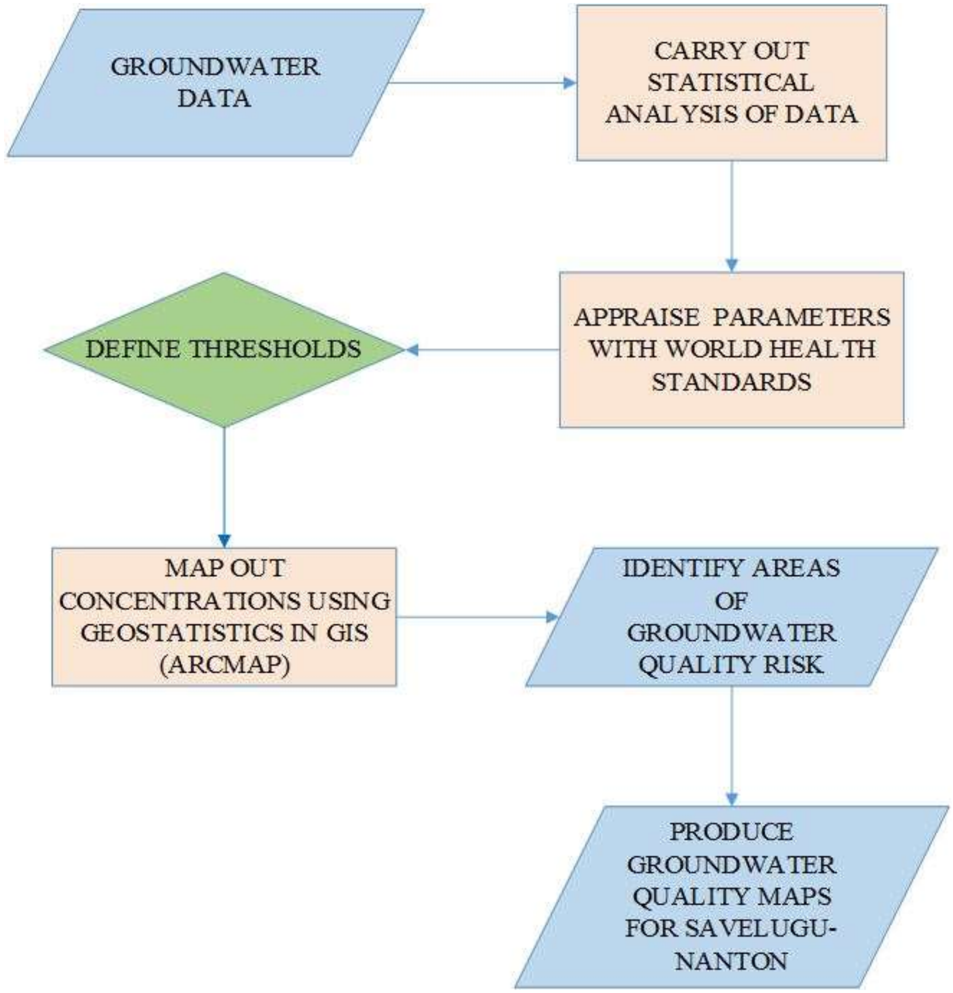

Figure 1: Conceptual Framework

2.0 RESEARCH METHODOLOGY

2.1 The Study Area

The Savelugu-Nanton Municipality is located at the northern part of the Northern Region of Ghana (Figure 2). The Municipality also has a total land area of about 2022.6 sq. km. with a population density of 68.9 persons per sq. km. (Ghana Statistical Service, 2014).

