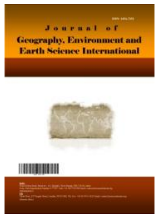

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Assessment of Spatial Variation of Physicochemical Parameters of Groundwater in Some Communities of Yenagoa Metropolis

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Authors' contributions

This work was carried out in collaboration between both authors. Authors AWO and AOO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AWO managed the analyses of the study. Author AOO managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Water is a basic need of life, and more so, potable water is critical for healthy living. Shallow boreholes are now popular as the main source of drinking water in the Yenagoa metropolis due to the contamination of surface water and rainwater caused by poor management of wastes and crude oil facilities in the area. However, there are concerns about variations in the quality of groundwater across communities in the Yenagoa metropolis. Thus, this study assesses the spatial variations of physicochemical parameters of groundwater samples from 50 boreholes in the area, and results compared with recommended standards prescribed by the World Health Organization (WHO). Parameters analyzed were pH, electrical conductivity (EC), salinity, total dissolved solids (TDS), nitrate, chloride, sulfate, total alkalinity (TA), total hardness (TH), calcium, magnesium, sodium, potassium, and iron. Global Information System (GIS) technology was adopted to present the groundwater quality in respect to each physicochemical parameter, in thematic maps. The maps showed that groundwater was slightly acidic in most communities in Central and Northern Yenagoa like Ekeki, Swali, Akaba, and Okolobiri. In communities like Ogbogoro, Ekeki, Azikoro and Yenegwe the EC was higher than the standard permissible value according to the WHO. A very high

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concentration of iron was observed across all communities except a few like Nedogo, Okolobiri, Tombia, Gbarantoru, Ayama, Famgbe, and Ikibiri having iron-free groundwater. Concentrations of TDS, calcium, magnesium, nitrates, sulfates, potassium, and sodium were within permissible limits across all communities. Communities like Ayama-Ijaw, Obololi, Ikibiri, Ikudu, Bomodi, Tombia, and Akaibiri had good groundwater while Ekeki, Famgbe, Yenaka, and Kpansia boast of excellent groundwater quality, and other areas had either poor or unsuitable groundwater for consumption. Treatment is recommended for parameters with higher concentrations than the standard value stipulated by the WHO.

Keywords: Physicochemical; thematic maps; groundwater quality; yenagoa metropolis.

1. INTRODUCTION

The importance of water to life cannot be overstated. Water is naturally abundant in the earth and occurs as rainwater, surface water and underground water. Yenagoa is part of the Niger Delta region of Nigeria, drained by several surface water bodies, such as the River Niger, creeks, streams and swamps all emptying into the Atlantic Ocean. There are also large bodies of underground water and torrential rainfall owing to the geology and climate of the Niger Delta. As a prolific delta, the Niger Delta region is characterized by hydrocarbon exploration and exploitation activities, and due to poor environmental management practices (e.g., gas flaring, CO_2 emissions, oil spills from accidental or deliberate damage to pipeline, indiscriminate dumping of waste, etc.), rainwater and surface water bodies have been heavily polluted in nearly all parts of the Niger Delta region including the present study area, Yenagoa [1-4].

Consequently, underground water sourced mainly from shallow drilled boreholes have become the main source of portable water for most people in the area.

The quality of water consumed by a people directly affects their health and general wellbeing, several researchers have used different methods to assess the quality of groundwater. Some have employed statistical and graphical methods [5-6].

Reports of variations in the quality of groundwater across communities in Yenagoa necessitated this study [1,3]. In some cases, even neighboring communities are known to have very obvious differences in their groundwater quality status [7]. Groundwater from shallow boreholes across the area were analyzed for various physicochemical parameters since the underlying cause of variations in water quality was the constituent parameters, results obtained were compared to the World Health Organization (WHO) standard for portable water and thematic maps generated for individual parameters using a GIS software to show spatial variations of these parameters across the area.

2. MATERIALS AND METHODS

2.1 Geology of Study Area

The location under study is Yenagoa metropolis of Bayelsa State, Nigeria, it lies within latitudes $4^0$50’00” N and $5^0$04’30” N, and longitudes $6^0$07’30” E and $6^0$26’30” E (Fig. 1). Its topography is generally low lying with elevations extending from below sea level in the southwestern flank to about 20 ft above sea level further inland making it easier to be submerged during flood seasons and heavy rainfall. The area lies within the freshwater and salt swamp geomorphic units of the Niger Delta sedimentary basin [8]. Yenagoa is drained by creeks and tributaries of the River Nun and Orashi River which empties into the Atlantic Ocean.

The study area lies within the lower delta plain believed to have been formed during the Holocene of the Quaternary period by the accumulation of sedimentary deposits. The major geological characteristic of the area is sedimentary alluvium.

The entire area is formed of abandoned beach ridges and due to many tributaries of the River Niger in this plain, considerable geological changes still abound. The major soil types in Bayelsa state are young, shallow, poorly drained soils and acid sulfate soils. There are variations in the soils of Bayelsa state, some soil types occupy extensive areas whereas others are limited extent. However, based on physiographic differences, several soil units could be identified in the state

Yenagoa metropolis is within the Niger Delta basin characterized by Tertiary subsurface lithostratigraphic units (Akata, Agbada, and Benin Formations) as shown in Fig 2, with erratic Quaternary sediments on the surface [9]. From bottom to top, the Akata, Agbada and Benin Formations show a gross coarsening-upward deposition, in marine, deltaic, and fluvial environments respectively [10]. The Akata Formation consists mainly of marine shales with some sand beds ranging from about 550 m to 6,000 m in thickness. The Agbada Formation is a parallel sequence that consist of inter-bedded sands and shales. Its thickness ranges from 300 m to 4,500 m and thins both seawards and in the direction of the delta margins. The top unit is the Benin Formation which is thickest in the central region of the Delta. It is mainly composed of sandstones (above 90%) with intercalations of clay. The Benin Formation is the water-bearing unit of the Niger Delta basin [11] with the clay intercalations producing a multi-aquifer system with shallow unconfined aquifer occurring at depths of 20 m to 40 m [12,8,13] .

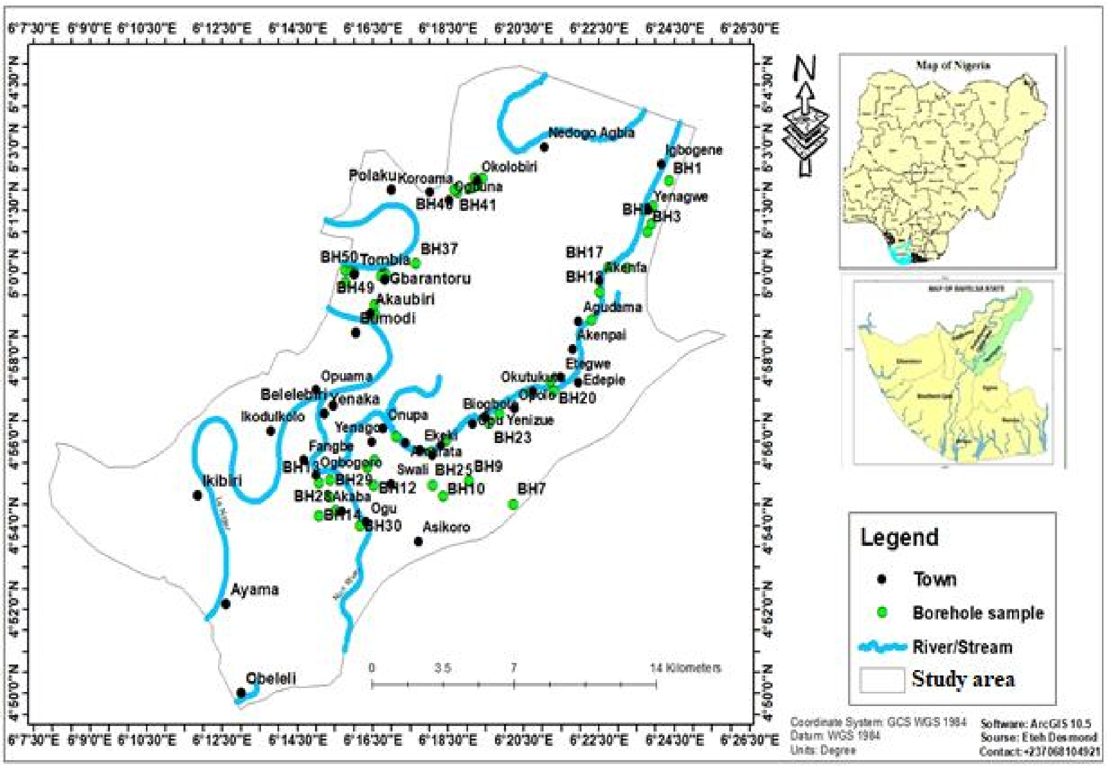

Fig. 1. Map of Yenagoa metropolis showing sampled points

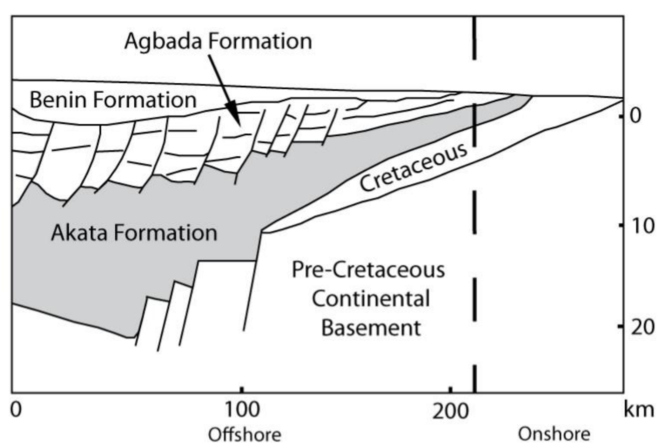

Fig. 2. Schematic of cross section of the Niger Delta [14]

