Original Research Article

Groundwater Quality Assessment in Aba (Abia State)Using WQI and GIS Techniques

---

ABSTRACT

Groundwater is considered as the most important source of freshwater for human consumption and activities in the urban environment. The assessment of groundwater quality is critical to avoid the negative effects of polluted groundwater on human health, agriculture, and the economy.In this study, the quality of groundwater in Aba (Abia State) was assessed.Thirty-two water samples were taken from sixteen boreholes during the rainy and dry seasons,and analysed for pH, Electrical Conductivity, Total Hardness, Turbidity, Temperature, BOD_5, COD, Pb, Cd, Cr, NH_3, TDS, SO_4, NO_3 and PO_4.TheWeightedAverageWaterQualityIndex (WAWQI) approach was used to compute the Water Quality Index (WQI). Geostatistical analysis methods such as Ordinary Kriging, Empirical Bayesian Kriging (EBK), Inverse Distance Weighting (IDW) and Spline interpolation methods were compared in the spatial evaluation of variable concentrations using ArcGIS. In the dry season, 100% of the borehole locations had Water Quality Index values above 100 which is Unsuitable for drinking purpose. For the rainy season, 87.5% of the borehole locations had WQI values above 100 which is Unsuitable for drinking purpose, 6.25% had WQI which was of very poor quality and 6.25% had WQI within the range of good water quality. With a mean error of 0.372483, RMSE of 0.5515, and RMSSE of 1.030492 for the dry season and a mean error of 0.05625, RMSE of 10, and RMSSE of 0.986448 for the rainy season, the EBK interpolation approach was the best fit model for the WQI determination. WQI values for rainy season were generally lower than the WQI values of the dry season, attributable to surface water run-off during the rains.

Keywords: [Water quality index, WAWQI, Aba, Groundwater quality, Geostatistical analysis]

1. INTRODUCTION

Globally, about a third of the freshwater used is derived from groundwater, which is critical for domestic, industrial, and agricultural use, especially in arid and semi-arid regions where water is scarce and unevenly distributed. More than 1.5 billion people around the world are said to be reliant on groundwater for their basic needs [1]. Groundwater, with its potential to deliver water during drought years, remains the most stable and sustainable source of water, particularly where surface water supply is inadequate [2].

More than 40% of the world's population is already suffering from water shortages, a number that is only expected to grow as the temperature rises [3]. Though the water hygiene of 2.1 billion people has improved since 1990, decreasing water resources are impacting every continent. Increased drought and desertification are already causing water stress in many countries. At least one-fourth of the world's population will be affected by water scarcity by 2050, according to current estimates[4]. To ensure that everyone has access to safe and inexpensive drinking water by 2030 in accordance with the United Nations Sustainable Development Goal (SDG-6), it is important to make infrastructure investments, install sanitation facilities, and promote good hygiene. It is critical to protect and restore water-related ecosystems. Providing safe and cheap freshwater to everyone requires targeting over 800 million individuals who lack essential necessities and strengthening service accessibility and safety for more than two billion people [4].

Groundwater quality is critical for consumption, agriculture, and household use [5]. Water quality is inextricably connected to human health and poverty reduction, promoting gender equality, ensuring the safety of food and the livelihoods of people, and maintaining ecosystems, while also promoting economic growth and social progress in our societies [6]. When it comes to drinking water quality, groundwater is measured against a set of quality criteria that includes biotic, biochemical, and physical properties [7].

In Nigeria, borehole water is now the most easily accessible and affordable commercialized source of freshwater. Nonetheless, groundwater quality can decrease with time and seasons [8]. Heavy metal contamination of Nigeria's groundwater (containing zinc, copper, chromium, nickel, cadmium, lead, and mercury) can occur from a variety of places, including chemical and metallurgical plant discharges and landfill leaks. Groundwater contamination may lead to contaminated drinking water, water shortages, costly clean-up expenses, and the need for expensive alternative water sources, as well as other health issues [9]. Among the most common pollutants found in groundwater are inorganic salts, toxic metals, cations (such as potassium, sodium, calcium, and magnesium) and anions (such as chloride, bicarbonate, carbonate, and sulphate).

Groundwater quality varies between locations. As a result, one important challenge is locating optimal places for good quality groundwater for drinking purposes. Geostatistical approaches for analysing spatial connections are useful for predicting variables in places where sampling is not practicable. Geostatistics examines not only the incidence of a variable, but also its position, the spatial connection of values, and the influence of geographical factors on the distributionof variables at a given site [10].

For various reasons, people residing in most rural areas in developing countries such as Nigeria enjoy less contaminated water from various channels, which is not the case for others residing in urban areas because industrial effluents, municipal refuse dumps, and disposal of toxic, metallic, and organic wastes aggravate the situation of poor water quality in these regions [11]. Poor urban land-use implementation threatens various aspects of the environment, especially water supply sources, in Nigeria and other developing countries. Among these urban land-use practices are burying municipal solid and industrial waste improperly, using leaky septic tanks and on-site sanitary facilities, and discharging effluent directly into the groundwater [12].

Groundwater resources may be jeopardized as a result of additional leachate penetration as a consequence of unclean landfilling. Leachates, as a potentially hazardous waste of landfill sites, can impair nearby groundwater, surface water quality, and soil quality, especially if they include toxic chemicals. As a result, controlling leachates to avoid their infiltration into groundwater sources, in addition to more regular monitoring of water quality in regions around dump sites, is critical [13]. These have led to a growing interest in groundwater quality concerns, which have been extensively investigated across the world, including Nigeria, China, India, and the United States of America [1].

This study aims at evaluating the groundwater quality parameters of selected boreholes in the research area, determining the water quality index of selected boreholes in the research area and compare the results with standards, and developing spatial interpolation maps of the water quality in the research area using ArcGIS software.

