

Surface Water Quality Profiling Using Physicochemical Parameters in Open Defecation Free and Non-Open Defecation Free Local Government Areas in Benue State, Nigeria

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Abstract

Physicochemical parameters of surface water sources in the study of local government areas (LGAs) were assessed using standard procedures. The mean physicochemical parameters for pH (5.49), NO₂ (0.23 mg/L), SO₄ (0.77 mg/L), Na (28.72 mg/L), Ca (28.94 mg/L), Mg (17.50 mg/L), Cl (11.65 mg/L), TSS (6.27 mg/L), TDS (104.23 mg/L), BOD (2.83 mg/L) and F (0.87 mg/L) were below WHO standards irrespective of their defecation status. The values for electrical conductivity (EC) (2770.50 µs/cm, turbidity (481.24 NTU), dissolved oxygen (DO) (5.32 mg/L), chemical oxygen demand (COD) (445.50 mg/L), K (125.06 mg/L), PO₄ (0.78 mg/L) and Fe (0.57 mg/L) were above the WHO limits for safe water. Higher EC and COD values obtained in the study is evidence of pollution of the water sources by organic matter.

Keywords

Open Defecation, Surface Water, Water Quality Standard, Physicochemical Parameters

1. Introduction

Surface water refers to anybody of liquid water found on the earth's surface. Water quality is related to the health of the people drinking it. Once people drink water with quality problems, it will have a huge impact on people's health and cause a range of diseases [1]. Supply of clean, safe and potable drinking wa-

ter to the community is of utmost importance in maintaining positive health measures. The drinking water must be free from pathogenic microorganisms. Water is, in fact, one of the vehicles for the transfer of a wide range of diseases of microbial origin.

Defecation on boundaries of water bodies results in microbial contamination. Open defecation remains the predominant norm in developing countries and poses one of the biggest threats to the health of the people. Community-led total sanitation (CLTS) is a widely used, community-based approach to tackle open defecation and its health-related problems. It is one of the latest innovations in encouraging individuals and communities to adapt in order to keep free from any activities injurious to good health, especially, human defecation. It has attracted much attention for its simplicity of approach and the rapid results that follow. Success stories of the CLTS approach in rural areas show that after a single-day triggering event in which communities are led to experience disgust at the present sanitation situation, villages achieve open defecation free (ODF) status within a month or more [2].

Rural communities suffer most from inadequate hygiene and sanitation facilities because of vulnerability to social and economic aspects [3]. Improvements in access to water and sanitation facilities, water quality and personal hygiene are effectively reducing diarrhea morbidity [4]. Majority of Benue State rural water sources for drinking are still the traditional ones including wells, rivers, streams and ponds.

A range of tools have been developed to evaluate water quality data; the Water Quality Index (WQI) model is one such tool. WQI models are based on an aggregation function that allows analysis of large temporally and spatially-varying water quality datasets to produce a single value. The general norm for reporting water quality parameters has been by comparing the different analysed parameters with their respective permissible limits and standards set by regulating bodies at local, regional, national or international levels. Parameters including BOD, temperature, turbidity, conductivity and so on have been used [5].

In order to rank the overall water quality, the Canadian Council of Ministers of Environment CCME [6] established the use of an index that mathematically combines all water quality measures and provides a general and readily understood description of the quality of water. Over the years, many countries have accepted the CCME scheme representing the water quality index for water quality monitoring and assessment of surface and underground water in terms of their chemical, biological and nutrient constituents and overall aesthetic condition.

The aim/purpose of the study was to determine the surface water quality profiling using physicochemical parameters in open defecation free and non-open defecation free LGAs in Benue state, Nigeria.

2. Methodology

2.1. Field Analysis

The Local Government Areas in Benue State lie within the lower river Benue

trough in the middle belt region of Nigeria. The geographic coordinates are longitude $7^{\circ}47'$ and $10^{\circ}0'$ East. Latitude $6^{\circ}25'$ and $8^{\circ}8'$ North (**Figure 1**). The area is characterized by savanna vegetation with two distinct seasons; dry and rainy seasons, and experiences a single rainy season from April/May to September/October with a peak season in August/September. The dry season starts from November to March with day temperatures ranging from 33°C to 39°C while mean night temperatures range from 20°C to 26°C . The mean annual day sunshine is approximately 7.5 hours. The water resources are streams, hand-dug wells, boreholes and rivers used by households for drinking, cooking and other domestic activities.

The study was carried between January and December spanning 2 seasons-dry and wet seasons in 6 Local Government Areas of Benue State that have been declared open defecation-free by the National Task Group on Sanitation. Several field trips to the study area were undertaken to make direct observations and ensure that the constructed latrines were being used with the proper use of ash, latrine cover (fly proof) and hand wash station near such latrines. The method of Movik and Mehta [7] for CLTS triggering had been used to motivate the construction of latrines/toilets leading to the declaration of ODF by the National Task Group. The community members had been counselled to construct their pit latrines at least 20 meters away from existing wells and other surface water sources [8].

