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Spatial Overview of the Quality of Groundwater in Some Selected Districts in the Northern Region of Ghana

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Abstract The quality of any water for drinking purposes has grave consequences on the health and wellbeing of humans. As a result, the monitoring of groundwater in any region is crucial. Geographic Information Systems (GIS) can be used to monitor the quality of groundwater in any area with respect to time and space to avoid health challenges that may be encountered. This study aimed to access the quality of groundwater in three districts in the Northern Region of Ghana using GIS. Water quality data of 254 boreholes from the three districts were used for this study, for which the following parameters were considered: Fluoride, Chloride, Manganese and Iron. The GPS coordinates of the boreholes were used to produce a spatial distribution map using Geographic Information Systems (Arc GIS Version 9.3) in detailing the selected water quality attributes in the three districts. Fluoride concentration in Gushiegu was very high in the central part of the district. Savelugu-Nanton also had high concentrations of fluoride scattered within the district. It is recommended in communities where the groundwater was not suitable for drinking purposes, it may be used for agricultural purposes, or the water be treated before use.

Keywords: *spatial overview, groundwater, water quality, geographic information systems, district, pollutants*

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1. Introduction

Groundwater is the most important natural resource required for drinking for many people around the world, especially in rural and peril-urban areas [8]. Access to safe and sufficient water and sanitation is a basic human need and is essential to human wellbeing [21] but presently, close to a billion people mostly living in the developing world do not have access to safe and adequate water [23]. Worldwide, water b diseases are a major cause of morbidity and mortality in humans [22]. The World Health Organization (WHO) estimates that around 94% of the global diarrheal burden and 10% of the total disease burden are due to unsafe drinking water, inadequate sanitation and poor hygienic practices [6,15], while 80% of all illness in developing countries is related to unsafe drinking water and inadequate sanitation [18].

Approximately 6000 children, most of them in developing countries, die every day of diseases related to inadequate sanitation and a lack of access to safe drinking water [11]. The majorities of the population in developing countries are not adequately supplied with potable water and are thus compelled to use groundwater from sources like shallow wells and boreholes that are unsafe for domestic and drinking purposes due to high possibilities of contamination [25].

Although groundwater has historically been thought to be free of microbial contamination, recent studies have indicated that groundwater can be contaminated and this could easily result in water borne diseases if consumed without treatment [13,14]. Groundwater may be contaminated by both natural and anthropogenic activities. Natural factors may include the dissolution of several anions and cations into ground waters in an aquifer system due to groundwater-rock interactions and weathering of rocks [2]. Climatic variations (rainy and dry seasons) may also have impact on groundwater quality either positively or negatively making it suitable or otherwise for human consumption. Anthropogenic activities such as the use of agro-chemicals (i.e. chemical fertilizers, weedicides, and pesticides), release of toxic heavy metal and non-metals during mining activities, industrial and domestic waste disposals can in the long term contribute to the deterioration in the quality of groundwater [20].

Groundwater quality has come under pollution threats from indiscriminate drilling of boreholes, increasing demand and withdrawals, geology and geochemical conditions, climate change, mineral exploitation, industrialization and agricultural land use [1,4,12].

In this study, GIS mapping of groundwater quality was aimed to provide a synoptic view of groundwater quality of the region and was used as a tool for the monitoring groundwater quality across the study area. The groundwater quality map was also used to help in decision making process by identifying the most sensitive zones that need immediate attention. This process will also enhance in foreseeing the quality fluctuations and decide upon priority schedule, corrective, and protection measures.

The people of Savelugu-Nanton municipality, Gushiegu and Karaga districts of Ghana, depend of groundwater sources for drinking and for domestic purposes, it is therefore necessary that the quality of the water in these districts be monitored to assure its quality and help in increasing the quality of information given to Water Resource Managers, District Assemblies, NGOs, etc. to decide on its suitability for domestic, agricultural and industrial purposes and also implement measures to help protect groundwater quality.

2. Materials and Methods

2.1. Study Area

Savelugu-Nanton, Gushiegu and Karaga are three of the twenty-six (26) districts in the Northern Region of Ghana. The Savelugu-Nanton District lies between latitude 90 37'N and longitude 0028'W (Figure 1). It is bounded by West Mamprusi District to the north, Karaga District to the east, Tolon District to the west and Tamale Metropolitan Assembly to the south, and has a total land area of about 2,022.6 sq. km., with a population density of 68.9 persons per sq. km. The Gushiegu District is located on the eastern corridor of the region and shares boundaries to the east with the Saboba and Chereponi Districts, Karaga District to the west, East Mamprusi District to the north and Yendi Municipality and Mion District to the south. The total land area of the District is approximately 2,674.1 sq. km. It is about 114 km from the Northern Regional capital, Tamale. Karaga district lies between latitudes 9030' South and 10030' North and longitudes 00 East and 45'West and has a total land area of 3,119.3 sq. km. It shares common boundaries with four districts in the Northern Region namely West and East Mamprusi Districts to the north, Savelugu-Nanton to the west and Gushiegu to the south and Karaga to the east [7].

