Hydrochemical Assessment of Delta Central (South Southern Nigeria) Aquifers

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ABSTRACT

Twenty-One (21) water samples collected from seven (7) wells and fourteen (14) boreholes groundwater sources in the Delta Central region of Delta State of Nigeria were analyzed for hydrochemical constituents, to assess their quality. Physiochemical Parameters investigated include PH, temperature, total dissolved solids (TDS), electrical conductivity (EC), turbidity, and total suspended solid (TSS). Anions such as CL^-, SO_4^{2-}, NO_3^-, PO_4^{2-} and cations such as Ca^{2+}, and Mg^{2+} were determined, employing Atomic Absorption Spectrometer (AAS). Dissolve Oxygen (DO) biochemical oxygen demand (BOD), chemical Oxygen demand, and total coliform count were also determined (except for sample water from Ovwian (SW3), Electrical conductivity (EC), Total Hardness, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{2-}, Ca^{2+}, Mg^{2+}, BOD, COD, Cd, Zn and Cu were found to be below the desirable range recommended by WHO. The PH values range from 3.75 to 4.80 for the fourteen boreholes and 5.03 to 6.23 for the seven wells, indicating a predominance of acidic and slightly acidic water respectively. Total hardness values (mgl-1), Cl^- (4 to 37.12), HCO_3^- (<0.001 to 18.90), and total iron (0.01 to 0.2947) are geochemically significant. Heavy metals, including copper, Zinc, Cadmium, and lead are present at a trace level. The water samples are chemically dominated by Cl- and HCO_3^-, with lesser Ca^{2+} and Mg^{2+}. The predominance of chloride constitutes a major attribute of seawater intrusion. At the same time, the heavy metals (high level of lead in Ogborikoko (SW1) and Oviorie (SW3) reflect the increasing impacts of anthropogenic pollution and contamination in the two areas. All cases of groundwater resource development in the Delta Central area require thorough investigation to ascertain the scope and type of pre-use treatment required.

Key Points:

1. Heavy metal contamination in groundwater
2. Ground water quality analysis
3. A comprehensive assessment of groundwater resource development in the Delta Central area is required to identify the essential pre-use treatment measures.

Key words: Groundwater, hydrochemical, physicochemical, permissible, anions.

INTRODUCTION

The Delta central region of Delta State (South Southern Nigeria) is characterized by many surface and groundwater. These water bodies are usually harnessed and used for drinking, and domestic needs including agricultural activities and other industrial activities. Groundwater has been globally recognized as an important natural water resource that serves as a primary source of portable drinking water for more than 2.5 billion people worldwide (WHO/UNICEF, 2018). The plane in the Delta Central region of Delta State alone supplies water to nearly 2.5 million people. Groundwater quality tends to degrade and also become scarce as the population of any geographical region increases (Molle*et al.*, 2018). A population increase inevitably leads to the construction of more houses, the installation of additional septic tanks for domestic and industrial sewage disposal, and a rise in waste generation. Septic tank systems are installed in homes and industries for waste disposal. The discharge of wastewater from domestic and industrial activities into soil above groundwater aquifers is common in Nigeria and many other developing countries that lack centralized wastewater disposal systems. Also Delta Central is an operational base of major oil producing and servicing companies in Nigeria. Petroleum exploration and exploitation have triggered adverse environmental impacts in the Delta area of Nigeria through incessant environmental, socio-economic, and physical disasters that have accumulated over the years due to limited scrutiny and lack of assessment (Amadi*et al.,* 2016). In Nigeria, vast areas of mangrove forests have been devastated due to petroleum exploitation, leading to severe environmental degradation and the destruction of traditional livelihoods in the region. This environmental damage has also caused pollution that has impacted weather patterns, soil fertility, groundwater, surface water, and both aquatic and wildlife. If this trend continues unchecked, the food web systems in this wetland could face an even greater threat from potential heavy metal contamination (Onyena and Sam 2020). This ongoing environmental concern continues to attract the attention of experts, underscoring the importance of evaluating the effects of exploration and exploitation activities in Nigeria's coastal areas. This research emphasizes addressing the over-exploitation of groundwater, which is being heavily relied upon to meet the growing water demand for domestic, agricultural, urban, and industrial purposes, leading to the degradation of groundwater quality in coastal regions. Increasing urbanization is taking place along this coastline of the Delta Central region and causing increased use of groundwater and it has a large impact on the quality and quantity of groundwater system in the area. In many countries around the world, including Nigeria, groundwater supplies may have become contaminated through various human activities, which have an impact on the health and economic status of the people. The discharge of untreated wastewater, soak away, pit-latrine as well as agricultural water runoff from farms can all lead to the deterioration and contamination of groundwater in coastal aquifers via infiltration through the overlying formation (Ijioma, 2021).