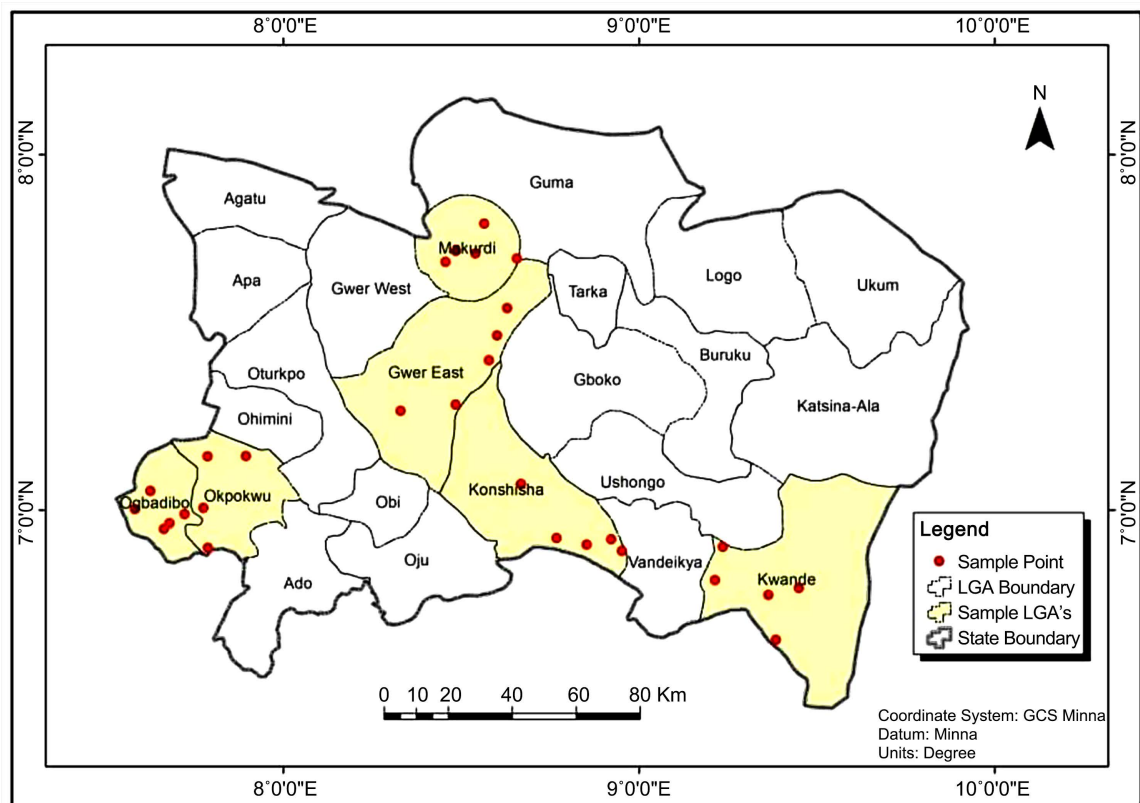


Figure 1. Map of Benue State indicating the sample LGAs and sample points.

2.2. Sampling Techniques and Sample Collection

The purposive sampling technique was used as the study is targeted at the ODF LGAs. Water samples were collected at 5 sites in each of the study LGAs cutting across stream/river flowing water, hand-dug wells, dams and boreholes. The samples were numbered from 1 to 5 against their LGAs and sources.

Water samples for physicochemical analysis were collected in specific bottles according to [9]. Dissolved oxygen (DO), electrical conductivity, and pH were measured *in situ* as field parameters by YSI meter (model: 1945), while BOD, COD, TSS, Turbidity, PO₄, SO₄, NO₃ were analyzed in the laboratory. BOD was analyzed as described by 5-day test, and COD was assayed by means of the open reflux method [10]. Additionally, total suspended solids (TSS) were determined by total solids dried at 105°C and liquid-liquid, partition-gravimetric methods, respectively [9]. Moreover, turbidity, phosphate, sulfate and nitrate were assayed by Absorptometric, Acid Ascorbic, Sulfa Ver 4, Cadmium Reduction, and Nessler methods, respectively [9]. The equipment (HACH, 2003 DR/500 Spectrophotometer) was calibrated prior to use based on the manufacturer's directions.

2.3. Physicochemical Analysis of Water Source in the Study Area and Calculation of Water Quality Index (WQI)

Values of Nineteen (19) physicochemical parameters obtained consisting of BOD, pH, EC, TSS, TDS, Turbidity, DO, COD, Na, K, Ca, Mg, Fe, Cl, F, SO₄, PO₄, NO₂ and NO₃ were considered in the calculation of WQI. The CCME Water Quality Index (CCME WQI) method was used in the study. The CCME WQI provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience and incorporates three elements: *scope* - the number of parameters not meeting water quality guidelines; *frequency* - the number of times these guidelines are not met; and *amplitude* - the amount by which the guidelines are not met. The index produces a number between 0 (worst water quality) and 100 (best water quality). These numbers were divided into five descriptive categories to simplify presentation. The Global Environmental Monitoring Systems [11] adopted the Water Quality Index (WQI) developed by the Canadian Council of Ministers of Environment (CCME) and based its development on the combination of three factors into one index. The detailed formulation of the WQI, as documented by CCME [12] comprises three factors which are the three measures of variance from selected water quality objectives (scope, frequency, and amplitude). Scope (F1) represents the percentage of variables that do not meet their objectives, frequency (F2) the percentage of individual tests that do not meet objectives, and amplitude (F3) the amount by which failed test values do not meet their objectives. These three factors combine to produce a value between 0 and 100 that represents the overall water quality, where 0 represents the "worst" water quality and 100 represents the "best" water quality.

