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Spatial Analysis of Groundwater Quality Indices across Yenagoa Communities in Bayelsa State, Southern Nigeria

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Authors' contributions

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

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ABSTRACT

Water Quality Index (WQI) and Geographical Information Systems (GIS) was successfully integrated to assess and present the groundwater quality status of communities of Yenagoa in a map form. Physico-chemical analysis was carried out on fifty (50) representative groundwater samples from shallow boreholes across communities in the area. Result obtained was used to compute the WQI of samples and classify them into groups of excellent (24%), good (18%), poor (52 %) and unsuitable (6%). Results from classification and borehole location information was then manipulated using GIS software to generate a WQI map for the area that can be interpreted by all and sundry. The presented map showed communities in the North-Eastern parts of Yenagoa comprising Nedogo-Agbia, Akemfa and Yenegwe and some random areas comprising Ogu, Akempai, Azikoro and Swali have poor groundwater. South-Western parts of the city the showed good water, this was observed in Ayama-Ijaw, Obololi, Ikibiri and Ikudu communities. Central

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communities of Bomodi, Tombia and Akaibiri had good groundwater. Ekeki, Famgbe, Yenaka and Kpansia showed excellent groundwater quality, while some communities in Eastern and North-Eastern Yenagoa had very poor groundwater which is unsuitable for consumption as seen in Edepie, Agudama and Igbogene. Appropriate treatment measures are strongly recommended for places on the WQI map of Yenagoa showing poor and unsuitable groundwater quality to forestall health challenges that may be associated with using such water directly.

Keywords: Groundwater; WQI; GIS; Yenagoa.

1. INTRODUCTION

Water is a very essential requirement necessary for life to thrive in any environment. It exists naturally and abundantly across the Earth's surface. The Niger Delta of Nigeria is drained by numerous surface water bodies like Rivers Nun and Niger, creeks, streams and swamps which all empty into the Atlantic Ocean. It is also one of the most prolific deltas of the world with vast quantities of hydrocarbon in its subsurface reservoirs making it an economic hub and an area with a beehive of hydrocarbon exploration and exploitation activities. Owing to poor environmental management practices like vandalism of hydrocarbon processing and transportation facilities, poor sewage management, indiscriminate dumping of waste and poor enforcement of environmental policies by the government most surface water bodies have been extensively contaminated and polluted in most areas of the Niger Delta including Yenagoa the study area [1,2,3,4] as such, surface water bodies are not recommended for most domestic and industrial uses. A large population particularly in urban areas of the Niger Delta source for potable water by drilling boreholes into subsurface aquifers.

Water Quality Index (WQI) is an effective mathematical tool that has been used successfully over the past decades to classify the quality of groundwater into different groups from excellent to unfit for drinking based of attributing varying computational weights to different physico-chemical properties of a given water sample. Weights are assigned based on how each property either physical or chemical influences the general quality of water. WQI has been proven to work effectively especially in areas where very large volume of water data was involved [5,6,7,8,9,10,4].

Geographical Information Systems (GIS) involves storing, analyzing, manipulating and presentation of spatial and attribute data in the form of maps, which are easily understood by the public. In recent times large datasets from the analysis of groundwater have successfully been manipulated by GIS to generate insightful information which cannot easily be gotten by other means. It has been used to develop solutions for water resource challenges both locally and regionally by the production of very informative, user friendly maps [11,12,13,4,14]. There have been reports of the quality of groundwater varying from one place to another across Yenagoa communities [1,3]. In some cases, neighboring communities in the area are documented to have very different groundwater quality status [10]. This research will employ results from physico-chemical analysis of groundwater samples across the area to compute the Water Quality Index of individual boreholes across the communities, the result of WQI computations would be used to classify borehole water in groups of excellent, good, poor and very poor and unsuitable for consumption. Information of classes of water from all boreholes would be manipulated by a GIS software to generate a water quality map of the area that can be understood and appreciated by all and sundry. This research would go a long way in water quality management, also in guiding choices in the area for real estate development, location of bottled water companies and other industries requiring good water with minimal treatment.