2. MATERIALS AND METHODS

2.1 Study Area

The study area, Aba city in Abia state is the main economic nerve centre of Abia State, Nigeria (Figure 1). It serves the commercial needs of important cities in the south-eastern, and south-southern geopolitical regions of Nigeria. Over one million people are estimated to be living in the 236km^2 area. The vegetation and climate conditions are humid equatorial rainforest, with annual mean rainfall ranging from 2150 to 2460 mm, and mean daily temperatures ranging between 22 $^{\circ}$C and 33 $^{\circ}$C for the average minimum and maximum daily temperatures [12].

Aba lies approximately within longitude 7°19′ E to 7°37′ E and latitude of 5°3′ N to 5°12′ N in the Niger Delta Basin and is underlain by the Benin Formation that is highly aquiferous. The aquifer type is mostly unconfined and the water table elevation range 26 m – 33 m below ground level, with an average elevation depth of 28.6 m [14, 12]. The water table elevation implies that the wells are deep, and the groundwater is usually abstracted from tube-wells with submersible motor pumps. The area is predominantly flat, with poor drainage networks.

The growing population is putting pressure on the poorly implemented urban land-use in the area. Refuse dumpsites are sporadically sited and are used as municipal waste disposal, public water supply system is dysfunctional, and the central sewage system is non-existent to manage residential and industrial effluents. The dysfunctional state of the public water supply system has led to the proliferation of private pumps, which provide groundwater for domestic, commercial, and industrial purposes. In the absence of the central sewerage, use of cesspools, septic systems, direct discharge of effluents into the aquifer system have been observed in the area. These current practices have the potential to contaminate the quality of the groundwater in the area [12].

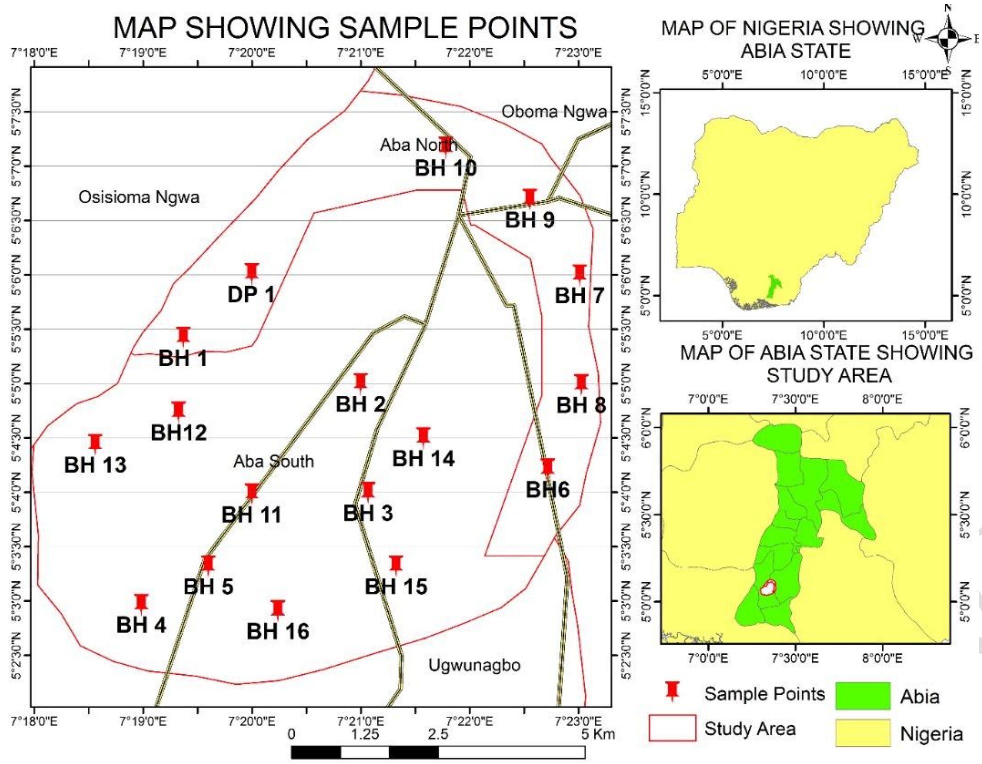

Figure 1: Map of the study area showing sampling points

2.2 Collectionof Groundwater Samples

Thirty-two Samples were taken from boreholes in Aba during the dry and rainy seasons, at evenly distributed sampling points by inserting a grid on the map of Aba using ArcGIS software and taking water samples from boreholes on the nodes of the grid for laboratory analysis. Borehole locations were selected based on spatial distribution on the grid of the map of Aba (Figure 1). Leachate sample was taken from the existing dumpsite in Aba.The water samples were taken in properly sterilized bottles that had been thoroughly cleaned. Before obtaining a water sample, the bottles were washed rinsed three times with the groundwater sample. Following that, the obtained samples were put in an ice bag and transferred to the laboratory.

2.3. Analysis of Groundwater Samples

The concentrations of the groundwater quality parameters (pH, Electrical Conductivity, TDS, Turbidity, PO_4, NO_3, COD, SO_4, Total Hardness, BOD_5 and Pb) were analysed. All analyses were carried out in accordance with established methods and as described in the literature [13, 15]. The study employed drinking water quality standards provided by the World Health Organization drinking water guideline to detect excessive quantities of these parameters.

2.3 Calculation of Water Quality Index

The water quality index is a useful tool for determining the overall state of water quality. It also aids in characterizing water quality in order to identify potable issues and makes protecting efforts more convenient [7]. The physicochemical parameters (pH, EC, TDS, BOD, COD, TH, SO_4, NO_3, Turbidity, Pb and PO_4) were used to calculate the WQI in this study[16].The Water Quality Index (WQI) was calculated using the Weighted Average Water Quality Index (WAWQI) method [10] which involved:

Step 1: gathering information on the water quality metrics that will be used to calculate the WQI.

Step 2: computation of k using Equation (1)

$$k = \left(1/\ \sum_{i=1}^{n} \frac{1}{s_i}\right) \quad (1)$$

where: k = proportionality constant

S_i = Standard permissible limit

Step 3: compute the nth parameter's quality rating, using Equation(2).

$$q_n = 100\left(\frac{(v_n - v_{io})}{(s_i - v_{io})}\right) \quad (2)$$

where: v_n= estimated concentration of the nth parameter of the given sampling location.

v_{io} = ideal value of the nth parameter in pure water.