Scope, F₁, the number of variables whose objectives were not met and calculated as:

$$F_1 = \left[\frac{\text{Number of Failed Variables}}{\text{Total Number of Variables}} \right] \times 100 \quad (1)$$

Frequency, F_2 , the frequency with which the objectives were not met:

$$F_2 = \left[\frac{\text{Number of Failed Tests}}{\text{Total Number of Tests}} \right] \times 100 \quad (2)$$

Amplitude, F_3 , the amount by which the objectives were not met. F_3 was calculated in three steps:

a) The number of times by which an individual concentration was greater than (or less than, when the objective is a minimum) the objective was termed an “excursion” and was estimated as follows:

i) When the test value must not exceed the guideline:

$$\text{Excursion}_i = \left[\frac{\text{Failed Test Value}_i}{\text{Objective}_i} \right] - 1 \quad (3)$$

ii) For the cases in which the test value must not fall below the guideline:

$$\text{Excursion}_i = \left[\frac{\text{Objective}_i}{\text{Failed Test Value}_i} \right] - 1 \quad (4)$$

b) The collective amount by which individual tests were out of compliance was calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse), was calculated as:

$$nse = \left[\frac{\sum_{i=1}^n \text{excursion}}{\text{Number of Tests}} \right] \quad (5)$$

c) F_3 was thereafter calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100 as given in Equation

$$F_3 = \left[\frac{nse}{0.01nse + 0.01} \right] \quad (6)$$

Hence the water quality index was calculated thus for each LGA:

$$\text{CCME WQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] \quad (7)$$

The divisor 1.732 in equation is used as a normalizing factor to ensure the resultant WQI is in the range of 0 to 100 where 0 denotes the “worst” water quality and 100 the “best” [12]. The factor of 1.732 arises because each of the three individual index factors (F_1 , F_2 and F_3) can have a maximum value of 100 giving a maximum value for the numerator of 173.2 [12].

2.4. Statistical Analysis

Data obtained from this study was subjected to statistical analysis using the Sta-

tistical Package for Service Solutions (SPSS version 20). The following statistical tools were used: descriptive statistics (means, standard deviation, standard error) and ANOVA (Analysis of variance) on the mean values

3. Results

The results in **Tables 1-6** show that the following physicochemical parameters were within the acceptable standards: pH, BOD, TSS, TDS, NO₂, NO₃, SO₄, Na, Ca, Mg, Cl, DO and F. Electrical conductivity, turbidity, PO₄, COD, K and Fe fell outside the recommended standard in all the 6 LGAs of study. **Table 7** also shows the mean values of all the physicochemical parameters in all 6 LGAs of study (ODF and OD) as indicated for each physicochemical parameter. For pH, there was no significant difference in the mean values in all the 6 LGAs of the study. There was no significant difference in the mean values of EC between Gwer East, Konshisha and Makurdi LGAs and no significant difference between Kwande, Ogbadibo and Okpokwu LGAs. There was no significant difference in the observed TSS mean values between Gwer East and Konshisha LGAs; no significant difference was also observed between Kwande and Makurdi LGAs. There was a significant difference between Okpokwu, Ogbadibo and the rest of the LGAs under study in the values of TSS observed in the study. For the mean values of TDS, there was no significant difference between Kwande, Konshisha, Makurdi, Ogbadibo and Okpokwu LGAs while a significant difference was observed between Gwer East and the other 5 LGAs. No significant difference for the observed turbidity mean values between Gwer East, Kwande, Konshisha LGAs and Ogbadibo LGAs with a significant difference between Makurdi and Gwer East, Kwande, Konshisha LGAs and Ogbadibo LGAs. Turbidity values in Okpokwu LGA also showed significant difference between Okpokwu and the other 5 LGAs in the study. For the DO mean values, no significant difference existed between Gwer East LGA and Kwande, Konshisha, Makurdi and Okpokwu LGAs with a significant difference existing between Ogbadibo LGA and the other 5 LGAs. There was no significant difference in the mean value of NO₂ in the 6 LGAs of study with no significant difference in the values of NO₃ in Gwer East, Kwande and Makurdi LGAs while there is a significant difference in the NO₃ mean values between Konshisha and the other 5 LGAs with Ogbadibo showing a significant difference with the rest of the LGAs. No significant difference existed in SO₄ mean values between Gwer East and Konshisha LGA with result showing no significant difference between Kwande, Makurdi and Ogbadibo LGAs. Values of SO₄ in Okpokwu LGA showed a significant difference with the other 5 LGAs. There was no significant difference in the mean values of PO₄ in 5 LGAs of study except in Okpokwu LGA where there was a significant difference in the PO₄ mean values with the rest of the LGAs. No significant difference between Gwer East LGA and Konshisha LGA in the COD mean values with a significant difference existing between Kwande and the other 5 LGAs. A significant difference existed in the mean values of COD in Makurdi LGA and the other 5 LGAs with

Ogbadibo and Okpokwu LGAs showing significant differences with the other 5 LGAs respectively. There was no significant difference between Gwer East, Konshisha, Kwande and Makurdi LGAs in the BOD mean values. There was also no significant difference in the BOD values between Ogbadibo and Okpokwu LGAs. No significant difference existed in the mean values of K, Na, Ca, Cl and Fe in all the 6 LGAs in the study. There is no significant difference in the mean values of Mg between Konshisha, Makurdi and Okpokwu LGAs; no significant difference in the mean values of Mg between Gwer East and Ogbadibo LGAs. There is a significant difference in the mean value of Mg between Kwande LGA and the other 5 LGAs. No significant difference existed in fluoride mean values among the LGAs in the study.

Table 1. Physicochemical parameters in Gwer East LGA.

