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Application of Water Quality Index to Assess Suitability of Groundwater Quality for Drinking Purposes in Kaltungo and Environs, North-East Nigeria

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Abstract:
A total of 30 groundwater samples were collected from Hand dug Wells and Bore holes at Kaltungo area and environs aimed at assessing the suitability of groundwater for drinking purposes using water quality index (WQI). 15 parameters were considered for calculating the WQI: Sodium, potassium, calcium, magnesium, chloride, bicarbonate, Sulphate, nitrate, iron, pH, Total Hardness, Conductivity, TDS, fluoride, and phosphate. The computed value of WQI for the samples ranges from 46.68 to 176.24 with an average value of 84.35. The majority of groundwater samples estimated fall in good category (86%) others fall in excellent category (4%) indicating groundwater is fit for drinking purposes although (10%) of the water fall in poor water category. Therefore, (90%) fall in the acceptable water class and thus, suitable for drinking purposes. But, the groundwater quality needs further investigations to see if there exists threat in its quality as far as irrigation activities is undertaking.

Keywords: *Water quality index, groundwater, water quality, parameters and Kaltungo*

1. Introduction

Groundwater is the most essential natural resource, which forms the core of the ecological system and thus, become the major source of domestic supply, agricultural, industrial, recreational, as well as environmental activities (Kwami *et al*., 2019). Groundwater is that water found within the saturated voids beneath the ground (Abdulrahman*et al.*, 2017). The source of groundwater is chiefly from precipitating atmospheric moisture which has percolated down into the soil and subsoil layers. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid population growth and the accelerated pace of industrialization. However, in developing countries, like Nigeria, human health is threatened by most of the agricultural activities particularly in relation to excessive fertilizers application and improper sanitary conditions. Also, the quality and availability of groundwater have been affected due to adverse effect of excessive groundwater withdrawal and improper waste management, especially in rapid developing cities (Ramakrishnaiah *et al*., 2009). Intensive irrigated agricultural discharges into the groundwater can led to considerable change in the groundwater quality. Therefore, once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the sources. The ground water quality evaluation and determination for human consumption is essential for the wellbeing of the ever-increasing population (Ishaku, 2011).It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it.

Water quality index (WQI) is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers (Kwami *et al*., 2018). Therefore, becomes an important parameter for the assessment and management of groundwater. Water quality index is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water (Tiwari and Manzoor, 1988, Ramakrishnaiah *et al*., 2009). Horten (1965) proposed the concept of WQI that represent gradation in water quality and calculated in such a way that presents the suitability of groundwater for human consumption.

This study is aimed at discussing the application of water quality index (WQI) in the assessments of groundwater suitability for human consumption.

2. Study Area

The study area is Kaltungo town and environs and is defined by Latitudes 9°45' and 9°51' N and Longitudes 11°15’ and 11°21’ Eand covers an area of about 121km²which fall within Gongola Sub basin and situated in Gombe State, Nigeria (fig. 1). It has been described as part of a rift basin in central West Africa that extends NNE–SSW for about 800 km in length and 150 km in width. The study area consists of basement complex and partly cretaceous sediments that were deposited during the major transgresses episode in the Eastern Benue Trough. The study area is characterized by tropical continental (Sudan) climate. It is also characterized by two seasons; a rainy season, which starts in April and ends in October and the dry season, which normally spans between November and April. The vegetation of the area is of Sudan Savannah type which covers more than half of northern Nigeria. It is characterized by short grasses with sporadic thorny bushes and scattered trees. The topography of the area is generally hilly with some parts having elevations more than the other surroundings. The elevation ranges from about 450m to 850m (fig 1). A surface drainage system in the area comprises numerous streams formed in the direction of the river basin towards the southeast.