The climate of the study area is that of tropical rainforest with distinct wet and dry seasons, the wet season is characterized by a prolonged period of rainfall which extends from April to November, while the dry season is characterized by a period of dry hot weather extending from late November to early April. Annual rainfall in the area ranges from about 4,700 mm on the coast to about 1,700 mm in the North of the state [8].

2.2 Sample Collection

Sterilized plastic water bottles (50 cl each) were used to carefully collect 50 untreated water samples pumped from boreholes in various locations. Air bubbles created in the bottles during collection were allowed to settle to a minimum before pH and temperature readings were taken, using a pH meter and a thermometer respectively. Samples were then put in a cooler with ice packs to reduce the rate of chemical reaction while in transit to the laboratory for further analysis. Sample collection, preservation and transportation were all done in accordance with [15] guidelines. Sample locations were determined by the use of Global Positioning System (GPS) and were appropriately labeled in the field before preservation.

2.3 Physicochemical Analysis

The physicochemical parameters analyzed are pH, electrical conductivity, salinity, total dissolved solids (TDS), nitrate, chloride, sulfate, total alkalinity (TA), total hardness (TH), calcium, magnesium, sodium, potassium and iron. The American Society for Testing and Materials (ASTM) was adopted. The determination of physicochemical parameters involved field and laboratory analyses. The field analysis involved in situ measurements of physical parameters that could be altered during transportation to laboratory. These include pH, salinity and electrical conductivity, measured using a portable Orion Model 290 pH meter, Mohr's method, and Oakton Model 35607 conductivity meter, respectively. All other parameters were determined by standardized laboratory procedures using HACH TDS meter for TDS; Hach DR. 4000 spectrophotometer for nitrate; atomic absorption spectrophotometer Hach DR/2010 for chloride, calcium, magnesium, sodium, potassium, and iron; titrimetric method for total hardness; turbidimetric method for sulfate.

2.4 Geographical Information Systems (GIS) analysis

Esri 2012 application usually referred to as ArcGIS version 10.6 for thematic data processing (see Figure 3) was used for the analysis. Inverse distance weighting (IDW), Spline, and Kriging are common interpolation methods used to model the spatial distribution of point data [16-17]. However, the IDW approach has been adopted in the present study to delineate the location distribution of water pollutants or constituents. This method uses a defined or selected set of sample points for estimating the output grid cell value. It determines the cell values using a linearly weighted combination of a set of sample points and controls the significance of known points upon the interpolated values based upon their distance from the output point thereby generating a surface grid as well as thematic isolines. IDW interpolation explicitly makes the assumption that those things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, hence the name inverse distance weighted.

IDW is an algorithm for spatially interpolating or estimating values between measurements. We selected IDW because it is implemented in ArcView 10.6 GIS software. This distance term is often raised to a power "to control the significance of locational separation in the estimation". In a comparison of several different deterministic interpolation procedures, [18] found that using IDW with a squared distance term yielded results most consistent with original input data.

IDW is a deterministic spatial interpolation approach to estimate an unknown value at a location using some known values with corresponding weighted values. The basic formula can be seen in Equation 5. Where x^* is unknown value at a location to be determined, w is the weight, and x is known point value. The weight is inverse distance of a point to each known point value that is used in the calculation. Simply the weight can be calculated using Equation 6.

$$x^* = \frac{w_1 x_1 + w_2 x_2 + w_3 x_3 + \ldots + w_n x_n}{w_1 + w_2 + w_3 + \ldots + w_n} \quad (5)$$

Weight Formula

$$w_i = \frac{1}{d_{ix^*}^P} \quad (6)$$

Considering Eqn. 2, there is a *P* variable which stands for Power. There is no rule in defining the *P* value, but from the equation, we can see that the higher *P* value will give lower weight

3. RESULTS AND DISCUSSION

Results of physicochemical analysis of the groundwater samples studied are presented in Table 1, and are discussed below:
pH is an important parameter which determines the acidity or basicity of water for various purposes. pH level of 7 is the desired level which means the water is neutral while between 6.5 to 8.5 is the acceptable standard, any level less or more is not suitable as specified by [19] (see also Table 1). From the analysis, it was observed that pH ranged from 5.6 to 6.91 in the study area, with a mean value of 6.23. From the spatial distribution map for pH levels across the area (Fig. 4), it was observed that Ekeki, Swali, Akaba which are communities in central Yenagoa and Okolobiri in the Northern part of Yenagoa fall within the acceptable limit by [19] while other areas did not.

Electrical conductivity is the capacity of electrical current to pass through a material. It is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness. From the analysis, electrical conductivity varied from 77 us/cm to 1652 us/cm in the study area with a mean value of 424.67 us/cm (Table 1). [19] standard for Electrical Conductivity is 500 us/cm. A spatial distribution map of electrical conductivity in the area (Fig. 5) shows that values across almost the whole communities of Yenagoa fall within the acceptable limit by [19] except for a few communities in central Yenagoa like Ogbogoro, Ekeki and Asikoro and Yenegwe in North Eastern Yenagoa.