Parameter	Unit	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
BOD	mg/L	2.67	2.52	2.43	2.66	2.26	5
pH		5.6	5.8	5.51	5.2	5.3	8.5
EC	µs/cm	630	538	467	526	533	300
TSS	mg/L	5.63	5.85	5.67	6.21	6.32	25
TDS	mg/L	359.8	354.3	156.7	258.2	456.9	500
Turbidity	NTU	526	531	467	482	396	5
DO	mg/L	6.31	5.62	5.8	6.7	6.9	4
NO ₂	mg/L	0.05	0.18	0.17	0.98	0.97	48.2
NO ₃	mg/L	2.41	2.37	2.36	2.41	2.22	3
SO ₄	mg/L	0.78	0.76	0.63	0.67	0.91	200
PO ₄	mg/L	0.71	0.63	0.65	0.66	0.53	0.3
COD	mg/L	526.2	552.4	552.4	529.3	484.4	250
K	mg/L	98.2	153.1	167	153	113.3	10
Na	mg/L	46	27	36.5	22.5	32	200
Ca	mg/L	18	22.4	45.3	22.2	24.5	75
Mg	mg/L	21	32	16	19	11.6	30
Cl	mg/L	12	9.7	5.5	10.3	15.2	250
F	mg/L	0.76	0.35	1.2	0.97	1.42	1.5
Fe	mg/L	0.13	0.41	0.73	0.82	0.96	0.3

Table 2. Physicochemical parameters in Kwande LGA.

Parameter	Unit	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
BOD	mg/L	2.33	2.67	3.2	3.20	2.4	5
pH		5.2	5.32	5.56	5.41	5.9	8.5
EC	µs/cm	4531	4560	4801	5651	5361	300
TSS	mg/L	5.3	5.42	6.14	6.1	5.58	25

Continued

TDS	mg/L	61.2	53.4	55.7	62.3	61.12	500
Turbidity	NTU	532	551	546	452	463	5
DO	mg/L	6.2	5.32	5.8	6.21	7.01	4
NO ₂	mg/L	0.05	0.03	0.18	0.61	0.84	48.2
NO ₃	mg/L	3.1	2.4	2.2	2.56	2.39	3
SO ₄	mg/L	0.82	0.62	0.53	0.71	0.92	200
PO ₄	mg/L	0.53	0.71	0.76	0.68	0.81	0.3
COD	mg/L	425.01	419.2	553.2	530	561.2	250
K	mg/L	74.2	153.1	187	113	128.3	10
Na	mg/L	23.6	12.1	31.5	18.9	28.03	200
Ca	mg/L	16	31.4	42.3	22.2	34.3	75
Mg	mg/L	37	33	26	12	27.6	30
Cl	mg/L	14.3	8.6	7.5	16.3	13.2	250
F	mg/L	0.35	0.55	1.8	0.72	0.42	1.5
Fe	mg/L	0.19	0.21	0.39	0.87	0.27	0.3

Table 3. Physicochemical parameters in Konshisha LGA.

Parameter	Unit	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
BOD	mg/L	2.22	2.34	2.41	2.67	2.37	5
pH		5.1	5.3	5.6	5.2	5.8	8.5
EC	µs/cm	468	522	533	532	565	300
TSS	mg/L	6.32	6.52	6.6	5.6	5.9	25
TDS	mg/L	61.1	53.2	62.3	52.1	59.1	500
Turbidity	NTU	452	461	464	438	521	5
DO	mg/L	5.72	5.51	5.62	5.8	6.2	4
NO ₂	mg/L	0.07	0.06	0.13	0.16	0.63	48.2
NO ₃	mg/L	3.1	3.22	2.56	2.27	2.35	3
SO ₄	mg/L	0.82	0.77	0.83	0.86	0.73	200
PO ₄	mg/L	0.68	0.69	0.71	0.58	0.56	0.3
COD	mg/L	463	482	589	526	497	250
K	mg/L	182	163.1	117	123	118.2	10
Na	mg/L	36	23	39.5	24.5	41.2	200
Ca	mg/L	14.7	36.4	45.3	20.12	17.5	75
Mg	mg/L	11	18	13	18	12.6	30
Cl	mg/L	18	16.7	11.5	12.3	11.8	250
F	mg/L	0.93	0.38	1.4	0.77	1.03	1.5
Fe	mg/L	0.43	0.49	0.64	0.52	0.73	0.3

Table 4. Physicochemical parameters in Makurdi LGA.

Parameter	Unit	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
BOD	mg/L	2.41	2.47	2.53	2.53	2.36	5
pH		5.8	5.62	5.82	5.73	5.83	8.5
EC	µs/cm	483	561	378	477	488	300
TSS	mg/L	5.88	5.85	5.79	5.75	5.82	25
TDS	mg/L	58.91	56.8	59.3	56.78	58.81	500
Turbidity	NTU	5.36	5031	5.38	529	563	5
DO	mg/L	6.34	6.56	6.32	5.78	5.92	4
NO ₂	mg/L	0.06	0.16	0.13	0.13	0.08	48.2
NO ₃	mg/L	1.36	1.57	1.58	2.32	2.92	3
SO ₄	mg/L	0.66	0.63	0.93	0.65	0.67	200
PO ₄	mg/L	0.68	0.73	0.94	0.92	0.86	0.3
COD	mg/L	463.2	463.2	473.6	249.3	412.3	250
K	mg/L	88.2	145.1	129	137	73.3	10
Na	mg/L	36	26	35	23.7	17	200
Ca	mg/L	48	21.7	31.5	20.3	20.2	75
Mg	mg/L	21	12.8	10.3	14.5	11.6	30
Cl	mg/L	13	11.7	5.8	13	12.7	250
F	mg/L	1.6	0.43	0.72	1.16	0.63	1.5
Fe	mg/L	0.36	0.31	0.32	0.62	0.76	0.3

Table 5. Physicochemical parameters in Ogbadibo LGA.

