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ORIGINAL ARTICLE

Assessment of underground water quality in Okobo local government area of Akwa Ibom State, Nigeria

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Abstract
The ground water quality of Okobo Local Government Area was investigated. Sixteen boreholes (BHs) water samples were collected from four zones (Okopedi, Ekeya, Ukwong and Okiuso) in Okobo. Standard analytical procedures were used to analyze the physicochemical, bacteriological and heavy metal parameters in the water samples and the results compared to Nigerian standard for drinking water quality (NSDWQ). some physicochemical parameters investigated were within the acceptable limits set by NSDWQ except pH (5.99 ± 0.37), DO (0.31 ± 0.06) mg/L, BOD5 (6.26 ± 0.4) mg/L and Nitrate (62.53 ± 5.96) mg/L. Bacteriological parameter like fecal coliform (128.69 ± 31.40) MPN/100 mL and total coliform (287.63 ± 40.31) MPN/100 mL were also above the limits set by NSDWQ implying organic pollution due to fecal contamination. Heavy metals were also within the acceptable limit except Lead (0.1 ± 0.1) mg/L, Chromium (0.4 ± 0.2) mg/L, and Manganese (0.16 ± 0.2) mg/L which were slightly above acceptable limits in all the zones. Water quality index calculation results grouped the BHs into; BH7 (26–50) very good; BH1, BH3, BH4, BH8, BH11, BH14, and BH16 (51–75) poor; BH2, BH5, BH6, BH9, BH12, BH13 and BH15 (76–100) very poor and BH 10(> 100) unsuitable for drinking. Pearson coefficient correlation, principal component analysis (PCA) and cluster analysis (CA) were used to establish interrelationship among the parameters, common sources of the pollutants and grouping of the BHs affected by these pollutants. PCA extracted six principal components (PCs) from the investigated parameters in the BHs, with sources of pollution either natural mineral or anthropogenic source. CA grouped all the sixteen BHs investigated into three clusters with various levels of contamination from pollutant sources. Consequently, the polluted BHs require treatment using high test hypochlorite (HTH) as the pollutant common to all the BHs is mostly bacterial pollutant; moreover, BHs should be sited 15 m away from septic tank or latrine to reduce contamination from coliform.

Keywords Okobo · Borehole water · Water quality index · Multivariate analysis

Introduction

Water which is an essential compound in which life depends is derived mainly from sources like surface water; rain water and ground water. (Abdullahi et al. 2020; Ighalo and Adeniyi 2020).

When required for domestic consumption, it should posses a high degree of purity. Some natural sources of water like ground water is expected to be less contaminated, however its polarity and hydrogen bond makes water able to dissolves, absorbs, adsorbs or suspends impurities, (Ajala et al. 2020) therefore water from natural sources could get contaminants from natural and anthropogenic sources from its surrounding.

Recently, heavy metals contamination in ground water has been considered a serious environmental issue (Ighalo

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et al. 2021). These metals are found in groundwater in soluble form (Essumang et al. 2011).Their presence in water could either come from eroded mineral within sediments, draining of mineral deposits and volcanic eruption residues or from human activities like solid or liquid discharged from industrial or domestic processes. (Essumang et al. 2011).

Bacteriological contaminants in borehole water could be coliform, protozoan and viruses. These microorganisms could be vectors for water borne diseases such as dysentery, typhoid fever, cholera and other illness when such water is used domestically (Udoh et al. 2021). Human and animal wastes are major sources of bacterial contaminants in ground water. Sources of bacterial contamination are run-off from land use for rearing of animals, site used for manure preparation and seepage from poorly constructed sewage disposal facility. Pathogens from here can diffuse into the borehole water that do not have water tight casings.

Recently, multivariate statistical analyses like principal component analysis(PCA), cluster analysis(CA) and water quality index analysis(WQI) has been successfully used in water quality assessment studies (David et al. 2020), using these methods, data generated can be simplified and organized to yield useful information for decision making. (Amadi 2011; Kaiser 1985; Mohammed et al. 2016).

Borehole water is the major source of drinking water in the study area with limited information on the ground water quality. This research is tailored to assess the ground water quality in the area under consideration, evaluates the portability of the boreholes in terms of WQI, inform borehole water owners on the health implications associated with consumption of contaminated borehole water, recommends factors to be considered before sitting of BH and BH water treatment procedures.

Materials and methods

Study area

The study area is Okobo Local Government Area which is located in latitude 4° 4′ 59.98″N and longitude 7° 50′ 59.99″ E. It is bounded on the west by Oron, North by Urue Ofong Oruko and Esit Eket, south by Uruan and East by Nsit Atai. Politically, Okobo is divided into seven districts namely: Eta, Odu, Egbuhu, Okiuso, Atabong, Ibighi, Ukwong with 65 villages. Okopedi is the headquarter. The major occupations of Okobo people are subsistence farming, fishing and petty trading. For spread of sampling points, the seven districts were divided into four zones in which four BHs were randomly selected from four different villages in each zone. Table 1 and Fig. 1 shows the coordinates the sampling points and map of the study area.