S_i = standard permissible limit of the nth parameter.

Step 4: using Equation (3), determine the unit weight of the nth parameter.

$$W_n = \left(\frac{k}{S_i}\right) \quad (3)$$

Step 5: Using Equation (4), calculate the Water Quality Index.

$$WQI = \left(\frac{(\sum w_n * q_n)}{\sum w_n}\right) \quad (4)$$

The water quality index rating, graded A – E, is shown on Table 1.

Table 1: Water Quality Index (WQI) Ratings

WQI value	Water Quality Rating	Grade
0 - 25	Excellent	A
26 - 50	Good	B
51 – 75	Poor	C
76 - 100	Very Poor	D
Above 100	Unsuitable for drinking purpose	E

Source: [17, 10]

3. RESULTS AND DISCUSSION

3.1 Concentration of Water Quality Parameters

Thirty-two samples were collected from sixteen boreholes in the study area and analysed for water quality parameters. The Water quality parameters measured included: Temperature, pH, Turbidity, Electrical Conductivity, Nitrate, Phosphate, Total Hardness, Carbonate, Sulphate, BOD, COD, Ammonia, Lead, Cadmium, Chromium and TDS.Tables 2 and 4present the input data for developing Water Quality Index (WQI) in the dry and rainy seasons, respectively.According to [18], the water quality parameters should be reduced to an optimum – just enough to guarantee functional sense and scientific equilibrium.

The Descriptive statistics for water quality parameters for dry season and rainy season are presented in Tables 3 and 5, respectively.The average pH of the borehole water samples was 6.47 during the dry season and 6.92 during the wet season. In addition, during the dry season, groundwater in 93.75 percent of the analyzed boreholes was mildly acidic, whereas during the rainy season, it was mildly acidic in 81.25 percent of the boreholes tested. Electrical conductivity was found to have a mean value of 212.50 S/cm during the dry season and 270.71 S/cm during the rainyseason.Mean concentrations of phosphates throughout the dry and wet seasons were 0.2879 and 0.148 mg/l, respectively. In the wet season, lead concentrations were on average 0.0777 mg/l, lowest at 0.003 mg/l in BH11, highest at 0.563 mg/l in BH1, with a range of 0.56 and a standard deviation of 0.1347. Lead concentrations during the dry season varied from 0.025 mg/l in BH7 to 2.187 mg/l in BH1, with a mean value of 0.459 mg/l across the board and a standard deviation of 0.5652

Table 2: Measured water quality parameters from sampled boreholes for dry season

Borehole	**Ph**	**Temp.** $^{\theta}$c	**EC** (S/cm)	**TDS** (mg/l)	**Turbidity** (NTU)	**NH_3** (mg/l)	**PO_4** (mg/l)	**NO_3** (mg/l)	**COD** (mg/l)	**$S0_4$** (mg/l)	**Total Hardness** (mg/l)	**BOD_5** (mg/l)	**Pb** (mg/l)	**Cd** (mg/l)	**Cr** (mg/l)
BH1	5.74	22.3	315.7	202.048	0.315	1.863	3.39	23.14	96.41	170.15	183.01	2.53	2.18741	0.01631	6.03985
BH2	6.35	22	100.1	64.064	0.133	0.762	0.07	-0.075	67.84	0.009	84.1	3.01	0.39081	0.00427	0.32011
BH3	6.49	21	37.4	23.936	0.183	0.056	0.07	0.041	61.44	0.006	50.4	3.91	0.25314	0.00431	0.81973
BH4	6.65	22	190.8	122.112	1.392	0.527	0.056	0.83	55.68	0.014	54.1	1.98	0.15424	0.01203	0.91031
BH5	6.57	26.2	269.4	172.416	0.284	0.072	0.079	12.02	53.76	0.05	181.3	4.03	0.36182	0.00894	0.84391
BH6	6.31	26.8	558.9	357.696	0.365	0.143	0.14	10.53	17.68	0.023	150.4	1.89	1.28294	0.0362	0.52413
BH7	5.97	22.5	123.5	79.04	0.249	0.078	0.073	1.252	47.36	0.015	98.3	3.65	0.02451	0.01386	2.00317
BH8	6.82	27	255.9	163.776	0.241	0.814	0.056	0.751	60.16	0.019	79.6	4.62	0.89121	0.03102	1.93115
BH9	6.48	23.7	315.2	201.728	0.174	0.126	0.126	13.7	45.44	0.031	120.5	2.38	0.08475	0.00178	1.02131
BH10	6.74	26.4	254.3	162.752	0.428	0.089	0.056	0.625	62.72	0.009	77.6	2.85	0.23149	0.00394	1.25231
BH11	6.32	26.9	196.2	125.568	0.118	0.073	0.07	1.295	65.28	0.011	147.6	1.33	0.08631	0.00658	1.5231
BH12	6.93	23.6	311.2	199.168	0.591	0.112	0.112	16.35	75.52	0.031	52.6	2.47	0.12558	0.00821	1.42874
BH13	6.24	22.1	19.11	12.2304	0.187	0.056	0.056	0.112	52.87	0.012	44.2	1.24	0.52016	0.009346	0.98533
BH14	5.77	27	78.3	50.112	0.802	0.098	0.098	0.256	75.52	0.057	26.9	2.87	0.12374	0.00173	0.42103
BH15	7.35	22.3	58.2	37.248	0.713	0.511	0.056	-0.071	62.72	0.007	118.9	2.06	0.31238	0.01187	0.74987
BH16	6.73	27	315.8	202.112	0.124	0.039	0.098	0.23	51.2	0.035	63.2	2.87	0.31539	0.01247	1.03511

