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Spatial Groundwater Quality Assessment by WQI and GIS in Ogbia LGA of Bayelsa State, Nigeria

Oki Austin Oyinkuro[1*] and Eteh Desmond Rowland[1]

[1]Department of Geology, Niger Delta University, Bayelsa State, Nigeria.

Authors' contributions

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

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ABSTRACT

An integrated approach to investigate the spatial groundwater quality in Ogbia LGA in Bayelsa State using WQI and GIS was made. Results from 10 (ten) physicochemical parameters (pH, conductivity, TDS, sulphate, nitrate, sodium, calcium, chloride, magnesium, hardness, iron) analysed on each of the 50 (fifty) groundwater samples from shallow boreholes across the area was used to compute WQI using WHO 2006 as a standard for potable water. Based on calculated WQI, boreholes were classified into excellent, proper, weak, very poor, unsuitable for drinking. Kriging method was then used to generate a digitised WQI map of Ogbia communities based on WQI classes. The map showed excellent to good water was accessible in some parts of Onuebum, Otuasega, Otuoke, Otuogila, Elebele, Emeyal and Oloibiri, whereas, very poor to unfit water occurred at some parts of Ewol, Opume, Akipli and Otuabagi.

Keywords: Groundwater; WQI; GIS; Kriging; Ogbia.

**Corresponding author: E-mail: ustin_oki@yahoo.com;*

1. INTRODUCTION

Groundwater is an essential renewable and widely distributed natural resource across the world. It is the primary source of drinking water in most parts of the Niger Delta, where surface water bodies have been contaminated by incessant hydrocarbon spills coupled with poor waste management practices [1,2,3]. The availability of good quality water is a significant component of groundwater protection and conservation strategies which aids planning and management of groundwater resource [4]. The quality of groundwater is usually defined regarding its physical, chemical and biological components, which in turn is dependent on the quality of recharge water, atmospheric precipitation, surface-groundwater interaction and geochemical processes [5]. The importance of good quality water to a community cannot be overemphasised as it directly impacts the health, economic development and social prosperity of the populace which utilises it. It also determines the functionality of the ecosystem of the area. Periodic monitoring and evaluation of groundwater quality are thus essential to forestall negative implications associated with the use of contaminated water.

Water Quality Index (WQI) has served as an efficient numerical tool for the classification of water quality for over half a century. It provides a yardstick for classification of water into groups of excellent to unfit for consumption [6,7,8,9,10]. Geographic Information Systems (GIS) have also emerged in more recent times as a potent tool for storing, analysing and displaying of spatial and attribute data [11,12,13]. It has been employed successfully in the development of solutions for water resource problems associated with water quality assessment and availability at both local and regional scale by the production of informative and user-friendly maps.

This research was prompted by reports of poor borehole water quality in some communities in Ogbia Local Government Area of Bayelsa State. We analysed some physicochemical parameters of groundwater in the area, which we used to classify the quality of water across the region, information of water classes were then fed into a GIS software to generate a WQI map which distinctly showed the spatial distribution of types of groundwater across the area.

2. PHYSIOGRAPHY AND GEOLOGY OF THE STUDY AREA

The location under study is Ogbia Local Government Area of Bayelsa State in Nigeria. It lies within longitudes 6.3400°E and 6.3900°E of the prime meridian and latitudes 4.6000°N and 4.9000°N of the Equator (Fig. 1). The topography of the area is low lying with elevations ranging from below sea level in the southwestern flank to about 20 m above sea level further inland. It lies within the salt and freshwater swamp geomorphic units of the Niger Delta sedimentary basin [14]. The area is drained by tributaries and creeks linked to the River Nun which includes the Orashi River and Kolo Creek. Ogbia is traversed by a good network of major and minor roads. Also a system of hydrocarbon pipelines connecting flow stations and tie points crosses the area. The research area falls under the Niger Delta Basin which has a geologic sequence consisting of three main tertiary subsurface lithostratigraphic units, overlain by varying types of quaternary deposits [15]. The base of the groups is the Akata Formation. It is comprised mainly of marine shales with some sand beds ranging in thickness from about 550 m to 6,000 m. Above the Akata is the Agbada Formation, it is a parallel sequence consisting of inter-bedded sands and shales with a thickness of 300 m to about 4,500 m, thinning both seawards and towards the delta margins. Overlying the Agbada is the most recent Benin Formation; it is comprised of over 90% sandstones with some intercalations of clays. This unit is the thickest in the central area of the Delta. The Benin Formation is the water-bearing unit of the Niger Delta Basin [16]. The clayey intercalations of the Formation give rise to a multi-aquifer system with the shallow unconfined aquifer occurring at depths ranging from 20 m to 40 m across the area [17,14,18].