Sample collection and preservation

Samples were obtained from sixteen (16) BHs. The sample containers were pre-cleaned with acetone, rinsed with distilled water and kept in a dust free enclosure (American society for testing and materials (ASTM) (2016). Three replicate samples were obtained at each BH. Physicochemical parameter and metals samples were preserved in a two liter polyethene bottle. Sample for DO, BOD5 and bacteriological analysis were kept in glass bottle. Sample was allowed to flow from the tap for ten minutes before collecting for physicochemical parameters. For metals analysis, the sample collected was dosed with 1 mL of 2 M nitric acid. To obtained sample for DO, BOD_5 and bacteriological analysis,

Table 1 Sampling location in okobo logal government area

Zone	District	Village	Borehole	Latitude	Longitude
OKOPEDI	ETA	AMMONG	BH1	4°51 34″N	8°7′59″E
		ODOBO	BH2	4°49 32″N	8°6′32″E
		NUNG ATAI	BH3	4°51 0″N	8°7′60″E
		OKOPEDI	BH4	4°51 0.4″N	8°7′30.19″E
EKEYA	ODU	ANUA EKEYA	BH5	4°51′ 4.4″N	8°7′15.75″E
		EBIGHI ODU	BH6	4°51′53″N	8°51′53.1″E
		UBE	BH7	4°50′9.2″N	8°10′47.55’’E
		AKIBA OBO	BH8	4°52′56.5″N	8°8′36.6″E
UKWONG	UKWONG	UTINE EYEKUN	BH9	4°49′24″N	8°7′1.30″E
	ATABONG	OTI ORON	BH10	4°49′25″N	8°10′16″E
		UKOT IQUO	BH11	4°51′17″N	8°11′29″E
		IKOT ODUNG	BH12	4°50′59″N	8°11′32″E
OKIUSO	EBUGHU	NSIE	BH13	4°47′56″N	8°5′32.3″E
		UDUNG AFIAN	BH14	4°42′7″N	8°4′41.1″E
		TAK OKIUSO	BH15	4°47′24″N	8°8′16.16″E
		URUE ITA	BH16	4°44′25″N	8°3′4.46″E

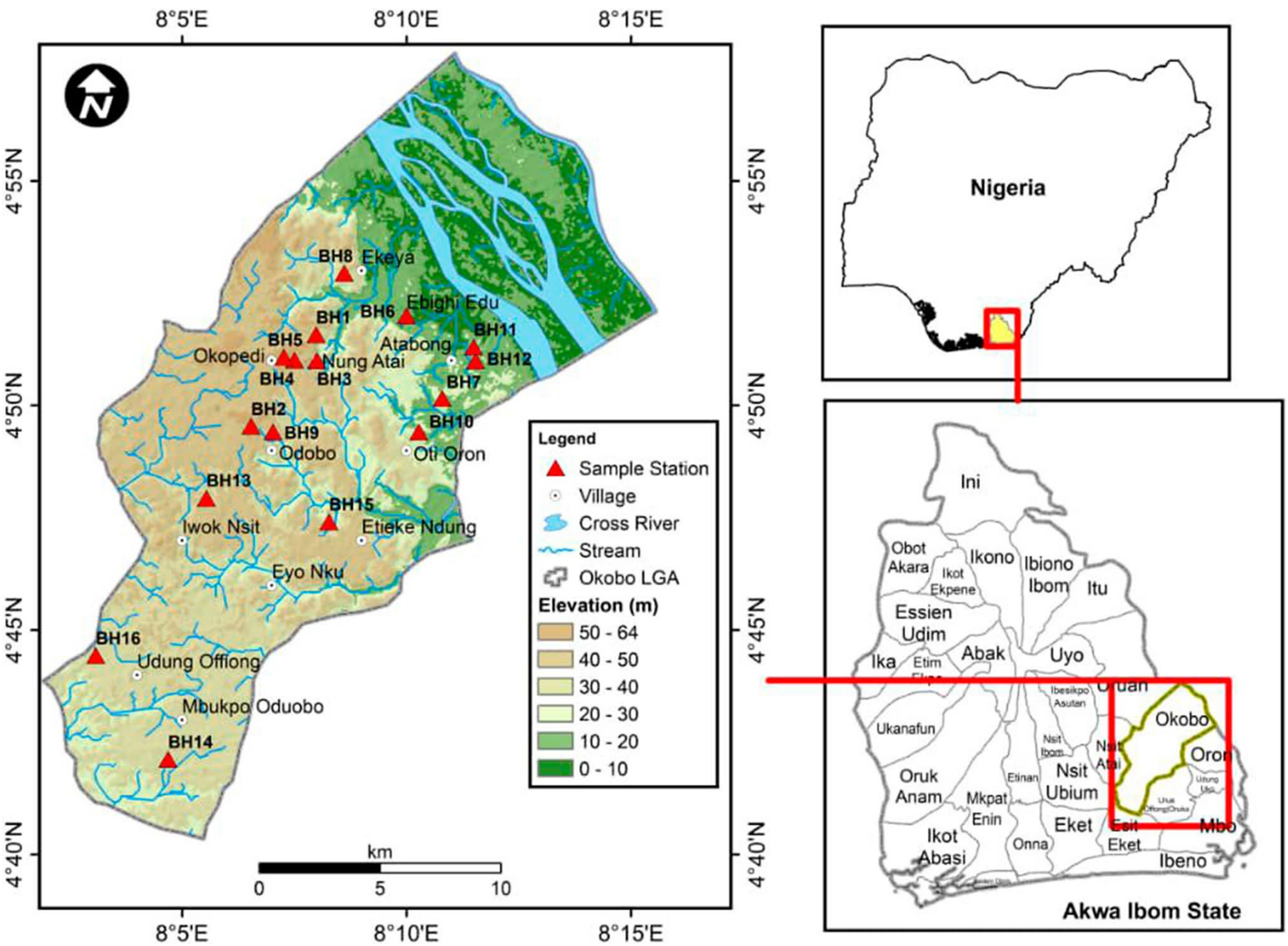

Fig. 1 Map of the study area

pre-heating of the water tap with hot flame was required to eliminate possible bacteria present in the mouth of the tap and then the water was allowed to flow for five minutes before samples were obtained. All the samples were properly labeled, stored in an iced insulated container and transported to the laboratory for analysis. (USEPA 2002).