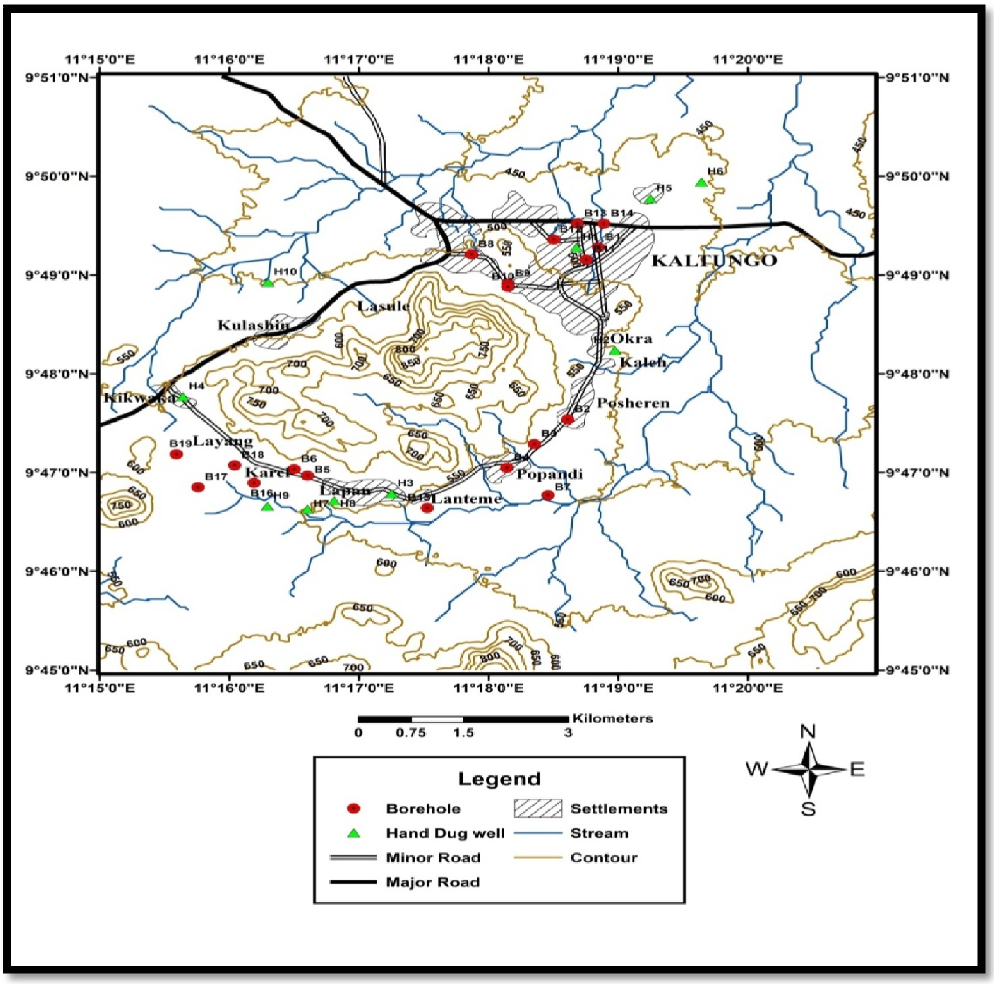

Figure 1: Topographical Map of the Study Area Showing Water Sample Points

3. Geology of the Study Area

According to Ntekim and Orazulike (2004) the tectonic setting of the area is influenced by the late Cretaceous intense compressional earth movements dominated by series of long and narrow simple fold structures. The reactivation of the major basement faults is responsible for sinistral faults in Kaltungo, Teli-Wuyo and Gombe areas. Coarse Porphyritic Granite, Biotite Granite, Bima Sandstone and Basalts represent the rocks of the Kaltungo area (fig. 2). Groundwater occurs in the weathered portion of the basement rock as well as fractures in the basement rocks. Field studies revealed that the study area is underlain by Pre Cambrian Basement Complex rocks and Cretaceous sediments. The basement Complex rocks are represented by Coarse Porphyritic Granite and Biotite Granites, the Cretaceous sediment is represented by Bima Formations and the Tertiary Volcanic Rock is represented by Basalt (Fig. 2). Studies indicate that the rocks in the area were subjected to a wide range of tectonic disturbances involving Faulting. The orientation of the fault is mainly trending NE-SW. The continental Bima formation is the basal part of the sedimentary successions in the study area. It lies unconformably on the Precambrian Basement Complex. It ranges in age from Upper Aptian to Lower Albian (Allix *et al.*, 1981). The sediments consist of poorly sorted, angular, highly arkosic pebbly sandstones, granulestones and pebble conglomerates (Zarborski *et al.*, 1997). However, over 50% of the area is underlain by coarse porphyritic granite intruded by small portion of fine grained biotite granites on the extreme south western part of the map (Fig. 2), Volcanic rocks are also common. The southern, northern and eastern portion of the study area is underlain by Bima Sandstone with intrusions of basalt to the southern part, which belongs to the Tertiary Volcanic Basalt that intruded in to the Benue Trough.