3. MATERIALS AND METHODS

3.1 Physico-Chemical Analysis

Fifty (50) representative water samples were collected from shallow boreholes across communities in Ogbia LGA during the August break. Samples were collected with sterilised 50 cl plastic bottles and delivered to the laboratory within 12 hrs for analysis. Collection, preservation and transportation was done with strict compliance to the [19] guidelines. Sampling points were determined by the use of Garmin

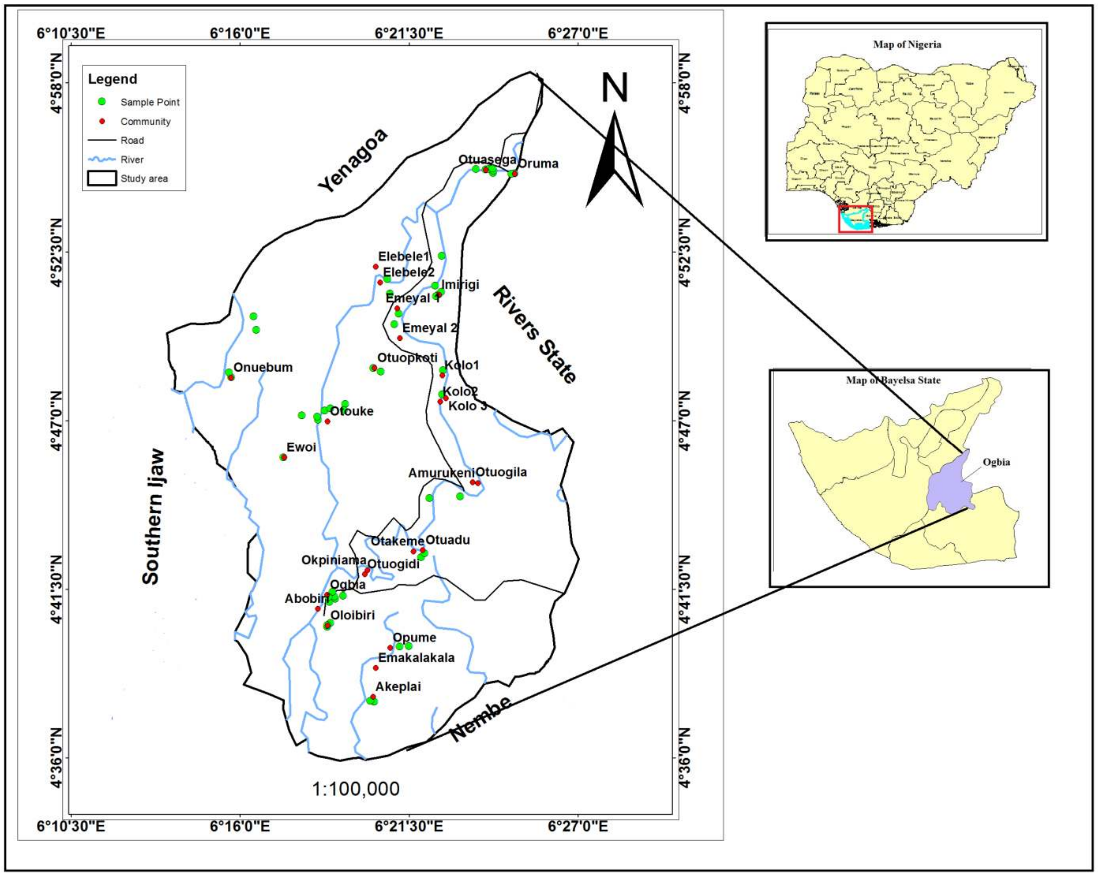


Fig. 1. Map of sampled points in Ogbia local government area

Global Positioning System device and recorded accordingly. On the field a pH meter was used to determine pH, while conductivity meter was used to determine conductivity and Total Dissolved Solids (TDS). Seven (7) other chemical parameters (sulphate, nitrate, calcium, chloride, magnesium, hardness, iron) were analysed.

3.2 WQI Analysis

Parameters selected for the computation of WQI was dependent on the intended use of water for consumption and other domestic purposes [20]. The weighted arithmetic index method for the computing of WQI was employed. The concept of weighted average was used to compute overall WQI because of its simplicity involved in data handling, minimal data processing and flexibility for use under different environmental conditions. Weighted average also provides adequate depression in the WQI values due to low sensitivity function value for variables, i.e., relative importance of a parameter determines its influence on the final outcome. Classification of water quality based on WQI method gave WQI of 0 to 25 as excellent, 26 to 50 as good, 51 to 75 as poor, 76 to 100 as very poor and greater than 100 to be unsuitable for drinking [21,22]. For computation sheet of WQI see Table 1.