Table 3: Descriptive statistics for water quality parameters for dry season

Parameter	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
pH	16	1.610	5.740	7.350	103.460	6.46625	.105672	.422688	.179
Temp	16	6.000	21.000	27.000	388.800	24.30000	.582022	2.328089	5.420
EC	16	539.790	19.110	558.900	3400.010	212.50062	35.334158	141.336632	19976.043
TDS	16	345.466	12.230	357.696	2176.006	136.00040	22.613861	90.455444	8182.187
Turbidity	16	1.274	.118	1.392	6.299	.39369	.084675	.338701	.115
NH_3	16	1.824	.039	1.863	5.419	.33869	.120904	.483618	.234
PO_4	16	3.334	.056	3.390	4.606	.28788	.206915	.827660	.685
NO_3	16	23.215	-.075	23.140	80.986	5.06163	1.871880	7.487519	56.063
COD	16	78.730	17.680	96.410	951.600	59.47500	4.212027	16.848108	283.859
SO_4	16	170.144	.006	170.150	170.479	10.65494	10.633005	42.532019	1808.973
TH	16	156.110	26.900	183.010	1532.710	95.79437	12.349017	49.396068	2439.972
BOD_5	16	3.380	1.240	4.620	43.690	2.73063	.239445	.957778	.917
Pb	16	2.163	.025	2.187	7.346	.45912	.141294	.565177	.319
Cd	16	.034	.002	.036	.183	.01143	.002431	.009724	.000
Cr	16	5.720	.320	6.040	21.809	1.36307	.334407	1.337628	1.789
Valid N (listwise)	16								

Table 4: Measured water quality parameters from sampled boreholes for rainy season

Borehole	**pH**	**Temp. $^{\theta}$c**	**EC (μS/cm)**	**TDS (mg/l)**	**Turbidity (NTU)**	**NH$_3$ (mg/l)**	**PO$_4$ (mg/l)**	**NO$_3$ (mg/l)**	**COD (mg/l)**	**S0$_4$ (mg/l)**	**Total Hardness (mg/l)**	**BOD$_5$ (mg/l)**	**Pb (mg/l)**	**Cd (mg/l)**	**Cr (mg/l)**
BH1	6.64	20.4	586.19	375.1616	0.480	0.035	1.870	19.57	57.13	130.93	150.96	3.54	0.56317	1.692082	0.00396
BH2	6.78	20.2	590.21	377.7344	0.043	0.074	0.029	0.284	52.72	64.25	45.30	3.87	0.03572	0.00115	0.25167
BH3	6.81	19.8	470.3	300.992	0.015	0.056	0.035	0.162	29.63	51.94	28.9	2.68	0.08641	BDL	0.11851
BH4	6.77	20.3	318.1	203.584	0.023	0.042	0.018	0.157	35.11	22.63	50.6	3.22	0.10365	0.00593	0.36973
BH5	6.83	24.7	286.4	183.296	0.01	0.084	0.062	0.139	48.39	19.84	105.2	1.79	0.02014	0.00167	0.84202
BH6	6.89	23.5	410.6	262.784	0.036	0.042	0.014	0.820	32.05	24.11	130.4	2.58	0.00873	0.00256	0.34516
BH7	6.88	20.0	153.8	98.432	0.018	0.028	0.033	0.402	22.69	52.69	22.8	1.63	0.01784	0.00487	0.10803
BH8	6.86	25.0	210.3	134.592	0.008	0.118	0.051	0.360	41.82	63.72	55.1	2.41	0.06213	BDL	0.08917
BH9	6.91	22.0	94.3	60.352	0.014	0.042	0.021	0.087	45.31	58.23	175.3	2.79	0.09524	0.00172	0.02635
BH10	6.87	25.1	177.2	113.408	0.021	0.056	0.068	0.565	27.03	42.91	110.9	3.64	0.1219	0.00163	0.52718
BH11	6.93	24.2	83.7	53.568	0.036	0.041	0.037	0.48	50.94	74.86	85.2	3.2	0.00315	0.00201	0.20963
BH12	6.86	23.0	182.6	116.864	0.027	0.098	0.026	0.466	24.13	13.22	90.3	2.65	0.01971	0.00658	0.01781
BH13	7.20	21.6	110.9	70.976	0.011	0.028	0.051	0.017	47.04	17.39	70.6	1.74	0.01877	0.00275	0.1931
BH14	6.94	23.6	250.1	160.064	0.003	0.084	0.013	0.144	36.17	29.18	113.2	2.29	0.02457	BDL	0.35178
BH15	7.13	21.2	186.2	119.168	0.017	0.052	0.018	0.097	40.51	43.63	60.8	1.56	0.03648	0.00113	0.19001
BH16	7.43	24.0	220.4	141.056	0.005	0.071	0.022	0.109	33.84	25.72	42.1	1.92	0.02571	BDL	0.81387

*BDL -Below Discoverable Level

Table 5: Descriptive statistics for water quality parameters for rainy season

Parameter	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
pH	16	.79	6.64	7.43	110.73	6.9206	.04726	.18905	.036
Temp	16	5.30	19.80	25.10	358.60	22.4125	.48372	1.93490	3.744
EC	16	506.510	83.700	590.210	4331.300	270.70625	40.776848	163.107394	26604.022
TDS	16	324.166	53.568	377.734	2772.032	173.25200	26.097183	104.388732	10897.007
Turbidity	16	.477	.003	.480	.767	.04794	.028949	.115794	.013
NH_3	16	.090	.028	.118	.951	.05944	.006575	.026298	.001
PO_4	16	1.857	.013	1.870	2.368	.14800	.114878	.459510	.211
NO_3	16	19.553	.017	19.570	23.859	1.49119	1.206472	4.825887	23.289
COD	16	34.440	22.690	57.130	624.510	39.03188	2.644668	10.578673	111.908
SO_4	16	117.710	13.220	130.930	735.250	45.95313	7.425949	29.703797	882.316
TH	16	152.500	22.800	175.300	1337.660	83.60375	11.131771	44.527085	1982.661
BOD_5	16	2.310	1.560	3.870	41.510	2.59438	.186862	.747449	.559
Pb	16	.560	.003	.563	1.243	.07771	.033663	.134652	.018
Cd	16	1.692	.000	1.692	1.724	.10776	.105623	.422492	.178
Cr	16	.838	.004	.842	4.458	.27862	.064619	.258477	.067
Valid N (listwise)	16								