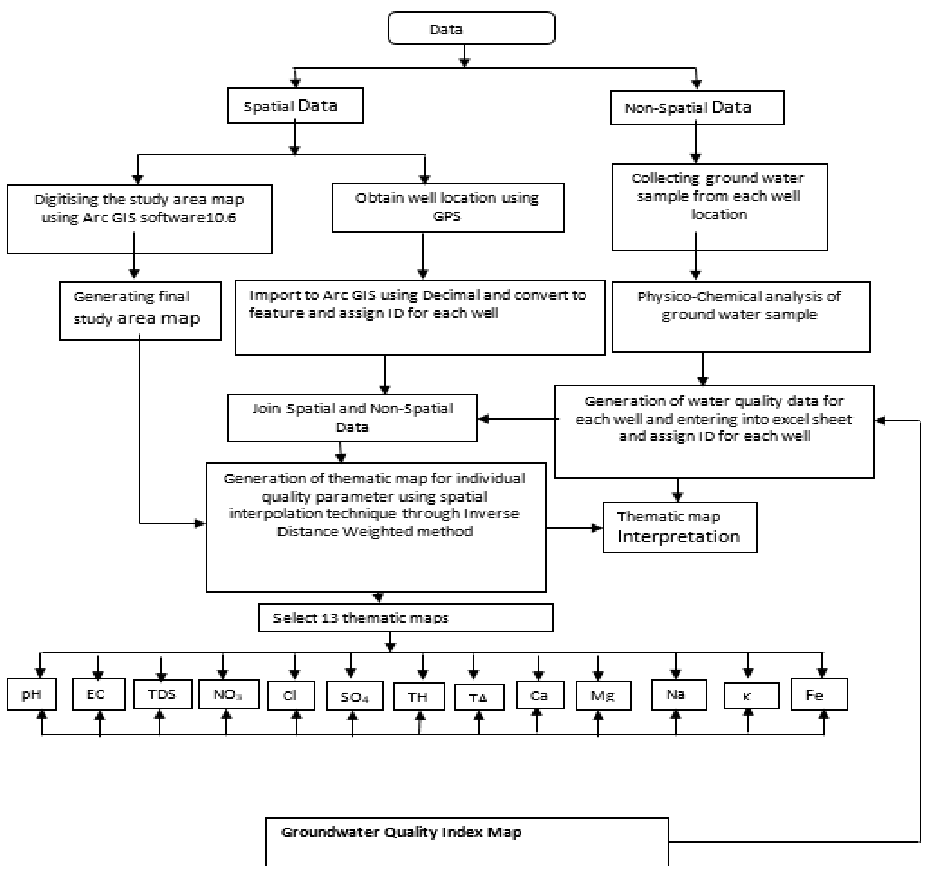

Fig. 3. Flowchart for thematic map generation

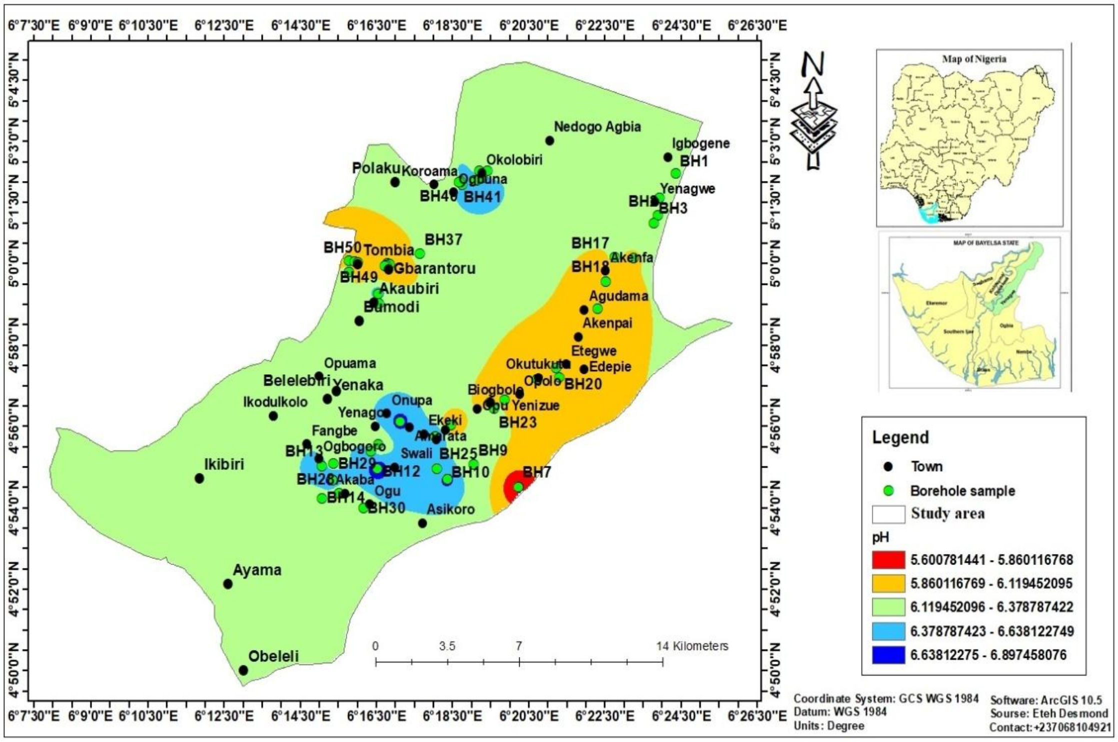

Fig. 4. Spatial distribution map of pH across Yenagoa metropolis

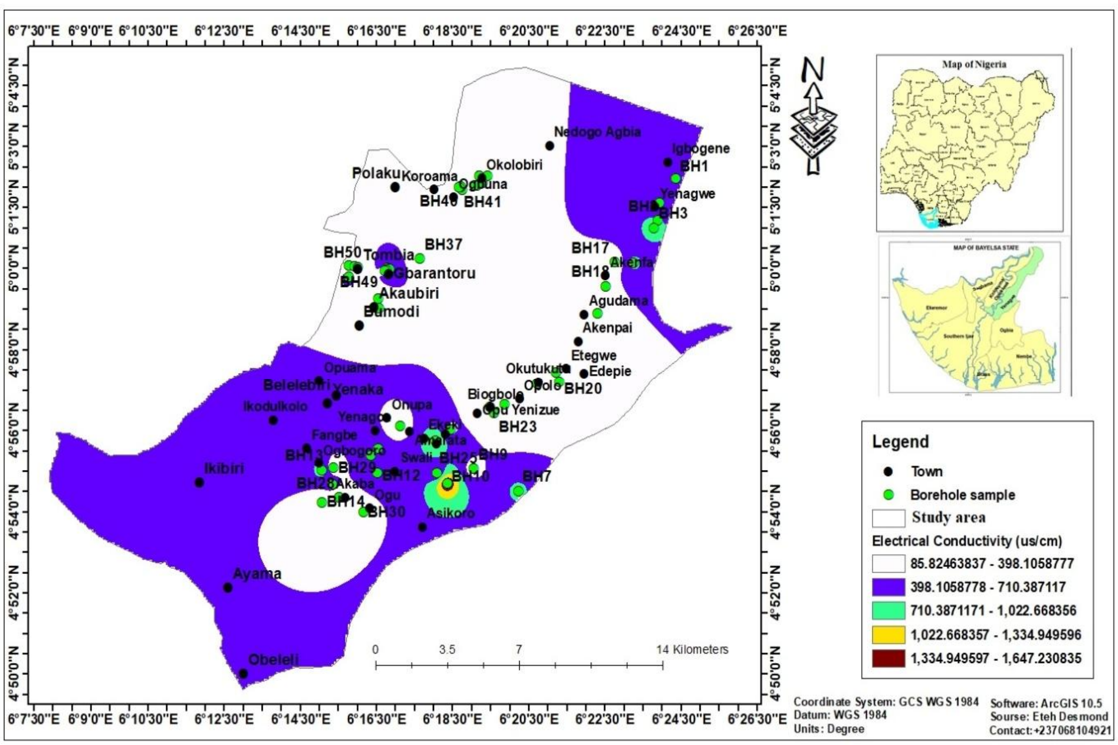

Fig. 5. Spatial distribution map of Electrical Conductivity across Yenagoa metropolis

Table 1. Result of physicochemical analysis on groundwater from Yenagoa communities

Borehole	Lat	Long	Town	pH	EC	TDS	NO_3	Cl	SO_4	TA	TH	Ca	Mg	Na	K	Fe
BH1	5.036889	6.405972	Igbogene 1	6.12	406	203	0.36	39	1.4	26	25	22.4	6.35	10.86	4.2	0.6
BH2	5.01975	6.398167	Yenagwe1	6.3	715	356	0.165	15	0.8	15	45	8.5	2.48	4	1.46	0.14
BH3	5.016722	6.396528	Yenagwe 2	6.38	857	430	0.335	21	1.67	17	18	13.7	3	6.5	1.55	0.4
BH4	5.002366	6.387691	Akenfa 1	6.1	782	391	0.175	14	0.86	19	37	8.85	2.5	4.85	0.76	0.37
BH5	4.957417	6.35375	Etegwe 1	5.99	164	82	0.165	14	0.82	3	35	8.6	2.76	4.54	1.2	0.38
BH6	4.94325	6.324806	Biogbolo 1	5.93	175	84	0.094	16	0.48	5	32	9	2.85	5.2	1.4	0.3
BH7	4.908472	6.337083	Kpansia 1	5.6	763	383	0.085	14	0.45	16	30	7.4	2.38	4.74	1.2	0.15
BH8	4.929167	6.300806	Ekeki 1	6.69	1156	578	0.096	22	0.5	15	46	12.48	3.62	5.8	1.8	0.35
BH9	4.917722	6.317583	Kpansia 2	6.14	269	135	0.348	34	1.75	16	101	20	5.65	9.95	4	0.14
BH10	4.91175	6.305972	Yenizue Epie 1	6.74	1652	826	0.42	47	2.1	15	45	27.86	7.5	13.58	4.65	0.36
BH11	4.925861	6.275583	Amarata 1	6.05	422	211	0.204	37	0.96	18	91	21.48	6.2	9.84	2.62	0.16
BH12	4.916	6.2755	Swail 1	6.87	722	361	0.49	23	2.45	9	33	16.74	4.4	7.6	2.5	0.36
BH13	4.917028	6.251222	Ogbogoro 1	6.43	928	464	0.078	16	0.39	18	27	9.2	2.58	5.4	1.8	0.26
BH14	4.903722	6.251222	Ogu 1	6.2	160	80	0.162	24	0.8	12	56	14.56	3.8	6	2.26	0.12
BH15	4.91125	6.255611	Akaba 1	6.91	530	265	0.17	8	0.86	3	15	6.75	1.76	3.85	0.6	0.18
BH16	5.026869	6.398981	Igbogene 2	6.33	496	248	0.137	13	1.28	8	65	8.16	2.42	5.82	1.76	0.39
BH17	5.002678	6.379307	Akenfa 2	6.13	164	82	0.341	55	5.6	9	93	33.97	8.7	15.9	5.38	0.4
BH18	4.992793	6.375336	Agudama 1	5.88	334	167	0.23	58	5.5	16	200	34.5	8.84	17.4	5.4	0.7
BH19	4.98176	6.37166	Agudama 2	6.01	173	87	0.22	46	4.38	17	128	27.6	7.45	13.54	5.1	0.68
BH20	4.953314	6.355015	Etegwe 2	5.99	164	82	0.165	14	0.82	3	35	8.6	2.76	4.54	1.2	0.8
BH21	4.952838	6.34541	Okutukutu 1	5.85	91	46	0.132	14	1.42	14	56	8.78	1.96	4.62	0.78	0.32
BH22	4.94409	6.331098	Opolo 1	5.93	84	42	0.374	43	3.4	22	90	26.74	6.4	12.43	2.7	0.65
BH23	4.940728	6.326492	Opolo 2	6.38	94	48	0.41	65	5.6	24	115	35.6	7.64	14.9	5.4	0.4
BH24	4.933825	6.307698	Kpansia 3	5.86	348	174	0.127	14	1.38	12	26	9.5	2.64	4.86	1.36	0.11
BH25	4.916093	6.301615	Yenizue Epie 2	6.4	422	211	0.318	90	10.8	22	148	56.88	12.76	28.64	7.34	0.44
BH26	4.935199	6.285502	Amarata 2	6.74	194	97	0.187	22	0.28	10	47	12.69	4.2	6.38	2.42	0.112
BH27	4.923142	6.272686	Swail 2	6.46	486	243	0.172	19	1.64	17	116	11.28	3.54	5.38	1.34	0.35
BH28	4.905837	6.258554	Akaba 2	5.99	77	38	0.213	40	4	14	111	23.86	5.72	12.58	2.55	0.4
BH29	4.918221	6.25624	Ogbogoro 2	6.2	160	80	0.162	24	0.8	12	56	14.56	3.8	6	2.26	0.12
BH30	4.899849	6.269169	Ogu 2	6.28	172	86	0.348	52	5.25	4	41	29.78	6.88	16.7	4.4	0.43
BH31	4.983667	6.276111	Akaibiri 1	6.14	285	142	0.218	14	2.48	17	17	10.35	2.87	5.48	1.72	0.31
BH32	4.987861	6.275722	Akaibiri 2	6.59	355	178	0.231	20	3.5	18	34	14.36	3.54	7.6	1.3	0.364
BH33	5.000389	6.279556	Gbarantoru 1	6.01	420	210	0.31	20	4	20	52	13.3	4.2	6.5	2.6	0.136
BH34	4.999861	6.280667	Gbarantoru 2	5.97	583	292	0.318	34	4.8	18	48	22.18	5.68	9.45	2.8	0.32
BH35	4.999656	6.279361	Gbarantoru 3	5.96	363	182	0.22	20	3.85	12	36	14.7	2.53	6.84	1.76	0.36