Physicochemical parameter analysis

Physical parameters like Temperature, pH, conductivity, salinity, turbidity and dissolved oxygen were all done in-situ. Temperature was measured using mercury in glass thermometer, pH using HACH SESSION$^+$ digital pH meter, turbidity using HACH 20100N turbidity meter, conductivity, salinity, dissolved oxygen and total dissolved solid were measured using HACH 20100N conductivity meter. Colour was measured using LOVIBORD comparator and BOD_5 was measured using HACH 20100N conductivity meter after five days. Heavy metals and bacteriological parameters were evaluated following standard procedures as describe in (Marcovecchio et al. 2007; ASTM 2016).

Statistical data analysis

Multivariate and descriptive statistical analysis was applied on water parameter data. SPSS IBM version 23 was used for Pearson coefficient correlation, PCA and CA. Pearson correlation was used to determine interrelationship exiting in the physical parameters, PCA was used to determine major pollution sources while CA was used to determine BHs with similar pollutants (Ugochukwu et al. 2021; Wu et al. 2005).

Water quality index

This index was used to determine portability of water from the selected water parameters. The WQI was calculated using standards recommended by NSDWQ. Weighted Arithmetic index method (Asibor and Ofuya 2019) was applied for the determination of WQI. Water quality rating (q_a) was calculated using the expression in Eq. (1)

$$q_a = \frac{100\left[V_a - V_o\right]}{\left[S_a - V_o\right]} \quad (1)$$

where (q_a) represents the water quality rating of ath parameter, V_a represents the measured value of the ath parameter at a given water sampling station, S_a represents the standard allowed value of the nth parameter and V_o represents an ideal value of nth parameter in pure water (0 for all other parameters except the parameters pH and Dissolve oxygen 7.0 and 14.6 mg/L respectively; (Asibor and Ofuya 2019). The unit weight (w_a) was calculated by a value inversely proportional to the recommended standard value S_a corresponding to ath parameter Eq. (2).

$$W_a = \frac{K}{S_a} \quad (2)$$

K is the proportionality constant given in Eq. (3)

$$K = \frac{1}{S_a} \quad (3)$$

WQI is thus evaluated in Eq. (4)

$$\mathrm{WQI} = \frac{\sum_1^n w_a q_a \sum_1^n}{\sum_1^a w_a} \quad (4)$$

Water quality index classification is shown in Table 2 (Chatterji and Raziuddin 2002).

Results and discussion

Physicochemical parameters

Physicochemical, bacteriological and heavy metals concentration of BHs in the study area were investigated and results obtained were compared with NSDWQ Table 3a and b. A descriptive statistical analysis of the measured parameters is shown in Table 4.

The temperature range in the study area was from 27 °C to 29 °C with BH1 and BH10 having the lowest temperature while BH3, BH8, BH14 and BH15 had the highest temperature. The mean temperature was 28.08 ± 0.6 °C. This mean temperature for ground water was also reported by Adetinuke et al. (2016) in the assessment of ground water in BH in Lagos. The temperatures were in acceptable range as specified by NSDWQ.

pH defines the hydroxonium ion concentration in solution which expresses the degree of acidity and alkalinity. In the study area, the pH ranged from 5.20 to 6.70 and the mean pH was 5.99 ± 0.37. BH1 had the lowest pH of 5.2 while BH14 had the highest pH of 6.7. Except BH10 which had pH of 6.6, others had pH lower than the acceptable values specified by NSDWQ. The limit set by NSDWQ is ranged (6.5–8.5) (Standard organization of Nigeria, SON, 2015). This implies that the ground water in Okobo is slightly acidic. This trend was also reported by (Paschke et al. 2016). Similar observation was also reported by Enyoh et al. (2018). The possible reasons for the acidic level maybe as a result of breaking down of organic waste from human, animal waste and organic vegetation, or leaching of minerals into the BH water from mineral rich-rock (Enyoh et al. 2018).

Electrical conductivity (EC) in water is the ability of the water to conduct electricity due to the presence of dissolved mineral salts, total suspended solid, salinity and leaching of minerals into the water by mineral rich rocks. EC in the study area ranged from 50.0 µs/cm to 70.30 µs/cm. BH2 had the lowest EC value of 50.0 µs/cm while BH6 had the highest value of 70.30 µs/cm. The mean EC value was 61.76 ± 7.1 µs/cm. The measured EC values were all within the acceptable limit of 1000 µs/cm.

The value of colour obtained from the BHs water was 3 Hazen units. This value was within the NSDWQ acceptable unit of 15 Hezan units.

Turbidity is the level of cloudiness of water sample due to the presence of suspended particles. High turbidity value indicates the abundance of pathogens. Turbidity values were observed to be from 0.35 to 0.72 NTU. The mean value of turbidity in the study area was 0.505 ± 0.11 NTU. The mean turbidity value was in the specified range of 5 NTU.

Salinity is the amount of the salt content in water. The salts are mostly soluble chlorides and sulphates. High level of salinity in ground water is mostly due to seawater intrusion into the ground water. In the study area, mean salinity value was 42.03 ± 5.08 mg/L. BH4 had the highest salinity value of 48.4 mg/L while BH2 with value 33.2 mg/L was recorded the lowest. However, these values were within than the acceptable limits of 250 mg/L. From these results, it can be concluded that there is no seawater intrusion in the area under study.