2. MATERIALS AND METHODS

2.1 Geology of Study Area

The location under study is Yenagoa Local Government Area, the capital city of Bayelsa State, Nigeria. The area lies within latitudes 4°50'00" N and 5°04'30" N, and longitudes 6°07'30" E and 6°26'30" E (Fig. 1). The topography of the area is generally low lying with elevations ranging from below sea level in the south western flank to about 20 m further inland. It lies within the salt and freshwater swamp geomorphic units of the Niger Delta sedimentary basin [15]. Yenagoa town is accessible through the East-West major road and a series of other minor roads from smaller bordering communities, it is drained by creeks and tributaries of the River Nun and Orashi River all emptying into the Atlantic Ocean.

Several authors [16] and [17] gave a very good description of the depobelts, sedimentary history and geomorphology of the modern Niger Delta, they identified three major lithostratigraphic units in the subsurface of the Niger Delta as the Akata, Agbada and Benin Formations which decrease in age basinward, reflecting the overall regression of depositional environments within the Niger Delta clastic wedge. Stratigraphic equivalents units to these three formations according to [18] are exposed in Southern Nigeria.

The Akata, Agbada and Benin formations reflect a gross coarsening-upward sediments deposited in marine, deltaic, and fluvial environments respectively [18,19]. In lithologic logs from wells in surrounding communities studied by [15], the Benin Formation which the youngest extending to depths of up to 2,100 m. It consisted of massive porous coarse grained sands with localized clay/shale interbedding. It is the aquiferous zone in the region into which boreholes are drilled for water to satisfy domestic and industrial needs [20]. The Quaternary deposits at depths between 40 m – 150 m overlying the Benin Formation are the superficial sediments making up the present-day surface geomorphic zones in the delta and consist of alternating sequences of sand, silt and clay with the latter becoming increasingly more prominent seaward. 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 [21,15,22]. The water table is generally high in the region, varying from the ground surface at the Atlantic coast to 20 m to 40 m towards the apex of the delta.

2.2 Study Design

2.2.1 Physico-chemical analysis

This work comprised three major aspects; firstly, a physico-chemical analysis was carried out on water samples collected randomly from fifty (50) representative shallow boreholes across all communities of Yenagoa LGA. Water samples coming directly from the underground water pump was collected before undergoing treatment with sterilized 30 cl plastic bottles. On the field, a P^H meter was used to determine P^H, while conductivity meter was used to determine conductivity and Total Dissolved Solids (TDS). Analysis of Electrical conductivity, Nitrates, Chloride, Sulphate, Total Hardness, Total Alkalinity, Calcium, Magnesium, Sodium, Potassium and Iron were done in the laboratory. Samples were stored in ice packs to reduce the rate of chemical reactions during transportation and then delivered to the laboratory for analysis. Collection, preservation and transportation was done with strict adherence to the [23] guidelines. Sampling points were determined by the use of Garmin Global Positioning System device and recorded accordingly.

2.2.2 WQI analysis

Secondly, Water Quality Index was computed from results of physico-chemical analysis obtained for each sample. The Weighted Average method was employed for the computing of WQI. 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. This method 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 samples based on their WQI value yielded groups 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 [24,25,4].

2.2.3 GIS analysis

Lastly, a spatial representation of WQI results was generated and presented across the area. A map showing sample points was imported into ArcGIS software and digitized. Values at unmeasured locations where interpolated by Inverse Distance Weighting (IDW). It is a 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, in other words, it explicitly makes the assumption that things that are close to one another are more alike than those that are farther apart. IDW 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, as such, it gives greater weights to points closest to the prediction location and weights diminish as a function of distance, hence the name Inverse Distance Weighting. This method was used for its simplicity and accuracy in handling large volume of groundwater quality data. From analysis of the experimental Variogram a suitable model was then derived using weighted least squares method [26,27,12,4].