Borehole	Lat	Long	Town	pH	EC	TDS	NO_3	Cl	SO_4	TA	TH	Ca	Mg	Na	K	Fe
BH36	4.999222	6.2785	Gbarantoru 4	5.92	364	182	0.23	30	3.64	17	30	13.82	4.86	8.35	2.18	0.132
BH37	5.004056	6.294028	Gbarantoru 5	6.15	310	155	0.197	12	3	18	26	17.48	2.25	5.42	3.2	0.38
BH38	5.032306	6.312556	Ogbuna 1	6.49	379	189	0.271	13	4.3	17	43	9.47	2.84	5.46	1.85	0.348
BH39	5.033528	6.311917	Ogbuna 2	6.35	304	152	0.176	14	2.34	18	27	10.2	3	4.96	1.41	0.186
BH40	5.034	6.311778	Ogbuna 3	6.52	279	140	0.185	11	2.97	23	30	9.78	2.56	3.75	1.92	0.36
BH41	5.033361	6.311056	Ogbuna 4	6.08	285	143	0.121	12	2.58	15	21	8.5	2.58	4.34	6.98	0.372
BH42	5.038194	6.323444	Okolobiri 1	6.15	382	191	0.278	62	4.84	17	43	32.76	10.72	18.68	2.5	0.388
BH43	5.038	6.319889	Okolobiri 2	5.99	457	274	0.328	16	4.75	17	44	13.6	3.52	7.48	1.2	0.374
BH44	5.035417	6.321361	Okolobiri 3	6.6	348	174	0.281	12	3.84	26	41	9.55	2.84	4.72	1.48	0.328
BH45	5.034306	6.318833	Okolobiri 4	6.83	298	199	0.217	12	3.76	23	35	9.28	1.78	5.46	1.24	0.146
BH46	5.03425	6.31789	Okolobiri 5	6.62	306	153	0.227	13	4	28	35	10.32	2.1	4.8	1.2	0.346
BH47	4.996806	6.262944	Tombia 1	6.24	436	218	0.29	14	3.46	24	45	9.88	3	5.75	2.25	0.33
BH48	5.001417	6.263	Tombia 2	6.08	307	154	0.214	21	3.2	21	22	13.25	4.34	6.58	3.74	0.39
BH49	5.000861	6.265528	Tombia 3	6.1	376	188	0.245	32	4	22	19	18.72	5.63	9.36	3.96	0.136
BH50	5.000639	6.266833	Tombia 4	5.67	357	178	0.235	33	3.85	18	10	19.3	5.82	9.65	1.55	0.382
Minimum				5.6	77	38	0.078	8	0.28	3	10	6.75	1.76	3.75	0.6	0.11
Maximum				6.91	1652	826	0.49	90	10.8	28	200	56.88	12.76	28.64	7.34	0.8
Mean				6.23	424.67	214.19	0.24	27.42	2.94	15.98	54.44	17.20	4.51	8.56	2.62	0.34
WHO				6.5-8.5	500	500	50	250	100	100	500	70	30	200	12	0.3

Concentrations are expressed in milligrams per liter (mg/l) except pH with no unit and EC in μS/cm

Total Dissolved Solids (TDS) in water supplies originate from natural sources, sewage, urban and agricultural run-off, and industrial wastewater. High concentrations of TDS of about 1000 mg/l may produce distress in animals and cause a distinct taste in water. The [19] standard for TDS is 500 mg/l. Analysis showed values in the area under study ranging between 38.00 mg/l to 826.00 mg/l, with a mean value of 214.19 mg/l (Table 1). A spatial distribution map for TDS (Fig. 6) shows that all communities in Yenagoa had values within the accepted limits by [19] for portable water except Ekeki and Azikoro.

Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium. It may be temporary or permanent. Temporary hardness is usually caused by carbonate ions whereas permanent hardness is caused by bicarbonate ions. Total hardness (TH) is the sum of the temporary and permanent hardness. Water having hardness of less than 150 mg/l is considered soft, values between 150mg/l to 300mg/l is permissible for most purposes. Water having more than 300mg/l hardness is unsafe for consumption according to the [19] standard. Values of TH in the area ranged between 10 mg/l and 200 mg/l with a mean of 54.44 mg/l (Table 1). A spatial distribution map of Total Hardness (Fig.7) across Yenagoa communities show that the area is free of hard water.

The alkalinity of natural water is determined by the soil and bedrock through which it passes. The main sources for natural alkalinity are rocks which contain carbonate, bicarbonate, and hydroxide compounds. The Total Alkalinity values ranged from 3.00 mg/l to 28.00 mg/l with a mean value of 15.98 mg/l across the area (Table 1). The maximum acceptable limit for Total Alkalinity was put by [19] at 100 mg/l. A spatial distribution map for Total Alkalinity across Yenagoa communities (Fig. 8) shows that the Total Alkaline concentration in groundwater in the area is suitable for consumption.

Nitrate in groundwater originates primarily from fertilizers, septic systems, and manure storage or spreading operations. It is usually due to aerobic decomposition of nitrogen from organic matter. In urban areas the sources are from water derived from sewage and industrial effluents. For water to be potable, the concentration of nitrates should be less than 50mg/l [19]. Analysis of groundwater across Yenagoa communities showed that the nitrate concentration in the study area is ranged from 0.08 mg/l to 0.49 mg/l (Table 1) with a mean of 0.24 mg/l. The spatial distribution map of nitrates (Fig. 9) shows that the nitrate concentration is acceptable in the study area, thus, does not pose any risk.