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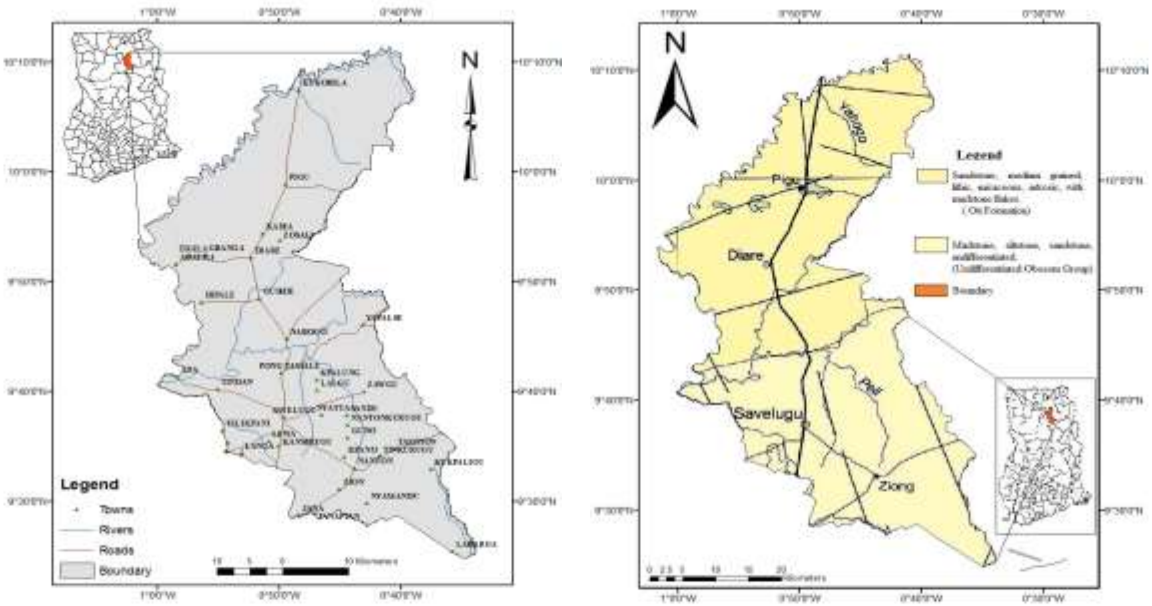

Figure 2: Location (left) and geology (right) maps of Savelugu-Nanton Municipality

The Voltaian (Neoproterozoic rocks) formation characterizes the geology of the Municipality. These are the Oti and Obosom group of sedimentary rocks. The Oti group covers the northern part and is medium grained, lithic, micaceous and arkosic sandstones with mudstone flakes. The Obosom group covers the southern part of the Municipality and consists of undifferentiated siltstone, shale and mudstone. Underground water potential is generally determined by this underlying rock formation, which has varying water compared to the Oti group formation (Figure 2) (Ghana Statistical Service, 2014).

2.2 Data collection and pre-processing

One hundred and sixty-eight (168) boreholes data was obtained from the Community Water and Sanitation Agency (C.W.S.A.) in the northern region of Ghana, and was used for this research. GPS coordinates of the boreholes with their corresponding chemical parameters was used for the analysis, using Microsoft Excel 97-2003 workbook (the format which supports ArcMap in GIS).

2.3 Data analysis

The chemical parameters analyzed for this study were chosen due to the fact that these have been found to be most problematic in the study area. Initial evaluation of the ground water quality for the following chemical parameters (Calcium, Flouride, Sodium, Patassium, Chloride, Nitrates and Sulphates), involved testing for the Minimum, Maximum, Mean, Standard deviation and Variance. Table 1 shows a summary of the statistical analysis performed on the data. This includes the mean, minimum value, maximum value, standard deviation and the variance.

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Table 1: Statistical analysis of groundwater parameters

Groundwater Parameter	**Statistical Parameter**				
	Mean	Minimum	Maximum	Standard Deviation	Variance
Calcium	44.267	2.3	705.0	103.6297	1.074
Fluoride	1.044	0.1	4.8	1.0373	1.076
Sodium	2.5516	0.90	2489.0	415.59357	1.727
Potassium	3.036	30.0	161.0	12.3301	152.031
Chloride	287.818	1.7	5160	862.0353	7.431
Nitrates	5.852	0.01	250.0	30.4256	925.715
Sulphates	34.318	2.2	2496.0	195.4371	3.820

2.4 Indicator Kriging using the Geostatistical analyst of ArcMap® in GIS

Kriging tool in the geostatistical wizard was used to analyze the shapefile (containing the groundwater quality data) as the input data. Indicator kriging was chosen as the preferred method and probability map selected to be the specific type of indicator kriging wanted. The World Health Organisation Standards of the groundwater quality parameters were used as the primary threshold. Limits were set into equal intervals and classes was set to six (6). Semi variance and covariance of the data were at this stage considered as a model. The type of model selected was the spherical which is the general standard one for all geostatistical works and comes as the default too based on the data been analyzed and the options or inputs made so far (Johnston *et al*., 2001). The nugget, major range, partial sill and lag size were produced and number lags were set to 10. The final surface generated was then added to the layers of ArcMap and then displayed automatically.