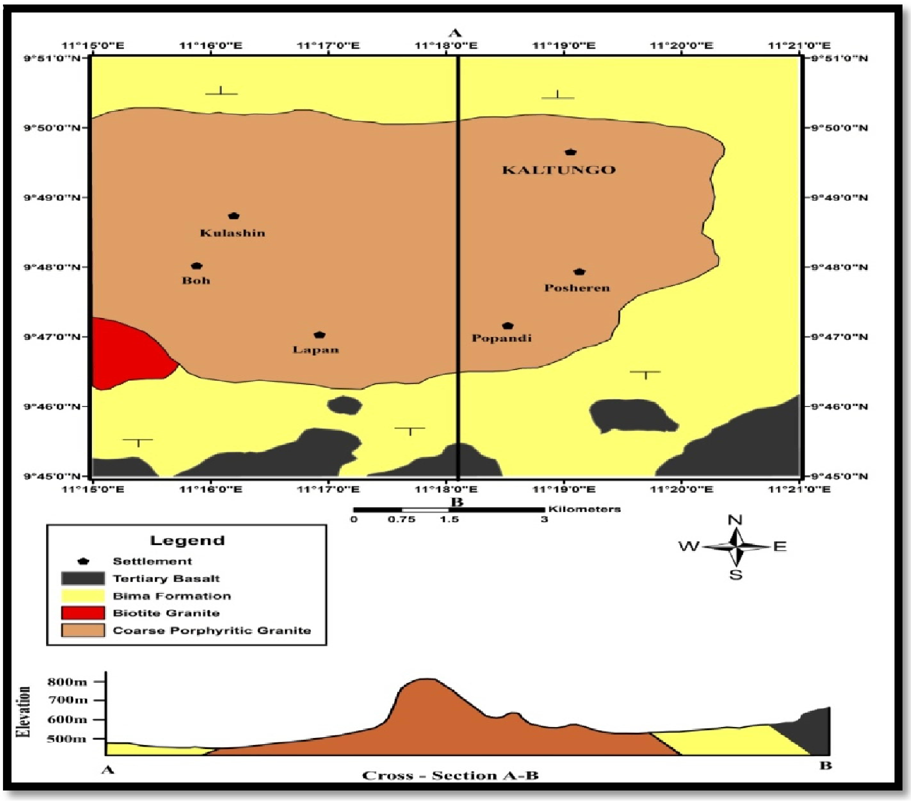

Figure 2: Geologic Map of the Study Area

4. Materials and Method

A total of 30 groundwater samples from hand dug wells and boreholes were collected (Fig. 1) in a container that was rinsed two to three times using the representative ground water samples according to Barcelona *et al*, (1985). Water samples were filtered with UNICEF standard filter to free them from suspended particles. Samples were kept in a field cooler throughout the period of the sampling exercise. The coordinates of each boreholes and hand-dug wells were determined using GPS (Model Garmine Trex HC Series), and later transferred to the base map of the study area. Immediately after sampling, field parameters such as: pH and Temperature were measured using Pen PH and Temperature meter (Model CT6021A), Turbidity was measured using Hand held turbidity meter (Model HAUX 2100Q), Conductivity was measured using Pen Conductivity meter (Model CT 3030), and Total Dissolved Solids (TDS) was measured using Pen TDS Meters (Model 21000). Carbonate and bicarbonate were determined in the field using titrimetric method by HACH Digital Titrator (Model 16900). All other parameters such as Potassium (K+), Calcium (Ca^{2}+), Copper (Cu^{2+}), Sodium (Na^{+}), Magnesium (Mg^{2+}), Iron (Fe^{2+}), Manganese (Mn-), Chloride (Cl^{-}), Nitrate (NO_3^{-}), Fluoride (F^{-}, Zinc (Zn^{2+}), Sulphate ($SO4^{2-}$), Lead (Pb^{2+})and Chromium (Cr^{6+}) were determined in the laboratory by spectrophotometry using HACH digital Spectrophotometer (Model DR2400, USA).