Total hardness (TH), is the amount of soluble magnesium or calcium carbonates, bicarbonates or both present in water. The total hardness is the reflection of the amount of magnesium and calcium carbonates or bicarbonates or both in the water. Total hardness in all the BHs ranged from 26.3 mg/L to 50.20 mg/L. However, mean TH of the study area was 36.34 ± 9.03 mg/L. This value is within the acceptable limits

Table 2 Water quality index and water quality

WQI	Interpretation
0–25	Excellent
25–50	Good
51–75	Poor
76–100	Very poor
> 100	Not portable

Table 3 Physicochemical parameter of borehole water in Okobo

Parameter	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	NSDWQ	Remark
(a)										
Temperature (°C)	27	28	29	28	28	28	28	29	Ambient	Within
Colour (HAZAN)	3.00	3.00	3.00	3.00	3	3	3	3	15.000	Within
pH	5.20	5.60	5.90	5.70	6.1	5.9	5.7	5.8	6.5–8.5	Above
EC (µs/cm)	52.00	50.00	51.00	53.00	63.2	70.3	65.4	62.3	1000.000	Within
TDS (mg/L)	34.80	33.50	34.20	35.50	42.3	47.1	43.8	41.7	500.000	Within
Salinity (mg/L)	34.90	33.40	34.10	35.60	43.1	48.4	44.8	42.5	250.000	Within
Turbidity (FTU)	0.45	0.39	0.42	0.45	0.672	0.72	0.54	0.449	5.000	Within
DO (mg/L)	0.44	0.36	0.28	0.20	0.37	0.34	0.25	0.29	5.000	Below
TH (mg/L)	26.30	27.10	28.20	27.60	29.7	28.7	27.1	28.4	150.000	Within
Nitrate (mg/L)	55.40	56.20	57.30	61.10	60.2	62.1	66.1	64.2	50.000	Above
Zinc	0.08	0.02	0.02	0.05	0.01	0.042	0.06	0.018	3.000	Within
Iron (mg/L)	0.22	0.30	0.28	0.24	0.217	0.25	0.176	0.256	0.300	Within
Magnesium (mg/L)	5.10	5.20	5.40	5.30	6.2	5.5	5.3	5.4	0.200	Above
Lead (mg/L)	0.0160	0.0120	0.0110	0.0130	0.019	0.002	0.003	0.015	0.010	Above
Cadmium (mg/L)	0.0010	0.0020	0.0020	0.0010	0.002	0.003	0.001	0.001	0.003	Within
Calcium (mg/L)	8.8600	9.9400	12.1000	11.0200	16.1	14.1	13.7	14	Not specify	
Chromium (mg/L)	0.04	0.03	0.01	0.06	0.09	0.03	0.04	0.06	0.030	Above
Manganese (mg/L)	0.18	0.16	0.16	0.18	0.21	0.152	0.176	0.123	0.200	Above
BOD5 (mg/L)	5.80	5.85	5.92	6.17	6.12	6.25	6.52	6.39	1–5	Above
Alkalinity	61.10	68.54	83.43	75.98	111	97.2	94.44	96.5	100–200	
Fecal coliform	80.00	96.00	105.00	120.00	115	140	175	160	10.000	Above
Total coliform	230.00	240.00	251.00	283.00	273	293	323	313	10.000	Above
Taste	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil		Within
Arsenic	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	Within

Parameter	BH9	BH10	BH11	BH12	BH13	BH14	BH15	BH16	NSDWQ	Remark
(b)										
Temperature (°C)	28	27	28	27	28	29	29	28	Ambient	Within
Colour (HAZAN)	3	3	3	3	3	3	3.0	3	15.000	Within
pH	6.2	6.6	6.1	6.3	6.7	5.9	6.200	6	6.5–8.5	Above
EC (µs/cm)	65	61	70	69	70	58	68.0	60	1000.000	Within
TDS (mg/L)	43.6	40.9	46.9	46.2	46.9	38.9	45.6	40.2	500.000	Within
Salinity (mg/L)	43.5	41.5	48.2	47.5	48.2	39.3	46.700	40.8	250.000	Within
Turbidity (FTU)	0.44	0.35	0.5	0.52	0.631	0.667	0.452	0.431	5.000	Within
DO (mg/L)	0.35	0.29	0.32	0.25	0.34	0.31	0.330	0.300	5.000	Below
TH (mg/L)	44.6	47.1	44.5	44.8	50.2	39.2	45.6	42.4	150.000	Within
Nitrate (mg/L)	63.5	72.2	67.2	75.9	54.7	61.5	57.6	65.4	50.000	Above
Zinc	0.07	0.062	0.063	0.029	0.06	0.07	0.080	0.09	3.000	Within
Iron (mg/L)	0.228	0.312	0.388	0.258	0.227	0.374	0.311	0.308	0.300	Within
Magnesium (mg/L)	5.51	5.82	5.5	5.54	5.82	5.5	5.720	5.62	0.200	Above
Lead (mg/L)	0.018	0.017	0.015	0.012	0.018	0.013	0.017	0.019	0.010	Above
Cadmium (mg/L)	0.002	0.003	0.001	0.002	0.002	0.001	0.002	0.001	0.003	Within
Calcium (mg/L)	12.11	12.8	12.1	12.2	14.8	14	14.5	14.2	Not specify	
Chromium (mg/L)	0.03	0.07	0.03	0.06	0.018	0.013	0.017	0.019	0.030	Above
Manganese (mg/L)	0.167	0.149	0.153	0.12	0.177	0.129	0.155	0.133	0.200	Above
BOD5 (mg/L)	6.34	6.93	6.58	7.17	5.72	6.16	5.890	6.42	1–5	Above
Alkalinity	83.47	88.23	83.4	84.09	102.02	96.5	99.650	97.88	100–200	Within
Fecal coliform	150	160	135	180	76	130	109	218	10.000	Above
Total coliform	303	340	330	350	220	284	253	313	10.000	Above

Table 3 (continued)