2.5 Generation of Maps of chemical parameters

The final surface produced from the geostatistical analysis was classified into standard and more understandable categories based on the intensity of various concentrations which ranged from minimum to maximum. The extent of the surface produced was then restricted to the boundary of the study area (Savelugu-Nanton Municipality). The coordinates of the boreholes were plotted as points on the map to easily identify where each particular borehole falls within with regards to the various concentrations of the parameters. The produced map was then exported into jpeg format and saved. The entire procedure from the geostatistical analysis was repeated for each of the seven (7) parameters analyzed.

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3.0 RESULTS AND DISCUSSION

3.1 Geostatistical Computations of the Various Parameters

3.1.2 Sill and Range

The sill is the value that the semi variogram model attains at the range (the value on the y-axis). The partial sill is the sill minus the nugget. The sill gives an idea of the general values of the dataset as to whether most of the values are high or low. In this study, calcium, chloride and fluoride had low sill values. The range is the distance where the model first flattens out. Samples closer to the range are auto-correlated while those far from it are not. Autocorrelation of samples primarily how similar they are. In this study, autocorrelation mostly occurred in Calcium and Chloride. This was evident in the final maps (Figures 10 and 11) as these ones showed the high values concentrated at a particular portion of the study area.

3.1.3 Nugget

The difference between measurements at zero separation distance (i.e., lag = 0) is the nugget effect. The nugget effect can be as a result of the measurement errors or variations in spatial sources at distances smaller than the sampling interval (or both). This however can best be corrected based on the sampling procedure. In the case of this study, the data samples were of uneven intervals which resulted in significant recordings of the nugget with the highest being Fluoride and Chloride (Table 2).

Table 2: Geostatistical Computations of the Various Parameters

Parameter	Sill	Nugget	Range
Sodium	0.00074472	0.22487	9.5974
Calcium	0.000055088	0.045405	9.5974
Chloride	0.032771	0.10036	0.253113
Fluoride	0.12079	0.11839	0.0085025
Potassium	0.00005208	0.0059004	2.05732
Nitrates	0.000087183	0.02891	9.64406
Sulphates	0.000041988	0.011776	9.5974

3.1.4 Semi Variogram Plots

Semi variograms (Figures 3 to 9) brought out information on the sill, nugget and range of the various parameters used. In the case of exploring the data, outliers were the target. There are two types of them which are global and local outliers. Global outliers are those with very high values which occur outside the range while local outliers fall within the range but around it is values lower than its own value. Global ones are evident in areas where there are generally very high values occurring separately in the surface produced (which are: Chloride, Calcium, Sodium and Fluoride) while local ones are those high values occurring as small clasts or points in the less concentrated areas.

ISSN: 2408-7920

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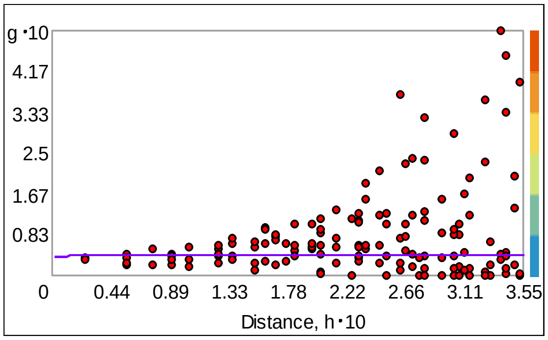

Figure 3: Calcium just naming it is not sufficient you need to describe what is happening