Savelugu-Nanton falls within the tropical climate typical of the Northern Region of Ghana. The area receives an annual rainfall averaging 600mm which is considered enough for a single farming season. The municipality is characterized by high temperatures with an average of 34°C. The maximum temperature could rise to as high as 42°C and the minimum as low as 16°C. Low temperatures are experienced from December to late February, during which the North-East Trade winds (harmattan) greatly influence the Municipality. The municipality's geology comprises of rocks such as sandstones, siltstones and shale which are found in the Voltaian formation. The municipality is located in the interior (Guinea) Savanna woodland which could sustain large scale livestock farming, as well as the cultivation of food crops such as rice, groundnuts, yams, cassava, maize, cowpea and sorghum.

The Gushiegu and Karaga districts lie entirely within the Voltaian sandstone basin, dominated by shales, sandstones, siltstones and minor limestones. The soils are mainly savannah ochrosals, groundwater laterites formed over granite and Volatain shales. The districts are covered by a tropical climate, which is marked by the alternation of dry and rainy seasons. The rainfall varies between 900 and 1,000mm but the heavy rains are normally recorded in July and August. Temperatures are high throughout the year with a maximum of 36°C recorded mainly in March and April. Low temperatures are recorded between November and February (the harmattan period). The vegetation is a typical guinea savannah type, characterized by tall grasses interspersed with drought resistant trees such as the Shea and Dawadawa [7].

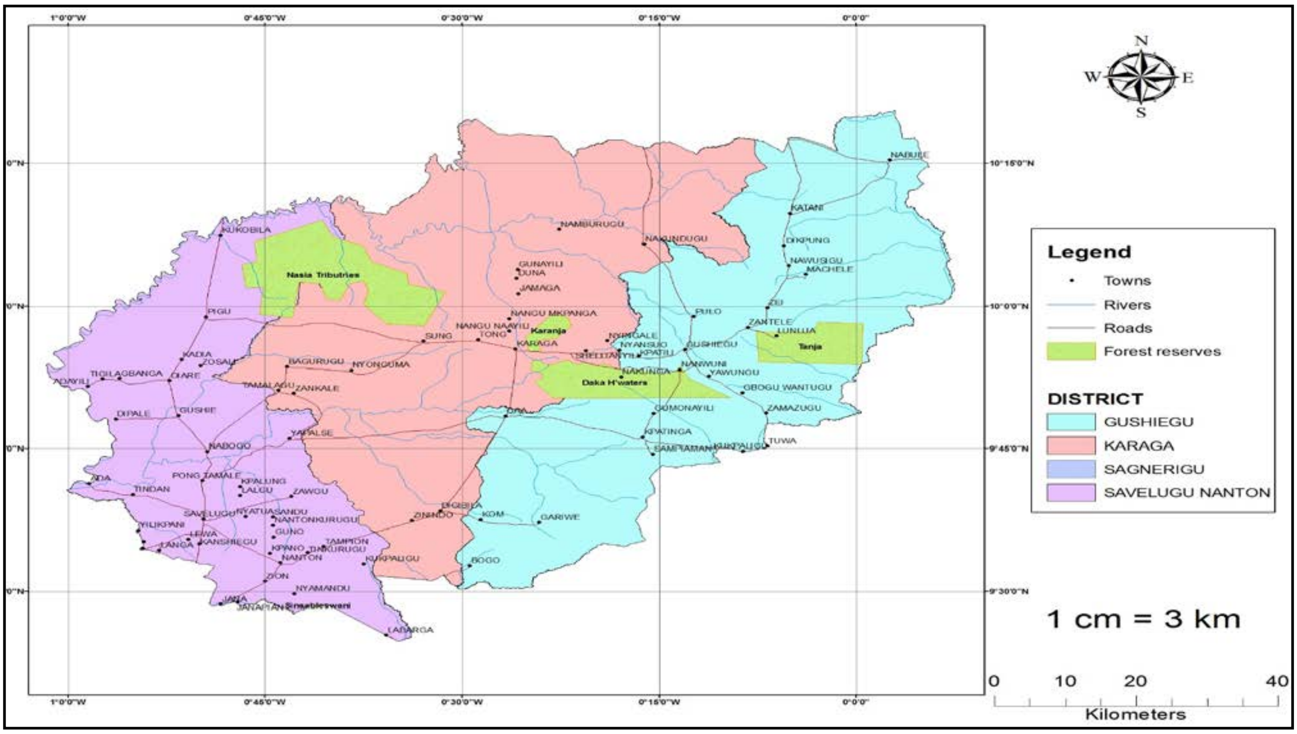

Figure 1. Map of study area

2.2. Data Sources and Collection

The data used was a secondary data on water quality of the three districts. The data contained GPS readings in latitudes and longitudes of various borehole locations in the three districts, as well as a physico-chemical analysis of the various water quality parameters. In this study four water quality parameters were used in producing the water quality map. These parameters are fluoride, chloride, manganese and iron, because of the health implications of these parameters when found in excess in drinking water. It is known that these four parameters (including arsenic) are the common and major contaminants found in ground waters in the Northern Region of Ghana. The secondary data (obtained in May, 2016) used, was obtained from the office of the Community Water and Sanitation Agency (CWSA), Tamale, in the Northern Region of Ghana.