Parameter	BH9	BH10	BH11	BH12	BH13	BH14	BH15	BH16	NSDWQ	Remark
Taste	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil		Within
Arsenic	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	Within

Table 4 Descriptive statistical analysis of parameter of borehole water of Okobo

Parameter	Borehole	Min	Max	Mean	STD
Temperature	16	27	29	28.06	0.68
pH	16	5.20	6.70	5.99	0.37
Turbidity	16	0.35	0.72	0.51	0.11
Salinity	16	33.40	48.40	42.03	5.28
Conductivity	16	50	70.30	61.76	7.17
Colour	16	3	3	3	0
Taste	16	–	–	–	–
TDS	16	35.50	47.10	41.90	4.96
DO	16	0.2	0.44	0.31	0.06
DOD5	16	61.10	111.0	88.92	13.06
Alkalinity	16	26.30	50.20	36.34	9.04
Hardness	16	26.30	50.20	36.34	9.04
Chlorine	16	0	0	0	0
Nitrate	16	54.70	75.90	62.53	5.96
Zinc	16	0.01	0.24	0.06	0.06
Iron	16	0.18	0.39	0.27	00.06
Manganese	16	0.12	0.21	0.16	0.02
Magnesium	16	5.10	6.20	5.53	0.27
Lead	16	0.00	0.02	0.01	0.01
Calcium	16	8.86	16.10	12.44	2.05
Chromiun	16	0.10	0.09	0.04	0.02
Cadmium	16	0	0	0	0
Arsenic	16	0	0	0	0
Total coliform	16	220	350	287	40.37
Fecal coliform	16	76	180	126	31.40

of < 150 mg/L as set by NSDWQ. World Health Organization (WHO2004), classifies water with calcium carbonate level (0–60 mg/L) as soft water, therefore considering that observed values of TH, it can be concluded that the water in the study area is soft.

Total dissolved solid (TDS) is the amount of total suspended solids and dissolved minerals presence in water. In the area under review, the measured TDS values were from 33.50 mg/L to 47.10 mg/L. The acceptable limit set by the regulatory body is 500 mg/L. Hence TDS values in the study area are within acceptable limits.

Alkalinity is the degree of buffering of acidity in water. Alkalinity in water is due to the presence of carbonate ions CO_3^{2-}, bicarbonates HCO_3^-, hydroxides OH^-(The mean value from the study area was 88.91 ± 13.06 mg/L. Alkalinity values from the study area was within the acceptable limit of 150 mg/L set NSDWQ.

Dissolved oxygen (DO), shows concentration of oxygen gas that dissolved in water. In the area under consideration, the measured DO ranged from 0.20 mg/L to 0.44 mg/L. BH4 had the lowest value while BH1 has the highest. Mean DO value of 0.313 ± 0.056 mg/L of the study area was below than the specified limit of 5 mg/L. Low value of DO may be associated with high level of organic waste decomposition, high bacteria activity and bacterial contamination (Elemile et al. 2019).

Biological oxygen demand (BOD_5) is the amount of oxygen needed for bacterial metabolic activities. It is an important water hygiene indicator. High value implies that the water is seriously contaminated with sewage, organic matter, nitrate and phosphate. Water samples in the study showed considerable high values of BOD5. The values ranged from 5.720 mg/L to 7.170 mg/L. BH1 had the lowest BOD5 value while BH12 had the highest value. Generally, BOD5 values were higher than the acceptable value of 1 to 5 mg/L.

Bacteriological parameter

Bacterial analysis of the BHs water in the study area indicates the presence of fecal coliform. Fecal coliform is an indicator of bacterial contamination from excreta of human and other warm blooded animal. (Enetimi Idah et al. 2020). High level of fecal coliform in water can affect public health and community economy. Fecal coliform cause diseases like cholera, dysentery and diarrhea. The mean value of fecal and total coliform was 126 ± 31.40 MPN/100 mL and 287 ± 40.37 MPN/100 mL respectively. see Table 2. These values were above the acceptable limits set by NSDWQ which is 10MPN/100 mL. The possible source of these high coliform is from excreta of human or warm blooded animal diffusing into the BH form poorly constructed septic tank.

Heavy metals

The heavy metals like Zinc, Iron, Lead, Cadmium, Chromium and Manganese in the BH water were analyzed in Table 2. Some heavy metals have the potential of being carcinogenic, causing kidney failure, neurological disorder and metabolic dysfunction. According to NSDWQ, Zinc has no known health impact in drinking water. Measured mean value for Zinc in the study area was 0.06 ± 0.06 mg/L. The permissible limit for zinc in portable water is 3 mg/L. High concentration of Iron affect the colour and taste of water. In the study area, the mean value for Iron was 0.27 ± 0.06 mg/L. The permissible limit for Iron is 0.3 mg/L. Lead is implicated in serious health issues like cancer, interference with vitamin D metabolism, toxic to central, peripheral nervous system and obstruction of proper infant mental development (Saheed and Abimbola 2021), measured mean value for Lead was 0.0137 ± 0.005 mg/L, BH6 and BH7 had measured values 0.002 mg/L and 0.003 mg/L respectively, others had values above permissible limits of 0.01 mg/L. Cadmium is a heavy metal known for its toxicity to kidney (Abdullahi et al. 2020)., mean measured value of Cadmium in the BHs was 0.002 ± 0.001 mg/L, this value was lower than the acceptable limit of 0.003 mg/L set by NSDWQ. Chromium is known to be carcinogenic especially Cr^{+6}, mean measured range of chromium in the study area was 0.010 mg/L to 0.090 mg/L, BH3, BH13, BH14 and BH15 had Chromium values within acceptable limit, others had values above acceptable limits of 0.02 mg/L.

