Engineering Heritage Journal (GWK)

DOI: http://doi.org/10.26480/gwk.01.2023.60.71

ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0904 (Print)
ISSN: 2521-0440 (Online)
CODEN: EHJNA9

CrossMark

RESEARCH ARTICLE

CONCENTRATION LEVELS OF PHYSICO-CHEMICAL PROFILES AND QUALITY ASSESSMENT OF GROUNDWATER: A CASE STUDY OF SOUTHERN IJAW, BAYELSA STATE, SOUTHERN NIGERIA

Nwankwoala, H.O[a], Peterside, A.N[b], Hart, A.I[b]

[a] Department of Geology, Rivers State University, Port Harcourt, Nigeria
[b] Institute of Natural Resources, Environment and Sustainable Development, University of Port Harcourt, Nigeria
****Corresponding author email: nwankwoala_ho@yahoo.com***

ARTICLE DETAILS

Article History:

Received 10 August 2023
Revised 13 September 2023
Accepted 16 October 2023
Available online 26 October 2023

ABSTRACT

This study examined the concentration levels of physico-chemical profiles of groundwater quality of communities in Southern Ijaw Local Government Area of Bayelsa State, Nigeria. The seasonal variation of groundwater quality were evaluated. Fifteen (15) communities within the LGA were selected and groundwater from hand-dug well (HDW-15samples) and borehole (BH-15samples) was sourced during the wet season (July) and dry season (March) and analyzed for seasonal variations. The difference in the mean of the parameters investigated during the dry and wet season revealed the difference in concentration level as influenced by the season attributes. The HDW showed a very strong correlation in wet and dry season physicochemical properties as well as no significant difference in the physicochemical properties of groundwater at both seasons. Also, the results of borehole water sample showed a very strong correlation in wet and dry season physic-chemical properties with no significant difference in the physicochemical properties of water at both seasons. There are similarities in various natural and anthropogenic activities influencing the concentrations during both wet and dry seasons. The mean values of parameters such as pH, TDS, TSS, Bicarbonate, Cl, SO_3^4, NO_2, Ca, Mg, K and P are within the permissible limit of WHO and NSDWQ during both seasons except TC.

KEYWORDS

Groundwater quality, physico-chemical properties, contamination, hand dug well, borehole

1. INTRODUCTION

Groundwater has been assumed by many to be safe and not polluted due to its hidden nature but hydrochemical analysis of groundwater has shown that groundwater in some areas are contaminated, polluted by activities of human, animal, industrial waste and natural conditions (Nwankwoala and Udom, 2011). The contaminant found in water ranges from physical, chemical, biological, radiological, bacteriological, organic, inorganic substances which could render water unsafe (Nwankwoala et al., 2014). Contaminated water resources have important implications on health and the environment (Peterson et al., 1971). The importance of water quality in human health has recently attracted a great deal of interest. In the developing world, 80% of all diseases are directly related to poor drinking water and unsanitary conditions (Olajire and Imeokparia, 2001). Groundwater quality can be affected by varied pollution sources. For example, Hamilton and Helsel, stated that a connection between agricultural and groundwater pollution is well established (Hamilton and Helsel, 1995). According to applications of nitrogen-phosphorous-potassium (NPK) fertilizers have been increasing (Chandio, 1999).

Many researchers stated that ground water typically have large range of chemical composition in relation to the diversity of factors that influence their quality (Hem, 1970; Drever, 1982; Matthess, 1990; Apello and Postman, 1993). A group researchers in their paper concluded that the chemical composition of groundwater is strongly influenced by dissolutions from the soil zone; the processes that contribute to the concentration of major ions in the groundwater also depend on carbonate dissolution and precipitation, seawater intrusion, cation exchange, evaporative concentration of solutes and to a minor extent aluminosilicates dissolution (Kortatsi et al., 2007).

Groundwater is of abundance and readily available in parts of Southern Ijaw Local Government Area of Bayelsa State of Nigeria. However, the quality of the water cannot be visually ascertained unless it is analyzed in the laboratory and compared with relevant standards like World Health Organization (WHO) and Nigeria Standard for Drinking Water Quality (NSDWQ) (Emeka et al., 2020). The activities of human beings can alter groundwater quality during any of the stages of hydrologic or water cycle which comprises of precipitation, surface run-off, infiltration, percolation, evaporation, and transpiration. Infiltration of water through underground rocks and soil may pick- up natural contaminants even with no human activity or pollution in the area.

In recent decades, as a result of economic development and rapid growth of the population, there have been clear changes in the use of land, resulting in increased demand for water for various civil, industrial and agricultural activities (Nag and Das, 2014; Al-Saffawi and Alshuuchi, 2018; Al-Saffawi et al., 2020). As a result of this demand, there is equally an increased pressure on agricultural production coupled with the limited area of land suitable for agriculture, as well as the reduction in the quantity and quality of water for irrigation (Al-Saffawi et al., 2020). The provision of adequate and safe water for drinking is important for sustaining life and the environment because water is an essential ingredient for good health and socio-economic development (Galadima et al., 2011). However, the utility of any water for domestic, industrial and agriculture purpose depends on the physical, chemical and biological characteristics of such

Quick Response Code	Access this article online	
	Website: www.gwk.com.my	**DOI:** 10.26480/gwk.01.2023.60.71

Cite the Article: Nwankwoala, H.O, Peterside, A.N, Hart, A.I (2023). Concentration Levels of Physico-Chemical Profiles and Quality Assessment of Groundwater: A Case Study of Southern Ijaw, Bayelsa State, Southern Nigeria. *Engineering Heritage Journal (GWK), 7(1): 60-71.*

water (Sunitha et al., 2012). This is because the status of water affects the health and well-being of humans, animals and plants that make use of it.

The quality of water that humans ingest is critical in determining the quality of their lives (Nwankwoala and Ngah, 2014). It is in line with the above that, the World Health Organization has repeatedly stressed that the single major factor adversely influencing the general health and life expectancy of a population in many developing countries is the ready access to safe drinking water. Therefore, the availability of water does not suffice, rather how qualitative it is, qualifies it as a resource. Consequently, great concern should be given to the quality of water as it is critical for the overall socio-economic development of any society and, should engage the attention of researchers, government and non-governmental organizations.

The study area is remarkably impacted by oil exploration activities. Like most of the coastal communities affected by oil exploration in the Niger Delta, clean water is a major challenge for the people. Most water sources are contaminated with hydrocarbon thereby compelling the inhabitant, to depend largely on water from seasonal ponds, streams and few boreholes with quality not evaluated. An assessment of groundwater quality in the study area would lend useful clues to the quality of water used for drinking and domestic purposes. It would also furnish invaluable facts and figures that would form the basis for any meaningful interventions that would protect the health of the people. This study, therefore assessed the water quality of boreholes (physicochemical properties) in parts of Southern Ijaw Local Government Area of Bayelsa State, Nigeria which uses groundwater as the main source of their water supply. Therefore, this study aims at assessing and evaluating the concentration levels of physico-chemical profiles of the quality of drinking water sources in the area for the protection of human health.

2. The Study Area Description

The study area is Southern Ijaw Local Government Area in Bayelsa State, Nigeria. The area lies within Longitude 6°00′10″N and 6°25′15″N and Latitude 4°40′07″E and 5°5′20″ (Figure 2). The study area has a tropical rain forest climate characterized by two seasons, namely the wet or rainy season and the dry season. The rainy season lasts for about 7 months between April and October with an intervening dry period in August. The dry season lasts for about 4 months, between November and March (Udom and Nwankwoala, 2012). The temperature varies between 25 and 32 ^{0}C. The mean annual rainfall is about 4,500 mm; about 85 % of the mean annual rain falls in the wet season (Akpokodje, 1986; Nwankwoala and Omemu, 2019).

The study area consists of alluvial deposits and an extensive, low-lying, typical deltaic plain with essentially flat topography which in conjunction with the high annual rainfall, is responsible for the extremely poor drainage conditions and the widespread development of marshes and back swamps. This area is usually submerged during the wet season where flood waters range from 0.5 to 4 m deep (Akpokodje 1986). There are a number of perennial streams, oxbow lakes and rivers in the area e.g. Kolo Creek, Epie Creek, Yenagoa and Nun river, etc. They all form a network which empties to the Atlantic Ocean through Nun River Estuary. These rivers are mostly turbid during the wet season possibly due to discharge of clay and silt (Amadi et al., 1987; Nwankwoala et al., 2013). The natural vegetation of the study area is that of the rain forest but this has been destroyed by the activities of man such as bush burning, farming, construction and illegal crude oil refining activities. The vegetation consists of various kinds of evergreen trees, including palms trees and a variety of shrubs. More than 70 % of the inhabitants of the study area are engaged in subsistent farming and fishing.

The geology of the Niger Delta has been described in details by various authors such as (Short and Stauble, I967; Kogbe, I976). The formation of the Delta started during Early Paleocene and resulted mainly from the buildup of fine grained sediments eroded and transported by the River Niger and its tributaries. The Tertiary Niger Delta is a sedimentary structure formed as a complex regressive off-lap sequence of clastic sediments ranging in thickness from 9,000m - I2,000m (Abam, 1999; Abam and Nwankwoala, 2020). Starting as separate depocenters, the Niger Delta has coalesced to form a single united system since Miocene. The Niger Delta is a large and ecologically sensitive region, in which various water species including surface and sub-surface water bodies exist in a state of dynamic equilibrium (Abam, I999). The Niger Delta is stratified by three lithologic succession; Benin Formation, Agbada Formation and Akata Formation.