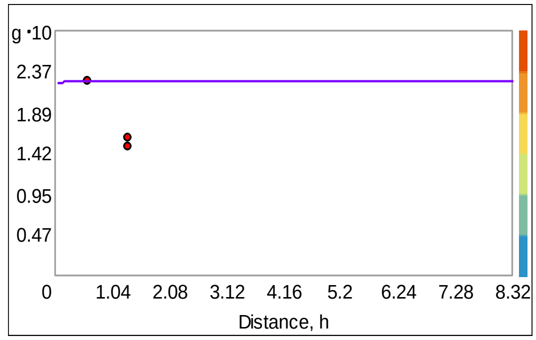

Figure 4: Sodium

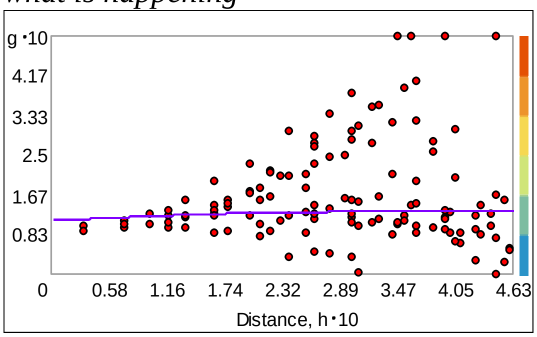

Figure 5: Chloride

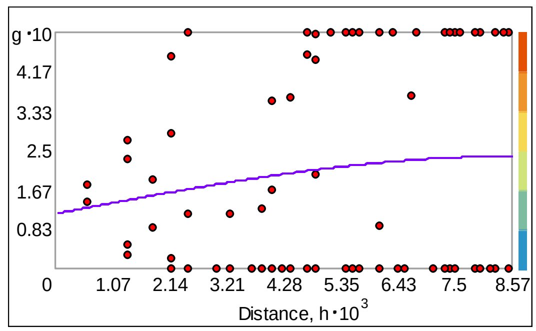

Figure 6: Fluoride

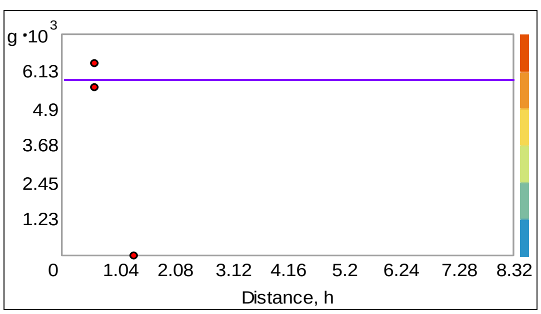

Figure 7: Potassium

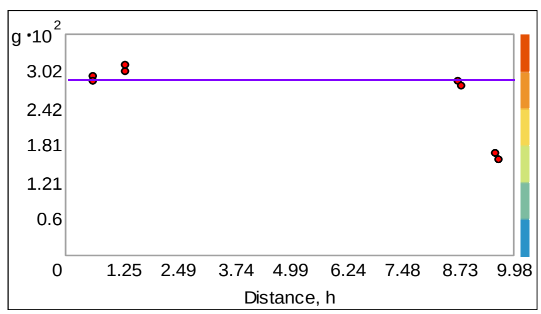

Figure 8: Nitrates

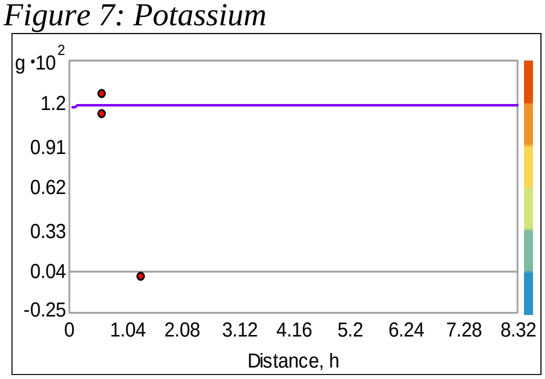

Figure 9: Sulphates

African Journal of Applied Research
Vol. 4, No. 1 (2018), pp. 93-105
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3.1.5 Distribution and Trend Analysis

Histograms of the parameters were viewed in both SPSS (with the normal curve being shown) and the explore option in the geostatistical toolbar. Calcium, Chloride and Sodium were skewed to the right (the long tail of their histogram plot was on the positive side of the peak which signified a lot of dis-similarities or variations in these parameters) with the exception of Fluoride and Sulphates which were close to normal distribution (signifying less variations or dis-similarities). Spatial modelling methods such as log transformations could be used to transform the non-normally distributed ones to be close to normal but this was not done in this study because it alters the final surface to be produced which does not reveal actual reality occurring in the groundwater.