3.2 Water Quality Indices for Dry and Rainy Season

Water quality index (WQI) was calculated using eleven parameters (pH, Electrical Conductivity, TDS, Turbidity, PO_4, NO_3, COD, SO_4, Total Hardness, $BOD_5$and Pb). The calculated water quality indices for dry and rainy seasons are presented in Table6. The graphical comparison of WQI for dry season and rainy season is presented in Figure 2.The weighted Arithmetic Water Quality Index (WAWQI) method was applied in calculating the Water quality index (WQI). In the dry season, 100% of the borehole locations had WQI values above 100 which is Unsuitable for drinking purpose. For the rainy season, 87.5% of the borehole locations had WQI values above 100 which is Unsuitable for drinking purpose, BH6 representing 6.25% had WQI which was of very poor quality and BH11 had WQI of 31 representing 6.25% which was within the range of good water quality. WQI values for rainy season were generally lower than the WQI values of the dry season. This could be attributed to surface water run-off during the rains.

Table 6: Water quality index for dry season and interpretation

Loc_ID	WQI - Dry season	Interpretation	WQI - Rainy season	Interpretation
BH1	21,531	Unsuitable for drinking purpose	5,545	Unsuitable for drinking purpose
BH2	3,847	Unsuitable for drinking purpose	352	Unsuitable for drinking purpose
BH3	2,492	Unsuitable for drinking purpose	851	Unsuitable for drinking purpose
BH4	1,518	Unsuitable for drinking purpose	1,020	Unsuitable for drinking purpose
BH5	3,562	Unsuitable for drinking purpose	198	Unsuitable for drinking purpose
BH6	12,628	Unsuitable for drinking purpose	86	Very poor
BH7	242	Unsuitable for drinking purpose	176	Unsuitable for drinking purpose
BH8	8,773	Unsuitable for drinking purpose	612	Unsuitable for drinking purpose
BH9	835	Unsuitable for drinking purpose	938	Unsuitable for drinking purpose
BH10	2,279	Unsuitable for drinking purpose	1,200	Unsuitable for drinking purpose
BH11	850	Unsuitable for drinking purpose	31	Good
BH12	1,236	Unsuitable for drinking purpose	194	Unsuitable for drinking purpose
BH13	5,120	Unsuitable for drinking purpose	185	Unsuitable for drinking purpose
BH14	1,219	Unsuitable for drinking purpose	242	Unsuitable for drinking purpose
BH15	3,075	Unsuitable for drinking purpose	359	Unsuitable for drinking purpose
BH16	3,105	Unsuitable for drinking purpose	253	Unsuitable for drinking purpose

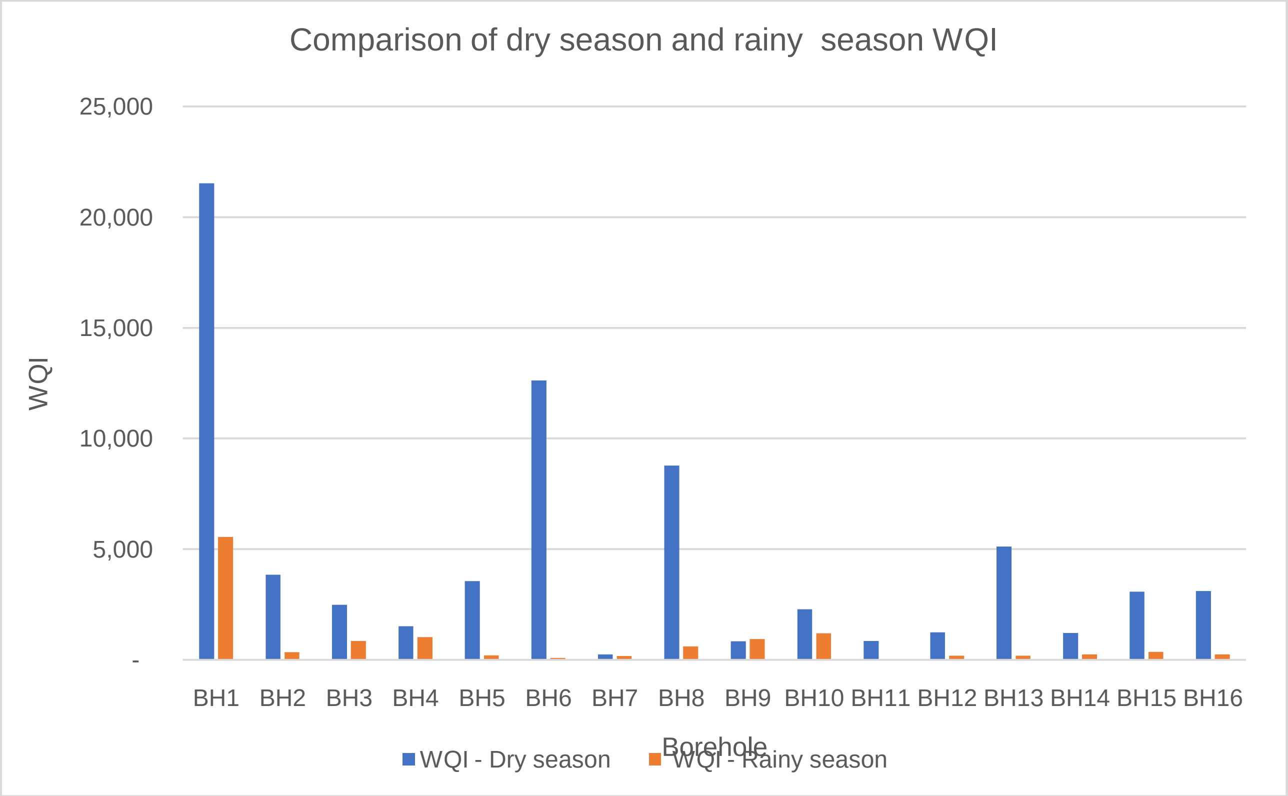

Figure 2: Comparison of dry season and rainy season WQI

3.3 Spatial Interpolation Maps for Dry and Rainy Season Water Quality Indices

The spatial interpolation maps for WQI during dry and rainy seasons using the Empirical Bayesian Kriging (EBK) are presented in Figures3and4 respectively for the study area.The accuracy of the geostatistical model usually depends on the values of the prediction errors from the interpolation maps. The accuracy of the model can be determined by considering the following conditions [10]:

- Mean Error should be closer to zero
- Root Mean Square Error should be low
- Root Mean Square Standardised Error should be closer to 1

The prediction errors are tabulated in Table 7. From Table 7, the best model for the WQI in the dry season was EBK with a mean error of 0.372483, RMSE of 0.5515and RMSSE of 1.030492. This is followed by Kriging with a mean error of 0.434983, RMSE of 0.8015 and RMSSE of 0.710252and then Spline with a mean error of0.649392, RMSE of 3.536and RMSSE of0.000225. The best model for the WQI in the rainy season was EBK with a mean error of 0.05625, RMSE of 10 and RMSSE of 0.986448. This is followed by Kriging with a mean error of 0.203125, RMSE of 28.875 and RMSSE of 0.961479, and then Spline with a mean error of 1.190625, RMSE of 1.125 and RMSSE of 0.000329.

Table 7: Best fit model for water quality index

	Interpolation Method	Mean Error	RMSE	RMSSE	Decision
WQI Dry season	Kriging	0.434983	0.8015	0.710252	
	EBK	0.372483	0.5515	1.030492	Best Fit
	SPLINE	0.649392	3.536	0.000225	
WQI Rainy season	Kriging	0.203125	28.875	0.961479	
	EBK	0.05625	10	0.986448	Best Fit
	SPLINE	1.190625	1.125	0.000329	