Quality rating or Sub-index (Qn) was determined by

$$Qn = 100 * \left\{\frac{Vn - Vi}{Sn - Vn}\right\} \quad (1)$$

Where:

Qn is quality rating for the nth water quality parameter
Vn is estimated value of the nth parameter at a given sampling point
Sn is standard permissible value of the nth parameter as given by WHO
Vi is ideal value of the nth parameter in portable water (0 for all parameters except pH=7)

The unit weight is inversely proportional to the standard value Sn, determined by

$$Wn = \frac{K}{Sn} \quad (2)$$

Where:

Wn is unit weight for the nth parameter
Sn is standard value for the nth parameter
K is constant of proportionality (value is 1)

Aggregating the quality rating with the unit weight linearly gives the overall water quality index

$$WQI = \frac{\Sigma QnWn}{\Sigma Wn} \quad (3)$$

3.3 Geographical Information Systems (GIS) Analysis

Geographical Information Systems offers a range of statistical methods to interpolate data recorded at irregular intervals (e.g. environmental, geological). Some of the most commonly used interpolation methods to model spatially distribution from point data are Inverse Distance Weighting (IDW), Spline and Kriging [23,24].

The IDW is simple and intuitive deterministic interpolation method based on principle that sample values closer to the prediction location have more influence on prediction value than sample values farther apart, it predicts cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being predicted, the more weight it has in the averaging process. Spline is a deterministic interpolation method which fits mathematical function through input data to create smooth surface, it can generate sufficiently accurate surfaces from only a few sampled points and they retain small features. Kriging is a geostatistical interpolation method which is most often employed in the fields of soil science and geology. It is similar to IDW in that it weights surrounding data points. In kriging, however, the weight is not dependent solely on distance; it also depends on the overall spatial arrangement of data points. Unlike IDW and Spline, Kriging is a method based on spatial autocorrelation, which implies the presence of a spatial structure where observations close to each other are more alike than those apart. It uses a Semivariogram to produce surface maps of predicted values, standard errors, probability and quintiles. It is an improvement over inverse distance weighting because prediction estimates tend to be less biased and are accompanied by prediction standard errors (quantification of the uncertainty in the predicted value).

In this study, a map showing sample points was imported into ArcGIS software and digitized. Values at unmeasured locations where interpolated by Ordinary Kriging method, this method was used for its simplicity and accuracy in handling groundwater quality data. The methodology employed an experimental Variogram measuring the average dissimilarity between the unsampled locations and the nearby data (see flowchart: Fig. 2). From analysis of the experimental Variogram a suitable model was then derived by using weighted least squares method [25,26,12].

Table 1. Water quality index computation sheet for groundwater from borehole**

S/No	Parameters	Estimated values (Vn)	Standard values (Sn)	Unit weight (Wn)	Quality rating (Qn)	QnWn
1	pH	**	7.5	0.133	**	**
2	Conductivity	**	300	0.003	**	**
3	Total dissolved solids	**	500	0.002	**	**
4	Nitrates	**	45	0.022	**	**
5	Chlorides	**	250	0.004	**	**
6	Sulphate	**	150	0.006	**	**
7	Total hardness	**	300	0.003	**	**
8	Calcium	**	75	0.013	**	**
9	Magnesium	**	30	0.033	**	**
10	Iron	**	0.3	3.333	**	**
				Σ = 3.563		Σ = ** $=\frac{\Sigma QnWn}{\Sigma Wn}$