2.3. Data Analysis

Water quality data of 254 boreholes from the three districts were used for this study. The parameters that were considered include the following: (Fluoride, Chloride, Manganese and Iron). The GPS coordinates of the boreholes were used to produce a spatial distribution map using Geographic Information Systems (Arc GIS Version 9.3) in detailing the selected water quality attributes in the three districts. Arc GIS 9.3 was used in transferring the water quality attributes for each sampling unit, thus from an excel form of data into GIS. The GPS coordinates were imported from excel form into GIS by exporting the coordinates into the shape file of the districts in GIS. When this was done, the various locations of the boreholes in the districts were represented, then an analysis of the water quality parameters were done to indicate communities in the districts which had the chosen parameters above, below or within the World Health Organization threshold values. Colour codes were assigned to indicate the various anomalies. The data was copied into excel for preparation. They were then saved in the ArcMap supported format (excel workbook 97-2003). Upon starting ArcMap, the data (XY data) which was saved in excel was imported and converted into a shape file. The Geostatistical Analyst toolbar was selected. The “explore data option” was selected and the semi variograms of the various attributes of the data were derived.

The geostatistical wizard was selected from the toolbar for the data analysis. The Inverse Distance Weighting (IDW) method was chosen, the data source selected in the data input field and various attributes selected. The next stage of the wizard showed the weights assigned to the dataset by the wizard after which the finish option was selected and the final surface produced was added automatically to the layers for viewing in the data view of ArcMap.

The surface produced was restricted to fit the boundaries of the districts and desired colours were chosen. The legend, north arrow and scale bar were added to the map in the layout view of ArcMap before it was finally exported into an image.

3. Results and Discussions

Water quality assessment on a regional scale requires not only an investigation of water pollution and the recognition of main pollution factors, but also the identification of polluted risky portions. For the purpose of this study, GIS was used to identify areas within the study with parameters of interest of concentrations above the national standards (colour-coded red), within the national standards (colour-coded green), and below the national standards (colour-coded blue).