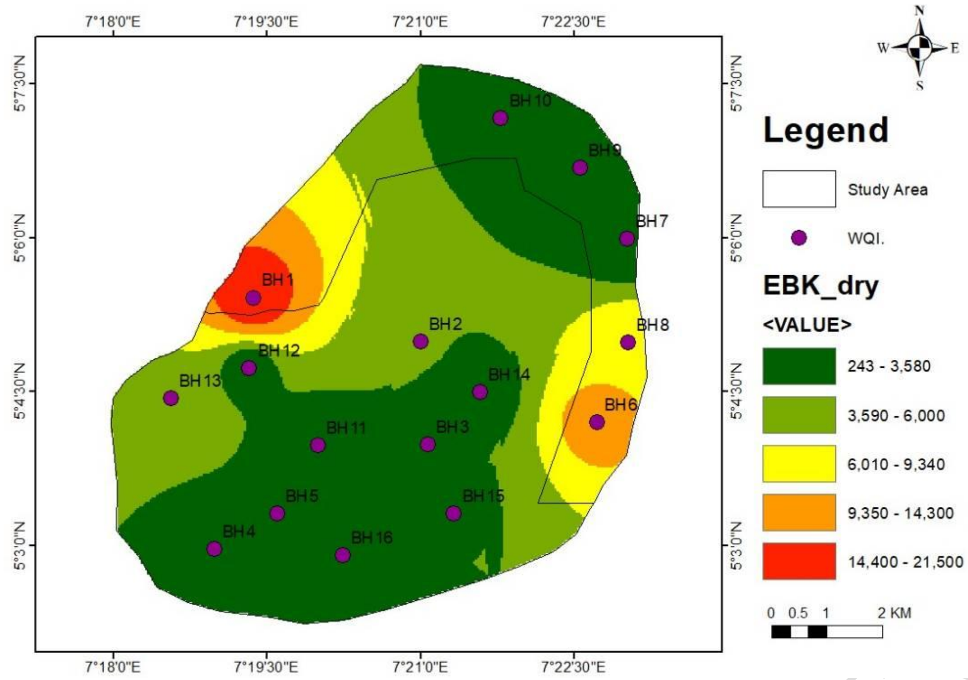

Figure 3: WQI dry season distribution map using EBK for Aba

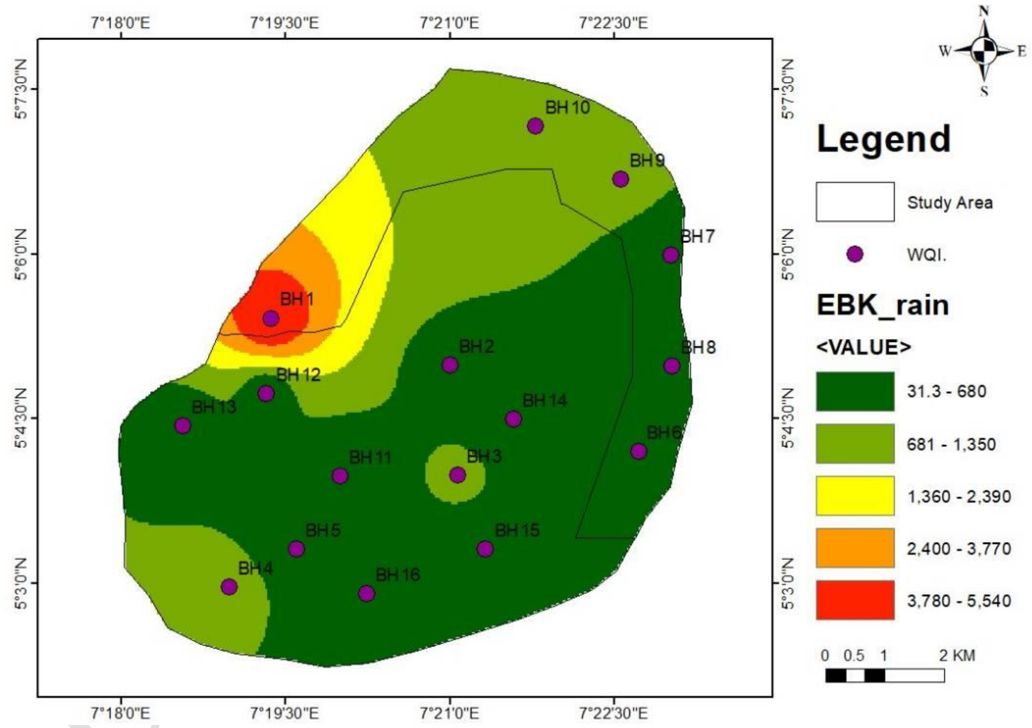

Figure 4: WQI rainy season distribution map using EBK for Aba

3.4 Correlation of water quality parameters fordry and rainy season

The correlation coefficient, r of the water quality parameters is presented in Tables 8 and 9 for both dry and rainy seasons. This was put to use in the study of the relationship between various parameters of water quality. In Table 10, we see how this correlation is to be interpreted. There was a significant positive correlation between Pb and Cd during the dry season (r = 0.86), suggesting a causal relationship between the two. Moreover, NO_3 and SO_4 were positively correlated at r = 0.64. With r = -0.15, -0.18, -0.22, -0.05, -0.23, and -0.23 correspondingly. Temperature showed a weak negative correlation with turbidity, NH_3, PO_4, NO_3, COD, and SO_4. There was a moderate negative association of pH with PO_4 and SO_4 (r = -0.46) but only a small negative correlation between pH and Total Hardness (-0.12), COD (-0.17), and NO_3 (-0.21). The relationship between electrical conductivity and nitric oxide (NO_3) is significant (r = 0.61), whereas the correlations of electrical conductivity with total hardness (r = 0.49), lead (r = 0.43), and cadmium (r = 0.48) are all medium.

There was a large positive correlation of TDS with PO_4, Pb, and Cd during the rainy season (r = 0.51). With r = 1.00, 1.00, 0.78, and 0.95 correspondingly, Turbidity showed a large positive correlation with NO_3, Cd, SO_4, and Pb. The pH correlation coefficient was just -0.03 for NH_3, -0.14 for COD, and -0.26 for Total Hardness. COD was positively correlated with BOD_5 (r = 0.25) and SO_4 (r = 0.54), although weakly and strongly, respectively.

Table 8: Correlation of WQI parameters fordry season.

	pH	*Temp.*	*EC*	*TDS*	*Turbidity*	*NH$_3$*	*PO$_4$*	*NO$_3$*	*COD*	*S0$_4$*	*T.H*	*BOD$_5$*	*Pb*	*Cd*	*Cr*
pH	1.00														
Temp.	0.02	1.00													
EC	0.03	0.51	1.00												
TDS	0.03	0.51	1.00	1.00											
Turbidity	0.18	-0.15	-0.09	-0.09	1.00										
NH$_3$	0.35	-0.18	-0.13	-0.13	0.23	1.00									
PO$_4$	-0.46	-0.22	0.22	0.22	-0.07	-0.39	1.00								
NO$_3$	-0.21	-0.05	0.61	0.61	-0.08	-0.29	0.66	1.00							
COD	-0.17	-0.23	-0.37	-0.37	0.12	0.18	0.57	0.22	1.00						
S0$_4$	-0.46	-0.23	0.19	0.19	-0.06	-0.33	1.00	0.64	0.58	1.00					
Total Hardness	-0.12	0.15	0.49	0.49	-0.30	-0.06	0.48	0.58	-0.07	0.47	1.00				
BOD$_5$	0.05	0.11	-0.05	-0.05	-0.22	0.23	-0.06	-0.06	0.08	-0.06	-0.04	1.00			
Pb	0.18	0.35	0.43	0.43	-0.16	0.29	-0.25	-0.10	-0.62	-0.25	0.09	0.06	1.00		
Cd	0.25	0.36	0.48	0.48	0.00	0.31	-0.27	-0.12	-0.65	-0.28	0.10	0.13	0.86	1.00	
Cr	0.30	0.22	-0.04	-0.04	-0.15	-0.04	-0.48	-0.31	-0.24	-0.48	-0.20	0.26	-0.02	0.32	1.00

Table9: Correlation of WQI parameters for rainy season.

	pH	*Temp*	*EC*	*TDS*	*Turbidity*	*NH$_3$*	*PO$_4$*	*NO$_3$*	*COD*	*S0$_4$*	*Total Hardness*	*BOD$_5$*	*Pb*	*Cd*	*Cr*
pH	1														
Temp	0.25	1.00													
EC	-0.51	-0.44	1.00												
TDS	-0.51	-0.44	1.00	1.00											
Turbidity	-0.43	-0.30	0.55	0.55	1.00										
NH$_3$	-0.03	0.52	0.02	0.02	-0.27	1.00									
PO$_4$	-0.40	-0.26	0.51	0.51	0.99	-0.24	1.00								
NO$_3$	-0.41	-0.26	0.52	0.52	1.00	-0.25	1.00	1.00							
COD	-0.14	-0.05	0.27	0.27	0.47	-0.09	0.46	0.44	1.00						
S0$_4$	-0.46	-0.28	0.40	0.40	0.78	-0.22	0.76	0.77	0.54	1.00					
Total Hardness	-0.26	0.30	-0.02	-0.02	0.40	-0.12	0.40	0.41	0.32	0.23	1.00				
BOD$_5$	-0.60	-0.09	0.48	0.48	0.40	-0.04	0.34	0.35	0.25	0.49	0.27	1.00			
Pb	-	-0.30	0.51	0.51	0.95	-	0.96	0.96	0.39	0.76	0.41	0.45	1.00		

	0.46					0.25									
	-					-									
Cd	0.40	-0.28	0.51	0.51	1.00	0.25	1.00	1.00	0.45	0.76	0.40	0.34	0.96	1.00	
			-	-			-	-	-	-			-	-	
Cr	0.39	0.50	0.04	0.04	-0.31	0.18	0.27	0.29	0.06	0.47	-0.09	-0.20	0.29	0.28	1

Table 10: Interpretation of Correlations coefficient values.