The challenge of ensuring usable water in sufficient quantities to meet the needs of humans and ecosystems emerged as one of the primary issues of the 21st century (Eden and Lawford, 2003). For example, inadequate quantity and quality of water supply have serious impact on water resources management and environmental sustainability (Chukwu, 2015).

This problem has been escalating in scope, frequency, and severity as water demand continues to rise, while the supply of renewable water remains unchanged. While it is agreed that water of the most important natural resources which has great implications for the development of any Society, the freshwater situation in Delta State is unfortunately not encouraging. Presently it is estimated that the majority of people in the Delta Central Region of Delta State live in a safe water-scarce environment. Many countries are already experiencing water scarcity conditions (Veldkamp, *et al.*, 2017). The amount of freshwater available for each person in Delta Central region of Delta State Nigeria is about one-quarter of what it was in 1990 (Uzoegbu and Uchebo, 2019; Edeki*et al*., 2023). In many countries, requirements for domestic freshwater use, sanitation, industry, and agriculture cannot be met. The situation is getting worse as a result of population growth, rapid urbanization, increasing agricultural activities, increasing industrial activities, and lack of adequate capacity to manage freshwater resources.

There is a global recognition that the quality of an aquifer is as important as its quantity. Current emphasis is not only on how abundant water is, but also on whether its quality status is good enough to sustain its various uses (USGS, 2020; UNESCO, 2021; WHO, 2021). The quality of groundwater determines its usability for domestic, industrial, and agricultural purposes.

The chemical composition of groundwater and the water types found in an environment is determined greatly by local geology, the type of minerals found in the environment through which the recharge and groundwater flows, anthropogenic activities such as mining and waste disposal as well as climate and topography (Akpan and Ezeigbe, 2010, Ren and Zhang, 2020). The underground water resources vary in extent and magnitude with geological formation with the coastal areas being known for continuous aquifers. These surface and underground waters are prone to impact from natural and anthropogenic activities, which may result in their degradation or contamination in the future (Okuo*et al.,* 2007). The quality status of water is a crucial factor in what the water is to be used for (Edokpayi*et al.,* 2020). For example, water meant for drinking and other domestic purposes must meet laid down local and international standards, otherwise, the consumer stands the risk of water-borne diseases such as typhoid fever, dysentery, diarrhea, and hepatitis.

The chemical constituent of water is known to cause some health risks, so supply cannot be said to be safe if specific information on water quality which is needed for sustainable resource development and management is lacking (Nwankwoala and Udom 2011). Little or no information is available on the quality status of groundwater in the study area.

Most people in the Delta Central region of Delta State use groundwater because of its advantages over surface water. It has therefore become necessary to study the groundwater potentials of the area for proper planning and execution of water projects. The research work highlights some of the hydrochemical parameters that could be useful in this direction. The result obtained could also add to the scanty hydrochemical information in the study area. This research aims to evaluate hydrochemistry as a means of identifying specific water signatures for each aquifer of interest in the Delta Central region in Delta State South Southern Nigeria.

MATERIALS AND METHODS

Study Area

Delta central region of Delta State is located in the western part of the Niger Delta, south of latitude 6ºN. It is contiguous territory of about 5000 square kilometers in the southern part of the Delta State of Nigeria. It is bounded by latitude 5º15'N and 6ºN and longitude 5º40' E and 6º25'E. The main towns are Warri, Sapele, Ughelli, Effurun, and Abraka.