Parameter	Unit	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
BOD	mg/L	3.21	3.36	2.87	3.68	3.74	5
pH		4.8	5.31	4.96	5.63	5.72	8.5
EC	µs/cm	4610	4760	3880	4890	4930	300
TSS	mg/L	4.67	4.32	5.53	5.69	5.58	25
TDS	mg/L	62.3	60.4	58.32	51.78	58.63	500
Turbidity	NTU	498	452	461	445	465	5
DO	mg/L	1.53	1.8	1.58	1.84	2.81	4
NO ₂	mg/L	0.13	0.14	0.15	0.11	0.12	48.2
NO ₃	mg/L	1.27	1.67	1.72	2.09	2.12	3
SO ₄	mg/L	0.71	0.62	0.84	0.75	0.73	200
PO ₄	mg/L	0.82	0.76	0.97	0.68	0.91	0.3
COD	mg/L	480.5	316.56	298	393	396	250
K	mg/L	121	103	87	98	112	10
Na	mg/L	22	31.4	26.7	36	27	200
Ca	mg/L	43	33	28	27.6	25	75
Mg	mg/L	12.7	17	14.6	23	13.7	30
Cl	mg/L	8.9	12	16	9.3	17	250
F	mg/L	0.7	1.82	0.27	0.92	0.87	1.5
Fe	mg/L	1.1	0.67	0.53	0.98	0.66	0.3

Table 6. Physicochemical parameters in Okpokwu LGA.

Parameter	Unit	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
BOD	mg/L	3.44	3.42	3.6	3.66	3.32	5
pH		5.55	5.53	5.3	5.77	5.64	8.5
EC	µs/cm	6620	6131	4162	5221	5320	300
TSS	mg/L	8.81	8.63	8.53	8.88	8.98	25
TDS	mg/L	79.02	69.3	78.3	75.6	76.2	500
Turbidity	NTU	S32	481	456	346	352	5
DO	mg/L	5.78	5.66	5.69	5.68	5.56	4
NO ₂	mg/L	0.14	0.12	0.14	0.17	0.15	48.2
NO ₃	mg/L	2.36	2.25	2.32	2.62	1.78	3
SO ₄	mg/L	0.93	0.86	0.93	0.96	0.99	200
PO ₄	mg/L	0.97	0.94	1.22	1.12	0.94	0.3
COD	mg/L	331.2	326.3	393.4	331.5	332.6	250
K	mg/L	57.8	133.6	176	136	111.4	10
Na	mg/L	31.6	32.7	30.5	21.5	22	200
Ca	mg/L	27.8	43.2	35.8	24.2	26.3	75
Mg	mg/L	18.2	10.2	13.9	11	12.3	30
Cl	mg/L	8.3	3.3	3.9	13.1	18.6	250
F	mg/L	1.14	0.32	0.62	0.52	1.32	1.5
Fe	mg/L	0.83	0.51	0.27	0.72	0.56	0.3

Table 7. Analysis of the physicochemical parameters in the study areas.

Parameter	GWE	KWD	KON	MKD	OGB	WHO	
						OKP	Standard
pH	5.48 (±0.24) ¹	5.48 (±0.27) ¹	5.4 (±0.29) ¹	5.76 (±0.09) ¹	5.28 (±0.41) ¹	5.56 (±0.17) ¹	8.5
BOD (mg/1)	2.51 (±0.17) ¹	2.77 (±0.41) ¹	2.4 (±0.17) ¹	2.46 (±0.07) ¹	3.37 (±0.36) ²	3.49 (±0.14) ²	5
EC (us/cm)	538.8 (±58.46) ¹	4980.8 (±501.36) ²	524 (±35.23) ¹	477.4 (±65.22) ¹	4614 (±428.99) ²	5490.8 (±942.42) ²	300
TSS (mg/1)	5.94 (±0.31) ²	5.71 (±0.39) ^{1,2}	6.19 (±0.43) ²	5.82 (±0.05) ^{1,2}	5.16 (±0.62) ¹	8.77 (±0.18) ³	25
TDS (mg/1)	317.18 (±113.96) ²	58.74 (±3.94) ¹	57.56 (±4.64) ¹	58.12 (±1.23) ¹	58.29 (±3.97) ¹	75.68 (±3.84) ¹	500
TURB (NTU)	480.4 (±54.651) ²	508.8 (±47.5) ^{1,2}	467.2 (±31.73) ^{1,2}	533.82 (±21.45) ²	464.2 (±20.44) ^{1,2}	433.4 (±81.8) ¹	5
DO (mg/1)	6.27 (±0.55) ²	6.11 (±0.62) ²	5.77 (±0.26) ²	6.18 (±0.32) ²	1.91 (±0.52) ¹	5.67 (±0.08) ²	4
NO ₂ (mg/1)	0.47 (±0.46) ¹	0.34 (±0.36) ¹	0.21 (±0.24) ¹	0.11 (±0.04) ¹	0.13 (±0.02) ¹	0.14 (±0.02) ¹	48.2
NO ₃ (mg/1)	2.35 (±0.08) ^{1,2}	2.53 (±0.34) ^{1,2}	2.7 (±0.44) ²	1.95 (±0.65) ^{1,2}	1.77 (±0.35) ¹	2.27 (±0.31) ^{1,2}	3
SO ₄ (mg/L)	0.75 (±0.11) ^{1,2}	0.72 (±0.16) ¹	0.8 (±0.05) ^{1,2}	0.71 (±0.12) ¹	0.73 (±0.08) ¹	0.93 (±0.05) ²	200
PO ₄ (mg/1)	0.64 (±0.07) ¹	0.7 (±0.11) ¹	0.64 (±0.07) ¹	0.83 (±0.12) ¹	0.83 (±0.12) ¹	1.04 (±0.13) ²	0.3
COD (mg/1)	528.94 (±27.8) ³	497.72 (±70) ^{2,3}	511.4 (±49.12) ³	412.32 (±94.22) ^{1,2,3}	376.81 (±72.84) ^{1,2}	343 (±28.28) ¹	250
K (mg/1)	136.92 (±29.5) ¹	131.12 (±42.37) ¹	140.66 (±29.95) ¹	114.52 (±31.79) ¹	104.2 (±13.03) ¹	122.96 (±43.23) ¹	10
Na (mg/1)	32.8 (±9.06) ¹	22.83 (±7.64) ¹	32.84 (±8.52) ¹	27.54 (±7.99) ¹	28.62 (±5.3) ¹	27.66 (±5.45) ¹	200
Ca (mg/1)	26.48 (±10.78) ¹	29.24 (±10.32) ¹	26.8 (±13.34) ¹	28.34 (±11.95) ¹	31.32 (±7.14) ¹	31.46 (±7.91) ¹	75