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

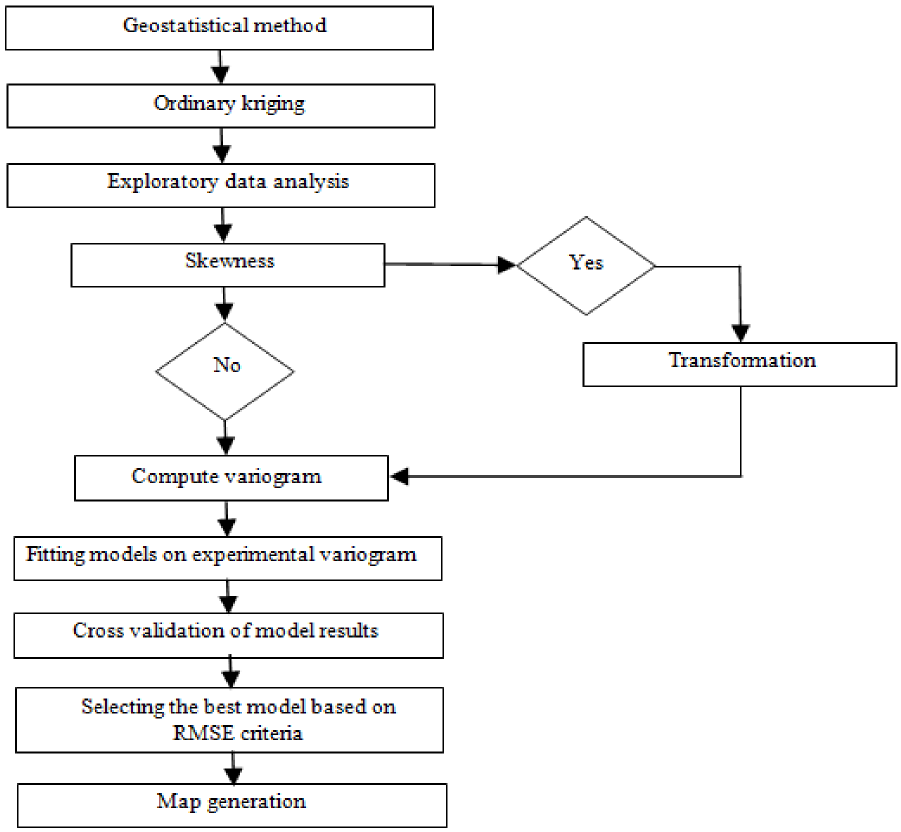


Fig. 2. Flow chart of Kriging method of map production

4. RESULTS AND DISCUSSION

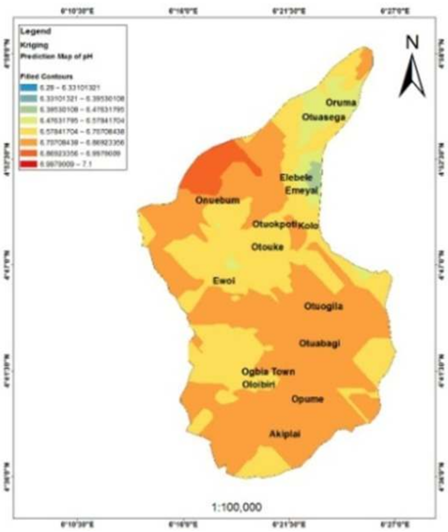
Results from the physico-chemical analysis and spatial distribution maps of pH (Table 2 and Fig. 3a) showed that groundwater across most Ogbia communities fell within the WHO permissible limit of 6.5 to 8.5, except for some areas of Otuasega, Elebele, Emeyal and Ewoi communities which were slightly acidic. The acidic nature of groundwater in some communities was mainly due to incessant gas flaring by oil companies in the area. Flared gas causes acid rain which serves as recharge for groundwater in the area. Magnesium (Fig. 3b) across the area was within the permissible limit of 50 mg/l. Spatial distribution map of Iron (Fig. 3c) showed the parameter was well within the WHO permissible limit of 0.3 mg/l in most areas across the communities, except at Otuokpoti, Kolo, Otuoke, Opume, Otuogila and Akiplai where Iron was quite higher than the recommended limit. High iron content was caused by anaerobic conditions in shallow boreholes due to high ratio of clays to sandstones in the topsoil, preventing oxidation of soluble Fe^{2+} to insoluble Fe^{3+} in the subsurface. As such, oxidation tended to occur when water is pumped out to the surface. Spatial distribution maps of Chloride (Fig. 3d) and Calcium (Fig. 3e) both showed parameters fell within the WHO permissible limits of 250 mg/l and 75 mg/l respectively across Ogbia communities. Maps of Total Hardness (Fig. 3f) showed most areas with the exception of Otuoke and Ewoi had potable water by WHO standards. Hard water is mostly caused by the presence of cations such as calcium and magnesium and anions such as carbonates, bicarbonates and chlorides. Maps of Total Dissolved Solids (Fig. 3g) and Sulphate (Fig. 3h) showed both parameters were within permissible limits of 1000 mg/l and 400 mg/l respectively by WHO. Spatial distribution maps of Nitrates (Fig. 3i) and Conductivity (Fig. 3j) showed parameters were within acceptable limits of 50 mg/l and 1000 mg/l for potable water by WHO.

Table 2. Results of physico-chemical analysis on groundwater samples from Ogbia LGA