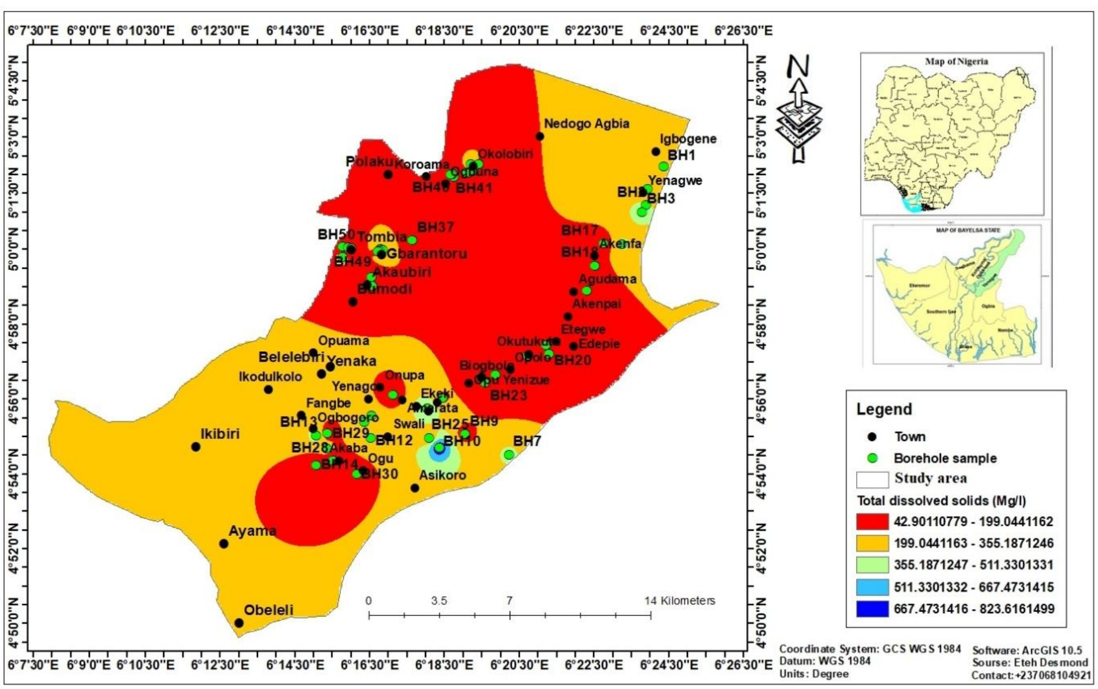

Fig. 6. Spatial distribution map of Total Dissolved Solid across Yenagoa metropolis