The WQI has been calculated to evaluate the suitability of groundwater quality for drinking purposes. Water quality index provides a single number (like a grade) that expresses overall water quality at a certain location and time based on several water quality parameters. The objective of an index is to turn complex water quality data into information that is understandable and useable by the public. The WHO (2004) standards for drinking purposes have been considered for the calculation of WQI. For the calculation of WQI 15 parameters such as: pH, TH, sodium (Na^{+}), potassium (K^{+}), magnesium (Mg^{2+}),calcium (Ca^{2+}), fluoride (F), iron (Fe^{2+}), phosphate (PO_4), electrical conductivity (EC) chloride (Cl^{-}), bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}), nitrate (NO_3^{-}) and total dissolved solids (TDS) have been used.

For computing WQI four steps were involved. In step 1, each of the 15 parameters has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes (Table 1). The maximum weight of 5 has been assigned to parameters like fluoride, TDS, and nitrate due to their major importance in water quality assessment (Srinivasamoorthy *et al.,* 2008). magnesium and phosphates are given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters like calcium, sodium, potassium, bicarbonates, iron and sulphate were assigned a weight between 1 and 4depending on their importance in the overall quality of water for drinking purposes.

Chemical Parameter (mg/L	Weight (wi)	Relative Weight (Wi)	WHO Standards
Na^{+}	2	0.0416667	200
K^{+}	2	0.0416667	12
Ca^{2+}	2	0.0416667	75
Mg^{2+}	1	0.0208333	50
Cl^{-}	3	0.0625	250
HCO_3^{-}	3	0.0625	120
SO_4^{2-}	4	0.0833333	250
NO_3^{-}	5	0.1041667	50
Fe^{2+}	4	0.0833333	0.3
pH	4	0.0833333	8.5
TH	3	0.0625	500
EC	4	0.0833333	500
TDS	5	0.1041667	500
F^{-}	5	0.1041667	1.5
PO_4	1	0.0208333	10
	$\sum wi$ =48	$\sum Wi$ =1	

Table 1: WHO Standards Weight (Wi) and Calculated Relative Weight (Wi) for Each Parameter

Step 2, the relative weight (Wi) is computed using a weighted arithmetic index method given belowTiwari and Manzoor(1988) in the following steps:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where, Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

Step 3, a quality rating scale (Qi) for each parameter is assigned by dividing its concentration ineach water sample by its respective standard according to the guidelines of WHO (2004) and then multiplied by 100:

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \quad (2)$$

Where Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and Si is the WHO drinking water standard for each chemical parameter in mg/l according to the guidelines of WHO (2004) (Table 3).

Step 4, the SIis first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SIi = Wi \times Qi \quad (3)$$

SIi is the subindex of ith parameter and Qi is the rating based on concentration of ith parameter. The overall water quality index (WQI) was calculated by adding together each sub index values of each Ground water samples as follows:

$$WQI = \sum SIi \quad (4)$$

Computed WQI values are classified into five classes (Table 2): excellent, good, poor, very poor and unfit water for drinking purposes (Ramakrishnaiah, *et al.,* 2009).This classification is presented in Table 2. Spatial distribution map of the water quality index was plotted using surfer 13.

WQI Values	Type of Water
< 50	Excellent Water
50.1-100	Good Quality Water
100.1-200	Poor Quality Water
200.1-300	Very Poor Quality Water
>300	Water Unfit for drinking

Table 2: Water Quality Classification WQI Values (Ramakrishnaiahet Al., 2009)

5. Results and Discussion

Groundwater quality results for physical, chemical and micro-biological analysis of the thirty (30) groundwater samples from the study area is presented in Table 3.The results indicate that Temperature of the waters ranges from 24.6°C - 29.70°C with a mean of 27.30°C. PH ranges from 4.99 - 10.1 with a mean of 7.23, indicating waters slightly acidic to mildly alkaline water (Olasehinde, *et al.,* 2015). Fluoride ranges from 0.88 – 1.94 mg/l with a mean of 1.65 mg/l. Nitrate ranges from 31.05 – 117.6 mg/l with a mean of 71.54 mg/l. Iron ranges from 0.5 – 1.7 mg/l with a mean of 0.92 mg/l. Majority of the water sources (90%) have elevated levels of Fluoride and Iron with corresponding elevated levels of nitrate. Total Dissolve Solids ranges from 64.99 - 211 with a mean of 120.75 indicating fresh water (Feter 1990).Total Hardness ranges from 68.19 – 113.85 with a mean 88.36, thus indicates fresh water (Rao *et al.,* 2010). Calcium (Ca^{2+})

ranges from 34.88 – 61.03 mg/l with a mean of 47.42 mg/l. Bicarbonate in the waters ranges from 201 - 412 mg/l with a mean of 265.31 mg/l. Chloride ranges from 20.67 – 89.12 mg/l with a mean of 44.51.