Location	Sample code	Longitude	Latitude	pH	COND	TDS	TH	No^3	Cl	So_4	Ca	Mg	Fe
Oruma	BH1	6.415639	4.9175	6.5	101	150	14.6	2.4	10	5	5.5	6.1	1.5
	BH2	6.413833	4.917361	6.9	76	96	13.5	2.6	15	4.8	7.5	6	1.4
Otuasega	BH3	6.403833	4.917917	7.1	74	100	16.07	1.1	20	4	9	7.07	2.01
	BH4	6.394694	4.919972	6.37	175	88	32	0.157	10	0.34	6.35	1.48	0.108
	BH5	6.39975	4.919694	6.42	307	154	49	0.307	10	73	5.78	1.96	0.134
	BH6	6.401528	4.920028	6.33	346	173	31	0.364	24	3.46	14.64	4.62	0.127
	BH7	6.404194	4.918972	6.33	253	127	26	0.235	15	2.54	8.92	3.28	0.135
	BH8	6.403667	4.920306	6.34	457	229	44	0.457	32	4.75	20.25	5.87	0.246
Imiringi	BH9	6.372528	4.856639	6.39	309	155	42	0.39	20	0.54	10.95	4.64	0.15
	BH10	6.376111	4.872833	6.38	885	443	53	0.588	31	8	27.42	5.87	0.32
	BH11	6.374333	4.851861	6.39	728	364	55	0.728	30	7.3	21.62	5.38	0.286
	BH12	6.375694	4.853361	6.33	385	193	70	0.358	17	0.39	10.25	2.06	0.186
	BH13	6.373	4.850944	6.32	320	160	39	0.302	20	0.45	10.58	3.87	0.124
Elebele	BH14	6.347944	4.852472	7	77	110	19.1	2.5	25	0.29	10.1	9	2.9
	BH15	6.346528	4.860139	7	76	79	20.1	2.3	27	19	10.1	7	2.5
Emeyal	BH16	6.352667	4.841333	6.8	100	59	15.7	0.9	30	16	12.6	6.1	2.3
	BH17	6.350278	4.83575	6.9	54	92	17.9	1.2	35	15	10.9	7	2.56
Otuokpoti	BH18	6.339	4.812	6.4	100	100	21.2	2.4	25	10	12.2	9	4.2
	BH19	6.343	4.81	6.5	100	1.02	20	2.4	25	10	12	5	3.8
Kolo	BH20	6.376722	4.810583	6.9	75	99	10.1	0	25	20	6	4.1	2.53
	BH21	6.376389	4.797667	6.5	100	99	13.5	0.01	27	27	9	4.5	2.55
Otouke	BH22	6.323583	4.792417	6.42	262	131	21	0.26	24	0.62	13.48	4.2	0.14
	BH23	6.308917	4.783722	6.4	158	79	31	0.158	29	0.58	16.7	4	0.065
	BH24	6.3085	4.785528	6.46	860	430	30	0.68	47	6.8	30.86	6.54	0.248
	BH25	6.312417	4.788722	6.4	180	90	24	0.18	13	0.36	7.46	2.78	0.106
	BH26	6.300028	4.786083	6.5	968	4.84	360	0.986	150	10.76	83.78	28.46	0.326
	BH27	6.323	4.789	7	74	56	13.1	1.6	10	9.6	10.1	3	0.56
	BH28	6.3155	4.790056	6.7	100	100	19.1	0.6	15	16	13.1	6	1.6
Onuebum	BH29	6.275278	4.832694	6.8	76	100	16.7	2	25	19	10.7	6	0.96
	BH30	6.273861	4.839917	7	74	24	6.4	0.6	16	12	4	2.41	0.1
	BH31	6.261889	4.806778	6.5	74	100	15.1	1.7	28	15	10	5.1	0.71
	BH32	6.260611	4.809417	7	55	59	5.9	1.6	15	10	3.9	2	0.1

Location	**Sample code**	**Longitude**	**Latitude**	**pH**	**COND**	**TDS**	**TH**	**No^3**	**Cl**	**So_4**	**Ca**	**Mg**	**Fe**
Ewoi	BH33	6.29	4.763	7	76	106	17.1	1.2	15	3.5	10	7.1	2.5
Otuogila	BH34	6.369361	4.740917	7	54	100	4.8	0	20	96	3	1.8	0.2
	BH35	6.386	4.742	6.8	100	100	6.41	0.5	26	20	4	2.14	2.3
Otuabagi	BH36	6.36475	4.708833	6.9	74	68	20	0.1	30	15	12	8	1.56
	BH37	6.366861	4.710889	6.5	110	70	21	0.01	29	17	12	9	2.2
Ogbia Town	BH38	6.315139	4.684417	6.28	178	89	47	0.178	17	0.87	9.65	2.87	0.14
	BH39	6.318306	4.686306	6.38	197	98.5	30	0.197	10	0.95	6.38	1.62	0.106
	BH40	6.31775	4.687361	6.39	208	104	29	0.28	9	0.8	6.54	1.8	0.12
	BH41	6.316861	4.689944	6.35	214	207	31	0.241	11	0.54	6.87	1.54	0.14
	BH42	6.322583	4.687889	7	76	59	8.1	0.01	26	18	5.1	3	0.75
	BH43	6.314611	4.687056	6.9	74	64	9.2	0.01	27	20	6.2	3	0.92
Oloibiri	BH44	6.315639	4.673056	7	72	96	13.1	0.01	28	22	9	4.1	2.45
	BH45	6.313833	4.670972	7	68	97	14.6	0.06	39	21	8.5	6.1	2.3
	BH46	6.314028	4.671917	6.5	187	94	41	0.168	6	0.38	3.66	0.98	0.105
Opume	BH47	6.358167	4.660528	6.5	100	110	20.6	0.1	25	20	12.6	8	3.2
	BH48	6.353278	4.660139	7	57	56	4.9	0.1	15	4.8	3	1.9	0.07
Akiplai	BH49	6.339278	4.630333	6.9	55	97	18.7	0.6	29	50	10	8.7	2.53
	BH50	6.337167	4.630722	6.5	59	99	17.7	0.15	30	21	10	7.7	2.49
WHO				6.5 – 8.5	1000	1000	150	50	250	400	75	50	0.3