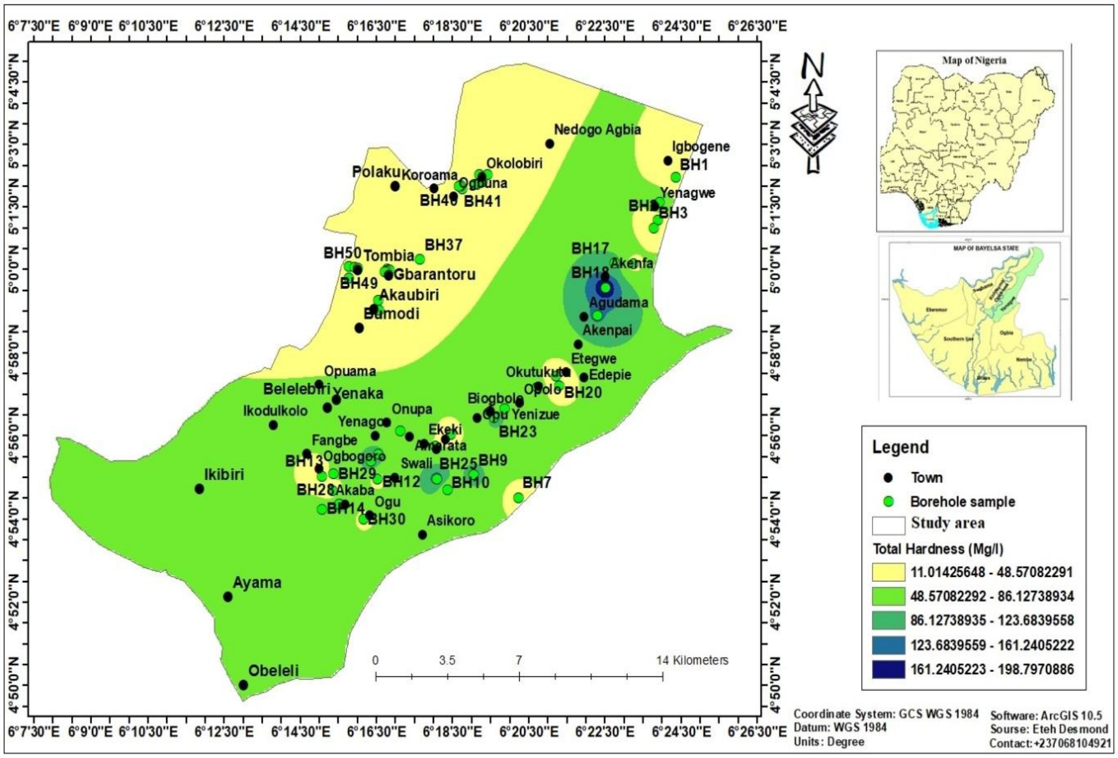

Fig. 7. Spatial distribution map of Total Hardness across Yenagoa metropolis

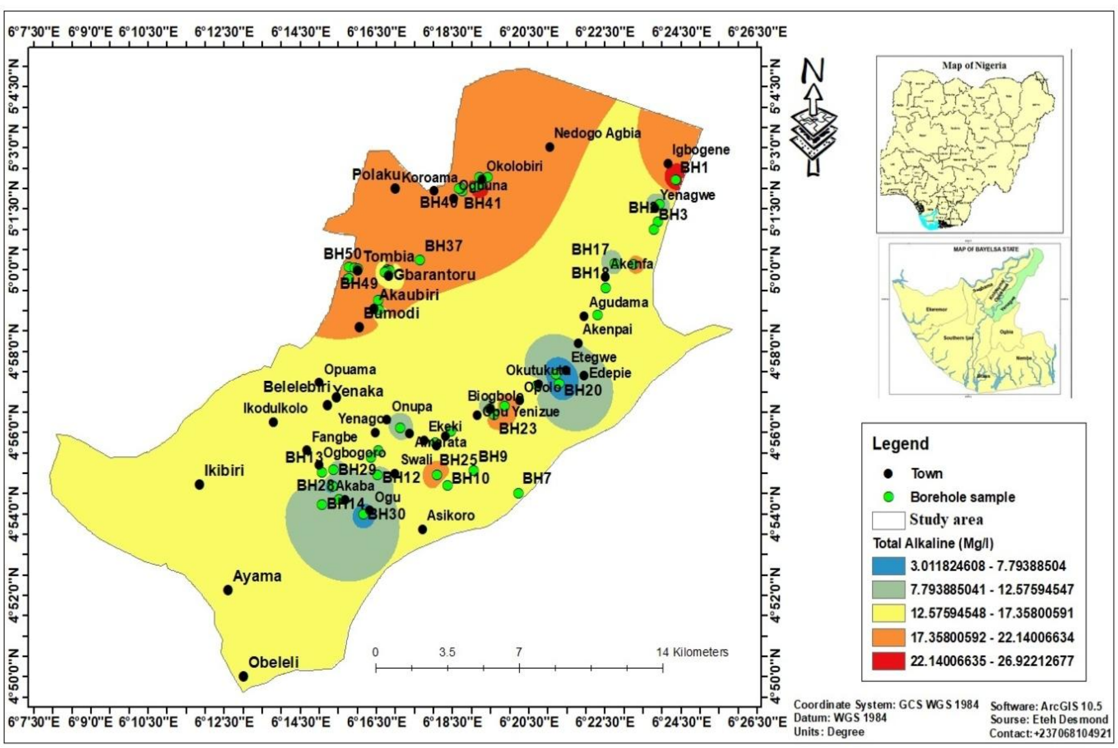

Fig. 8. Spatial distribution map of Total Alkalinity across Yenagoa metropolis

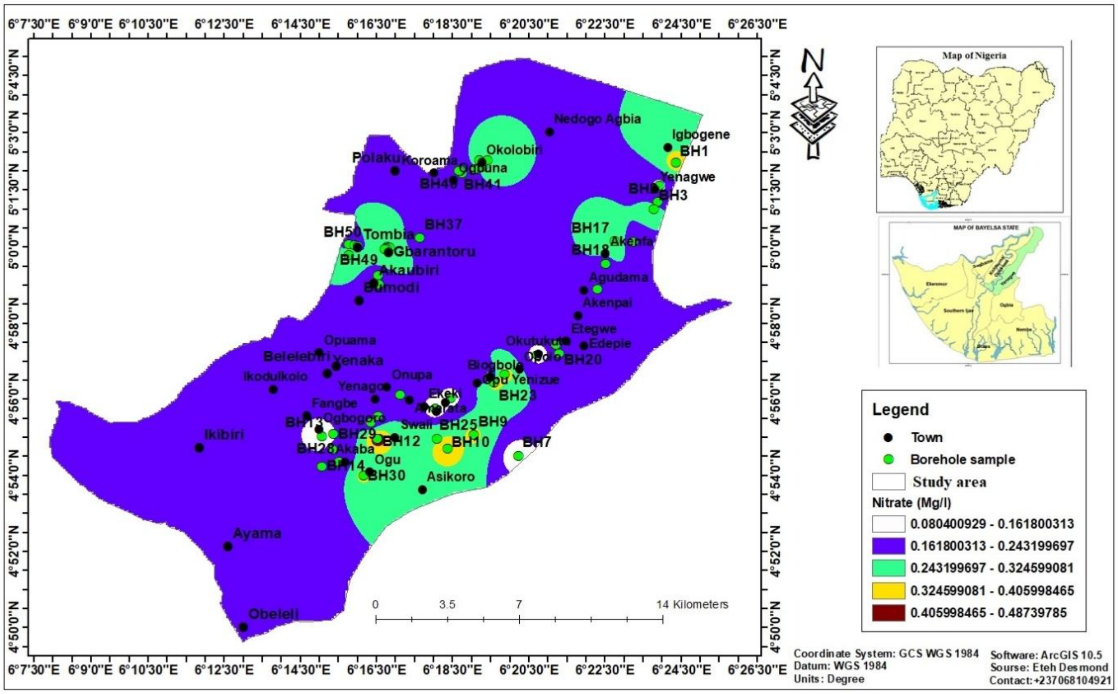

Fig. 9. Spatial distribution map of nitrates across Yenagoa metropolis

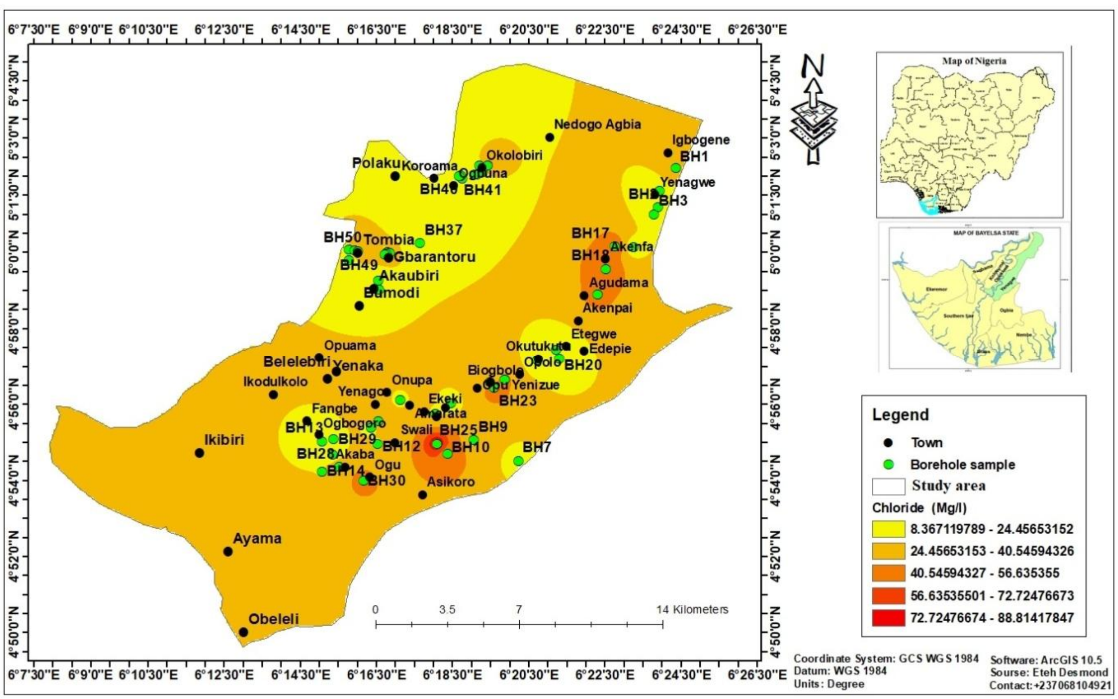

Fig. 10. Spatial distribution map of chloride across Yenagoa metropolis

Chloride is the most common anion found in groundwater. It is also known that the seawater contains very high amounts of chloride which can be transmitted to coastal aquifers by sea water intrusion. The pollution from industrial effluents is another source of chloride concentration in industrial areas. The acceptable limit for chloride in portable water is 250 mg/l [19]. Chloride concentration in the study area ranged from 8.00 mg/l to 90 mg/l with a mean value of 27.4 mg/l (Table 1). A spatial distribution map of chloride across Yenagoa communities (Fig. 10) shows the groundwater in the area is free from chloride pollution.

Sulfate concentration in groundwater is another source of concern. The primary natural sources of sulfate are atmospheric deposition, sulfate mineral dissolution, and sulfide mineral oxidation. High concentration in water can cause diseases of the alimentary canal. Excessively high concentration of sulfate in groundwater can impact health adversely. [19] places the permissible limit for sulfate in portable groundwater at 100 mg/l. Results from the analysis of groundwater across the area showed values ranging between 0.23 mg/l to 10.8 mg/l with a mean of 2.94 mg/l (Table 1). The spatial distribution map (Fig 11) shows that the concentration of sulfate in the study area is within the acceptable limit of [19].

For calcium concentration in groundwater, dissolution of carbonate rocks or carbonates in aquifer materials by carbonic acid, are the basic sources. From the physicochemical analysis results revealed calcium concentrations in the study area ranging from 6.75 mg/l to 56.88 mg/l with a mean concentration of 17.2 mg/l. Standard permissible limit by [19] was put at 70 mg/l (Table 1). A spatial distribution map of the calcium concentrations across the area (Fig. 12) showed that the concentrations are within the permissible level and do not pose a health risk to those consuming it.

Magnesium in groundwater results from dissolution of rocks, especially limestone, dolomite, and gypsum. Magnesium is found in large quantities in some brines. It is a major cause of water hardness, causing scales to form in boilers, water heaters and soap to form scum. High magnesium concentration can affect the quality of water for both domestic and industrial uses. [19] recommends its concentrations not exceeding 30 mg/l. From the analysis, it was observed that magnesium concentration in the study area ranged from 1.76 mg/l to 12.76 mg/l with a mean value of 4.5 mg/l (Table 1). A spatial distribution map (Fig. 13) showed that the concentrations of magnesium in the study area are within the [19] allowable limits, as such, it poses no risk for industrial and domestic use.

For sodium, high concentration in groundwater is peculiar to areas of saline water intrusion and discharge of effluents such as domestic and industrial wastes. Erosion of salt deposits and sodium bearing rock minerals, infiltration of surface water contaminated by road salt, irrigation and precipitation leaching through soils high in sodium are other sources of sodium in groundwater. Results of the groundwater analysis in the study area showed that the concentrations of sodium ranged from 3.75 mg/l to 28.64 mg/l (Table 1) with a mean concentration of 8.56 mg/l, as against the recommended standard limit of 200 mg/l [19]. A spatial distribution map of sodium across the area of study (Fig. 14) shows that sodium was well within acceptable standard limits.

Potassium concentration in groundwater also is a source of concern. Potassium contamination of groundwater comes from industrial and household chemicals, excessive fertilizers and pesticides used in agriculture, leaking underground oil storage tanks and pipelines, and sewage sludge. From Table 1 it was observed that the concentration of potassium in groundwater across the study area ranged from 0.60 mg/l to 7.34 mg/l with a mean value of 2.62 mg/l (Table. 1). The standard permissible limit for concentration of potassium was put at 12 mg/l [19]. A spatial distribution map of the concentration of potassium across the area (Fig. 15) showed that it posed no risk for domestic and industrial use.

Iron is an abundant metal found in the earth's crust as such it is usually unavoidably present in groundwater. A primary source of iron in groundwater is from weathering of iron bearing minerals and rocks e.g. lateritic soils. The [19] standard for permissible limit of iron concentration in portable water is 0.3mg/l, above this standard the color of water may turn brownish red due to the precipitation of insoluble Fe^{3+} particles from water when Fe^{2+} is oxidized. From the analysis, it was observed that iron concentration in the study area ranged from 0.11 mg/l to 0.8 mg/l with a mean value of 0.34 mg/l (Table 1). A spatial distribution map (Fig. 16) showed some communities of Yenagoa like Nedogo, Okolobiri, Tombia, Gbarantoru, Azikoro, Ayama, Famgbe, Ikibiri having water whose iron concentrations were within the acceptable limit, whereas some Central and Eastern Yenagoa communities like Akempai, Agudama, Amarata, Akaba, Ogu, Onopa had concentrations of iron higher than the acceptable limit for portable water.