The Niger Delta has two most critical aquifers, Deltaic and Benin Formations (Ngah and Nwankwoala, 2013). With a regularly dendritic waste system, this very penetrable sands of the Benin Formation enables simple penetration of water to revive the shallow aquifers. A group researchers depicted the aquifers here as an arrangement of various aquifer frameworks stacked on one another with the unconfined upper aquifers happening at the best (Nwankwoala et al., 2014; Ngerebara and Nwankwoala, 2008). The recharge of aquifers is immediate from invasion of precipitation, the yearly aggregate of which shifts between 5000mm at the drift to about 2540mm landwards. Groundwater in the zone happens in shallow aquifers of overwhelmingly mainland deposits experienced at penetrations of somewhere in the range of 45m and 60m. The lithology contains a blend of sand in a fining up arrangement, rock and mud. Well yield is phenomenal, with generation rates of 20,000 liters/hour normal and borehole achievement rate is typically high (Amadi et al., 2012).

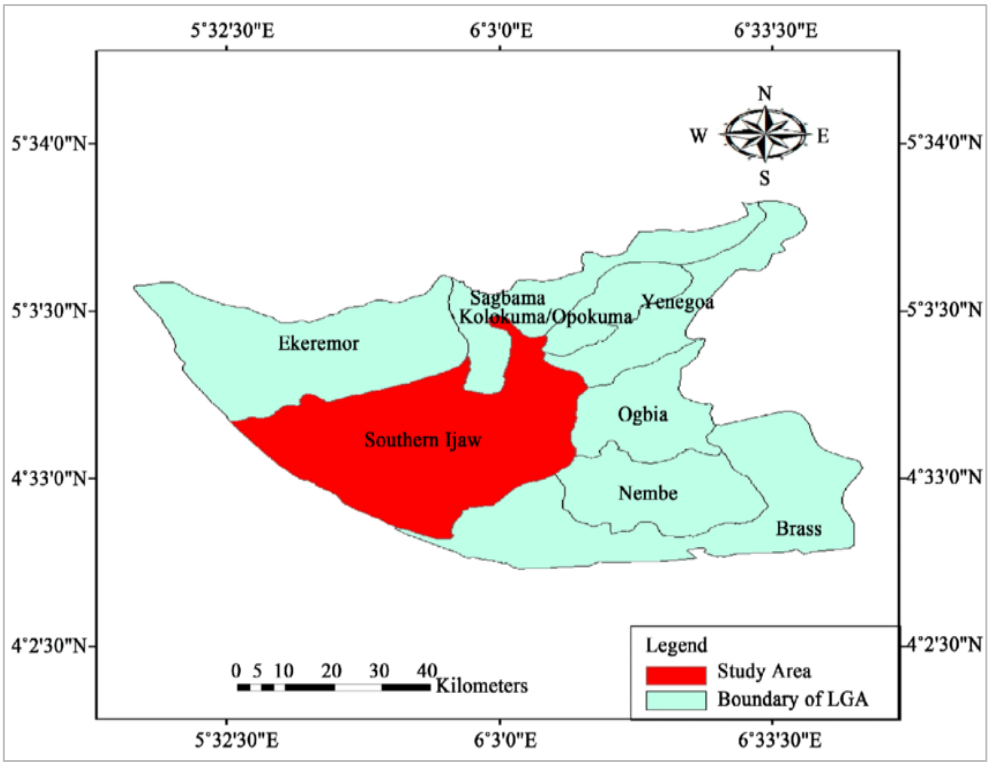

Figure 1: Overview of the Study Area

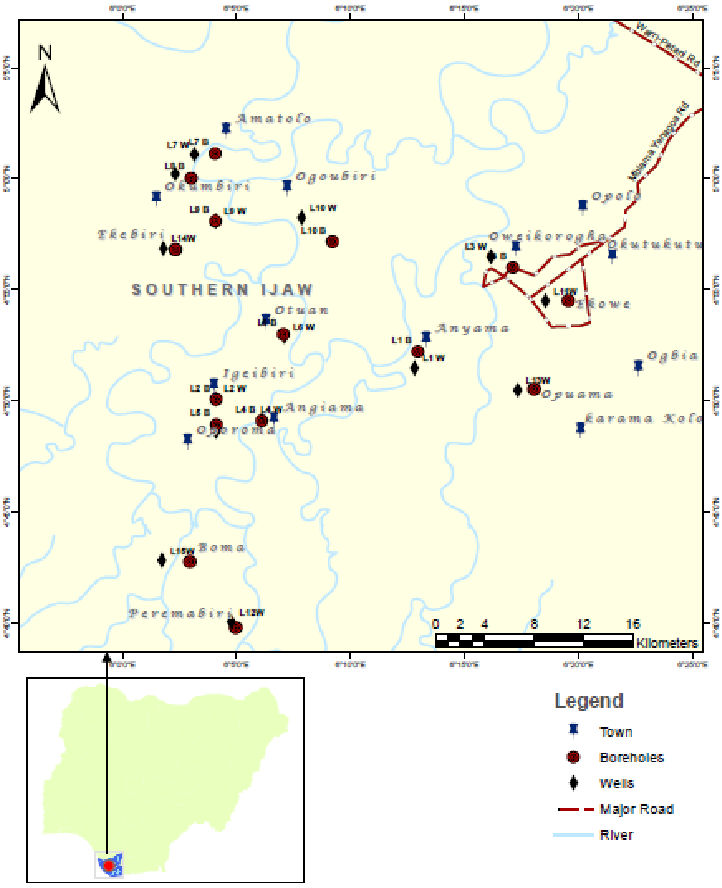

Figure 2: Map of the Study Area Showing Sampling locations

3. Materials and Methods of Study

The water samples for the study were collected during the dry season (March) and wet season (July) from boreholes and hand-dug wells around the study area. Specifically, water samples were collected from borehole (15) and groundwater (15) during the dry season and the process was repeated during wet season which implies that a total of forty (60) samples were collected for the study during both seasons for the same wells and boreholes. In order to prevent confusion and mixed up of the water sample, each sample will be tagged according to their sources, and the season they represent and with Roman figure to represent the position of the sample as presented;

i. Borehole (BH) Water during Wet Season (WS) = BHWS I-XIV

ii. Borehole (BH) Water during Dry Season (DS) = BHDS I-XIV

iii. Hand-dug well (HDW) Water during Wet Season (WS) = HDWWS I-XIV

iv. Hand-dug well (HDW) Water during Dry Season (DS) = HDWDS I-XIV

With the aid of labeled bottle, water samples were collected from various designated water source. Prior to the water collection, clean bottles were cleaned in order prevent impurities and other form of contamination. The water samples were collected from each designated point and the bottles were fully filled. Thereafter, the filled bottles were immediately placed in the ice-parked cooling medium to arrest continuous microbial activities and preserve the water before been taken to the laboratory for analysis. The laboratory analysis of APHA standard was used. The accuracy and precision of the analytical techniques were assessed by the analyses of reference materials and reagent blank before the samples were analyzed using deionized water and reagent blank. Calibration of equipment with standard and measuring a minimum of four different fresh dilutions of relevant standards regularly before the start of sample analysis.

Table 1: Analytical Methods Used for Groundwater Samples Analysis

Analysis	Parameter	Symbol	Unit	Type of Test	Laboratory Standard
Physio-Chemical	pH	pH		In-situ	APHA 4500-H⁺B
	Total Dissolved Solids	TDS	mg/L	In-situ	APHA 2540C
	Electrical Conductivity	EC	uS/cm	In-situ	APHA 2510B
	Sodium	Na	mg/L	Laboratory	APHA 3111B
	Calcium	Ca	mg/L	Laboratory	APHA 3111D
	Magnesium	Mg	mg/L	Laboratory	APHA 3111B
	Potassium	K	mg/L	Laboratory	APHA 3111B
	Sulphate	SO4	mg/L	Laboratory	APHA 4500/SO_4-E
	Nitrate	NO_3	mg/L	Laboratory	APHA 4500/NO_3-E
	Chloride	Cl	mg/L	Laboratory	APHA 3111B
	Bicarbonate	HCO_3	mg/L	Laboratory	APHA 3111B
Biological	Total Coliform	TC	(MPN/100ml)	Laboratory	APHA 9221C
Heavy Metals	Iron	Fe	mg/L	Laboratory	APHA 3111B
	Zinc	Zn	mg/L	Laboratory	APHA 3111B
	Manganese	Mn	mg/L	Laboratory	APHA 3111B
	Chromium	Cr	mg/L	Laboratory	APHA 3111D
	Lead	Pb	mg/L	Laboratory	APHA 3111B
	Cadmium	Cd	mg/L	Laboratory	APHA 3111B
	Copper	Cu	mg/L	Laboratory	APHA 3111B

3.1 Presentation of Results

Table 2: Concentration level of Hand-Dug Wells (HDW) and Boreholes (BH) from Communities in the Study area