6	Sample Location	Water Source	T(°C)	PH	EC (µs/cm)	TDS (mg/l)	NTU	TH	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{2+} mg/l	K^{+} mg/l	SO_4^{2-} mg/l	Cl^{-} mg/l	NO_3 mg/l	HCO_3^{2-} mg/l	CO_3^{2-} mg/l	Fe^{2+} mg/l	Mn^{2-} mg/l	Cu^{2+} mg/l	PO_4^{2+} mg/l	CC Cfu	F mg/l
1	Baganje	HDW1	27.5	5.11	210	137	0.006	88.49	39.66	39.9	2	4.9	17.49	49.87	80.11	202	0	1.63	0.016	0.46	1.05	27	1.12
2	Jewel Hotel	BH2	29.3	7.49	318	211	0.005	68.19	47.62	30.26	0.53	6	18.77	29.77	67.81	261	0	0.94	0.013	0.09	0.92	4	1.71
3	Gsss Kaltungo	BH3	29	9	116	78	0.01	90.29	36.33	34.67	0.78	6.21	21.05	29.89	69.17	362	1	0.84	0.011	0.22	0.59	2	1.59
4	Filling station	BH4	28.6	8.1	193	127	0.018	94.73	51.62	40.87	1.12	7	21.67	41.87	64.28	301	1.1	0.77	0.008	0.27	0.67	3	1.69
5	Kofar fada	BH5	25.9	7.62	115.9	77	0.012	99.48	57	36.33	0.4	4.66	18.67	28.77	50.44	259	1	0.93	0.006	0.23	0.59	4	1.75
6	Health tech.	BH6	27.5	8.6	176	116	0.004	113.85	34.88	58.07	1.11	7.12	19.08	44.73	70.12	312	0	0.98	0.009	0.27	1	2	1.64
7	Ledeben. B	HDW7	24.9	4.99	177.8	120	0.014	87.93	41	31.08	4.1	5.4	18.98	53.12	110.52	297	0	1.08	0.005	0.18	1.2	3	1.94
8	Gen. Hospital	BH8	28.3	8.2	137	90	0.008	113.85	49.62	59.83	0.37	6.9	21.81	31.62	62.41	300	0	0.95	0.011	0.42	0.73	3	1.44
9	Bakin Kasuwa	BH9	29.7	5.18	299.5	201.5	0.012	92.81	60.11	51.81	0.96	5.8	23.42	33.49	53.88	210	1	1.04	0.009	0.38	0.58	4	1.86
10	Opp.Graveyard	HDW10	27.4	5.04	131.6	87	5.16	84.33	53.87	31	5.12	6.31	24.67	89.12	117.6	204	2.1	0.7	0.007	0.4	1.36	2	1.55
11	Okra	HDW11	28.2	7.95	155.4	103	0.011	97.42	40.66	40.11	2.12	7.4	21	43.81	86.71	279	0	0.97	0.007	0.14	1.11	3	1.83
12	Termana	H12	26.8	5	212	141.5	0.011	84.92	48.11	37.62	1.86	6.1	19.42	46.7	73.41	215	0	1.01	0.011	0.31	1.1	3	1.67
13	Posheren	BH13	26.3	5.2	135.6	89.4	0.005	74.96	52.81	35.21	2.19	7.7	20.11	50	98.62	290	0	0.97	0.014	0.35	1.22	2	1.6
14	Popandi	BH14	27.8	10.11	153	101	0.007	107.14	51.01	49.88	0.33	4.9	20.93	20.67	44.52	412	0	1	0.004	0.3	0.89	2	1.82