Table 1: Sample location geographical coordination

Site	Site Code	Co-ordinate	Site description
1	SW1	5º53'88.21"N 5º76'43.79"E	Ugborikoko, Uvwie L.G. A
2	SW2	5º66'07.86"N 5º92'21.20"E	Oviorie-Ovu, Ethiope East L.G. A
3	SW3	5º49'41.50"N 5º78'27.30"E	Ovwian, Udu L.G. A
4	SW4	5º22'26.20"N 6º14'51.00"E	Okwagbe, Ughelli South L.G.A.
5	SW5	5º66'55.10"N 5º67'81.00"E	Sapele, Sapele L.G. A
6	SW6	5º85'93.71"N 5º63'92.18"E	Amukpe, Sapele L.G. A
7	SW7	5º66'55.10"N 5º71'57.76"E	Adeje, Okpe L.G. A
8	SW8	5º48'62.28"N 5º75'44.10"E	Aladja, Udu L.G. A
9	SW9	5º50'66.31"N 5º83'38.88"E	Orhuhworun, Udu L.G. A
10	SW10	5º55'76.81"N 5º79'17.19"E	Jakpa, Uvwie L.G. A

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11	SW11	5º59'23.18"N 5º70'70.20"E	Jeddo, Okpe L.G. A
12	SW12	5º56'49.18"N 5º74'04.29"E	Ekpan, Uvwie L.G. A
13	SW13	5º59'28.17"N 5º82'27.19"E	Osubi, Okpe L.G. A
14	SW14	5º55'76.78"N 5º78'61.89"E	Enerhen, Uvwie L.G. A
15	SW15	5º98'44.85"N 5º76'41.40"E	Otefe, Ethiope West L.G. A
16	SW16	5º43'80.60"N 5º85'58.71"E	Otu-Jevwe, Ughelli South L.G. A
17	SW17	5º53'26.93"N 6º07'29.58"E	Agbarha-otor, Ughelli North L.G. A
18	SW18	5º52'48.85"N 5º93'22.72"E	Eruemukochwenian, Ughelli North L.G. A
19	SW19	5º74'23.30"N 5º63'92.16"E	Elume, Sapele L.G. A
20	SW20	5º78'78.27"N 6º10'92.16"E	Abraka, Ethiope East L.G. A
21	SW21	5º62'84.68"N 6º03'62.52"E	Kokori, Ethiope East L.G. A

SW=Sample Water

Physiography and Climate

The Delta Central region of Delta State (South Southern Nigeria) is a typical coastal plain terrain, monotonously lowland and flat with a gentle slope towards the Ethiope River. The climate is equatorial, hot (23 to 37ºC) and humid (relative humidity, 50 to 70%). There is a dry season from about November to February and a wet season that begins in March, and peak in July and October. Six-year annual mean rainfall measured at the Delta State University weather station is 3317.8mm. Vegetation is rainforest, most of which has been decimated and replaced with farmland and secondary forest. However, lush, dense, and swamp primary forest flanks the river banks (Akpoborie, and Efobo, 2014).

Collection of Samples

A total of 21 water samples from hand-dug wells and boreholes were analyzed for the concentration of some hydrochemical parameters. Standard sampling and analytical procedures were adopted to obtain representative data from each of the sampling locations. The choice of sampling locations was based essentially on the spatial distribution of the different water points to cover the entire study area. These samples were taken at the boreholes after 15 min of pumping and after stabilization of the water temperature to eliminate the groundwater stored in the structure. The well samples were collected directly from the well using a polyethylene container. The collected samples were all labeled at the point of collection, preserved, and stored before taking them to the laboratory. Bottles were rinsed with water to be sampled before sample collection. Sufficient air space was left to create space for water expansion. This mode of sample collection is called the Ruthner sampling method. One advantage of this method is that it provides immediate knowledge of the water temperature at the same time of collection (Gordon and Enyinaya, 2012).