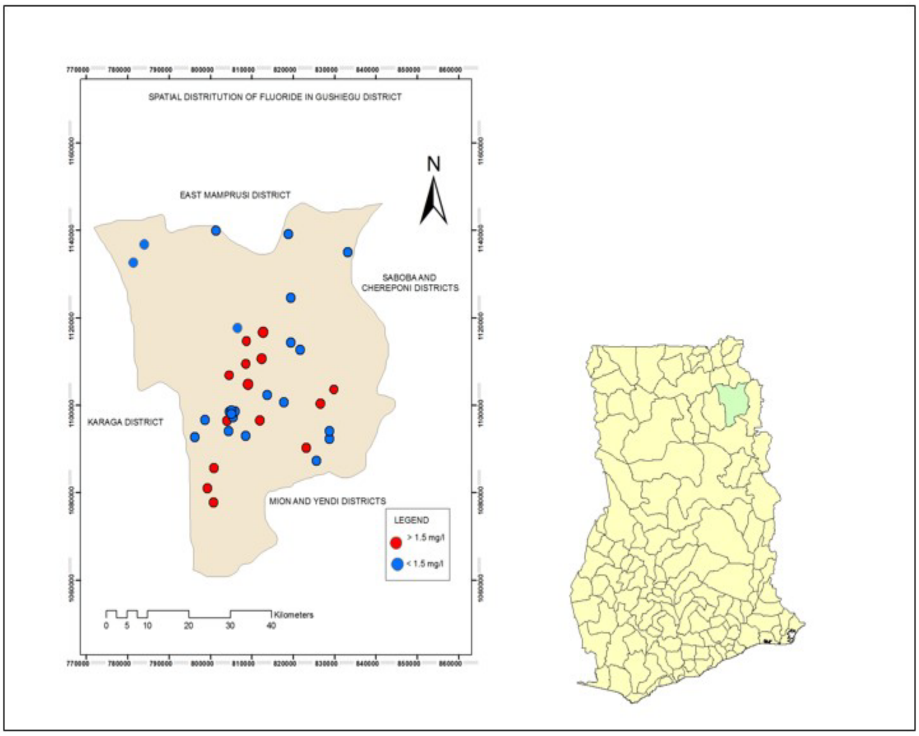

Figure 2. Fluoride concentration map of Gushiegu District

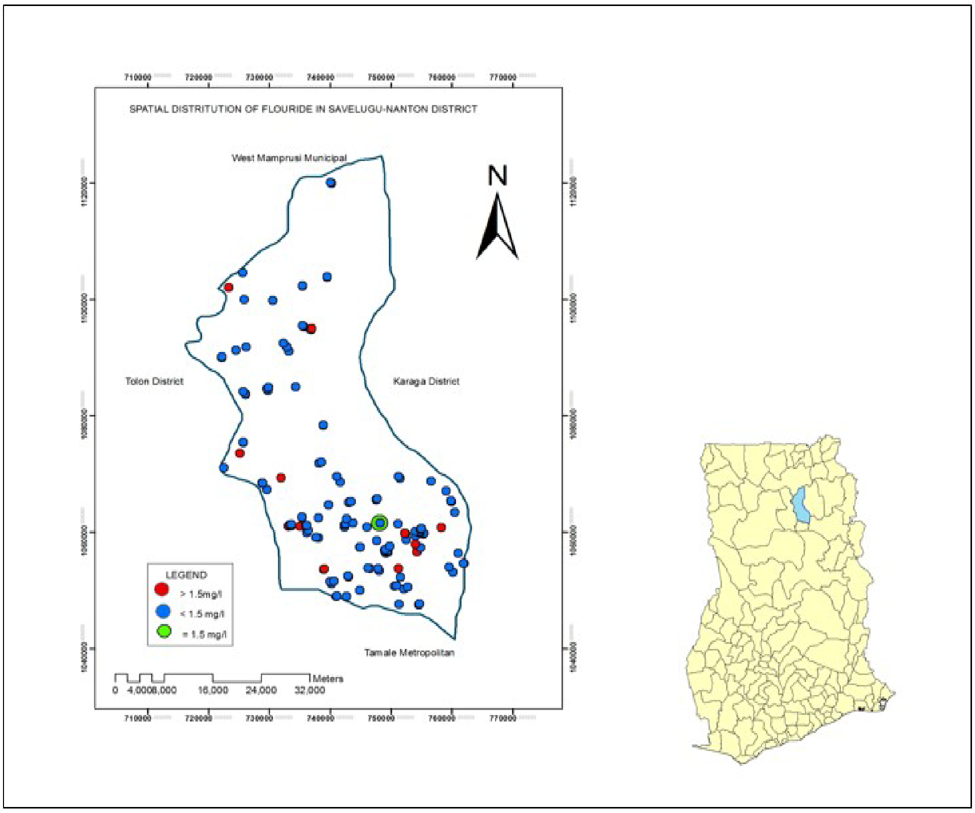

Figure 3a. Fluoride concentration map of Savelugu-Nanton Municipality

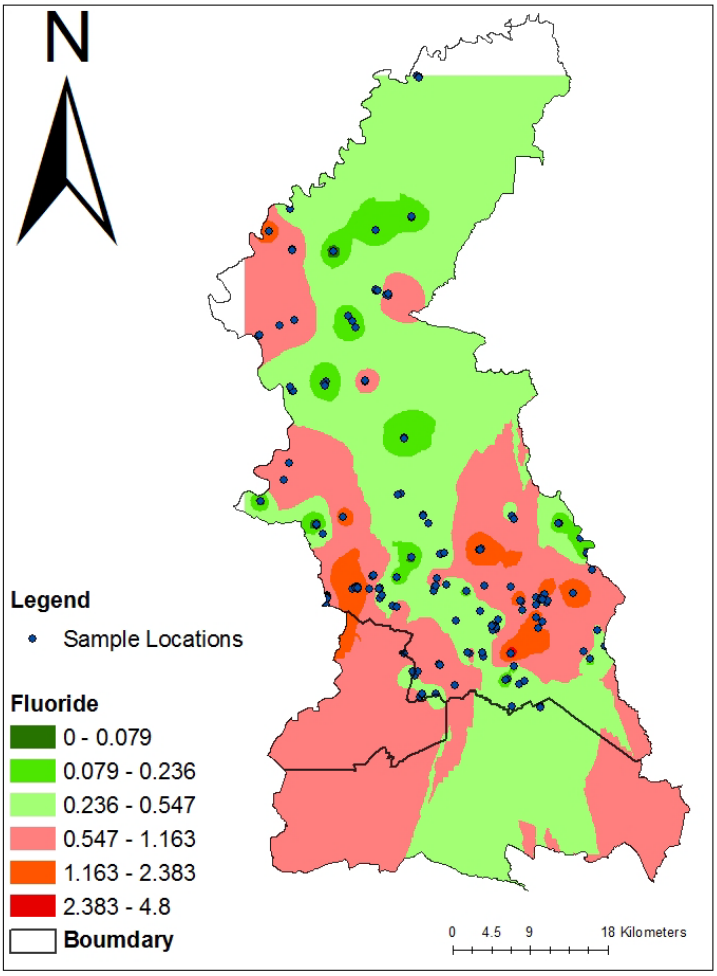

Figure 3b. Fluoride concentration map of Savelugu-Nanton, Gushiegu and Karaga

3.1. Fluoride (F-)

The fluoride in final water is always present as fluoride ions, whether from natural sources or from artificial fluoridation [24]. However, continuing consumption of fluoride above 1.2 mg/l causes dental fluorosis [16] and in extreme cases, skeletal fluorosis has also been linked with cancer [4]. The fluoride values of the groundwater within the study area ranged from a minimum of 0.14 mg/l to a maximum of 12.9 mg/l with an average of 1.21mg/l. Out of a total of 254 samples, 132 had their values within the acceptable <1.5 mg/l for drinking waters. However, Yisheigu in the Gushiegu district recorded the highest value of 12.9mg/l. Figure 2 and Figure 3 show the spatial distribution of Fluoride in the Savelugu-Nanton and Gushiegu districts, indicating where high and safe F- exists. The red dots indicate communities exceeding the WHO threshold value of 1.5 mg/l. In the Gushiegu district, the areas where the water concentrations of Fluoride exceed the W.H.O. and national standards, are located within the central to the southern portions of the district; while in the Savelugu-Nanton Municipality, the areas where these values exceed the national levels, are located in the western to the south-eastern portions.

The surface shows the low concentrations occurring at the northern part of Savelugu-Nanton and trending narrowly through the central parts to the south. High levels of concentration occurs vertically at both the eastern and western corridors of the entire surface.

3.2. Chloride (Cl^-)

According to World Health Organization [25], chloride in excess of 250 mg/L gives rise to detectable taste in water because pure water should not have taste. In high concentrations, chlorides give water odour and a salty taste that makes it undesirable for consumption. This high concentration of chlorides above the WHO guideline value of 250 mg/L in the sampled boreholes may be due to groundwater contamination as a result of seepage from sewage, waste dumps, fertilizers or animal wastes [9].