Water quality index

Calculated results of WQI for BH water are presented in Table 5. BH7 had WQI in the range of (26–50), which is regarded as very good. BH1, BH3, BH4, BH8, BH11, BH14 and BH16 had range (51 to 75), water quality in this range is regarded as poor. BH2, BH5, BH6, BH9, BH12, BH13 and BH15 had range (76 to 100), water quality in this range is regarded as very poor. BH10 had WQI in range > 100; hence is not portable.

Correlation analysis of water parameters

Correlation coefficient was used to determine the interrelation and common source of the investigated parameters Table 6. Significant correlation coefficient (r) were taken at $a = 0.05$* and $a = 0.01$**. Strong correlation ($r = 0.999$) were seen in salinity and EC, salinity and TDS, BOD5 and nitrates, BOD5 including total coliform at ($a = 0.05$); ($r = 0.989$) in TDS and conductivity at ($a = 0.05$); ($r = 0.837$) in pH and total hardness at ($a = 0.05$); ($r = 0.862$) in alkalinity and calcium, alkalinity and magnesium at ($a = 0.05$); ($r = 0.509$) TH and calcium, TH and magnesium at ($a = 0.01$). Negative correlation ($r = 0.508$) were found in DO and BOD5, DO and nitrates, DO and total and fecal coliform at ($a = 0.01$). From the above correlation, it can be deduced that salinity observed is due to the presence of soluble minerals from rocks. The EC is due to dissolved cations and anions from rock bearing minerals in the ground. High pH is due to the presence of soluble magnesium and calcium carbonates. Nitrate is one of the products of decomposition of organic waste. Availability of nitrates promotes the proliferation of bacteria. High value of Total and fecal coliform increases the consumption of oxygen which results in low DO and high BOD_5. Therefore, high values of nitrate, BOD5, and coliform are direct indicators of poor quality of water.

Principal component analysis

Principal component analysis (PCA) was applied to sets of parameters obtained from BHs water from the study area. PCs were extracted with their corresponding component plot rotated in space as shown in Tables 7 and 8 and Fig. 2. PC1 of 23.49% has a factor loading on BOD_5, nitrates, total coliform and fecal coliform. This indicates presence of organic waste which could be from sewage leakage or prolong use of fertilizer for agricultural purpose. Therefore, the source of pollutant is mainly anthropogenic. PC2 of 19.77% has a factor loading on salinity, conductivity, TDS, turbidity, total hardness. The source of these pollutants is mainly from leaching rock bearing minerals from the ground, hence natural source. PC3 explains 13.98% of the total variance with factor loading on pH, total hardness, magnesium, calcium and lead. The possible reason for total hardness is the presence of calcium and magnesium ion. This account for the low acidity observed on the BHs water. Lead appears to come from anthropogenic source. PC4 explains 11.26% of the total variance characterized by factor loading on temperature, alkalinity and calcium. PC5 and PC6 explain 10.72% and 8.72% respectively with factor loading on manganese and cadmium respectively. These are the only heavy metals that appear as pollutant in this study, the possible source is anthropogenic.

Cluster analysis

The CA result of sixteen BHs in Okobo is presented as a Dendrogram as shown in Fig. 3. BHs were grouped into three clusters. Cluster 1 has five BHs; BH7, BH10, BH8, BH11, and BH12, BHs in this cluster tend to have the

Table 5 Water quality index of borehole water in Okobo

Parameters	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11	BH12	BH13	BH14	BH15	BH16
Colour	3.00	3.00	3.00	3.00	3	3	3	3	3	3	3	3	3	3	3.000	3
PH	5.20	5.60	5.90	5.70	6.1	5.9	5.7	5.8	6.2	6.6	6.1	6.3	6.7	5.9	6.200	6
Conductivity	52.00	50.00	51.00	53.00	63.2	70.3	65.4	62.3	65	61	70	69	70	58	68.000	60
TDS (mg/L)	34.80	33.50	34.20	35.50	42.3	47.1	43.8	41.7	43.6	40.9	46.9	46.2	46.9	38.9	45.600	40.2
Salinity	34.90	33.40	34.10	35.60	43.1	48.4	44.8	42.5	43.5	41.5	48.2	47.5	48.2	39.3	46.700	40.8
Turbidity	0.45	0.39	0.42	0.45	0.672	0.72	0.54	0.449	0.44	0.35	0.5	0.52	0.631	0.667	0.452	0.431
DO	0.44	0.36	0.28	0.20	0.37	0.34	0.25	0.29	0.35	0.29	0.32	0.25	0.34	0.31	0.330	0.3
Total hardness	26.30	27.10	28.20	27.60	29.7	28.7	27.1	28.4	44.6	47.1	44.5	44.8	50.2	39.2	45.600	42.4
Nitrate	55.40	56.20	57.30	61.10	60.2	62.1	66.1	64.2	63.5	60.6	58.2	61.3	54.7	61.5	57.600	65.4
Iron	0.22	0.30	0.28	0.24	0.217	0.25	0.176	0.256	0.228	0.312	0.388	0.258	0.227	0.374	0.311	0.308
Magnesium	5.10	5.20	5.40	5.30	5.4	5.6	5.3	5.4	5.51	5.54	5.48	5.38	5.82	5.5	5.720	5.62
Lead	0.0160	0.0120	0.0110	0.0130	0.019	0.002	0.003	0.015	0.018	0.017	0.015	0.012	0.018	0.013	0.017	0.019
Cadmium	0.0010	0.0020	0.0020	0.0010	0.002	0.003	0.001	0.001	0.002	0.003	0.001	0.002	0.002	0.001	0.002	0.001
Chromium	0.04	0.03	0.01	0.06	0.09	0.03	0.04	0.06	0.03	0.07	0.03	0.06	0.018	0.013	0.017	0.019
Manganese	0.18	0.16	0.16	0.18	0.21	0.152	0.176	0.123	0.167	0.149	0.153	0.12	0.177	0.129	0.155	0.13
Total coliform	230.00	240.00	254.00	283.00	273	293	323	313	303	340	330	350	220	284	253.000	313
Water quality index	63.51	77.78	74.11	59.00	98.24	80.32	35.78	63.06	90.82	116.06	60.99	80.74	89.66	55	87.600	68.26