15	Popandi	BH15	28.2	7.8	164.7	109	0.012	79.33	39.63	37.82	0.85	3.8	20	32	58.66	264	1	0.85	0.012	0.33	0.78	2	1.94
16	Kaleh	BH16	26.4	7.75	286.5	192	0.005	89.04	61.03	31.87	2.9	4.9	19.68	40.18	72.89	268	0	1.02	0.008	0.08	1.09	3	1.6
17	Popandi	BH17	25.3	7.93	231	153	0.013	94.1	43.18	39.9	1.03	6.8	21.52	31.62	63.42	272	1.1	0.81	0.008	0.21	0.66	4	1.71
18	Lapan	HDW18	26.5	8.21	139.84	93.6	0.007	104.01	58.12	49.69	1.86	6.5	19.4	47.66	77.12	321	0	0.5	0.006	0.16	1.03	2	1.58
19	Lapan	BH19	29.5	5.41	252.87	169	0.011	95.22	57.81	36.87	2.11	6.19	19	48.11	81.62	212	0	0.74	0.009	0.12	1.16	2	1.72
20	Lapan	BH20	27.1	5.9	180.92	121	0.004	75.92	37.67	40.67	3.1	5.33	18.77	57.82	91.45	219	0	1.09	0.007	0.1	1.14	3	1.69
21	Lapan	BH21	24.6	8	171.5	116.65	2.1	90	49.66	47	3.97	6.7	22.67	61	88.07	306	2.1	0.81	0.005	0.16	0.91	9	1.8
22	Karel	BH22	28.4	7.96	161.7	109.1	1.95	77.38	40.05	38.15	0.98	6.4	19.86	49.88	60.85	262	1.95	0.93	0.002	0.11	0.76	7	1.64
23	Karel	BH23	27.5	6.11	201.5	133	0.055	70.08	41.93	30.09	1	7	21.12	23.48	34.63	217.5	0.06	0.72	0.005	0.26	0.59	2	1.71
24	Karel	BH24	28.1	7.93	212.99	140	1.505	71.67	39.98	31.45	3.05	6.1	22.08	48.7	53.85	221	1.51	0.59	0.006	0.36	1	8	1.65
25	Karel	HDW25	27.6	7.87	207	133.6	1.65	72.11	39.66	34.69	1.4	6.85	19.77	44.56	59.73	225	1.65	0.66	0.003	0.21	0.82	6	1.6
26	Layang	HDW26	26.4	7.88	99.4	64.99	2.05	81	49.91	48.91	1.88	7.5	22	50.89	100	201	2.05	0.84	0.004	0.25	1	8	1.59
27	Layang	HDW27	25.8	8.1	170.5	115.93	1.53	93.15	48.97	48.79	1.27	6.9	21.67	56.85	65.67	267	1.53	0.8	0.003	0.16	0.47	6	1.69
28	Layang	BH328	26.9	8.31	167.05	115.23	1.592	97.77	53.82	53.82	2.05	6.6	19.93	58.62	80.67	297.8	1.59	0.9	0.003	0.2	0.62	9	1.77
29	Layang	BH29	28.3	7.91	101.54	69.72	2	76.28	53.73	52.73	1.56	7.8	23.05	60.07	76.81	293	2	0.75	0.005	0.19	1.03	10	1.73
30	Kulishim	HDW30	27.5	6.42	158.9	107.22	0.087	85.27	43.11	43.11	0.63	6.4	21	30.41	31.05	209	0.09	1.7	0.004	0.09	0.7	2	0.8