Coefficient value	Strength of association
0.1 < | *r* | < .3	Small correlation
0.3 < | *r* | < .5	Medium/moderate correlation
| *r* | > .5	Large/strong correlation

4. CONCLUSION

In locations where groundwater supplies most of the drinking water, understanding the magnitude and distribution of groundwater quality is crucial.This study can be used to identify regions that are suitable for drinking water, manage the environment around groundwater, pinpoint crucial areas, implement management limitations to raise aquifer quality, and more.

The results of the laboratory analysis of water samples showed that the groundwater in Aba were of variable quality indicated by its physiochemical properties.During the dry months, every single borehole site had a WQI more than 100 and was thus classified as "Unsuitable for drinking purpose". With WQI values over 100 during the rainy season, 87.5% of the borehole sites indicate that the water is "Unsuitable for drinking purpose".

Therefore, it is recommended that a periodic examination of the groundwater quality be conducted to help detect potential threats and take preventative measures promptly.

REFERENCES

1. Zhang, Q., Xu, P., & Qian, H. (2020). Groundwater quality assessment using improved water quality index (WQI) and human health risk (HHR) evaluation in a semi-arid region of northwest China. *Exposure and Health*, 1–14.

2. Dube, T., Shoko, C., Sibanda, M., Baloyi, M. M., Molekoa, M., Nkuna, D., Rafapa, B., & Rampheri, B. M. (2020). Spatial modelling of groundwater quality across a land use and land cover gradient in Limpopo Province, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, *115*, 102820.

3. Zhang, Y., & Shen, Y. (2019). Wastewater irrigation: past, present, and future. *Wiley Interdisciplinary Reviews: Water*, *6*(3), e1234.

4. UNDP. (2021). Goal 6_Clean Water and Sanitation. *Sustainable Development Goals*. https://www.undp.org/sustainable-development-goals#clean-water-and-sanitation (Accessed 22/09/2021).

5. Bodrud-Doza, M. D., Islam, A. R. M. T., Ahmed, F., Das, S., Saha, N., & Rahman, M. S. (2016). Characterization of groundwater quality using water evaluation indices, multivariate statistics and geostatistics in central Bangladesh. *Water Science*, *30*(1), 19–40.

6. Jha, M. K., Shekhar, A., & Jenifer, M. A. (2020). Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index. *Water Research*, *179*, 115867.

7. Kadam, A. K., Wagh, V. M., Muley, A. A., Umrikar, B. N., & Sankhua, R. N. (2019). Prediction of water quality index using artificial neural network and multiple linear regression modelling approach in Shivganga River basin, India. *Modeling Earth Systems and Environment*, *5*(3), 951–962.

8. Nwaogazie, I. L., Osamudiamen, O. P., & Bovwe, O. (2018). Modelling groundwater quality index based on sensitivity analysis for wet and dry seasons in Obio/Akpor local government area, Rivers state, Nigeria. *Nigerian Journal of Technology*, *37*(3), 799–805.

9. Akakuru, O. C., Akudinobi, B. E. B., & Usman, A. O. (2017). Organic and heavy metal assessment of groundwater sources around Nigeria national petroleum cooperation oil depot Aba, South-Eastern Nigeria. *Journal of Natural Sciences Research*, *7*(24), 48–54.

10. Amah, V. E., & Agu, F. A. (2020). Geostatistical Modelling of Groundwater Quality at Rumuola Community, Port Harcourt, Nigeria. *Asian Journal of Environment & Ecology*, 37–47.

11. Ewuzie, U., Nnorom, I. C., Ugbogu, O., & Onwuka, C. V. (2021). Hydrogeochemical, microbial and compositional analysis of data from surface and groundwater sources in Southeastern Nigeria. *Journal of Geochemical Exploration*, *224*, 106737.

12. Ijioma, U. D. (2021). Delineating the impact of urbanization on the hydrochemistry and quality of groundwater wells in Aba, Nigeria. *Journal of Contaminant Hydrology*, *240*, 103792.

13. Saleh, H. N., Valipoor, S., Zarei, A., Yousefi, M., Asghari, F. B., Mohammadi, A. A., Amiri, F., Ghalehaskar, S., & Khaneghah, A. M. (2020). Assessment of groundwater quality around municipal solid waste landfill by using Water Quality Index for groundwater resources and multivariate statistical technique: a case study of the landfill site, Qaem Shahr City, Iran. *Environmental Geochemistry and Health*, *42*(5), 1305–1319.

14. Agharanya, U. P., & Dim, C. I. P. (2018). Water quality assessment and resource potentials: the case of Aba–Urban and its Environs, Niger Delta Basin. *Water Resources*, *45*(2), 250–267.

15. Rice, E., Baird, R., Eaton, A., & Clesceri, L. (2012). Standard methods: For the examination water and wastewater (22nd ed.). American Public Health Association, American Water Works Association, Water Environmental Federation. ISBN 978-087553-013-0. ISSN 55-1979.

16. Ishaku, J.M ., A.S. Ahmed, and M.A Abubakar (2021). Assessment of groundwater quality using water quality index and GIS in Jada, North Eastern Nigeria . *International Research Journal of Geology and Mining* (IRJGM) (2276-6618) Vol. 2 (3) pp. 54-6.

17. Odia, M., Nwaogazie, I. L., Nwachukwu, E. O., & Avwiri, G. O. (2016). Modelling leachate pollution index and potential for selected municipal solid waste dump sites: A case study. *British Journal of Applied Science and Technology*, *18*(6), 1–16.

18. Banda, T. D., & Kumarasamy, M. V. (2020). Development of Water Quality Indices (WQIs): A Review. *Polish Journal of Environmental Studies*, *29*(3).