Continued

Mg (mg/l)	19.92 (± 7.62) ^{1,2}	27.12 (± 9.52) ²	14.52 (± 3.26) ¹	14.04 (± 4.19) ¹	16.2 (± 4.12) ^{1,2}	13.12 (± 3.17) ¹	30
Cl (mg/l)	10.54 (± 3.54) ¹	11.98 (± 3.78) ¹	14.06 (± 3.05) ¹	11.24 (± 3.09) ¹	12.64 (± 3.74) ¹	9.44 (± 6.46) ¹	250
F (mg/l)	0.94 (± 0.41) ¹	0.77 (± 0.59) ¹	0.9 (± 0.37) ¹	0.91 (± 0.47) ¹	0.92 (± 0.57) ¹	0.78 (± 0.43) ¹	1.5
Fe (mg/l)	0.61 (± 0.34) ¹	0.39 (± 0.28) ¹	0.56 (± 0.12) ¹	0.47 (± 0.21) ¹	0.79 (± 0.24) ¹	0.58 (± 0.21) ¹	0.3

*Superscripts with the same values across rows did not show any significant difference.

4. Discussion

Physicochemical parameters are important for determining the quality of water as they provide valuable information about its physical and chemical characteristics. In this study, water quality was examined using chemical and physical methods. In chemical analysis, different parameters were tested, such as magnesium, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD) *etcetera* and the physical parameters include pH, total suspended solids (TSS), conductivity, chloride, sulphate, nitrate, calcium, sodium, potassium.

The mean pH value in this study had slight variations between LGAs but was within the WHO [13] (6.5 - 8.5) stipulated range. pH did not show significant difference among the LGAs. The lower pH value obtained in ODF LGAs (5.25 - 5.48) and OD LGAs (5.48 - 5.76) may be attributed to decomposed domestic wastes which may have contributed to the acidic nature of the water. Similar trends have been reported previously [14] in the Niger Delta areas of Nigeria. The findings in this study are however different from earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria.

The mean concentration values of sulphate obtained varied among the ODF (0.73 - 0.8 mg/L and NODF LGAs (0.71 - 0.93 mg/L). These values were below the permissible limit of 500 mg/L as stipulated by WHO/NESREA [13] [16] and hence sulphate does not pose any threat to freshwater vertebrates, humans inclusive in the LGAs studied. The findings agree with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria.

The concentration of PO₄ in the study was generally low across the study LGAs (0.64 - 1.04 mg/L) with the ODF LGAs having mean values of 0.64 - 0.83 mg/L and OD LGAs having 0.70 - 1.04 mg/L of phosphate. The recorded phosphate concentrations in this study were lower than the acceptable limit of 5 mg/L as recommended by NESREA [16]. The permissible amount of phosphate according to WHO is 1 - 2 mg/L [17] and this means that the concentration of phosphate in the water in the present study is allowable. The results of the study are consistent with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria. Phosphate reflects biochemical oxygen demand, therefore the number of microbes as *Escherichia coli* (bacterium) also increases tremendously as the number of *Escherichia coli* per unit volume of water is main parameter of water pollution [17].

Chloride in drinking-water originates from natural sources, sewage and in-

dustrial effluents, urban runoff containing de-icing salt and saline intrusion. The secondary drinking water standard is set at a maximum of 250 mg/L. Water is generally considered undrinkable at concentrations of more than 1000 mg/L. The mean values for chloride in the study is 9.44 - 14.06 mg/L in the 6 LGAs studied with no significant differences. These values in ODF LGAs (10.54 - 14.06 mg/L) and OD LGAs (9.44 - 11.98 mg/L) fall well below the maximum standard of 250 mg/L [18]. The chloride ranges 9.44 - 14.06 mg/L recorded in this study was below the maximum permissible limit of 250 mg/L as stipulated by NESREA [16] and consistent with earlier studies by Ogwo and Ogu [15] (2014) in Enugu, Nigeria. The findings appear close to the report of Iloba and Ehioghiren, [19] (17.75 - 142 mg/L), but varied pronouncedly with the work of Ideriah *et al.* [20] with very high chloride values (986 - 8398.0 mg/L) in surface water earlier investigated.