		Anyama Community (L1)				Igeibiri Community (L2)				Oweikorogha Community (L3)				Angiama Community (L4)			
		HDW		BH		HDW		BH		HDW		BH		HDW		BH	
S/N	Parameters	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
1	pH	5.27	6.57	7.42	6.72	5.74	6.46	7.23	6.80	6.70	6.90	7.66	6.43	6.45	6.99	6.90	6.50
2	T (°C)	27.8	31.7	29.9	31.9	30.5	31.8	31.0	31.7	39.4	31.9	29.6	31.8	34.6	31.9	30.1	31.9
3	EC (µS/cm)	647	432	288.8	158.3	864	253	100.7	112.2	985	700	274.8	191.7	856	856	254	235
4	TDS (mg/L)	204	216	78.0	79.2	117	127	60.0	56.1	546	350	102	96.0	624	426	119	118
5	TSS (mg/L)	0.003	0.004	0.011	0.014	0.004	0.006	0.020	0.092	0.001	0.010	0.043	0.036	0.002	0.034	0.032	0.048
6	Cl^- (mg/L)	15.0	40.0	2.00	4.00	16.9	54.0	2.30	2.00	12.0	54.0	10.6	10.0	30.0	54.0	23.5	24.0
7	S^- (mg/L)	7.9	10.6	77.9	69.2	4.33	49.3	2.41	0.510	20.6	49.3	8.32	8.91	33.4	43.5	5.34	5.01
8	N^-(mg/L)	1.23	0.832	0.97	1.27	0.43	4.85	1.23	0.015	3.22	4.85	0.055	0.085	3.10	2.96	0.400	0.500
9	BC (mg/L)	39.4	103	70.9	67.0	102.4	100	65.4	53.0	86.7	100	62.6	62.0	78.1	186	70.7	73.0
10	Ca (mg/L)	34.5	24.5	1.00	1.03	19.5	11.9	2.24	2.51	34.5	64.2	3.43	2.57	55.4	65.8	3.43	2.31
11	Zn (mg/L)	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*	0.003*
12	Cu (mg/L)	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*	0.004*
13	Mg(mg/L)	7.54	9.83	3.66	5.46	9.54	6.07	4.77	4.90	8.56	9.36	4.44	4.99	10.23	11.1	4.44	7.30
14	Fe (mg/L)	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*
15	K (mg/L)	6.41	6.41	1.08	1.75	5.30	5.30	1.23	1.88	12.4	12.4	0.92	1.01	10.2	10.2	0.92	2.27
16	P (mg/L)	0.084	0.084	0.033	0.042	0.066	0.066	0.021	0.043	0.066	0.066	0.095	0.044	0.052	0.052	0.095	0.048
17	Al (mg/L)	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*
18	TC	>1600	>1600	1200	>1600	920	920	1000	>1600	1600	1600	120	1600	94	94	120	14.0

Key: Hand-Dug Wells= HDW, Boreholes =BH, WS= Wet Season, DS= Dry Season
*BDL= Below Detection Limit

Table 3: Concentration Levels of Physico-Chemical Properties of Hand-Dug Wells (HDW) And Boreholes (BH) From Selected Communities

		Oporoma Community (L5)				Otuan Community (L6)				Amatolo Community (L7)				Okumbiri Community (L8)			
		HDW		BH		HDW		BH		HDW		BH		HDW		BH	
S/N	Parameters	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
1	pH	7.27	7.86	7.41	6.71	7.45	6.67	6.98	6.54	6.85	6.86	7.05	6.73	5.44	6.89	7.22	6.88
2	T (°C)	30.5	31.8	30.4	31.8	27.5	31.8	31.1	31.7	30.1	31.8	30.4	31.6	29.4	31.8	31.2	31.7
3	EC (µS/cm)	345	286	197.8	193.3	323	384	143.0	135.0	298	241	121.2	115.8	1143	861	132.8	124.8
4	TDS (mg/L)	274	143	100.2	96.8	208	192	111.6	67.5	171	121	55.8	57.9	543	431	66.6	62.4
5	TSS (mg/L)	0.009	0.026	0.021	0.028	0.021	0.008	0.0	0.062	0.030	0.026	0.028	0.008	0.021	0.036	0.054	0.006
6	Cl^- (mg/L)	7.00	8.00	2.06	2.00	7.00	20.0	11.2	10.0	12.00	2.00	4.34	4.00	29.0	44.0	4.46	4.00
7	S^- (mg/L)	12.4	12.4	1.74	0.410	12.4	14.3	5.33	6.01	6.52	9.61	0.900	0.910	55.6	75.5	0.880	0.910
8	N^-(mg/L)	0.56	0.417	0.436	0.659	0.56	1.04	0.210	0.130	1.45	0.136	0.799	0.889	2.03	1.27	0.401	0.468
9	BC (mg/L)	100	104	64.6	63.0	100	110	56.0	37.0	122	107	42.0	45.0	100	208	52.0	56.0
10	Ca (mg/L)	20.4	23.9	2.76	7.21	13.2	24.2	2.55	4.25	54.8	10.6	2.92	3.57	17.9	71.8	2.24	2.74
11	Zn (mg/L)	0.003*	0.003*	0.003*	0.003*	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003
12	Cu (mg/L)	0.004*	0.004*	0.004*	0.004*	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004
13	Mg(mg/L)	8.13	5.42	7.21	5.26	6.22	8.13	5.64	4.06	7.22	4.00	4.02	4.40	14.2	11.3	3.66	3.14
14	Fe (mg/L)	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	0.0046*	*0.0046	*0.0046	*0.0046	*0.0046
15	K (mg/L)	0.53	5.78	2.03	2.36	4.32	7.05	4.33	4.39	2.43	0.885	2.33	2.47	3.42	12.2	2.01	2.16
16	P (mg/L)	0.023	0.052	0.085	0.084	0.044	0.052	0.043	0.052	0.054	0.098	0.052	0.049	0.065	0.098	0.076	0.047
17	Al (mg/L)	0.03*	0.03*	0.03*	0.03*	*0.03	*0.03	*0.03	*0.03	0.03*	0.03*	0.03*	0.03*	*0.03	*0.03	*0.03	*0.03
18	TC	43	61	100	<1.8	>1600	49	1600	1600	54	>1600	893	920	>1600	>1600	80	47

Key: Hand-Dug Wells= HDW, Boreholes =BH, WS= Wet Season, DS= Dry Season*BDL= Below Dictation Class

Table 4: Concentration level of Hand-Dug Wells (HDW) and Boreholes (BH) from Studied Communities

		Toru-Ebeni Community (L9)				**Amassoma Community (L10)**				**Ekowe Community (L11)**				**Peremabiri Community (L12)**			
		HDW		**BH**		**HDW**		**BH**		**HDW**		**BH**		**HDW**		**BH**	
S/N	Parameters	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**
1	pH	7.01	7.35	6.98	6.74	7.40	7.04	7.00	7.15	7.04	7.43	7.42	6.56	6.34	7.35	6.92	6.34
2	T (°C)	30.0	32.0	31.0	31.9	30.5	31.8	31.7	31.8	39.40	31.10	31.50	31.80	25.40	31.80	29.90	31.70
3	EC (µS/cm)	714	417	196.4	174.0	777	743	89.6	83.7	1124.0	358.00	100.70	145.70	738.00	473.00	154.40	187.70
4	TDS (mg/L)	322	209	88.9	87.0	389	371	54.6	41.8	546.00	340.00	98.40	64.00	184.00	364.00	105.00	45.70
5	TSS (mg/L)	10.9	0.034	0.032	0.088	30.0	0.020	0.067	0.034	0.0	0.01	0.00	0.05	0.00	0.00	0.05	0.03
6	Cl^- (mg/L)	0.022	16.0	3.07	2.00	0.015	44.0	2.22	2.00	30.00	10.00	10.60	6.00	24.00	4.00	5.00	8.00
7	S^- (mg/L)	12.4	16.1	15.3	13.1	29.5	35.9	0.465	0.310	4.28	18.40	77.90	72.50	30.30	68.40	7.54	76.00
8	N^-(mg/L)	1.00	1.57	0.121	0.091	7.54	6.15	0.334	0.232	1.00	0.324	1.01	0.81	1.01	0.354	0.451	0.75
9	BC (mg/L)	143	117	66.0	76.0	156	127	87.0	36.0	102.5	1.24	50.60	89.40	10.2	193.00	84.60	45.70
10	Ca (mg/L)	29.8	33.4	5.34	5.75	49.0	58.2	2.43	2.51	36.20	45.80	2.25	2.35	22.6	33.60	2.56	5.75
11	Zn (mg/L)	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003
12	Cu (mg/L)	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004
13	Mg(mg/L)	4.22	6.42	5.43	5.58	6.62	7.56	3.22	3.35	4.22	10.80	3.28	6.78	3.25	6.50	4.12	7.30
14	Fe (mg/L)	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046
15	K (mg/L)	4.52	6.16	2.21	2.16	5.45	7.97	3.45	3.33	4.32	12.20	1.10	1.88	3.47	7.18	2.22	4.39
16	P (mg/L)	0.012	0.054	0.034	0.047	0.019	0.117	0.032	0.044	0.03	0.05	0.06	0.06	0.03	0.06	0.08	0.05
17	Al (mg/L)	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	*0.03	*0.03	*0.03	*0.03	*0.03	*0.03	*0.03
18	TC	114	130	654	430	196	240	343	240	225	>1600	>1600	>1600	>1600	>1600	>1600	>1600

Table 5: Concentration Levels Of Hand-Dug Wells (HDW) And Boreholes (BH) From Across Communities