Trend analysis revealed the spatial trend of the parameters. The analysis showed two main trends which were from north to south (data values decreased at the northern part of the study area and increased at the southern part); and from west to east (data values decreased at the western part of the study area and increased at the eastern part). Calcium, Fluoride and Chloride showed the trend increasing at the center (data values in the central part were high) as the north and south values were low. Calcium, Chloride and Fluoride also increased from the west to east (Figures 10, 11 and 12).

3.2 Chemical parameters

3.2.1 Calcium

The concentration values of calcium in the study area ranged from 2.3 mg/l to 705 mg/l. The standard value acceptable by the World Health Organisation is 200 mg/l. The map shows increasing concentration towards the eastern corridor of the Municipality (Figure 4.1). However, the most concentrated regime on the eastern part covers a small portion of the Municipality and decreases towards the central part. Low concentrations occur from the end of the high concentrations in the central part and increases towards both the northern and the southern part of the study area. This makes those areas the lowest concentrated parts of the Municipality.

3.2.2 Chloride

The groundwater data values of chlorine for the study area ranged from 1.7 mg/l to 5160 mg/l. The standard value acceptable by the World Health Organisation is 250 mg/l. However out of the 168 results, more than 100 fell below the acceptable limit. The map showed the highest concentrations occurring at the eastern corridor of the Municipality (Figure 4.2). High values also trend from the central eastern part towards the highest concentrations at the eastern corridor. Lower concentrations occurred at the northern part through the central and western parts to the southern part where lowest concentrations occurred.

3.2.3 Fluoride

The groundwater data obtained did not have fluoride records for all the 168 boreholes but accounted for about 120 which were used to do the analysis. The values ranged from 0.1 mg/l to 4.8 mg/l. The threshold limit by the World Health Organisation is 1.5 mg/l. The map showed the entire Municipality generally had high values of fluoride concentrations with few of the highest occurring at eastern part and some minor spots in the southern part (Figure 12).

The lowest concentrations occurred at the northern part and trends through the western part to the south where they occurred as small clasts.

3.2.4 Sodium

Sodium is an alkali metal that occurs in significant quantities in natural waters. The sodium values from the groundwater data ranged from 0.9 mg/l to 2489 mg/l. The standard value according to the World Health Organisation is 200 mg/l. The map showed the entire Municipality had high values of sodium concentration with a very small part of the southern part having low values (Figure 13). The highest concentrated areas occurred at the central eastern part and some small areas of the western side with some few clasts at the north-western parts. The rest of the entire Municipality was of higher concentrations occurring at the northern part through the center narrowly to the south and western parts.

3.2.5 Nitrates

Nitrates get into both surface waters and groundwater as a result of agricultural activities (excess application of inorganic nitrogenous fertilizers and manures in farmlands), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. The groundwater data values of calcium for the study area ranges from 0.01 mg/l to 250 mg/l. The standard value acceptable by the World Health Organisation is 10 mg/l. More than 150 values out of the 168 fell below the World Health Organisations's acceptable limit. This accounts for the reason why the map showed the entire areas of the northern through the central to the south-western part having lowest concentrations (Figure 14). The southern part was dominated by low concentrations with a very small area in the south-eastern corridor showing the highest concentration. Some few parts of the south however showed high concentrations.

3.2.6 Potassium

Potassium permanganate may be used in the treatment of drinking water process which can result in levels of potassium in drinking water being relatively low compared with levels resulting from the use of water softeners using potassium chloride (W.H.O., 2006). The data values for potassium ranged from a minimum of 30 mg/l to a maximum of 161 mg/l. The required limit by the World Health Organisation is 30 mg/l. The entire data had only about two values falling above the threshold limit. The Municipality generally shows lowest concentrations of potassium with high values narrowly aligning the south-eastern corner (Figure 15).