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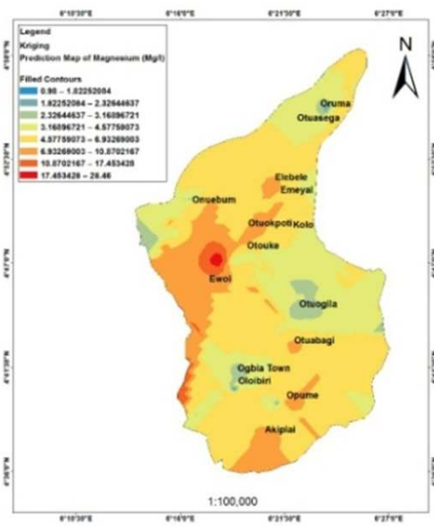
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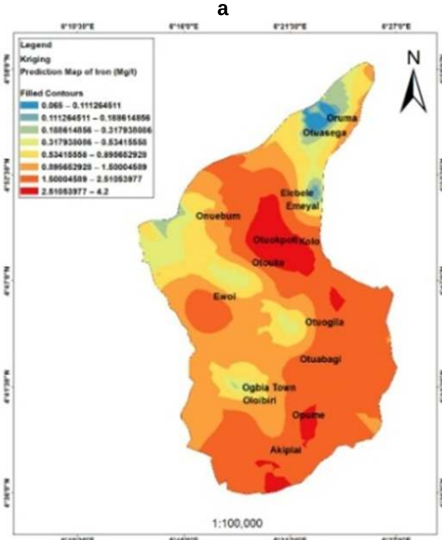
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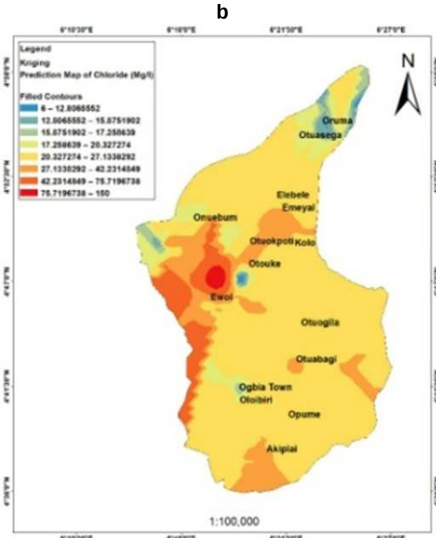