3. RESULTS AND DISCUSSION

Results of physico-chemical analysis carried out on samples are presented in Table 1, WQI was computed from these results with reference to globally accepted standards for potable water [28] and presented in Table 2. Samples where then classified as seen in Table 2 into excellent, good, poor and unsuitable for consumption (Brown et al., 1970) with excellent representing 24% of samples, 18% as good, poor samples composed 52% and samples unsuitable for use represents 6% of the total. Information of the different classes of water quality computed with their respective geo-location was fed into a GIS software to generate a WQI map for Yenagoa (Fig. 2). From the map it is very clear that groundwater in the area relatively falls into two major classes of good and poor, whereas excellent and unsuitable water existed across fewer areas. Most communities in the North-Eastern of Yenagoa comprising Okolobiri, Nedogo-Agbia, Gbarantoru and Yenegwe have poor groundwater. In the South-Western communities including Ayama-Ijaw, Obololi, Ikibiri and Ikudu, the subsurface had good water. Central Yenagoa communities comprising Bomodi, Tombia and Akaubiri had good groundwater. Some parts of Central Yenagoa communities comprising Ekeki, Famgbe, Yenaka and Kpansia boast of excellent groundwater quality, while some pockets of communities in Eastern Yenagoa including Edepie and on the North-East like Agudama and Igbogene had poor groundwater. Areas with excellent quality groundwater need no treatment at all. In areas where the groundwater is good, minimal treatment is required to make the water potable for use. Areas with poor water requires a high degree of treatment and areas with unsuitable water for consumption would require a very high degree of treatment before water can be consumed.