The study revealed that the mean values of F across the study LGAs of 0.77 - 0.94 mg/L are below the Nigerian standard (1 mg/L) and WHO guideline (1.5 mg/L). This implies that fluoride did not exceed the limit in all the sites in the LGAs of study. Epidemiological evidence shows that concentrations above the permissible value carry an increasing risk of dental fluorosis, and that progressively higher concentrations lead to increasing risks of skeletal fluorosis, that is bone and teeth. Low concentrations provide protection against dental caries, both in children and in adults. The protective effects of fluoride increase with concentration up to about 2 mg/L of drinking water [13].

The mean values of nitrate obtained in this study across the LGAs (1.77 - 2.7 mg/L) with OD LGAs having mean values of 1.95 - 2.53 mg/L and ODF LGAs with 1.77 - 2.7 mg/L; were all below the statutory limit of 9 - 10 mg/L given by NESREA [16] as well as below 50 mg/L as recommended by WHO, [13]. The findings are consistent with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria. Earlier reports have shown that nitrate is non-hazardous pollutant, but its high concentration (above 45 mg/L) in water can cause infant methemoglobinemia (blue baby symptom *i.e.* lack of oxygen in blood) [21] [22].

The mean values obtained for potassium in the study LGAs ranged from 104.2 - 140.66 mg/L. The high potassium concentration obtained could be linked to agricultural non-point sources as potassium originating from other human activities can enter aquatic ecosystems [22] and such potassium losses from agricultural land due to run-off and leaching are influenced by climatic conditions, agrotechnology, including fertilizer type and level, soil type and soil properties [23]. This study disagrees with earlier reports made by other researchers' study [24] [25].

The study showed that across the LGAs of study, the mean values of sodium were 22.83 - 32.84 mg/L with ODF LGAs having 28.62 - 32.84 mg/L and the OD LGAs having a range of 22.84 - 27.66 mg/L. These values are well below the 200 mg/L recommended limit [26]. Sodium in drinking water is a more serious concern if you have a medical condition such as high blood pressure, or certain

heart, kidney or liver diseases. Calcium ranged from 26.48 - 31.48 mg/L in the study LGAs with the mean value of 28.34 - 31.46 mg/L for the OD LGAs and 26.48 - 31.48 mg/L for the ODF LGAs. These values are well below the limit set by the WHO with the attendant potential consequences. Calcium functions as a stabilizer for pH and is also needed by the body for some essential health functions.

According to WHO standards, the permissible range of magnesium in water should be 50 mg/L. The mean values obtained in this study show lower levels of magnesium across the LGAs (13.12 - 27.12 mg/L). A similar value was reported by Soylak *et al.* [27] regarding drinking water in Turkey.

The results obtained for the iron content of the surface water in the study LGAs (0.39 - 0.79 mg/L) are rather very high signifying poor water quality, especially as the values recorded are all far above the regulatory agents' permissible limits. This high iron contents obtained was irrespective of the local governments and irrespective of open defecation or non-open defecation status. The presence of iron in the study LGAs could be related to the high organic matter and low dissolved oxygen content as pointed out in the report of Emoyan *et al.* [28]. High concentration of Fe above the USEPA and WHO-recommended threshold value have been reported in Nigeria territorial waters in Kano by Malami *et al.* [29]. However, lower concentrations of Fe in water than values obtained in this study have been reported by Emoyan *et al.* [28] (0.050 mg/L). The mean values for iron obtained in this study are comparable with Aghoghovwia *et al.* [30] (0.3 - 0.7 mg/L) for Warri River, Niger Delta. The use of water for drinking is in many cases limited by the presence of dissolved iron. This gives the water an unpleasant metallic taste, and stains food, sanitary wares and laundry. Research has shown that the presence of iron in water can promote the growth of bacteria like *E. coli* [31].

The mean electrical conductivity (EC) values obtained were generally higher than the allowable limit of 1000 $\mu\text{s}/\text{cm}$ in Nigeria [32], and varied across the LGAs (477.4 - 5490.8 $\mu\text{s}/\text{cm}$). There were variations between the ODF LGAs (524 - 4614 $\mu\text{s}/\text{cm}$) and the OD LGAs (477.4 - 5490.8 $\mu\text{s}/\text{cm}$). The findings are consistent with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria. Higher values (33,200 - 36,100 $\mu\text{s}/\text{cm}$) of EC had also been previously reported by Ide-riah *et al.* [20] in similar studies. The authors attributed the higher conductivity values to the combination of low precipitation and higher atmospheric temperature. Contrarily, lower EC values were reported by several authors including Ewa *et al.* [33] (391 - 462 $\mu\text{s}/\text{cm}$), Babalola and Agbebi [34] (582 - 820 $\mu\text{s}/\text{cm}$). However, the EC result of this study was similar to the report of Esi *et al.* [35] (1870 - 4599 $\mu\text{s}/\text{cm}$) in Delta State.