		Opuama Community (L13)				**Ikebiri Community (L14)**				**Boma Community (L15)**			
		HDW		**BH**		**HDW**		**BH**		**HDW**		**BH**	
S/N	Parameters	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**
1	pH	6.34	6.46	7.36	7.46	6.92	6.47	6.90	6.71	7.02	7.76	7.61	7.56
2	Temperature (°C)	25.40	32.30	30.40	31.60	38.20	31.80	31.10	31.80	30.50	31.60	29.40	31.90
3	EC (µS/cm)	738.00	758.00	120.50	165.50	294.00	747.00	226.10	191.60	634.00	325.00	148.40	156.50
4	TDS (mg/L)	184.00	234.00	88.00	65.60	284.00	145.00	102.60	83.80	152.00	121.00	75.20	67.70
5	TSS (mg/L)	0.00	0.02	0.07	0.06	0.00	0.04	0.00	0.01	0.00	0.01	0.03	0.01
6	Chloride (mg/L)	24.00	15.00	20.50	2.00	15.00	44.00	4.44	9.00	6.00	30.00	6.30	4.00
7	Sulphate (mg/L)	10.80	23.60	856.00	0.64	55.60	29.30	18.40	15.50	12.40	49.30	0.92	0.88
8	Nitrate (mg/L)	0.10	0.21	0.12	0.21	0.21	0.32	0.15	0.32	.014	0.15	0.31	0.25
9	Bicarbonate (mg/L)	70.50	104.00	48.50	78.50	148.00	48.00	70.80	43.40	102.40	1.20	54.80	68.50
10	Calcium (mg/L)	19.50	10.60	5.42	3.89	18.00	70.90	1.05	1.08	13.60	24.80	3.43	3.45
11	Zinc (mg/L)	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003	*0.003
12	Copper (mg/L)	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004	*0.004
13	Magnesium (mg/L)	14.20	9.80	7.41	4.58	10.18	6.50	5.64	4.40	7.34	7.28	4.08	6.48
14	Iron (mg/L)	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046	*0.0046
15	Potassium (mg/L)	3.33	5.22	0.64	2.18	0.42	7.40	4.34	1.08	2.46	6.16	2.25	2.49
16	Phosphorus (mg/L)	0.02	0.05	0.03	0.06	0.07	0.11	0.05	0.05	0.08	0.10	0.09	0.08
17	Aluminium (mg/L)	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*
18	Total Coliform (MPN/100ml)	>1600	>1600	>1600	>1600	>1600	241	>1600	>1600	>1600	154	>1600	>1600

Key: Hand-Dug Wells= HDW, Boreholes =BH, WS= Wet Season, DS= Dry Season

Table 6: Descriptive Statistics of the Water Source during Wet and Dry Season											
		Hand-dug Well (HDW)				Borehole (BH)					
		Wet Season		Dry Season		Wet Season		Dry Season			
S/N	Parameters	Means	SD	Means	SD	Means	SD	Means	SD	WHO*	NSDWQ*
1	pH	6.62	0.68	7.00	0.46	7.20	0.26	6.81	0.39	6.5-8.9	6.5-8.5
2	Temperature (°C)	31.77	4.30	31.79	0.25	30.59	0.71	31.77	0.10	Amt*	Amt*
3	EC (µS/cm)	674.67	294.21	522.27	227.82	169.95	65.73	158.05	39.48	600	500.00
4	TDS (mg/L)	329.47	167.04	252.67	115.48	87.06	20.91	72.63	20.72	1000	1000.0
5	TSS (mg/L)	4.10	0.71	3.87	0.62	3.642	0.61	3.621	0.58	5	NA
6	TC (MPN/100ml)	1600.00	.00	1600.00	.00	840.00	1074.8	823.50	1098.13	0/100	NA
7	Bicarbonate (mg/L)	105.33	30.52	95.71	66.65	63.10	12.77	59.57	16.12	200	50.00
8	Chloride (mg/L)	17.85	8.58	27.00	18.26	7.51	6.70	6.20	5.76	250	200.00
9	Sulphate (mg/L)	20.43	17.07	30.87	21.95	126.87	292.33	18.05	28.65	250	250.00
10	Nitrate (mg/L)	1.56	1.04	1.28	0.547	0.35	0.2	0.45	0.2	45	NA
11	Calcium (mg/L)	31.14	15.28	38.28	22.55	3.01	1.42	3.40	1.74	200	NA
12	Magnesium (mg/L)	8.44	2.94	8.00	2.25	4.84	1.38	5.20	1.31	150	0.30
13	Potassium (mg/L)	4.72	3.20	7.50	3.13	2.16	1.14	2.39	0.99	20	3.00
14	Phosphorus (mg/L)	0.05	0.02	0.07	0.02	0.06	0.02	0.05	0.01	0.1	1.00

*WHO (2012) * NSDWQ (2007), * Ambient, NA-Not Available

4. Discussion of Findings

4.1 pH

The mean pH values of the HDW during the wet and dry season showed 6.62 and 7.00 respectively at variation of 0.38 while the BH showed pH mean values of 7.20 and 6.81 during the wet and dry season respectively at variation of 0.39. However, the pH mean values of the water sources at different seasons are within the permissible limit of WHO of 6.5-8.9 (WHO, 2012). The finding corroborated with that of where the pH of the groundwater in their study was within the permissible limit, even though dry season is the season of maximum pH concentration (Ganiyu et al., 2018; Afolabi et al., 2021; Pearson et al., 1971). The variation in value showed no abnormal change and low value pH has no harmful effect (Mohamed and Zair, 2017; Awan et al., 2012).

4.2 EC

The Electrical conductivity (EC) showed a value range of 674.67 to 522.27µS/cm during the wet and dry seasons for HDW and 169.95 to 158.05µS/cm for BH during the seasons respectively. The EC values for HDW during the wet season indicated that it exceeded the permissible limit of 600µS/cm while the concentration is within the permissible limit of WHO during the dry season (WHO, 2012). The finding outcome differs from the outcome of where both seasons showed EC concentration exceeding the WHO limit (Afolabi et al., 2021; Mohamed and Zair, 2017). However, the EC values for BH are within the permissible limit during the wet and dry seasons. The finding showed similarity with the outcome (Sharma and Chhipa, 2016). According to the extent of EC can be influence by natural weathering as well as anthropogenic activities and it's directly proportional to the TSS (Nnaji et al., 2019; Hameed et al., 2010). From the Seasonal variation of electrical conductivity of Boreholes and Hand-dug wells it shows that seasonal variation has less effect on the Boreholes than the Hand-dug wells. The results obtained in this study also suggest that, electrical conductivity (EC) of Boreholes and Hand-dug wells in this area does not follow a particular pattern but rather depends wholly on human activities and natural geographical formation of a specific location. High level of EC mean values of Hand-dug wells were as a result of run-off, infiltration, percolation from dumpsite, Agricultural activities, abattoir, domestic waste, industrial waste, leachates etc. located near the wells and rivers, also, natural phenomena such as; erosion, flood, high temperature, soil type etc. This is possible because of the shallow nature of the Hand-dug wells (Temuagee et al., 2020)

4.3 TDS

The TDS values for HDW at dry and wet seasons were 329.47mg/L and 252.67mg/L with variation of 76.8mg/L respectively, while BH values during the dry and wet seasons were 87.06mg/L and 72.63mg/L with variation of 14.43mg/L. The TDS values of all the seasons are within the permissible limit of 500mg/l (WHO, 2012). The finding showed similarities with the study conducted by (Adebayo et al., 2015; Ganiyu et al., 2018). The TDS value of less than 1000mg/l implies that the water samples can be classified as freshwater. High TDS concentration in water could lead to laxative or constipation effects and the concentration can be influence by anthropogenic activities such as untreated wastewater and industrial discharge (Leelavathi et al., 2016; Afolabi et al., 2021; Mohamed and Zair, 2017).

4.4 TSS

The mean TSS values of the HDW during the wet and dry season showed 4.10mg/l and 3.87mg/l respectively while the BH showed TSS mean values of 3.87mg/l and 3.64mg/l during the wet and dry season respectively. The TSS mean values of the water sources at different seasons are within the permissible limit of 5mg/l (WHO, 2012). However, the outcome differs from the similar study conducted in Niger Delta communities where their values exceeded the permissible limit except the study conducted by (Woke and Babatunde, 2015; Woke and Umesi, 2018; Afolabi et al., 2021). High value of TSS (mg/l) is an implication for the presence of silt, decaying plants and animal matter (Elenwo et al., 2019).

4.5 TC

The mean Total Coliform (TC) values of the HDW during the wet and dry season showed >1600MPN/100ml and >1600MPN/100ml respectively with no variation at both seasons while the BH showed TC mean values of 840.0MPN/100ml and 823.50MPN/100ml during the wet and dry season respectively at variation of 16.5MPN/100ml. The finding showed that TC value was higher during the wet season for both HDW and BH than the dry season; however, all the values exceeded the permissible limit of 0/100mh/l (WHO, 2012). The finding showed similarity with the study conducted in Niger Delta communities where the TC values exceeded the acceptable limit for drinking water (Woke and Babatunde, 2015; Dick et al., 2018; Afolabi et al., 2021). This finding indicated that the water from the communities irrespective of the sources and seasons have been contaminated with microbes and possible pathogenic microorganisms which its source could be linked to human or animal origin (Elisante and Muzuka, 2016). As noted by high coliform counts seems to be attribute of rural areas water quality in Nigeria (Woke and Babatunde, 2015). The highest TC counts were significantly higher ($p < 0.05$) during the wet than the dry season owing to rising of water table and leaching during rainy season. Water sources that were located within 10 m of pit latrines had the highest coliform counts relative to those located beyond 10 m. Similarly, the highest coliform counts were observed in all shallow wells that (i) had low well head above the ground, (ii) were not covered, (iii) had casing materials which were not concrete and (iv) utilised traditional pumping (bucket/pulley) systems. This was due to contaminated storm water access, inoculation of microbes by exposed buckets and inefficiency of the casing material. Furthermore, the counts decreased with depths of boreholes and shallow wells during the two seasons probably due to retention and die-off (Elisante and Muzuka, 2016).