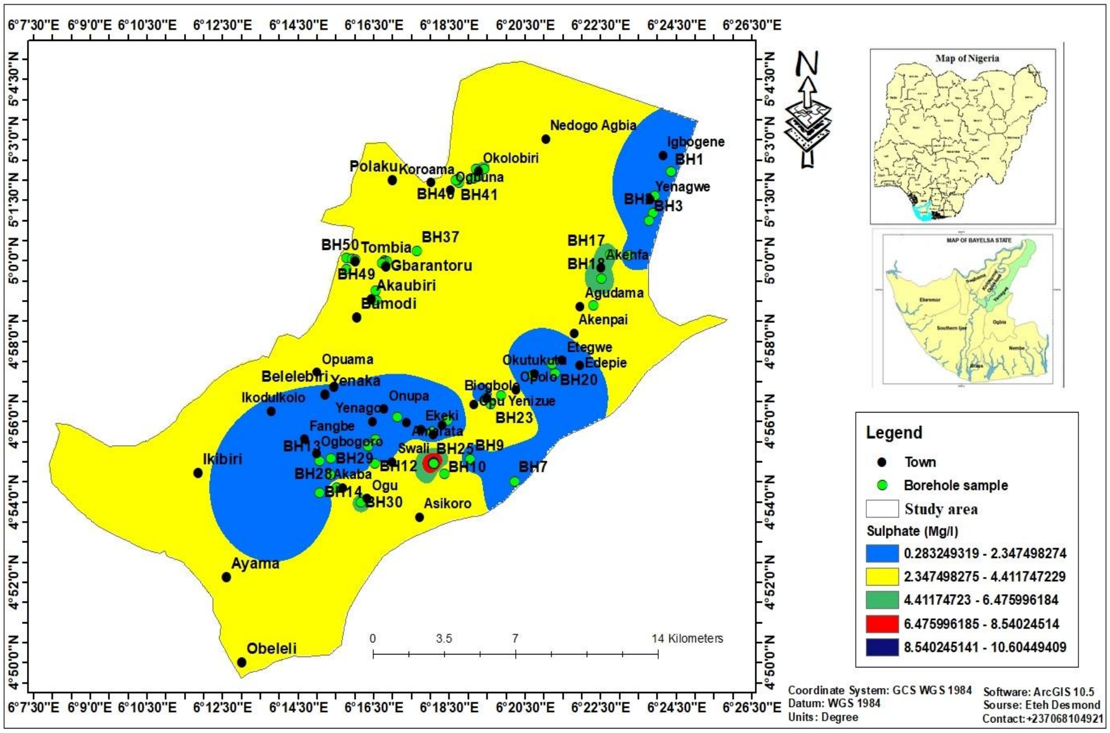

Fig. 11. Spatial distribution map of sulfate across Yenagoa metropolis

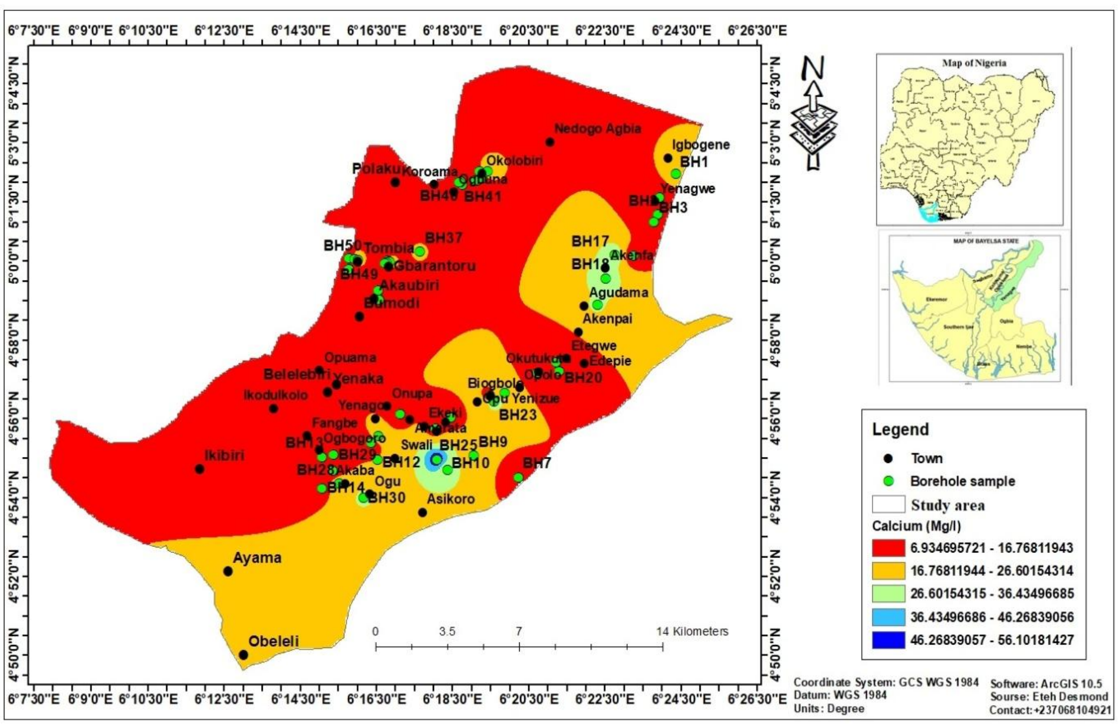

Fig. 12. Spatial distribution map of calcium across Yenagoa metropolis

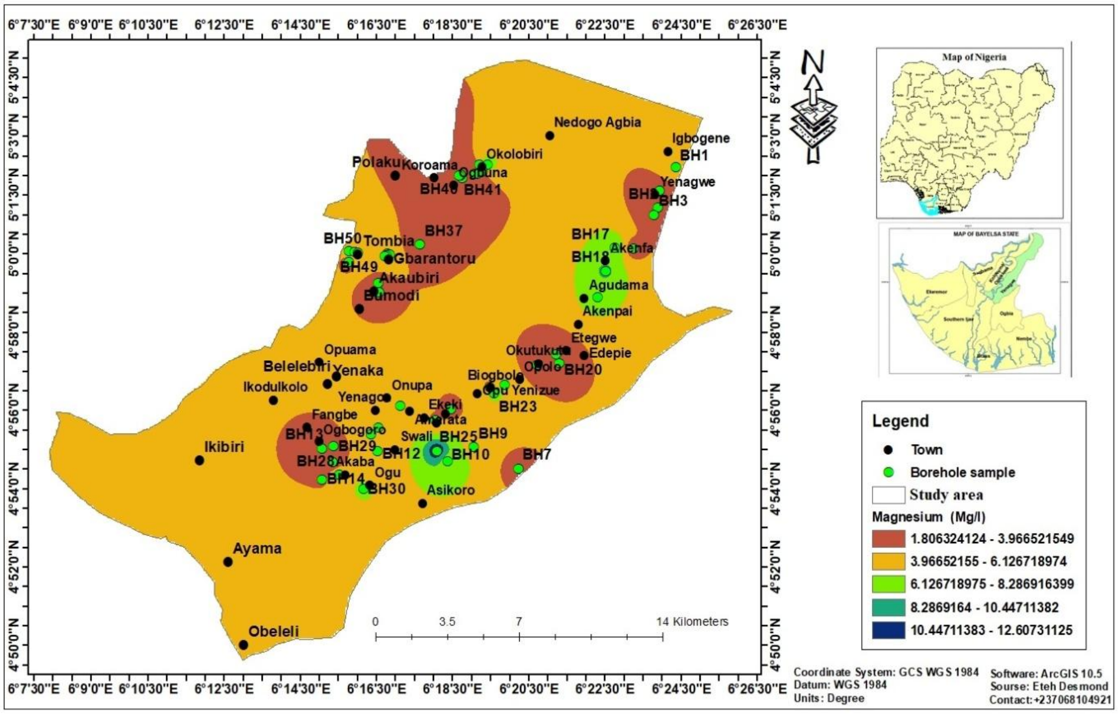

Fig. 13. Spatial distribution map of magnesium across Yenagoa metropolis

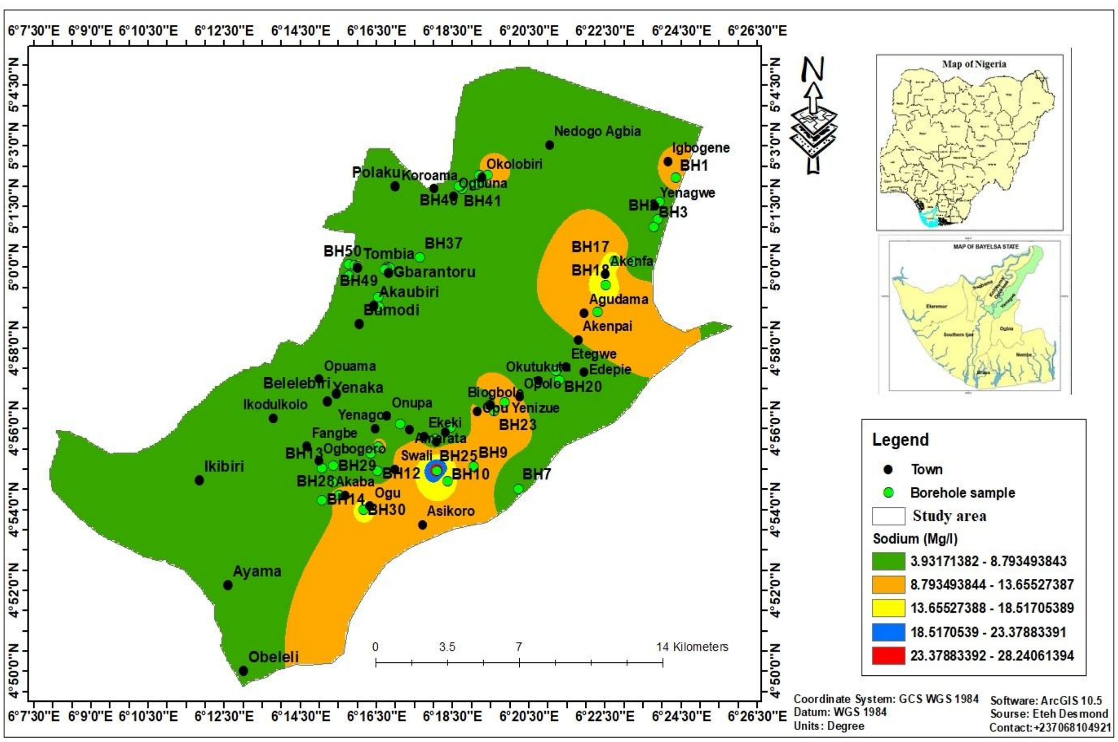

Fig. 14. Spatial distribution map of sodium across Yenagoa metropolis

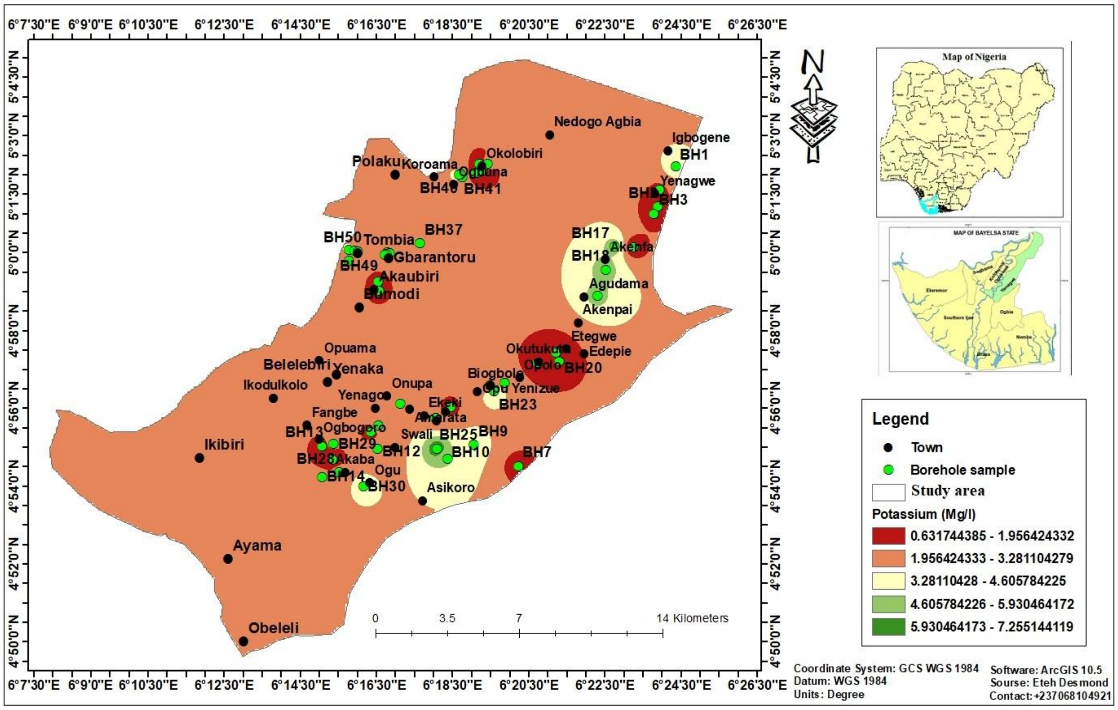

Fig. 15. Spatial distribution map of potassium across Yenagoa metropolis

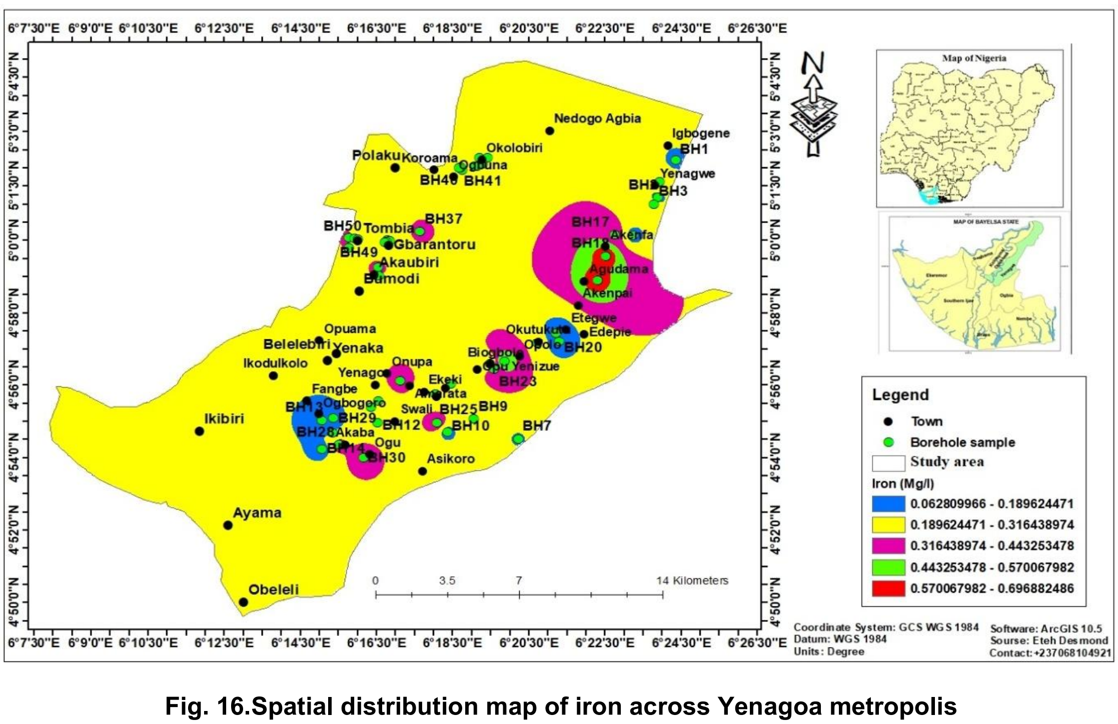

Fig. 16.Spatial distribution map of iron across Yenagoa metropolis

It can be observed that communities in North-Eastern Yenagoa comprising Okolobiri, Nedogo-Agbia, Gbarantoru and Yenegwe had groundwater with poor quality. In South-Western communities like Ayama-Ijaw, Obololi, Ikibiri and Ikudu, the groundwater was of good quality. Some Central Yenagoa communities comprising Bomodi, Tombia and Akaibiri had good groundwater, while others like Ekeki, Famgbe, Yenaka and Kpansia could boast of excellent groundwater quality. Some pockets of communities in Eastern Yenagoa including Edepie and on the North-East like Agudama and Igbogene had poor groundwater quality.

4. CONCLUSION