The mean turbidity values in the study shows for ODF LGAs (464.2 - 480.4 NTU) and OD LGAs (433.4 - 508.8 NTU) which are well above the limits of 5 NTU [13]. The findings agree with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria. The implication of the high turbidity above the WHO value of 5

NTU is that fish that rely on sight and speed to catch their prey are especially affected by high turbidity levels as these fish often flee areas of high turbidity for new territories [36]. For the fish that remain in the turbid environment, suspended sediment can begin to physically affect the fish. Fine sediment can clog fish gills and lower an organism's resistance to disease and parasites [36]. Some fish may consume suspended solids, causing illness and exposing the fish to potential toxins or pathogens on the sediment. If the consumed sediment does not kill the fish, it can alter the organism's blood chemistry and impair its growth and subsequently its reproduction as reported by USEPA [36]. The result in this study showed that turbidity had high values compared to standard in all the sites in the LGAs of study. There was no significant difference for the observed Turbidity mean values between Gwer East, Kwande, Konshisha LGAs and Ogbadibo LGAs with a significant difference between Makurdi and Gwer East, Kwande, Konshisha LGAs and Ogbadibo LGAs. Turbidity values in Okpokwu LGA also showed a significant difference between Okpokwu and the other 5 LGAs in the study.

The observed mean TDS (58.12 - 75.67 mg/L) values across the LGAs in the study were below the permissible limits (500 mg/L) adopted by NESREA [16], their variations among the ODF (57.56 - 58.29 mg/L) and OD LGAs (58.74 - 75.68 mg/L). The findings are inconsistent with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria. The range (58.12 - 75.67 mg/L) observed during the rains could be linked to dilution with the rainwater. A high level of TDS is an indicator of potential concerns and warrants further investigation. The result in this study showed that TDs did not exceed the limit and fell within normal range in all the sites in the LGAs of study. For the mean values of TDS, there was no significant difference between Kwande, Konshisha, Makurdi, Ogbadibo and Okpokwu LGAs while a significant difference was observed between Gwer East and the other 5 LGAs.

Healthy water should generally have dissolved oxygen concentrations above 6.5 - 8 mg/L and when dissolved oxygen levels fall between 4 - 6.5 mg/L, very few fish can survive and with a further decrease to about 3 - 4 mg/L, even the strongest fish may suffocate [36]. While the lowest dissolved oxygen mean values of 1.91 ± 0.52 mg/L obtained in Ogbadibo LGA was in unacceptable range, the highest value of 6.27 ± 0.55 mg/L obtained in this study was within the WHO [13] acceptable ranges (4 - 8 mg/L). The values for DO in the study LGAs range from 1.91 to 6.27 mg/L indicating that the water is not so healthy generally. The following requirements for DO concentration have been endorsed: 6 mg/L for drinking water, 4 - 5 mg/L for entertainment, 4 - 6 mg/L for fish and domesticated animals, and 5 mg/L for industrial applications [37] [38].

The levels of Biochemical Oxygen Demand (BOD) determined in the study varied across the various LGAs. The range of BODs levels (2.4 - 3.49 mg/L) amongst the LGAs of study were below the threshold limit of <5 mg/L as recommended by WHO [13]. The range of BOD levels in ODF LGAs (2.4 - 3.33

mg/L) and OD LGAs (2.4 - 3.49 mg/L) all fall within the range which show there was no much organic matter present in the water [17]. Generally, BOD, depends on temperature, extent of biochemical activities, concentration of organic matter and such other related factors. The findings are however inconsistent with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria. There was no significant difference between Gwer East, Konshisha, Kwande and Makurdi LGAs in the BOD mean values.

The higher the COD value, the more serious the pollution of organic matter by water [17]. The mean values obtained in the study range from 343 - 528 mg/L in all the LGAs, though the ODF LGAs had the range of 376.81 - 528.84 mg/L and the OD LGAs had 343 - 497.72 mg/L. These values are well above the maximum permissible limits of 250 mg/L [17]; an indicator of the contents of reducing substances in the water, which are organic, nitrite, sulfide, ferrous salts, etc. The findings are consistent with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria. The high value of COD in the study could be the decline in flow; as water flow declines, the growth of microorganisms increases profoundly providing another potential source of the high COD values [39].

The mean TSS values in the study for ODF LGAs (5.16 - 5.71 mg/L) and OD LGAs (5.71 - 8.77 mg/L) and the range for the entire LGAs (5.16 - 8.77 mg/L) are well below 10 mg/L considered good for drinking water. The findings are however inconsistent with earlier studies by Ogwo and Ogu [15] in Enugu, Nigeria who reported higher values. Low TSS is not a problem for the system, but it could indicate higher flows from low TSS sources and clear water inflows. Acceptable TSS levels in water quality can vary depending on the intended use of the water. In general, TSS levels below 10 mg/L are considered good for drinking water, while TSS levels of up to 30 mg/L may be acceptable for recreational uses such as swimming.

This work is limited to considering the physicochemical parameters of surface water in Open Defecation Free and Non-Open Defecation Free Local Government Areas in Benue State, Nigeria.

5. Conclusions

The physicochemical parameters pH, NO₂, SO₄, PO₄, Na, Ca, Mg, Cl and F were below WHO standards as measured in all the LGAs irrespective of the status of the LGA. The values for EC, turbidity, DO, COD, TSS, TDS, K and Fe were well above the WHO standard for safe water. Higher EC, TDS, TSS, BOD and COD values recorded for both ODF and non ODF LGAs are evidence of pollution of the water sources by organic matter as wind action or surface water runoff could transport debris and exposed fecal matter into the open water bodies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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