The collected samples were brought to the laboratory and analyzed within 24 hours, except for the biological oxygen demand, which requires five days of incubation at a temperature of 20ºC. This was achieved using standard methods as suggested by the American Public Health Association (APHA 2017). The physical parameters were measured in the field, using a multi-parameter HACH SL1000, which is the temperature (°C), the potential of hydrogen (pH), electrical conductivity (EC), salinity, total dissolved solid (TDS) and dissolved oxygen (DO) were also determined in situ. Others were measured in the laboratory of, from samples that were taken and stored in coolers at a temperature below 4 °C. These are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chlorides (Cl^{-}), sulfate (SO_4^{2-}), bicarbonates (HCO_3^{-}), nitrates (NO_3^{-}) and the dry residue. The methods used are those recommended by (Rodier*et al.*, 2009). The analysis of the ionic balance between cations and anions was calculated. It is less than 5% for all the data, demonstrating the reliability of the analytical results. The determination of Ca^{2+}, Mg^{2+}, Cl^{-}, and HCO_3^{-} were measured by the volumetric method (Annapoorna and Janardhana, 2015). The concentrations of SO_4^{2-} and PO_4^{2-}, NO_3^{-} were measured by spectrophotometry (HACH DR6000) and Flame Atomic Absorption Spectrophotometer (FAAS); Perkin Elmer was used to measure major cations of Na, Ca, K. For heavy metal concentrations ofPb, Cd, Fe, Zn, and Cu, the instrument of Inductive Couple Plasma Mass Spectrometry (ICP-MS PerkinElmer) was used to analyze the sample (Wilschefski and Baxter, 2019).

The data from laboratory analysis was analyzed using statistical analysis. In this study, the statistical software IBM SPSS Statistics 20 was used for analyzing descriptive statistics and the correlation coefficient between variables.

RESULT AND DISCUSSION

Table 2: Hydro-physiochemical analysis of underground water samples (Wells) in Delta Central Region of Delta

PHYSICAL PARAMETERS	**SON Limits**	**WHO Accepted Limits**	**WHO Max. Permissible Limits**	**SW1**	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**SW7**	**SW8**	**SW9**	**SW10**
pH	6.5-8.5	6.5-8.5	9.2	5.52	5.91	5.82	6.23	5.85	6.01	5.03	4.46	3.95	4.12
Temp (ºC)	Ambient	28		27.70	27.90	28.10	27.80	28.50	27.30	28.20	28.10	28.60	28.60
TDS (mg/L)	500	500		409.00	66.80	518.00	148.20	172.00	114.00	48.00	97.40	173.00	55.10
Conductivity (µs/cm)	1000	500	1400	736.20	120.20	932.40	310.90	274.00	205.20	86.40	175.30	311.40	99.50
Turbidity (N.T.U)	5	5	25	1.87	0.49	3.42	1.79	1.90	0.93	0.21	0.82	1.84	0.44
TSS (mg/L)	500	500		2.00	1.00	4.00	2.00	2.10	1.00	1.00	1.00	2.00	1.00
CHEMICAL PARAMETERS													
DO (mg/L)	NA	6.00	8.00	6.50	6.70	6.40	6.00	5.80	6.50	5.60	6.10	5.70	5.90
BOD_5 (mg/L)	NA	6-9		3.24	3.40	3.20	2.60	2.70	3.30	2.10	2.90	2.40	2.80
COD (mg/L)		40		8.15	8.50	8.00	6.40	7.27	8.25	5.25	7.25	6.00	7.00
Sulphate SO_4^{2-} (mg/L)	NA	0.05		5.38	1.15	6.17	4.89	3.85	3.46	1.76	2.11	5.10	1.98