A successful attempt has been made using ArcGIS to present groundwater quality across communities in Yenagoa LGA. Thematic maps generated showed that groundwater was slightly acidic in most communities in Central and Northern Yenagoa like Ekeki, Swali, Akaba and Okolobiri. In communities like Ogbogoro, Ekeki, Azikoro and Yenegwe the Electrical Conductivity was higher than the standard permissible value put forward by [19]. Very high concentration of Iron was observed across all communities with an exception of a few communities like Nedogo, Okolobiri, Tombia, Gbarantoru, Ayama, Famgbe and Ikibiri which could boast of having Iron free groundwater. Concentration of Total Dissolved Solids, Calcium, Magnesium, Nitrates, Sulfates, Potassium and Sodium were within permissible limits for portable groundwater across all communities. Communities like Ayama-Ijaw, Obololi, Ikibiri, Ikudu, Bomodi, Tombia and Akaibiri had good groundwater, while others like Ekeki, Famgbe, Yenaka and Kpansia could boast of excellent groundwater quality, other areas had either poor or unsuitable groundwater for consumption.

Treatment is recommended for parameters which had higher concentration than the standard value stipulated by the World Health Organization for portable water. Also, the quality status of groundwater in the area should be monitored in order to forestall the risk of health hazard that may occur due to contamination and subsequent pollution of groundwater from sources like effluents, leachate plumes from dumpsites, industrial waste-water spills and salt-water intrusion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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