Table 6 Pearson correlation

	Temp	pH	Turbidity	Salinity	Conduct	TDS	DO	BOD5	AKL	Hardness	NO_3-	Zn	Fe	Mn	Mg	Pb	Ca	Cr	Cd	TC	FC
Temp	1																				
pH	−.077	1																			
Turbidity	.144	.113	1																		
Salinity	−.062	.615	.484	1																	
Conduct	−.061	.620	.476	**.999****	1																
TDS	−.113	.613	.400	.988	**.989****	1															
DO	−.145	−.186	.151	−.054	−.045	−.042	1														
BOD5	−.437	.334	−.135	.386	.386	.384	**−.508***	1													
ALK	.403	.551	.571	.611	.605	.563	−.120	.077	1												
Hardness	−.143	**.837****	−.046	.564	.572	.544	−.032	.319	.299	1											
NO3−	−.420	.351	−.130	.399	.399	.393	−.515	**.999****	.097	.349	1										
Zn	−.192	−.317	−.202	−.358	−.353	−.352	−.442	.098	−.397	−.186	.100	1									
Fe	.271	.175	−.143	−.014	−.023	−.091	−.029	.133	−.019	.405	.159	−.031	1								
Mn	−.161	−.135	.174	−.157	−.149	−.098	.310	−.493	−.025	−.315	−.513	.141	−.541	1							
Mg	.012	**.751***	.360	.494	.494	.483	.073	.128	.779	.502	.143	−.359	.046	.204	1						
Pb	−.053	.357	−.320	−.082	−.071	−.062	.305	−.124	.075	.509	−.106	−.036	.222	.086	.458	1					
Ca	.349	**.645***	.389	.488	.486	.440	.046	.026	.862	.506	.054	−.392	.216	−.117	.860	.507	1				
Cr	−.459	.051	−.009	.037	.034	.073	−.134	.443	.073	−.206	.420	.139	−.361	.267	.333	.135	.110	1			
Cd	−.235	.525	.093	.250	.257	.290	.149	.108	.181	.231	.096	−.401	−.069	.056	.432	−.116	.161	.126	1		
TC	−.259	.249	−.105	.402	.405	.395	−.536	**.958****	.154	.248	**.959****	.163	.184	−.492	.093	−.166	.057	.375	−.018	1	
FC	−.140	.185	−.036	.397	.403	.388	−.562	**.889****	.201	.111	**.885****	.054	−.026	−.479	.019	−.344	.009	.364	.047	**.928****	1

Boldface implies *correlation is significance at 0.05 level (2-tailed). **correlation is significance at 0.01level (2-tailed)

TEM temperature, *Condcut* electrical conductivity, *TDS* total dissolved solid, *FC* fecal coliform, *TC* total coliform, *DO* dissolved oxygen, *ALK* alkalinity

Table 7 Rotated component matrix

	Component					
	1	2	3	4	5	6
Temperature	−.243	−.106	−.154	.764	−.437	−.135
pH	.226	.476	.637	.144	−.089	.344
Turbidity	−.190	.572	−.240	.467	.228	.047
Salinity	.236	.934	.113	.130	−.022	.146
Conductivity	.235	.935	.121	.121	−.020	.146
TDS	.229	.921	.123	.062	.035	.169
DO	−.677	.064	.103	−.235	.063	.357
BOD5	.950	.182	.101	−.178	.004	.066
Alkalinity	.098	.480	.232	.790	.091	.162
Hardness	.143	.501	.704	−.134	−.388	.096
Nitrate	.947	.195	.123	−.162	−.024	.051
Zinc	.192	−.253	−.016	−.237	.189	−.747
Iron	.122	−.125	.313	.075	−.750	−.005
Manganese	−.523	.003	.038	−.042	.738	−.093
Magnesium	.053	.337	.658	.466	.289	.338
Lead	−.209	−.145	.916	−.029	−.011	−.095
Calcium	.009	.322	.608	.678	−.028	.166
Chromium	.462	−.141	.201	.010	.767	.086
Cadmium	.048	.140	.094	−.067	.134	.849
Total_coliform	.946	.201	.035	−.049	−.048	−.066
Fecal_coliform	.924	.201	−.177	.053	.006	.033

Extraction method principal component analysis. *Rotation method* Varimax with Kaiser normalization

Rotation converged in 13 iterations

highest total and fecal coliform, nitrates, BOD5, turbidity, EC, lowest DO and heavy metals concentration. Cluster 2 has seven BHs; BH4, BH5, BH6, BH9, BH15 and BH16, this cluster tends to have the highest pH, alkalinity, Calcium, Magnesium, salinity, TDS, Iron and Zinc concentration. Cluster 3 has four BHs; BH1, BH2, BH3 and BH13, this cluster is characterized with BHs with lowest fecal and total coliform, nitrates, BOD5, conductivity, salinity, Calcium, Magnesium, Cadmium and Manganese, however, highest DO, pH, temperature and Chromium.