3.2.7 Sulphates

The presence of Sulphates in drinking-water can cause noticeable taste. The groundwater data values of Sulphates for the study area ranged from a minimum of 2.2 mg/l to a maximum of 2496 mg/l. The standard value acceptable by the World Health Organisation is 250 mg/l; highest concentrations occurred at the south-eastern part of the Municipality (Figure 16), the rest of the entire Municipality had very low concentrations.

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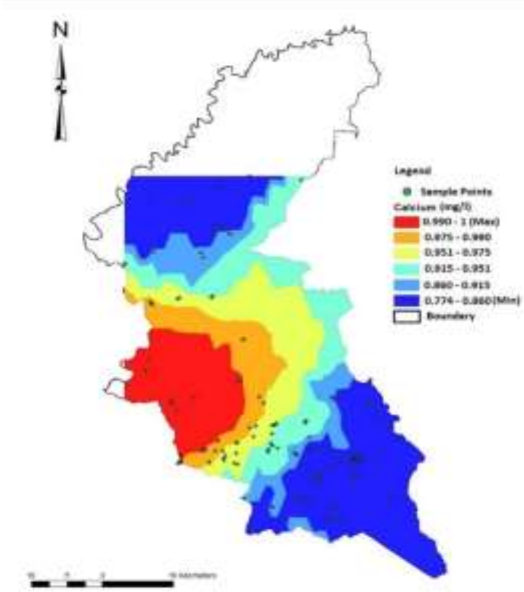