4.6 Bicarbonate

The mean Bicarbonate values showed that HDW had 105.33mg/l and 95.71mg/l during the wet and dry season respectively with variation of 9.62mg/l while the BH had 63.10mg/l and 59.57mg/l for the same seasons with variation of 3.53mg/l. The highest value of bicarbonate was recorded at HDW during dry season; however, none of the values exceeded the permissible limit of 150mg/l including that of the HDW during the wet season (WHO, 2012). The extent of bicarbonate in water can be influenced by the activities of atmospheric CO_2 and CO_2 from decomposed organic materials (Umapathy, 2011).

4.7 Chloride

The mean values of Chloride are found in the range of 17.85mg/l and 27.0mg/l for HDW during the wet and dry seasons at variation of 9.15mg/l. The Chloride values for BH ranged from 7.51mg/l and 6.20mg/l for wet and dry season at variation of 1.31mg/l. The highest chloride value was recorded during the dry season of HDW; however, none of the water samples exceeded the permissible limit of 250mg/l (WHO, 2011). The finding showed similarities with the study conducted for Niger Delta communities (Ngah and Nwankwoala, 2012; Afolabi et al., 2021; Dick et al., 2018; Mohamed and Zair, 2017). According to chloride in drinking water is comparatively harmless (Omole et al., 2017). However, the extent of chloride in water could be influenced by natural and anthropogenic activities such as salt formation, application of inorganic fertilizer and industrial effluents (Rehman and Rehman, 2014; Bundela et al., 2012; Afolabi et al., 2021).

4.8 Sulphate

The mean value of Sulphate showed that HDW had 20.43mg/l and 30.87mg/l during the wet and dry season with variation of 10.44mg/l while BH had 126.87mg/l and 18.05mg/l with variation of 108.82mg/l. The outcome showed that the highest value of sulphate was recorded during the dry season for HDW and wet season for BH with obvious variation between the season concentrations; however, none of the values exceeded the permissible limit of 250mg/l (WHO, 2012). The finding corroborated with that (Omole et al., 2017). Higher values of sulphate could lead to intestinal disorder and odour under aerobic conditions (Rehman and Rehman, 2014).

4.9 Nitrate

The mean Nitrate value of 1.56mg/l and 1.28mg/l was recorded for HDW during the wet and dry seasons while 0.35mg/l and 0.45mg/l was recorded for BH during the wet and dry seasons. All the values are within the permissible limit of 45mg/l (WHO, 2012). The study found similarities with that (Ganiyu *et al*., 2018; Mohamed and Zair, 2017). Naturally, nitrate is found in soil and water; however, the concentration can increase as a result of anthropogenic activities such as industrial waste and domestic waste (Jameel and Hussain, 2011).

4.10 Calcium

The mean value of Calcium for HDW during the wet and dry season was 31.14mg/l and 38.28mg/l with variation of 7.14mg/l while BH has mean values of 3.01mg/l and 3.40mg/l during the wet and dry season. All of the values are within the permissible limit of 200mg/l (WHO, 2012). The outcome corroborated with similar study conducted in Niger Delta communities while the high concentration during the dry season of HDW could be attributed to reduction in water level attributed to high sunshine resulting in an increase concentration of calcium (Dick et al., 2018; Afolabi et al., 2021).

4.11 Magnesium

The mean value Magnesium for HDW during the wet and dry season was 8.44mg/l and 8.00mg/l while BH has mean values of 4.84mg/l and 5.20mg/l during the wet and dry season. All of the values are within the permissible limit of 150mg/l (WHO, 2012). The outcome corroborated with similar study conducted in Niger Delta communities (Dick et al., 2018).

4.12 Potassium

The mean value potassium for HDW during the wet and dry season was 4.72mg/l and 7.50mg/l with a seasonal variation of 2.78mg/l while BH has mean values of 2.16mg/l and 2.39mg/l during the wet and dry season. All of the values are within the permissible limit of 20mg/l (WHO, 2011). The outcome corroborated with similar study conducted (Ganiyu et al., 2018; Afolabi et al., 2021).

4.13 Phosphorus

The mean value of phosphorus ranged from 0.05mg/l and 0.07mg/l for HDW during the wet and dry seasons and 0.06mg/l and 0.05mg/l for BH during the wet and dry seasons. All of the values are within the permissible limit of 0.1mg/l (WHO, 2012). The low values in phosphorus corroborate with the report of and that reported for Niger Delta communities (Ezeribe et al., 2012; Afolabi et al., 2021). The concentration of phosphorus in groundwater can be influenced by natural and anthropogenic activities such as weathering and percolation of domestic sewage (Mohamed and Zair, 2017).

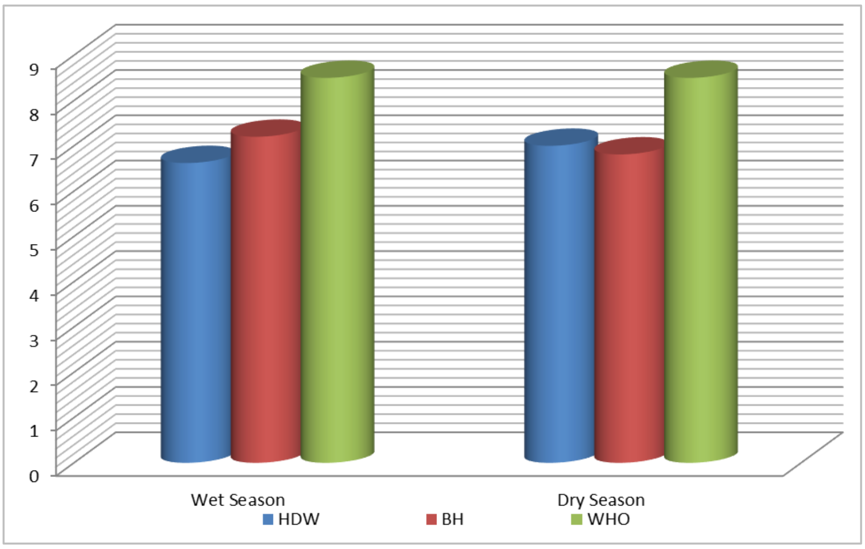

Figure 4: pH concentration from HDW, BH during Wet and Dry as Compared with WHO

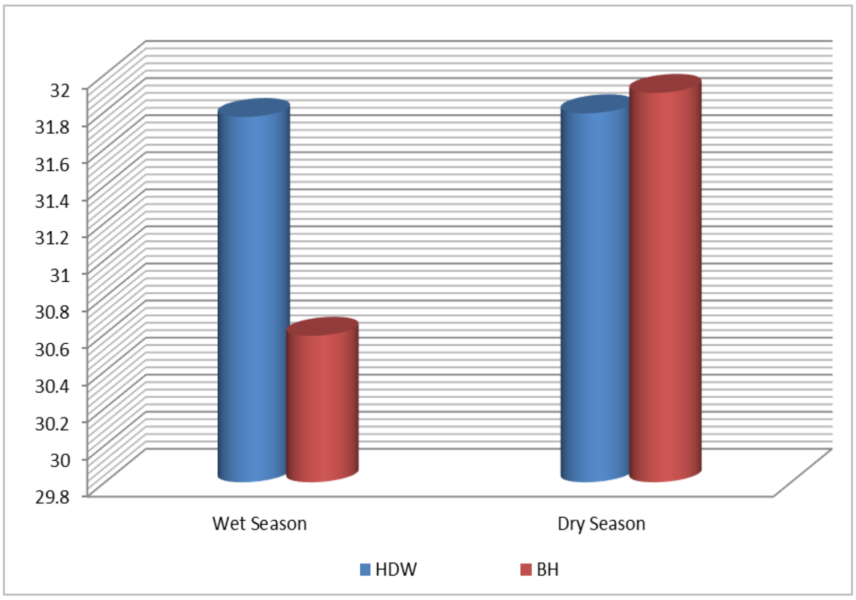

Figure 5: Temperature (°C) concentration from HDW, BH during Wet and Dry as Compared with WHO