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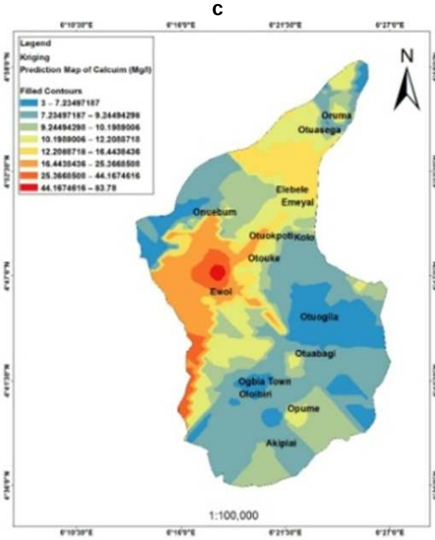
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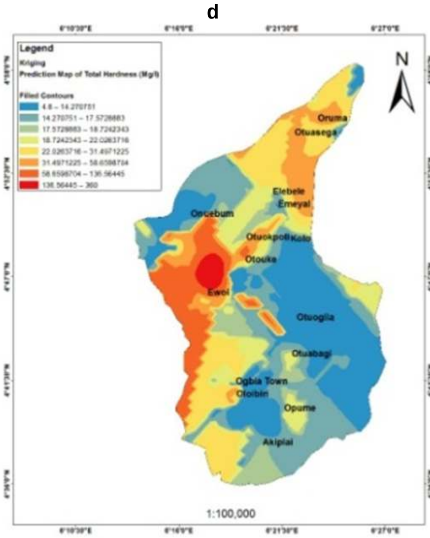
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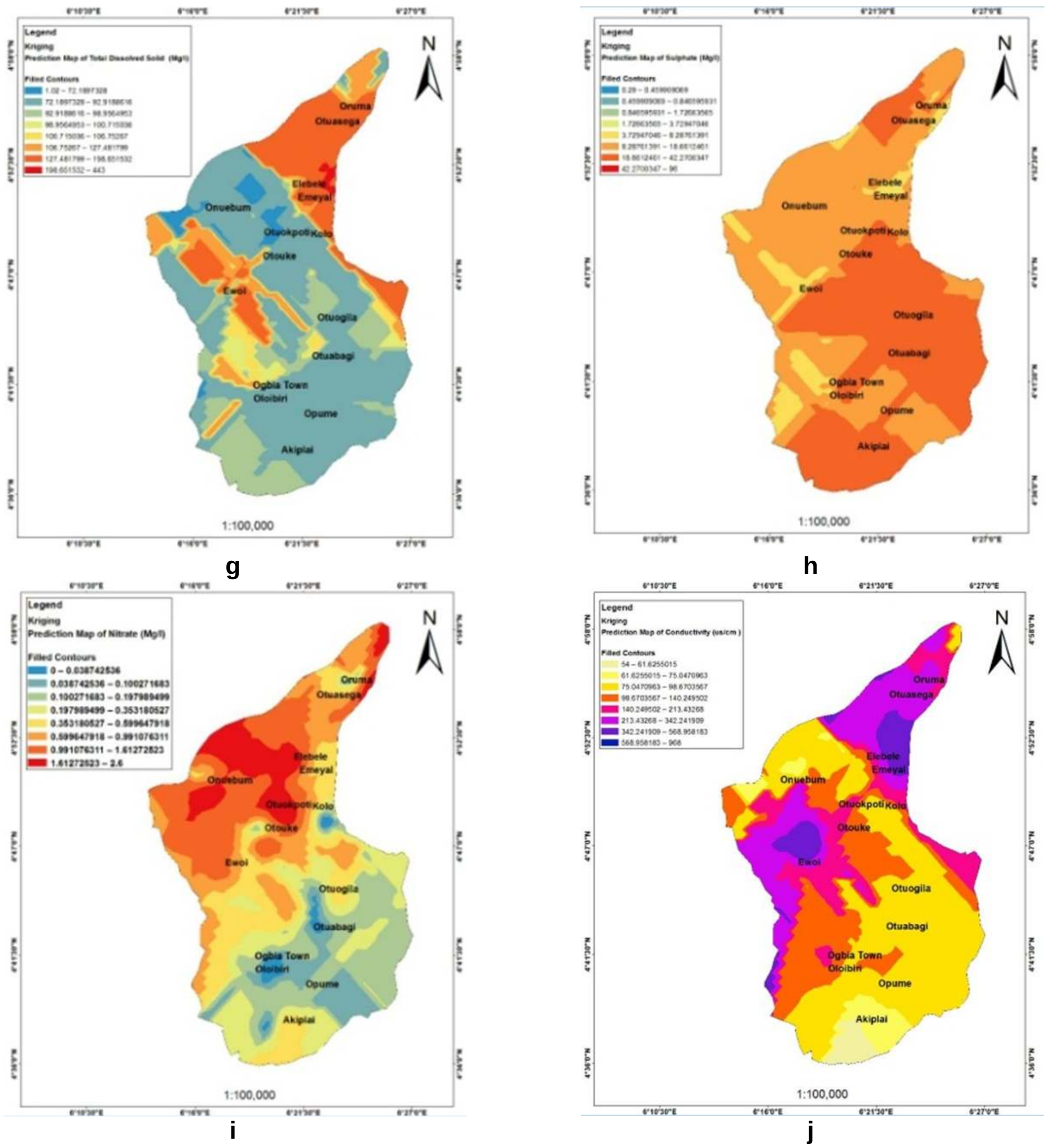