Figure 10: Concentration of Calcium

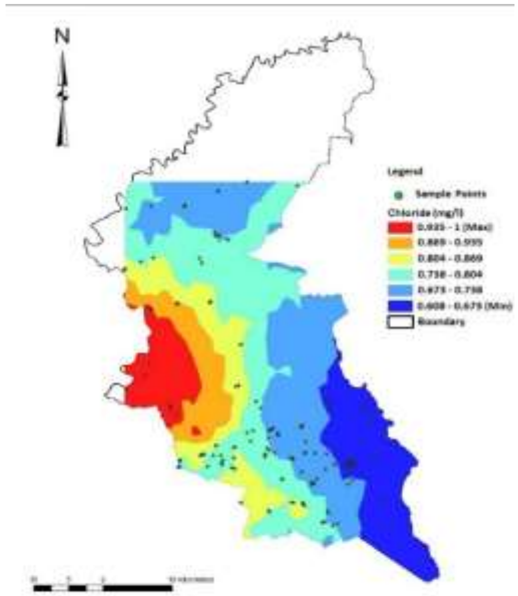

Figure 11: Concentration of Chloride

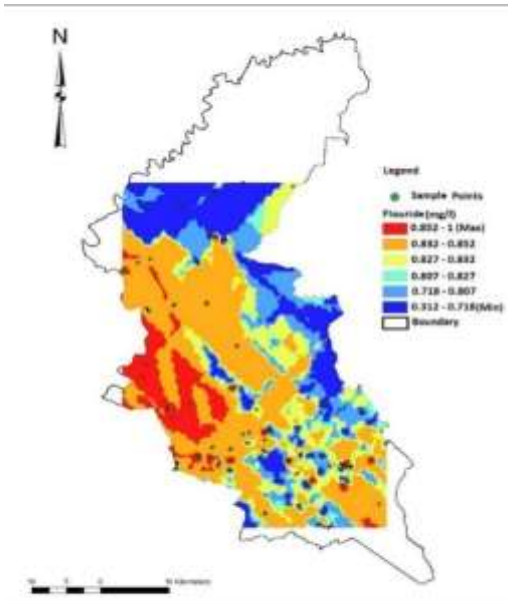

Figure 12: Concentration of Fluoride

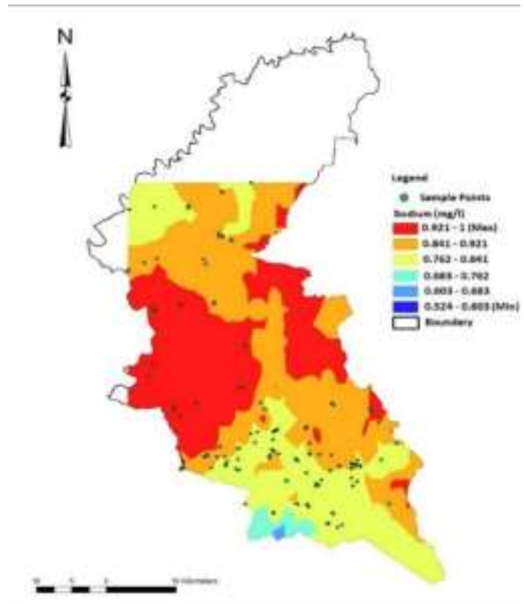

Figure 13: Concentration of Sodium

African Journal of Applied Research
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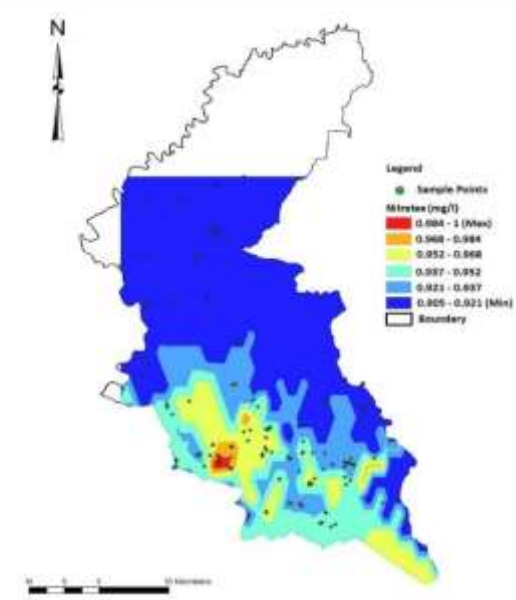