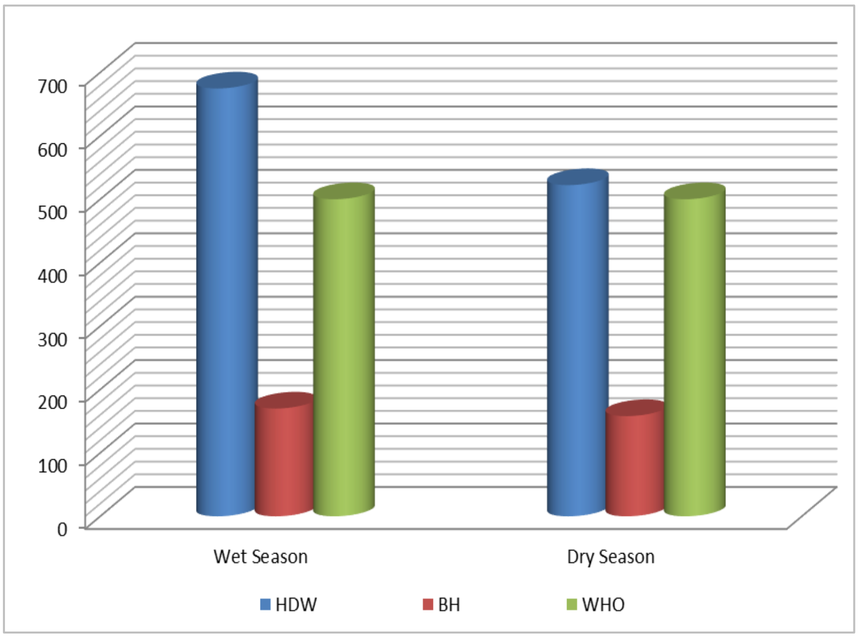

Figure 6: EC (µS/cm) concentration from HDW, BH during Wet and Dry as Compared with WHO