Table 8 Total variance explained

Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	4.934	23.493	23.493
2	4.153	19.774	43.267
3	2.938	13.989	57.256
4	2.365	11.261	68.517
5	2.252	10.722	79.239
6	1.831	8.720	87.959

Extraction method principal component analysis

Conclusion

Physicochemical, bacteriological and heavy metal analysis of BHs water in Okobo, Akwa Ibom state shows that the water is slightly acidic, most physicochemical parameters measured were within the acceptable limits set by NSDWQ. However, DO, BOD5, nitrate, fecal and total coliform, lead, chromium and manganese were not within the limit set by NSDWQ. PCA shows that there are six principal pollutants whose sources are mostly organic waste from human excreta probably due to proximity of BH with broken or bad casing to septic tank and natural source due to leaching of minerals from rocks. CA shows that there are three groups of BHs with these pollutants. Water quality index calculation shows that only BH7 was portable, others require treatment. Since the major pollutant is fecal coliform, there is need to site BHs 15 m away from septic tank, BH casing should be constructed during the construction phase, calculated amount of high test hypochlorite (HTH) should be used to treat the water before consumption, Individuals and BHs owners should be adequately educated on the health impact associated with sitting BHs close to pollution source (WHO 2007). Finally, regular monitoring and evaluation system should be put in place to periodically monitor the suitability and pollution state of ground and surface water.

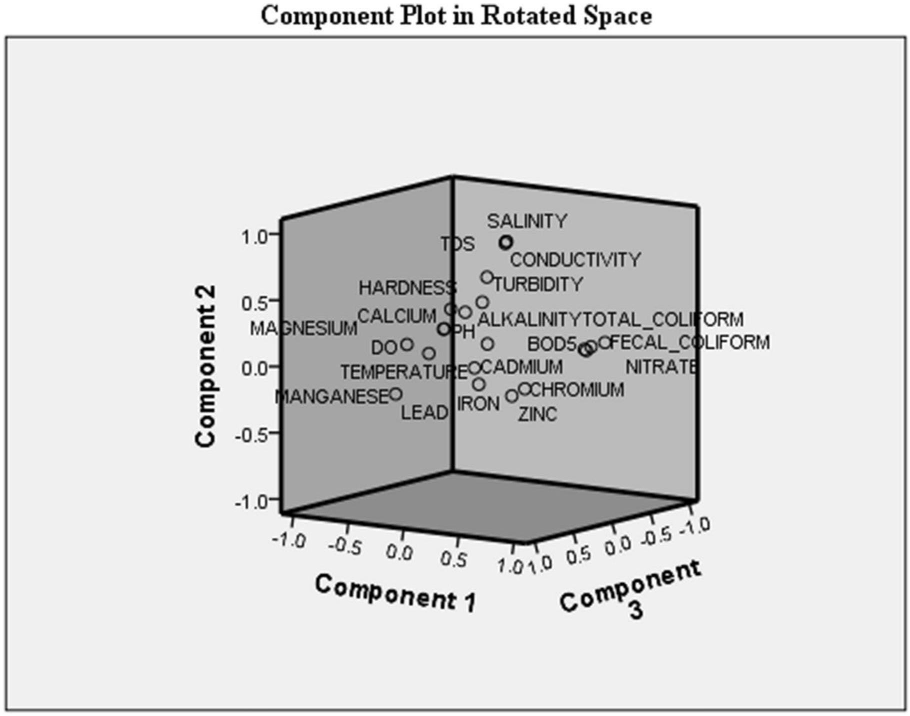

Fig. 2 Component plot for rotated space for boreholes water in Okobo

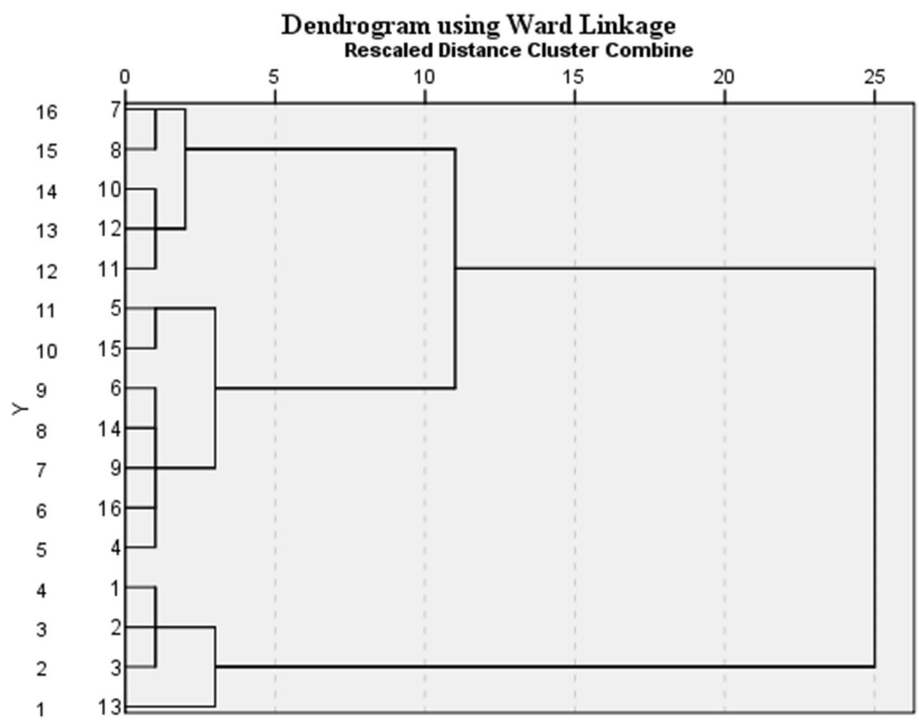

Fig. 3 Dendrogram for cluster analysis of 16 boreholes in okobo using ward's method, square Euclidean distance

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Declarations

Conflict of interest The authors declare that there is no conflict of interest in the submitted work.

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