Fig. 3 (a – j). Map of spatial distribution of analysed physico-chemical parameters of groundwater in Ogbia local government area

Table 3. Computed WQI values for all sample points

Code	WQI value	Class of water	Code	WQI value	Class of water
BH 1	73.81	Poor	BH 26	86.28	Very poor
BH 2	69.65	Poor	BH 27	37.09	Good
BH 3	90.15	Very poor	BH 28	77.62	Very poor
BH 4	27.39	Good	BH 29	54.72	Poor
BH 5	25.76	Good	BH 30	18.71	Excellent
BH 6	24.09	Excellent	BH 31	25.09	Good
BH 7	20.95	Excellent	BH 32	19.11	Excellent
BH 8	32.79	Good	BH 33	110.49	Unsuitable
BH 9	24.54	Excellent	BH 34	25.36	Good
BH 10	44.93	Good	BH 35	98.04	Very poor

Code	WQI value	Class of water	Code	WQI value	Class of water
BH 11	39.75	Good	BH 36	76.63	Very poor
BH 12	29.16	Good	BH 37	100.58	Unsuitable
BH 13	24.32	Excellent	BH 38	21.30	Excellent
BH 14	134.17	Unsuitable	BH 39	20.61	Excellent
BH 15	111.33	Unsuitable	BH 40	18.96	Excellent
BH 16	101.77	Unsuitable	BH 41	22.19	Excellent
BH 17	113.83	Unsuitable	BH 42	44.28	Good
BH 18	174.01	Unsuitable	BH 43	50.91	Poor
BH 19	156.45	Unsuitable	BH 44	108.81	Unsuitable
BH 20	111.76	Unsuitable	BH 45	104.24	Unsuitable
BH 21	114.12	Unsuitable	BH 46	18.53	Excellent
BH 22	21.92	Excellent	BH 47	137.60	Unsuitable
BH 23	18.46	Excellent	BH 48	17.10	Excellent
BH 24	41.47	Good	BH 49	112.80	Unsuitable
BH 25	17.99	Excellent	BH 50	114.50	Unsuitable

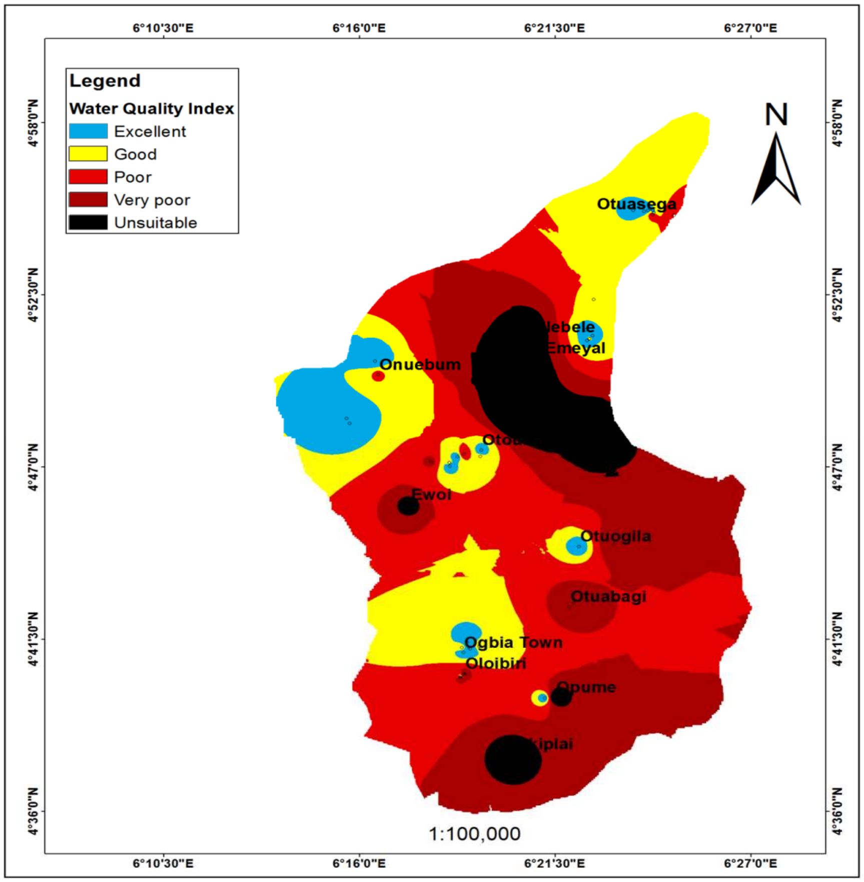

Fig. 4. WQI map of Ogbia local government area

Results from the computation and spatial distribution map of WQI in Ogbia LGA (Fig. 4) from 50 groundwater sample locations using WHO (2006) standard for potable water as a yardstick showed that 30% represented by 15 points of the area had excellent water, this is depicted on the map by areas such as parts of Onuebum, Otuasega, Elebele and Emeyal. 22% representing 11 sampled points had good water, this included some parts of Otuosega, Otuogila, Oloibiri, Onuebum, Emeyal and Otuoke. Poor quality groundwater existed in 8% of Ogbia communities representing 4 sample points, this consisted of some parts of Elebele and Otuabagi. 10% representing 5 sample points was observed to have inferior groundwater quality, this was followed at communities like Otuabagi and some parts of Ewoi. Shallow groundwater unsuitable for domestic purposes was found at 30% of Ogbia communities representing 15 sampled locations, common areas with inadequate water are Akiplai and parts of Ewol and Opume.

5. CONCLUSION

A successful attempt has been made using WQI and GIS to assess the spatial quality of groundwater in Ogbia communities of Bayelsa State. Result obtained underpins the effectiveness of WQI and GIS in analysing a large volume of datasets and presenting them in a simplistic manner easily understandable by policy makers and end users. The WQI map of Ogbia showed most communities have water suitable for drinking. For areas with inferior and unsuitable water; mostly due to high acidity, hardness and high iron content; appropriate treatment procedures are highly recommended. This research could serve as a basis for time-lapse groundwater modelling for efficient monitoring and predictions of changes in groundwater quality in the area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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