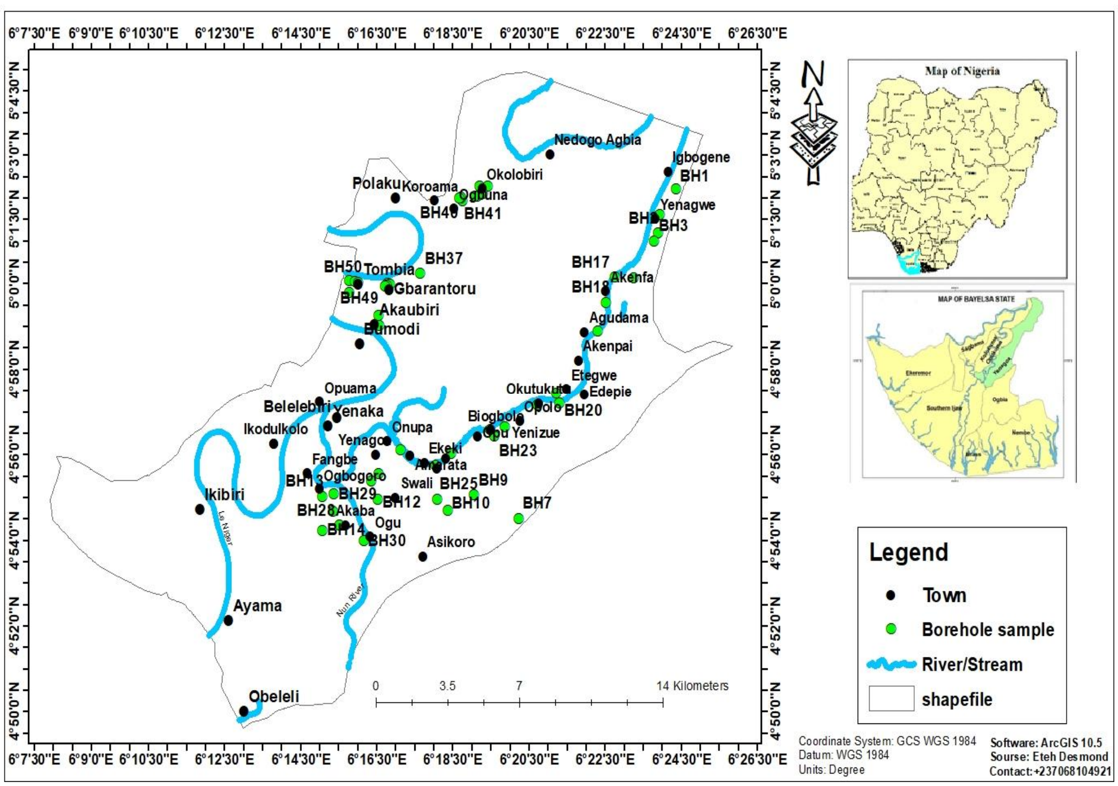

Fig. 1. Map of sampled points in Yenagoa Local Government Area

Table 1. Result of physico-chemical analysis of Groundwater in Yenagoa

Borehole	Lat.	Long.	Town	pH	EC	TDS	NO3	Cl	SO4	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	5.019750	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	6.353750	Etegwe 1	5.99	164	82	0.165	14	0.82	3	35	8.6	2.76	4.54	1.2	0.38
BH6	4.943250	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	4.911750	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	4.916000	6.275500	Swali 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	4.911250	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	4.981760	6.371660	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	6.345410	Okutukutu 1	5.85	91	46	0.132	14	1.42	14	56	8.78	1.96	4.62	0.78	0.32
BH22	4.944090	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	Swali 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	6.256240	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

Borehole	Lat.	Long.	Town	pH	EC	TDS	NO3	Cl	SO4	TA	TH	Ca	Mg	Na	K	Fe
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
BH36	4.999222	6.278500	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	5.034000	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	5.038000	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	5.034250	6.317890	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	6.263000	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/c

Table 2. Result of WQI analysis of Groundwater in Yenagoa

Borehole	Town	Lat	long	Water Quality Index (WQI) Value	Class of Water
BH1	Igbogene 1	5.036889	6.405972	180	Poor water
BH2	Yenagwe1	5.019750	6.398167	42	Excellent water
BH3	Yenagwe 2	5.016722	6.396528	120	Poor water
BH4	Akenfa 1	5.002366	6.387691	111	Poor water
BH5	Etegwe 1	4.957417	6.353750	114	Poor water
BH6	Biogbolo 1	4.943250	6.324806	90	Good Water
BH7	Kpansia 1	4.908472	6.337083	45	Excellent Water
BH8	Ekeki 1	4.929167	6.300806	105	Poor water
BH9	Kpansia 2	4.917722	6.317583	42	Excellent Water
BH10	Yenizue Epie 1	4.911750	6.305972	108	Poor water
BH11	Amarata 1	4.925861	6.275583	48	Excellent Water
BH12	Swali 1	4.916000	6.275500	108	Poor water
BH13	Ogbogoro 1	4.917028	6.251222	78	Good Water
BH14	Ogu 1	4.903722	6.251222	36	Excellent Water
BH15	Akaba 1	4.911250	6.255611	54	Good Water
BH16	Igbogene 2	5.026869	6.398981	117	Poor water
BH17	Akenfa 2	5.002678	6.379307	120	Poor water
BH18	Agudama 1	4.992793	6.375336	210	Very Poor water
BH19	Agudama 2	4.981760	6.371660	204	Very Poor water
BH20	Etegwe 2	4.953314	6.355015	240	Very Poor water
BH21	Okutukutu 1	4.952838	6.345410	96	Good Water
BH22	Opolo 1	4.944090	6.331098	195	Poor water
BH23	Opolo 2	4.940728	6.326492	120	Poor water
BH24	Kpansia 3	4.933825	6.307698	33	Excellent Water
BH25	Yenizue Epie 2	4.916093	6.301615	132	Poor water
BH26	Amarata 2	4.935199	6.285502	33.6	Excellent Water
BH27	Swali 2	4.923142	6.272686	105	Poor water
BH28	Akaba 2	4.905837	6.258554	120	Poor water
BH29	Ogbogoro 2	4.918221	6.256240	36	Excellent Water
BH30	Ogu 2	4.899849	6.269169	129	Poor water
BH31	Akaibiri 1	4.983667	6.276111	93	Good Water
BH32	Akaibiri 2	4.987861	6.275722	109.2	Poor water
BH33	Gbarantoru 1	5.000389	6.279556	40.8	Excellent Water
BH34	Gbarantoru 2	4.999861	6.280667	96	Good Water