The Chlorine (Cl-) concentration values of the groundwater within the study area ranged from a minimum of 2mg/l to a maximum of 5160mg/l with an average of 200.68mg/l. Out of a total of 254 boreholes, almost 83% (210) had their values within the acceptable 250 mg/l for drinking waters, whiles 17% (32) had values above WHO acceptable guideline values. However, Sankpem, Jankpiang, Manguli, Jana and Sahanaayili in the Savelugu–Nanton municipality recorded very high chloride values compared to Gushiegu and Karaga districts, with 2097mg/l, 4998mg/l, 5160mg/l, 2678mg/l and 1288mg/l respectively (Figure 4). The spatial distribution of high Cl- concentrations seems to be located in the western to the south of the municipality (Figure 4).

The entire surface generally shows high chloride concentrations. The highest majorly occur at the central part of Savelugu-Nanton Municipality with a very small area in the north-eastern part showing low concentration.

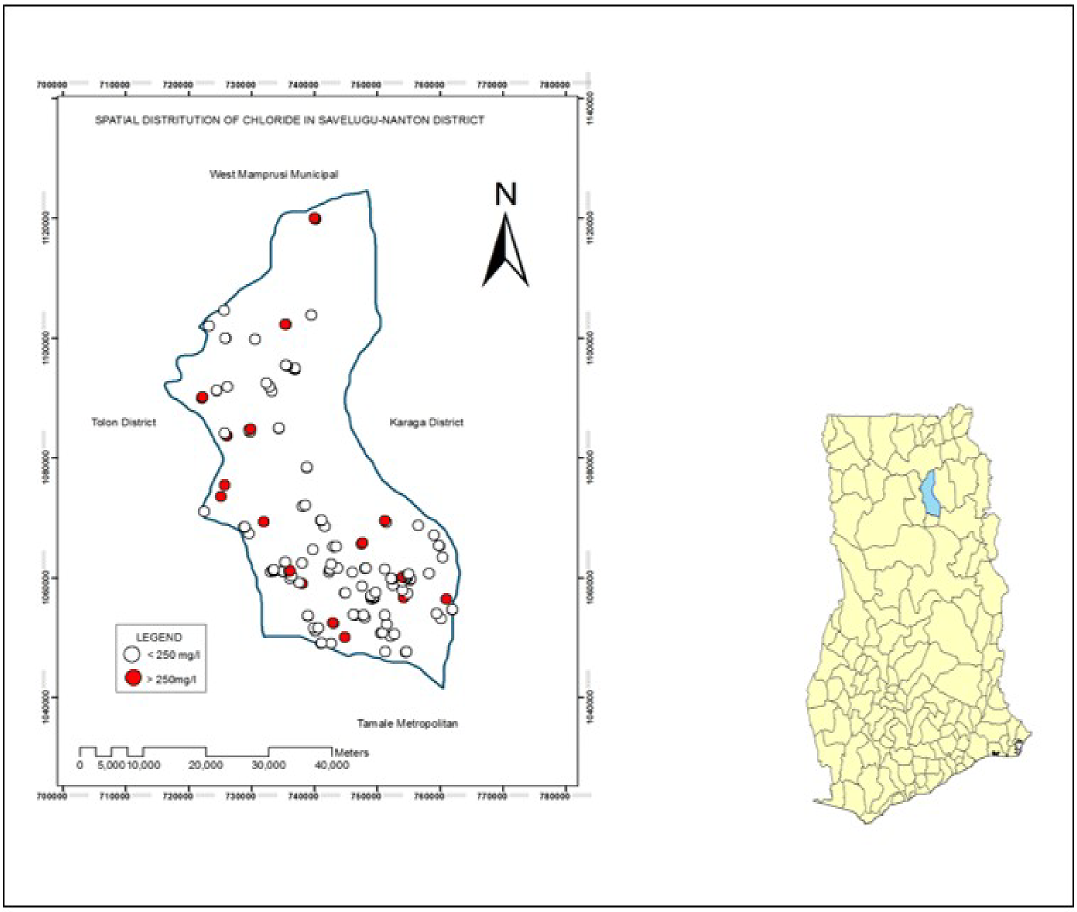

Figure 4a. Chloride concentration map of Savelugu-Nanton Municipality

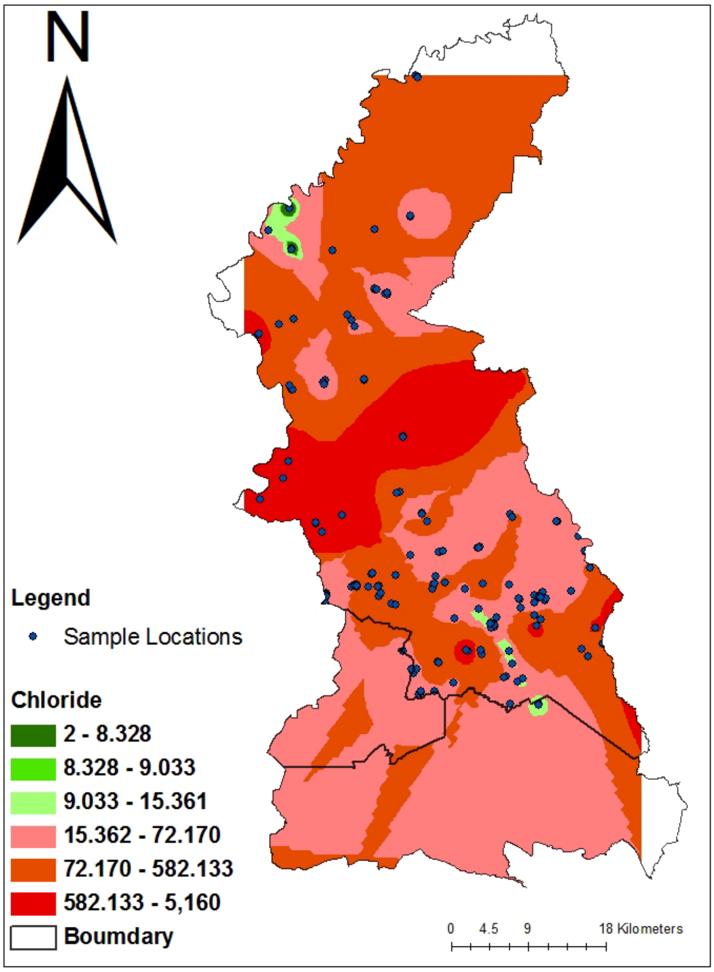

Figure 4b. Chloride concentration map of Savelugu-Nanton, Gushiegu and Karaga

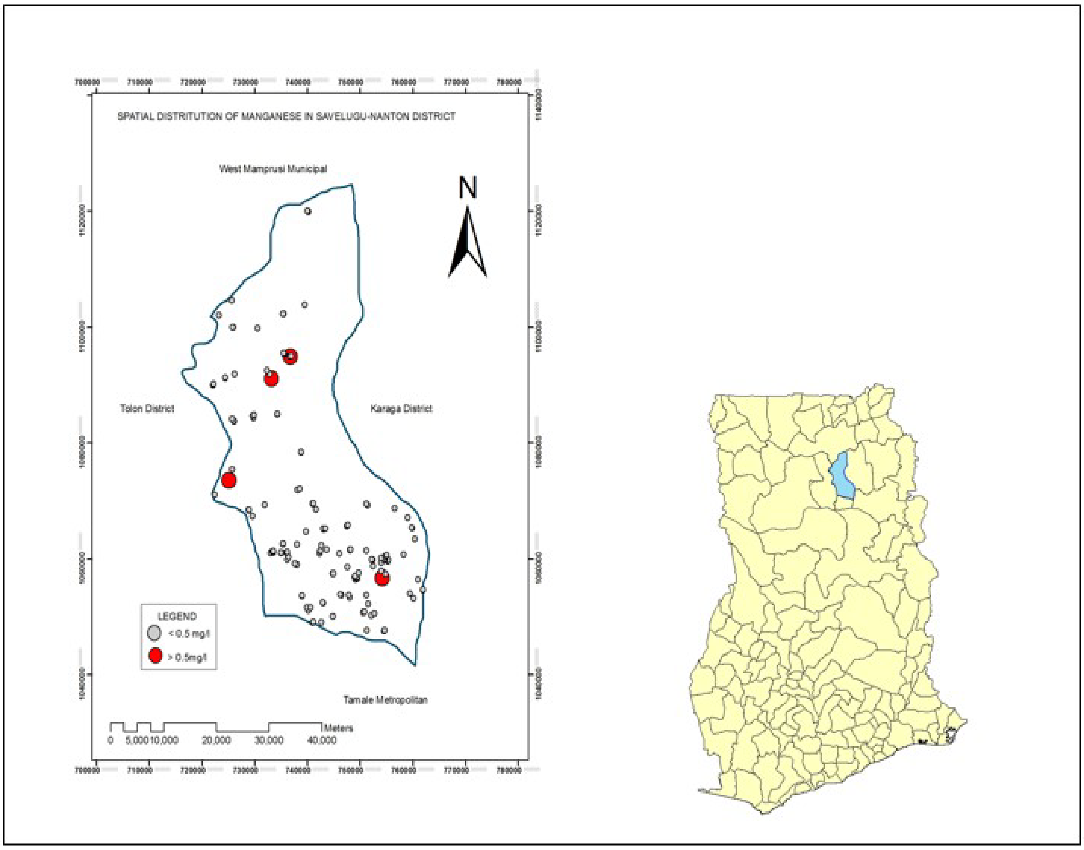

Figure 5a. Manganese concentration map of Savelugu-Nanton Municipality

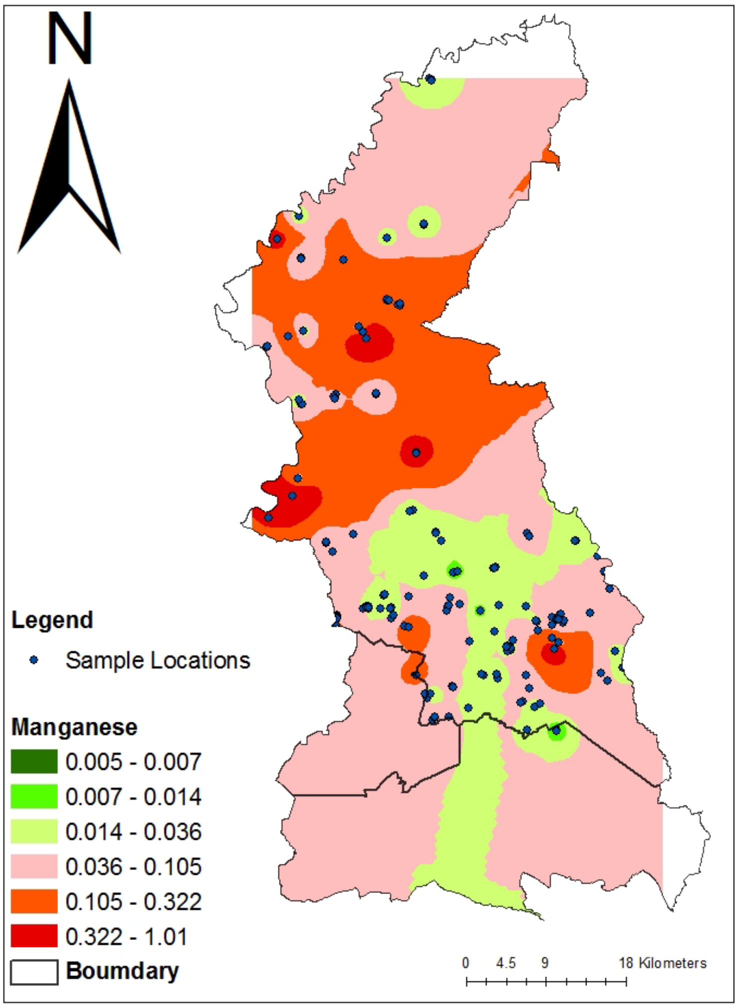