Table 3

The groundwater quality suitability for drinking purposes was evaluated using WQI.It is also used to access the influence of natural and anthropogenic activities on groundwater quality. The value of calculated WQI ranges from 46.68 to 176.24 with an average value of 84.35. From the computed values,Twenty six 26 sampling points have good water quality rating of grade B, whereas three 3 water sources have poor water quality rating of grade C and excellent water quality rating of grade A is found only in one 1 location (Table 4).The map of the study area showing Spatial distribution of Water Quality Index (Fig 4) revealed that Excellent quality water are found at Kulushin area, mostly toward the North Western part of the study area, whereas good quality water covers most portion of the area and poor water quality are concentrated around the north eastern portion of study area around Obasanjo Quarters. It is observed that eighty six percent (86%) were of good quality while Ten percent (10%) were of poor quality water, and only four percent (4%) were found to be of excellent quality. However, Groundwater of the area is fit for drinking purposes. Therefore, the water quality index of the study area is influence by bicarbonate, nitrate, iron and fluoride.

S/N0	Sample Location	Water Source	WQI	Rating
1	Baganje	HDW1	176.24	Poor Water
2	Jewel Hotel	BH2	91.16	Good Water
3	GSSS Katungo	BH3	85.23	Good Water
4	Filling Station	BH4	84.3	Good Water
5	Kofar Sarki	BH5	80.63	Good Water
6	Health Tech. Kaltungo	BH6	91.24	Good Water
7	Ladeben B	HDW7	102.6	Poor Water
8	Gen. Hospital Kaltungo	BH8	86.06	Good Water
9	Kaltungo Market	BH9	112.2	Poor Water
10	Obasanjo Quarters	HDW10	86.83	Good Water
11	Okra	HDW11	94.53	Good Water
12	Termana	BH12	88.22	Good Water
13	Posheren	BH13	93.94	Good Water
14	Popandi I	BH14	91.63	Good Water
15	Popandi II	BH15	73.83	Good Water
16	Kaleh	BH16	92.63	Good Water
17	Popandi III	BH17	84.14	Good Water
18	Lapanng I	HDW18	78.95	Good Water
19	Lapang II	BH19	84.47	Good Water
20	Lapang III	BH20	92.94	Good Water
21	Lapang IV	BH21	93.13	Good Water
22	Karel I	BH22	85.06	Good Water
23	Karel II	BH23	72.53	Good Water
24	Karel III	BH24	73.07	Good Water
25	Karel IV	HDW25	76.04	Good Water
26	Layang I	HDW26	86.85	Good Water
27	Layang II	HDW27	56.2	Good Water
28	Layang III	BH28	74.96	Good Water
29	Layang IV	HDW29	85.93	Good Water
30	Kulishhin	HDW30	46.68	Excellent Water

Table 4: Water Quality Index Rating of Water from the Study Area

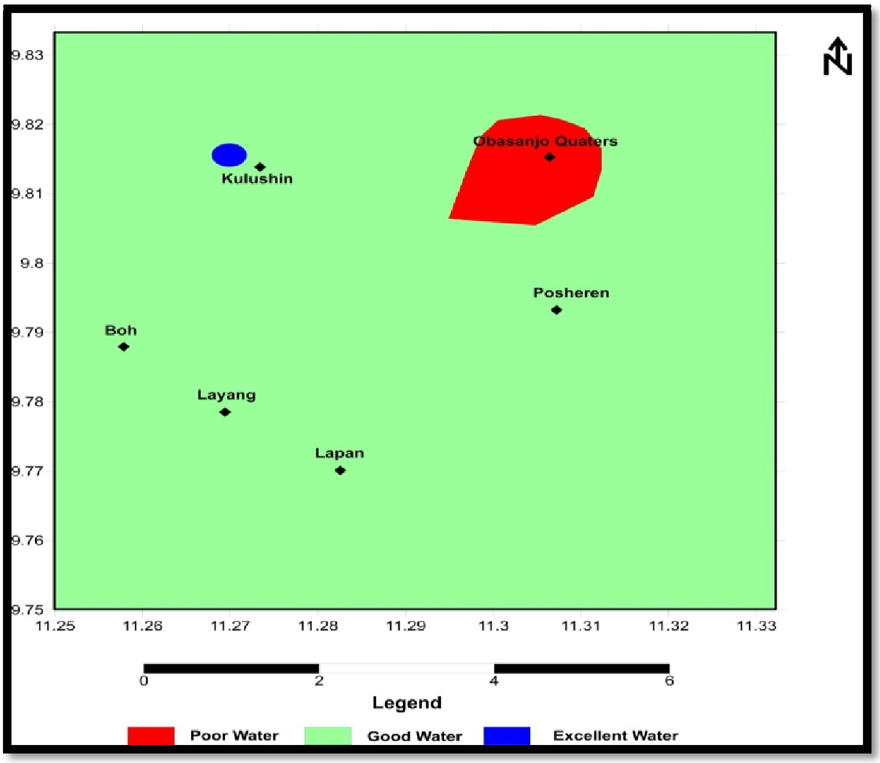

Figure 4: Spatial Distribution of Water Quality Index in the Study Area

6. Conclusion

The WQI has proven to be very essential in assessing the suitability of groundwater for drinking purposes. Thus, enables to conduct water quality management as the water quality indices are among the most effective ways to communicate the information on water quality trends to the general public and the policy makers. The results of water quality index revealed values ranging from 46.68 to176.24indicating excellent to poor quality water. Eighty six percent (86%) of the samples analyzed were good quality water while Ten percent (10%) are poor quality water, and four percent (4%) are excellent quality water. This suggest that groundwater in the area is fit for drinking purpose. But, the groundwater quality needs further investigations to observe if there exists threat in its quality as far as irrigation and other activities is undertaking.

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