Borehole	Town	Lat	long	Water Quality Index (WQI) Value	Class of Water
BH35	Gbarantoru 3	4.999656	6.279361	108	Poor water
BH36	Gbarantoru 4	4.999222	6.278500	39.6	Excellent Water
BH37	Gbarantoru 5	5.004056	6.294028	114	Poor water
BH38	Ogbuna 1	5.032306	6.312556	104.4	Poor water
BH39	Ogbuna 2	5.033528	6.311917	55.8	Good Water
BH40	Ogbuna 3	5.034000	6.311778	108	Poor Water
BH41	Ogbuna 4	5.033361	6.311056	111.6	Poor Water
BH42	Okolobiri 1	5.038194	6.323444	116.4	Poor Water
BH43	Okolobiri 2	5.038000	6.319889	112.2	Poor Water
BH44	Okolobiri 3	5.035417	6.321361	98.4	Good Water
BH45	Okolobiri 4	5.034306	6.318833	43.8	Excellent Water
BH46	Okolobiri 5	5.034250	6.317890	103.8	Poor Water
BH47	Tombia 1	4.996806	6.262944	99	Good water
BH48	Tombia 2	5.001417	6.263000	117	Poor water
BH49	Tombia 3	5.000861	6.265528	40.8	Excellent Water
BH50	Tombia 4	5.000639	6.266833	114.6	Poor water

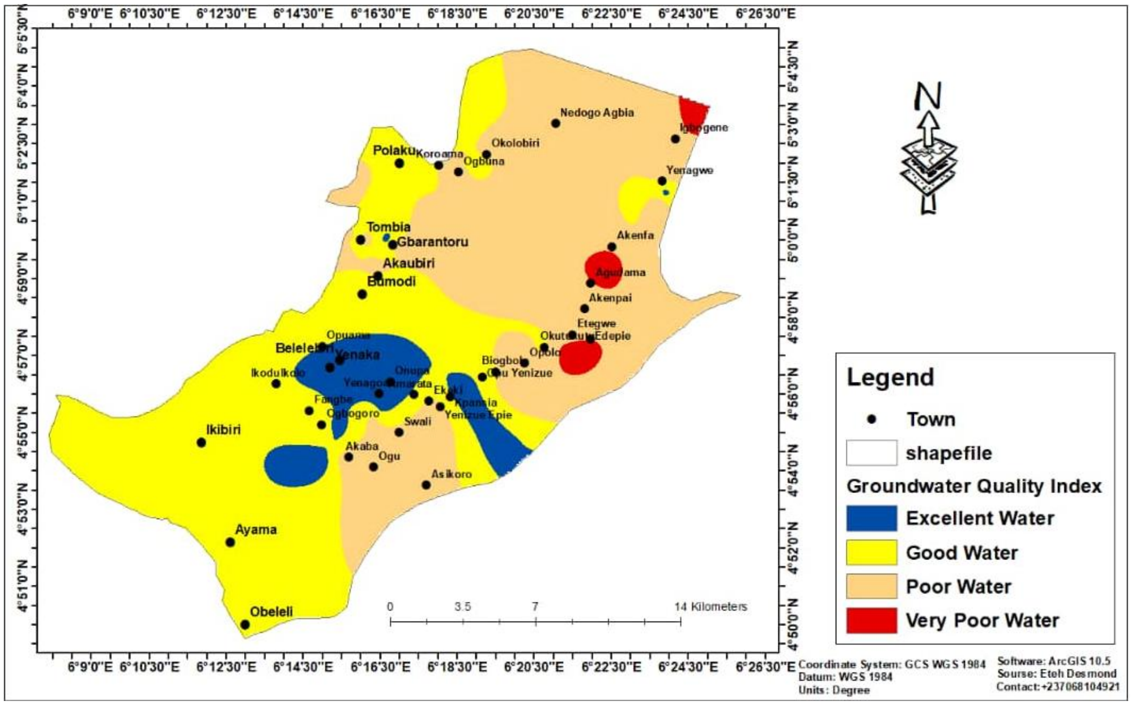

Fig. 2. Water quality index map of Yenagoa communities

4. SUMMARY AND CONCLUSION

WQI and GIS was successfully integrated to generate a WQI map showing groundwater quality status of communities of Yenagoa. The WQI map generated clearly shows areas with excellent, good, poor and very poor water which is unsuitable for consumption. Appropriate treatment measures are strongly recommended for places having poor and unsuitable groundwater. This research would serve as a very good background for groundwater quality monitoring to checkmate health hazards associated with use of poor quality water and location of industries requiring good water with minimal treatment like bottled water companies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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