Figure 5b. Manganese concentration map of Savelugu-Nanton, Gushiegu and Karaga

3.3. Manganese (Mn)

Manganese is one of the most biogeochemical and active transition metals in aquatic environments [5] and often occurs with iron (Fe). At concentrations higher than 0.5 mg/l, manganese impacts a bitter taste to water, stains cloths and metal parts and precipitate in foods when used for cooking and it also promotes the growth of algae in reservoirs [20]. Though the high manganese concentrations in water does not pose human health problems, but it has the ability of discoloring water, (black coloration) and also has the potential of staining laundry and sanitary wares [22]. Spatially, high Mn concentrations were not widespread in the Savelugu-Nanton municipality (Figure 5), while no such high values were reported in the Gushiegu and Karaga districts. The Manganese values of the groundwater within the study area ranges from a minimum of < 0.005 mg/l to a maximum of 1.01mg/l with an average of 0.075mg/l. Out of a total of 254 boreholes, about 50% (128) had their values within the acceptable <0.5 mg/l for drinking.

Manganese concentration is generally high. Highest levels occur at in between the northern and southern parts of the Savelugu-Nanton Municipality with some few clasts at the southern part. Lesser levels of concentration occur in tabular shape from the southern part of the Savelugu-Nanton to the bottom of the entire surface.

3.4. Iron (Fe)

The primary source of the Fe in groundwater is geological. High Fe levels in ground waters could be attributed to natural sources such as the geochemical and biochemical processes [19] and dissolution of iron oxides within their aquifers [17]. Excess iron may impact a metallic taste in water and staining of laundry (Gosselin et al., 1984). Although high iron concentrations may not pose health hazards to users, the occurrence of the yellowish-brown coloration may cause rejection of such waters by the communities [3]. The major disadvantage of the presence of iron in water is that it increases the hazard of pathogenic organisms because most of these organisms need iron to grow [10].

The Fe concentration values of the groundwater within the study area ranges from a minimum of <0.01 mg/l to a maximum of 1.79 mg/l with an average of 0.135mg/l. Out of a total of 250 boreholes, 137 (54.8%) had their values within the acceptable < 0.3 mg/l for drinking waters.

Six communities in the Karaga district reported high Fe concentrations, > 0.3mg/l. Spatially, these communities are not located within a single area, but rather spread within the entire district (Figure 6). The Fe concentrations for ground waters in the Savelugu and Gushiegu districts reported no issues.