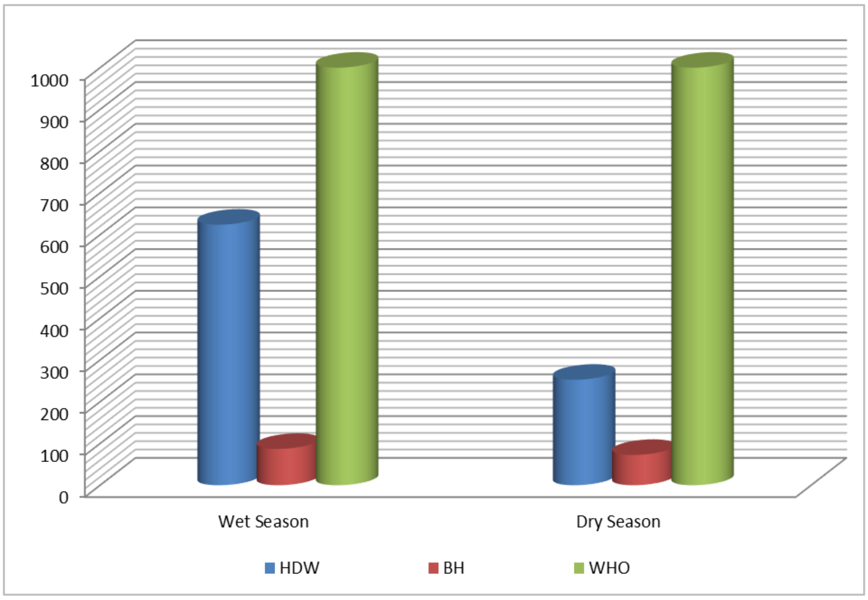

Figure 7: TDS (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

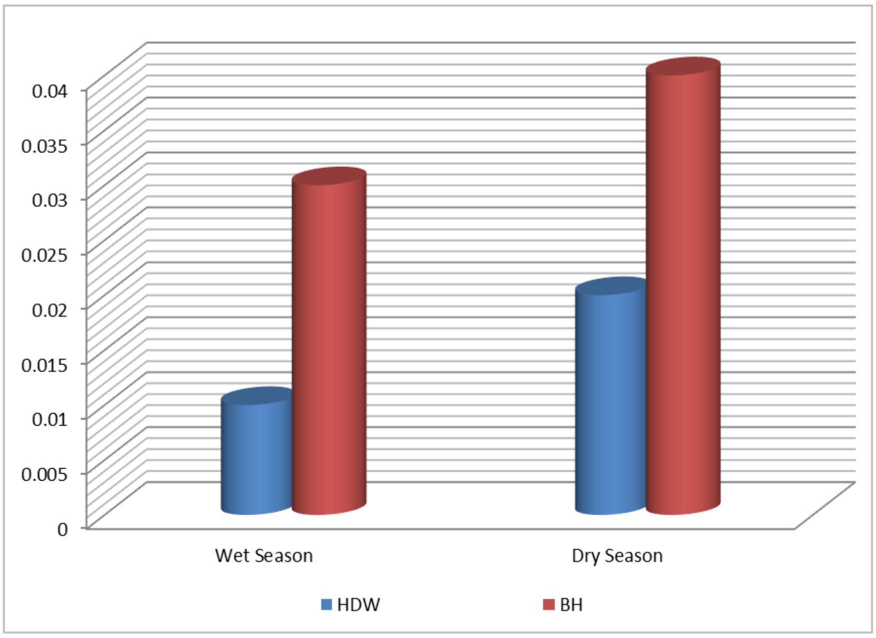

Figure 8: TSS (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

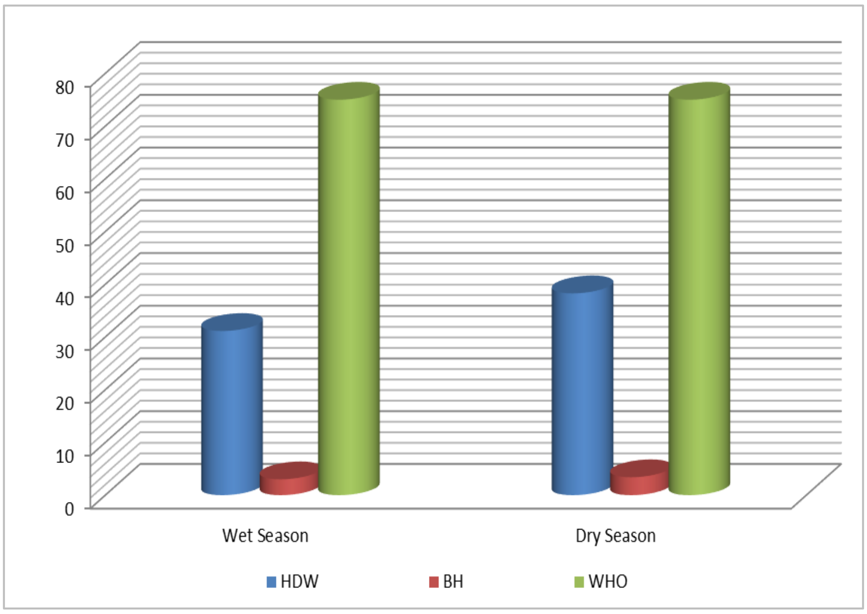

Figure 9: Ca (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

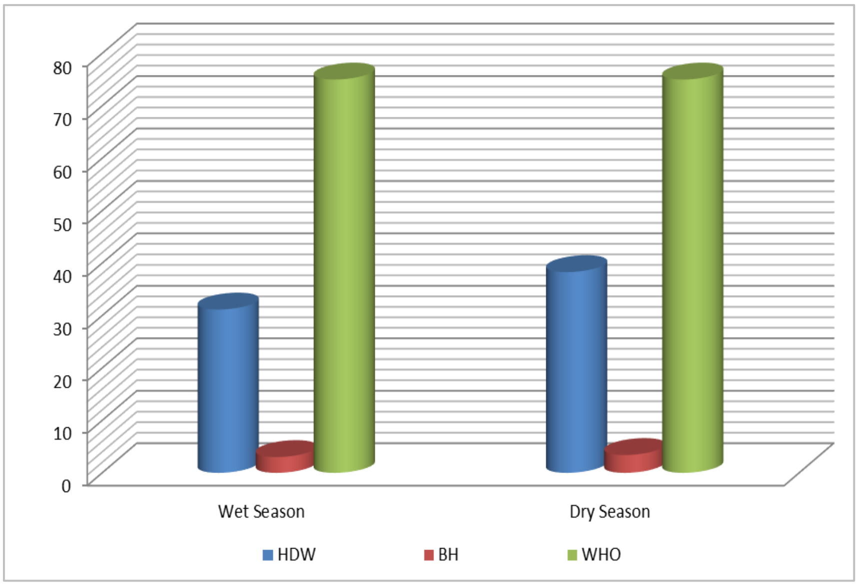

Figure 10: Mg (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

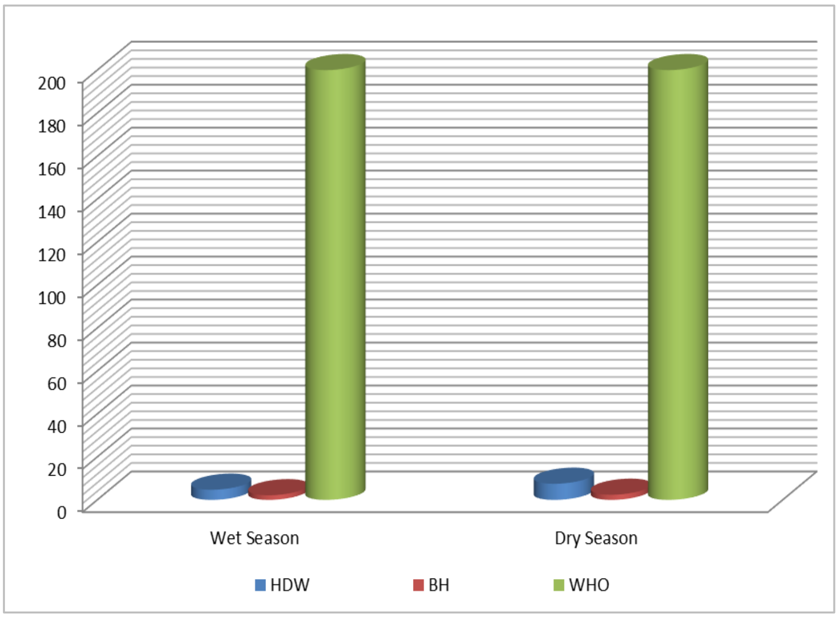

Figure 11: K (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

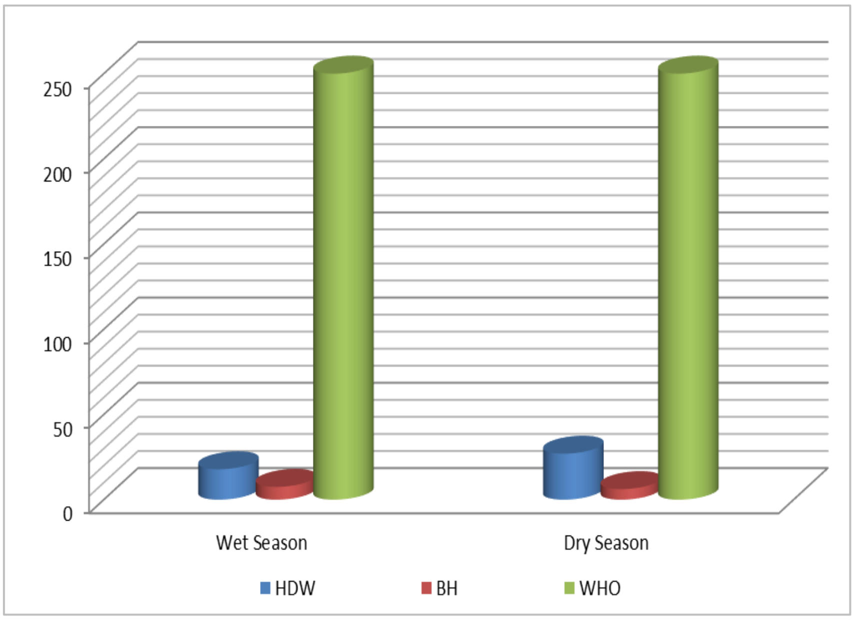

Figure 12: Cl (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

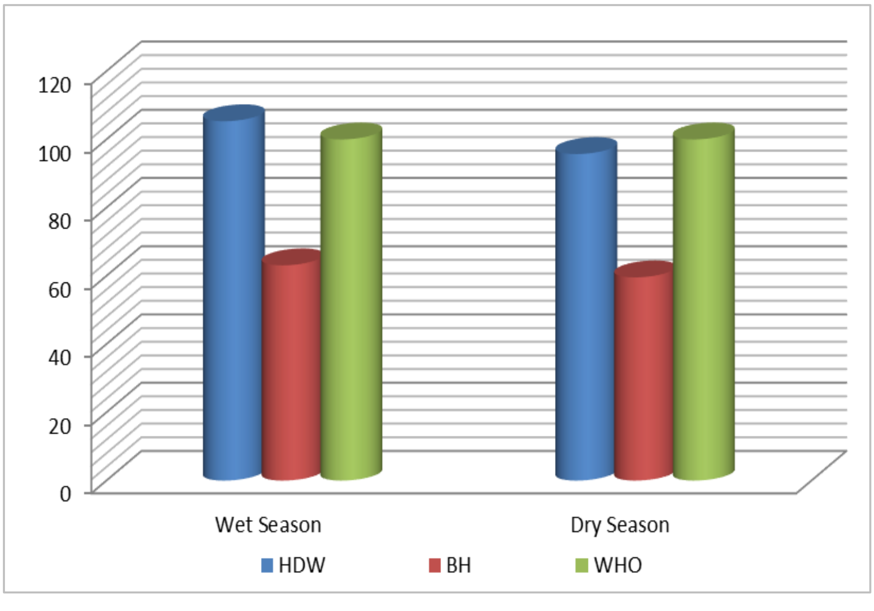

Figure 13: BC (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

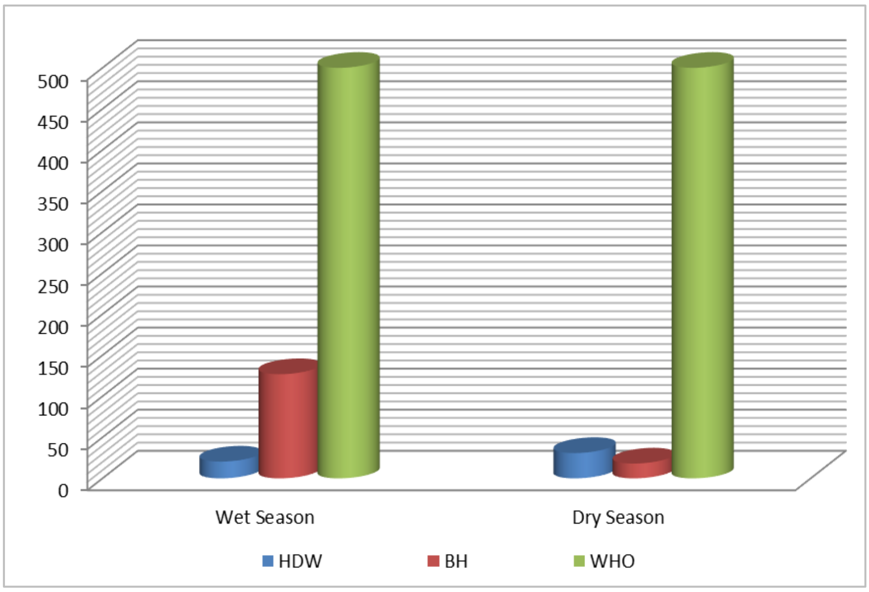

Figure 14: SO_3 (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

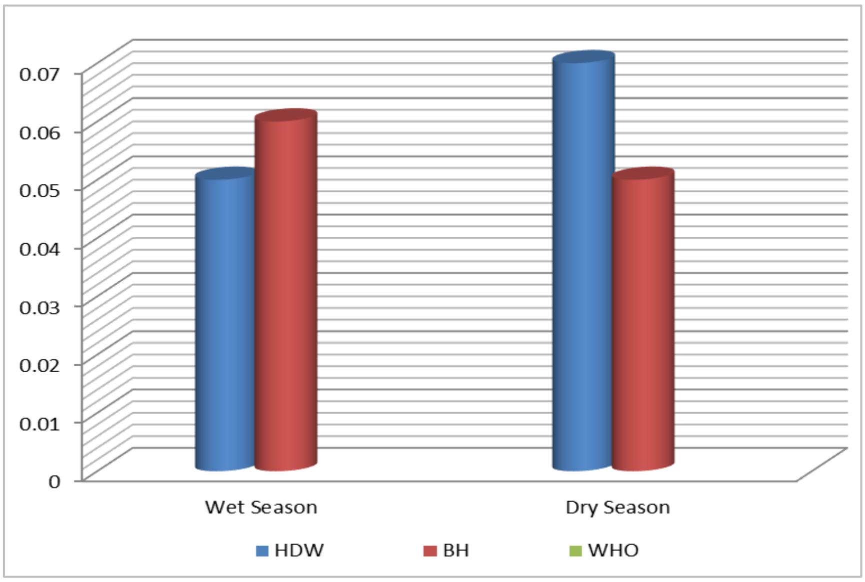

Figure 15: P (mg/l) concentration from HDW, BH during Wet and Dry as Compared with WHO

5. Conclusion

This study examined the concentration of physico-chemical profiles of groundwater quality of communities in Southern Ijaw Local Government Area of Bayelsa State, Nigeria. In carrying out the study, fifteen communities within the LGA were selected and groundwater in form of HDW and BH was sourced for the assessment during the wet season (July) and dry season (March). The sourced groundwater was analyzed for concentration levels of physico-chemical properties of groundwater in the area. This study concluded that the mean values of parameters such as pH, TDS, TSS, Bicarbonate, Cl, $SO_3{}^4$, NO_2, Ca, Mg, K and P of groundwater sourced from HDW and BH during the wet and dry seasons are within the permissible limit of WHO and NSDWQ. Also, the EC of the groundwater was within the permissible limit of WHO and NSDWQ except for HDW during the wet season. The finding revealed that TC value was higher during the wet season for both HDW and BH than the dry season; however, all the values exceeded the permissible limit of WHO and NSDWQ. Groundwater in the area should be treated against coliform contamination prior to utilization as potable water. More so, continuous monitoring of the water quality is key for improved wellbeing of the people in the area. This study may serve as a reference for future studies on the assessment of groundwater quality in the study area.

References

Abam, T.K.S., 1999. Dynamics and Quality of Water Resources in the Niger Delta. Proc. of IUGG Symposia HS5, IAHS Publ., 259, Pp. 429-437.

Abam, T.K.S., and Nwankwoala, H.O., 2020. Hydrogeology of Eastern Niger Delta: A Review. Journal of Water Resource and Protection, 12, Pp. 741-777.