Figure 14: Concentration of Nitrates

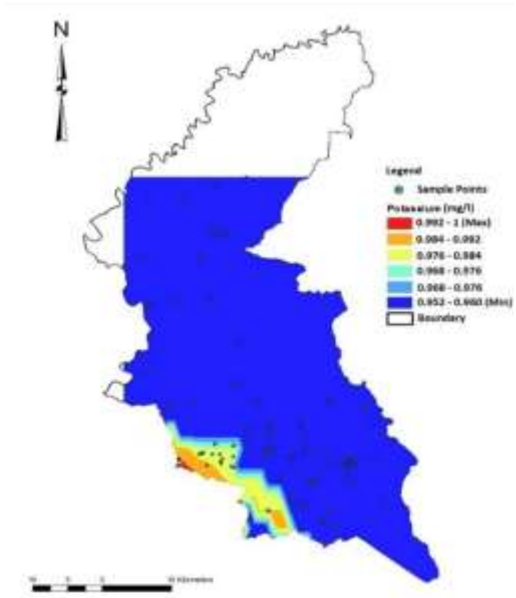


Figure 15: Concentration of Potassium

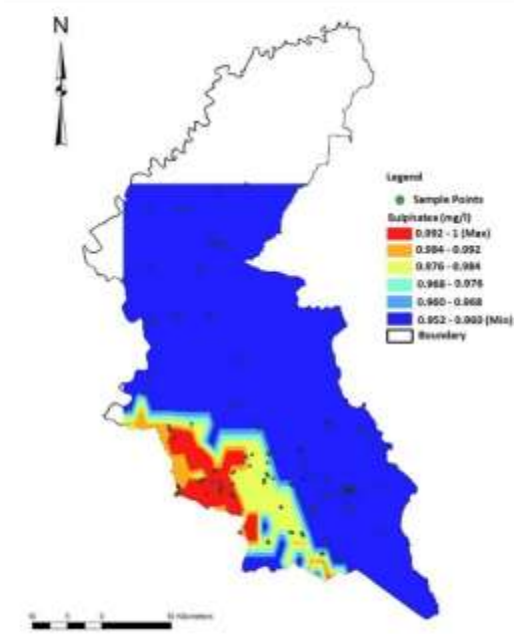


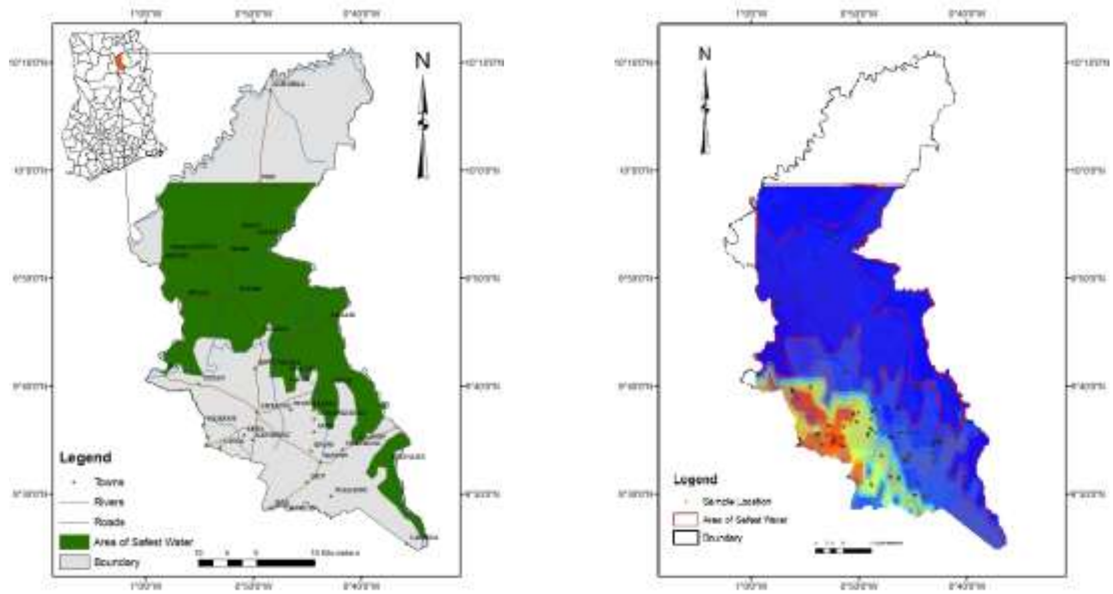
Figure 16: Concentration of Sulphates

3.3 Selection of the area with the best potable water

Potable water refers to any water that is safe and suitable for drinking. The area of best potable water in this study was defined as the area having values which did not fall above the World Health Standards among all the seven parameters analyzed. The area of safest drinking water occurred at the northern part and trends narrowly through the western parts of

ISSN: 2408-7920

the Municipality (17). Even though all the seven parameters analyzed did not prove these areas to be much secured, five parameters out of the seven (which are: calcium, chloride, nitrates, potassium and sulphates) makes the northern part and the south-western part safe. The uncoloured portions (10° 0' 0"N and 10° 0' 0"N) (Figure 17b) were considered as safe water areas in the Municipality.



(a) **(b)**

Figure 17: Area of Best Potable Water

4.0 CONCLUSION AND RECOMMENDATIONS

The comprehensive groundwater maps produced from the analysis of all the chemical parameters except Nitrates shows the highest concentrations occurring at the south-eastern part of the Municipality with the trend increasing towards the eastern boundary. Sodium showed generally high values of concentrations (0.9-2489 mg/l) across the entire Municipality with some few of the southern parts showing low concentrations. This indicates the risk in boreholes located from central part towards the south-eastern part of the Municipality and those yet to be drilled. Area of safe water was defined at the northern part trending narrowly through the western corridor to the southern part (Figure 17). It is recommended that the maps produced be used as a guide (as reference for the various parameters analyzed) for upcoming groundwater projects in order to assure the quality of borehole drinking water in the Municipality. It is also recommend that boreholes in the areas of higher concentrations which occurred in the following towns (Jana, Tindan, Zion, Nyamandu, Kanshiegu, Langa, Lewa, Nanaton, Kpano, Savelugu and Guno) be passed through the necessary water treatment processes.

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