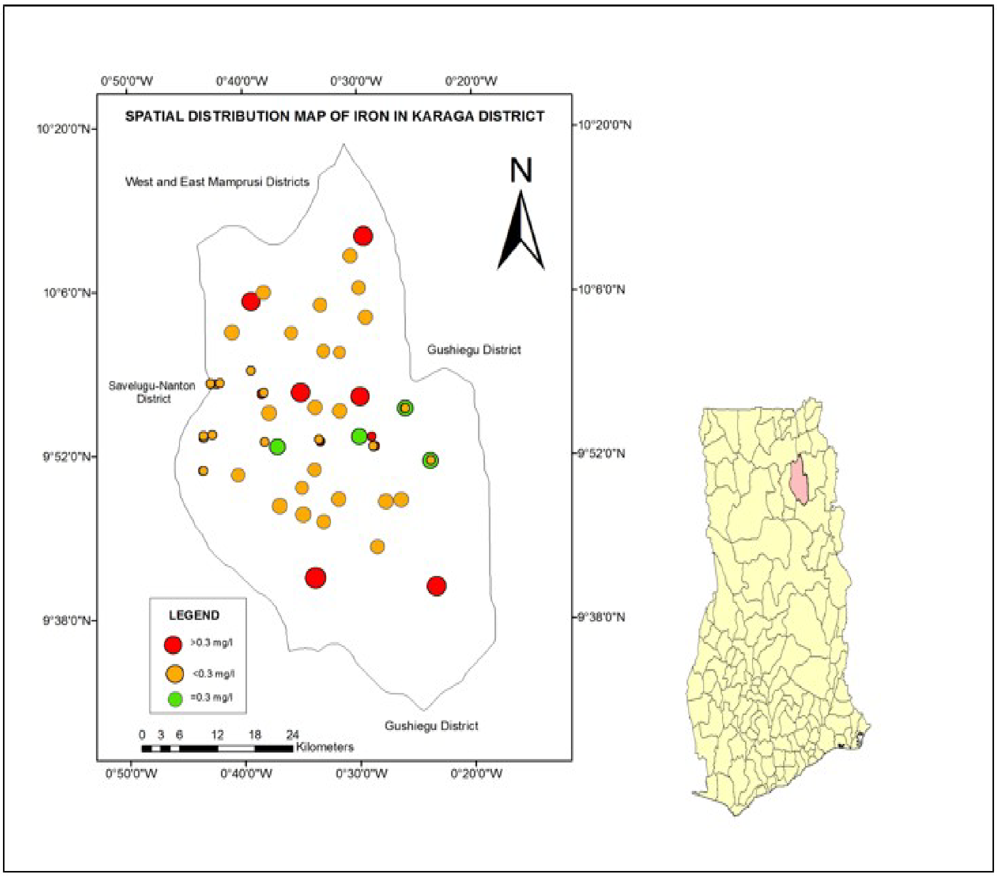

Figure 6a. Iron concentration map of Karaga District

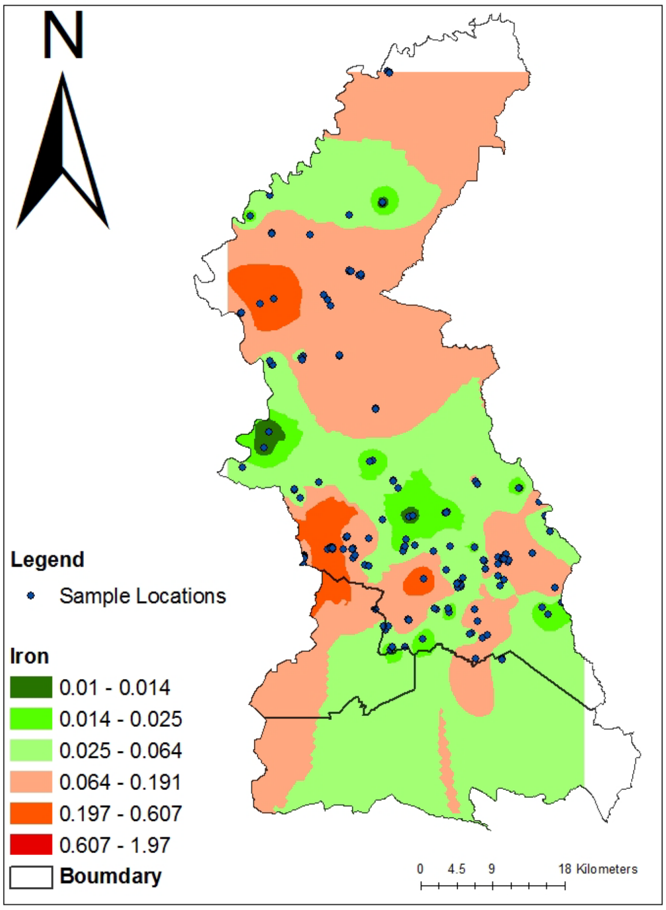

Figure 6b. Iron concentration map of Savelugu-Nanton, Gushiegu and Karaga

Low levels of concentration trend from the middle of the entire surface to the southern part with some few area occurring at the northern part. Least concentrations occur as clasts in the low concentration levels. High levels occur at the northern part of the Savelugu-Nanton Municipality with some few ones trending at the south-eastern corridor of the entire surface. Few areas of the middle part in the south also show higher values.

4. Conclusions

The study revealed that groundwater quality in the three districts is generally good, and that groundwater is acceptable for drinking in the three districts. The study also shows that manganese and iron are not of much concern as fluoride and chloride. Fluoride had very high concentrations recorded in Gushiegu and Savelugu-Nanton. This study has developed water quality maps that can be used in the monitoring of the groundwater quality in the three districts. From the maps created, it is evident that fluoride concentration in Gushiegu is very high in the central part of the district. Savelugu-Nanton also has high concentrations of fluoride scattered in the district. The presence of the parameters in water can be attributed to either anthropogenic activities, natural causes or both. Anthropogenic causes can be through the use of fertilizers and manures during farming, also seepage from waste dumps, etc. Natural sources can also be from natural leaching of naturally occurring deposits. The production of these maps were done using discrete distinct locations. As a result, communities whose water quality data was not captured, cannot have their borehole water monitored. Further geo-statistical data analysis can be carried out for the entire study area for comprehensive water quality monitoring and water quality prediction. This study can be conducted to inform investors, Water Resource Managers and other organizations about the quality of groundwater in the three districts and also inform them about the problematic areas for further work (treatment before human usage, or recommend for use for agricultural purposes) to be done.

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