Adebayo, A.S., Ariyibi, E.A., Awoyemi, M.O., Onyedim, G.C., 2015. Delineation of contamination plumes at Olubonku Dumpsite using geophysical and geochemical approach at Ede Town, Southwestern Nigeria. Geosciences, 5 (1), Pp. 39–45. https://doi.org/10.5923/j.geo.20150501.05

Adetunde, L.A., and Glover, R.L.K., 2011. Evaluation of Bacteriological quality of drinking water used by selected secondary schools in Navrongo in Ghana. Journal of Microbiology Research, 1 (3), Pp. 47-51.

Afolabi, O.O., Wali, E., and Ihunda, C.E., 2021. Seasonal Variation Influence on Groundwater Quality of Selected Communities in Sagbama Local Government Area of Bayelsa State, Nigeria. Journal of Research in Environmental and Earth Sciences, 7 (7), Pp. 1-7.

Amadi, A.N., Nwankwoala, H.O., Olasehinde, P.I., Okoye, N.O., Okunlola, I.A., Alkali, Y.B., 2012. Investigation of aquifer quality in Bonny Island, Eastern Niger Delta, Nigeria using geophysical and geochemical techniques. Journal of Emerging Trends in Engineering & Appl Sci., 3 (1), Pp. 180–184.

Appelo, C.A.J., and Postma, D., 1993. Geochemistry, Groundwater and Pollution. Rotterdam: Balkema.

Awan, A.N., Chaudhry, A., Sattar, A., Khan, M.A., 2012. Physical analysis of groundwater at thickly populated area of Faisalabad by using GIS. Pakistan Journal of Agricultural Science, 49, Pp. 541-547.

Bundela, P.S., Gautam, S.P., Pandey, A.K., Awasthi, M.K., Sarsaiya, S., 2012. Municipal solid waste management in Indian cities–A review. International Journal of Environ Science, 1, Pp. 591-606.

Dick, A.A., Solomon, L., and Okparanta, S., 2018. Assessment of selected physico-chemical and microbial parameters of water sources along Oproama River in Oproama Community in Rivers State, Nigeria. World Rural Observation, 10 (1), Pp. 69-74.

Drever, J., 1982. The Geochemistry of Natural Waters, Prentice Hall, Englewood Cliffs NJ.

Elenwo, E.I., Elenwo, O.P., and Dollah, O.C., 2019. Physicochemical and microbial analysis of selected borehole water in Obio/Akpor Local Government Rivers State, Nigeria. International Journal of Advances in Scientific Research and Reviews, 4 (2), Pp. 103-111.

Elisante, E., Muzuka, N.N., 2016. Sources and seasonal variation of coliform bacteria abundancein groundwater around the slopes of Mount Meru, Arusha, Tanzania., Environmental Monitoring and Assessment, 7, Pp. 188 – 195.

Emeka, C., Nweke, B., Osere, J., and Ihunwo, C.K., 2020. Water Quality Index for the Assessment of Selected Borehole Water Quality in Rivers State. European Journal of Environment and Earth Sciences, 1 (6), Pp. 1-6.

Ezeribe, A.I., OShieke, K.C., and Jreuro, A., 2012. Physico-chemical properties of well from some villages in Nigeria with cases of stained and mottle teeth. Science World Journal, 7 (1), Pp. 2112.

Ganiyu, S.A., Badmus, B.S., Olurin, O.T., and Ojekunle, Z.O., 2018. Evaluation of seasonal variation of water quality using multivariate statistical analysis and irrigation parameter indices in Ajakanga area, Ibadan, Nigeria. Applied Water Science, 8 (35), Pp. 1-15.

Hamilton, P.A., and Helsel, D.R., 1995. Effects of Agriculture on Groundwater Quality in Five Regions of the United States, Groundwater, 33, Pp. 217-226.

Hem, J.D., 1970. Study and Interpretation of the Characteristics of Natural Waters, Geological SURVEY Water Supply Paper, Pp. 1473.

Jameel, A.M., and Hussain, Z.A., 2012. Monitoring the quality of groundwater on the bank of Uyyakondan channel of river Cauvery at Tiruchirappalli, Tamil nadu, India. Environmental Monitoring and Assessment, 183, Pp. 103-111.

Kogbe, C.A., 1976. The Cretaceous and Paleogene Sediments of Southern Nigeria. In: Kogbe, C.A., Ed., Geology of Nigeria, Elizabethan Publishers, Lagos, Pp. 273-282.

Kortatsi, B.K., Tay, C.K., Anornu, G., Hayford, E., and Dartey, G.A., 2007. Hydrogeochemical Evaluation of Groundwater in the Lower Offin, Ghana, Ghana. Environmental Geology, 53 (8), Pp. 1651-1662.

Matthess, G., 1990. Die Beschaffenheit Des Grund Wassers, Band 2,

Mohamed, H.M., Zahir, H.A., 2017. Seasonal Variations of Groundwater Quality in and around Dindigul Town, Tamilnadu, India. Der Chemica Sinica, 8 (2), Pp. 235-241.

Nag, S.K., and Das, S., 2014. Quality Assessment of Groundwater with Special Emphasis on Irrigation and Domestic Suitability in Suri I & II Block, Birbhum District, West Bengal, India. American Journal of Water Resources, 2, Pp. 81-98.

Ngah, S.A., and Nwankwoala, H.O., 2013. Assessment of Static Water Level Dynamics in Parts of the Eastern Niger Delta. The International Journal of Engineering and Science, 2, Pp. 136-141.

Ngerebara, O.D., and Nwankwoala, H.O., 2008. Groundwater Resources Potential in the Offshore Niger Delta, Nigeria. Journal of Environmental Hydrology, Pp. 28.

Nigerian Standard for Drinking Water Quality (NSDWQ). 2007. Nigeria, Ministry of Water Resources, Nigeria, Pp. 1-2.

Nwankwoala, H.O., Amadi, A.N., and Oborie, E., 2013. Hydrochemical factors and correlation analysis in groundwater quality in Yenagoa, Bayelsa State. Nigeria Journal of Applied Ecology and Environmental Sciences, 2 (4), Pp. 100–105.

Nwankwoala, H.O., and Ngah, S.A., 2014. Groundwater Resources of the Niger Delta: Quality Implications and Management Considerations. International Journal of Water Resources and Environmental Engineering, 6 (5), Pp. 155 – 163.

Nwankwoala, H.O., and Omemu, S.O., 2019. Quality implications of physico-chemical properties and heavy metals concentration levels in groundwater sources in Elebele community, Bayelsa State, Nigeria. Journal of Environment and Health Science, 5 (1), Pp. 52-58.

Nwankwoala, H.O., and Udom, G.J., 2011. Hydrogeochemical Evaluation of Groundwater in Parts of Eastern Niger Delta, Nigeria. Journal of Academic and Applied Studies, 1 (2), Pp. 33 – 35.

Olajire, A.A., and Imeokparia, F.E., 2001. Water Quality Assessment of the Osum River, Studies on Inorganic Nutrients. Environmental Monitoring and Assessment, 69, Pp. 17-28.

Olajire, A.A., and Imeokparia, F.E., 2001. Water Quality Assessment of the Osum River, Studies on Inorganic Nutrients, Environmental Monitoring and Assessment, 69, Pp. 17-28.

Omole, D., Bamgbelu, O., Tenebe, I., Emenike, P., and Oniemayin, B., 2017. Analysis of groundwater quality in a Nigerian Community. Journal of Water Resource and Hydraulic Engineering, 6 (2), Pp. 22-26.

Petersen, G.R., Warren, H.V., Delavault, R.E., and Fletcher, K., 1970. Heavy metal content of some freshwater fishes in British Columbia. Fisheries Technical Circular No. 2. Fish and Wildlife Branch, Victoria, B.C.

Rehman, F., and Rehman, F., 2014. Water importance and its contamination through domestic sewage: Short review. Greener Journal of Physical Sciences, 4 (3), Pp. 045-048.

Short, K.C., and Stauble, A.J., 1967. Outline Geology of the Niger Delta. AAPG Bulletin, 54, Pp. 761-779.

Temaugee, S.T., Wariebi, A., Saakorun, M.L., 2020. Seasonal Variation of Electrical Conductivity of Groundwater and Its Implication on the Residents of Lafia Municipal Area, Nasarawa State, Nigeria. International Journal of Environmental Protection and Policy, 8 (1), Pp. 22 -30. doi: 10.11648/j.ijepp.20200801.13

Udom, G.J., Nwankwoala, H.O., and Jepthah, H.A., 2012. Seasonal variation of Groundwater Chemistry in parts of Yenegoa, Bayelsa State. International journal of Innovation Environmental Studies Research, 1 (2), Pp. 40-54.

Umapathy, S., 2011. A study on groundwater quality of Neyveli area, Cuddalore district, Tamilnadu. International Journal of Geomatics and Geosciences, 2, Pp. 49-56.

WHO. 2012. World Health Statistics. WHO Department of Health Statistics and Informatics of the Innovation, Information, Evidence and Research Cluster, France, Pp. 162.

WHO/UNICEF. 2011. Joint Monitoring Programme for Water Supply and Sanitation, 2011 estimates for water and sanitation.

Woke, G.N., and Babatunde, B.B., 2015. Assessment of groundwater quality in Emohua LGA, Rivers State, Nigeria. Journal of Natural Sciences Research, 5 (24), Pp. 8- 13.

Woke, G.N., and Umesi, N., 2018. Evaluation of water quality in selected communities in Obio/Akpor L.G.A, Rivers State. International Journal of Research in Agriculture and Forestry, 5 (4), Pp. 13-16.