Phosphate PO_4^{2-} (mg/L)		0-5	5	2.55	0.71	2.90	1.72	1.22	1.04	0.84	1.21	1.84	1.18
Nitrate (mg/L)	NA	20-45	45	0.94	0.38	1.06	20.00	0.46	0.48	0.26	0.43	0.53	0.33
Chlorine (mg/L)	250	250		36.16	19.00	64.05	5.80	28.60	39.00	18.00	20.50	26.00	18.29
Alkalinity (mg/L as $CaCO_3$)	400	500		18.29	20.20	19.70	12.00	8.91	24.00	17.70	6.55	<0.001	<0.001
Bicarbonate HCO^{3-} (mg/L)	150			11.30	12.11	11.81	4.00	5.18	14.39	10.61	3.93	<0.001	<0.001
T/Hardness (mg. L as $CaCO_3$)	100	500		18.00	28.00	22.00	18.00	22.00	10.00	20.00	27.00	19.00	4.00
Calcium hardness (mg/L as $CaCO_3$)				8.00	11.00	10.00	10.00	10.00	4.00	11.00	13.00	9.00	2.00
Magnesium hardness (mg/L as $CaCO_3$)				10.00	17.00	12.00	8.00	12.00	6.00	9.00	14.00	10.00	2.00
Ca^{2+} (mg/L)		75	200	3.20	4.40	4.00	1.72	2.48	1.60	3.60	4.20	3.60	0.80
Mg^{2+} (mg/L)		30	150	2.40	4.15	3.42	2.98	2.20	1.47	3.17	3.42	2.26	0.49
Total coli form count MPN/100ml		0.05		0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead (mg/L)		0.30		0.031	0.015	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium (mg/L)		0.01		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron (mg/L)	1	0.1	1	0.281	0.104	0.294	0.01	0.208	0.191	0.092	0.116	0.235	0.103
Zinc (mg/L)	1	5	15	0.422	0.215	0.463	0.52	0.482	0.274	0.168	0.241	0.326	0.184
Copper (mg/L)	1.5	0.5	1.5	0.077	0.063	0.081	0.0213	0.042	0.036	0.020	0.031	0.063	0.063

BOD = Biochemical Oxygen Demand

COD = Chemical Oxygen Demand

DO = Dissolve Oxygen

SON = Standard Organization of Nigeria

Table 3: Hydro-physiochemical analysis of underground water samples (Boreholes) in Delta Central Region of Delta

PHYSICAL PARAMETERS	**SON Limits**	**WHO Accepted Limits**	**WHO Max. Permissible Limits**	**SW11**	**SW12**	**SW13**	**SW14**	**SW15**	**SW16**	**SW17**	**SW18**	**SW19**	**SW20**	**SW21**
pH	6.5-8.5	6.5-8.5	9.2	4.50	4.52	4.67	3.75	4.80	4.52	3.90	3.82	4.20	4.60	4.65
Temp (°C)	Ambient	28		27.90	28.60	28.50	27.90	28.00	27.20	26.50	28.10	27.80	28.00	27.80

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TDS (mg/L)	500	500		32.40	42.00	163.70	172.20	138.00	112.00	207.40	185.95	156.00	45.00	98.60
Conductivity (μs/cm)	1000	500	1400	58.30	75.60	294.70	309.2	150.00	180.5	140.00	120.90	212	82.85	158.00
Turbidity (N.T.U)	5	5	25	0.18	0.33	1.27	1.81	0.81	0.78	2.20	1.98	0.85	0.38	2.07
TSS(mg/L)	500	500		1.00	1.00	2.00	2.00	2.0	2.0	1.80	1.00	2.00	1.00	1.00
CHEMICAL PARAMETERS														
DO (mg/L)	NA	6.00	8.00	6.30	6.00	5.50	5.50	5.80	6.20	4.80	4.62	5.20	5.80	6.20
BOD_5 (mg/L)	NA	6-9		3.05	3.00	1.90	2.29	3.50	2.90	275	2.18	2.60	2.30	3.70
COD (mg/L)		40		7.63	7.50	4.75	5.73	8.70	7.10	8.00	7.50	6.80	6.20	4.80
Sulphate SO_4^{2-} (mg/L)	NA	0.05		0.93	1.41	3.88	4.61	6.82	0.82	2.24	2.12	3.25	5.02	1.25
Phosphate PO_4^{2-} (mg/L)		0-5	5	0.46	0.93	1.26	1.72	3.10	0.47	0.62	0.48	0.98	1.80	0.86
Nitrate (mg/L)	NA	20-45	45	0.24	0.31	0.55	0.59	0.14	0.21	0.07	0.30	1.05	0.35	0.10
Chlorine (mg/L)	250	250		4.75	15.07	30.53	37.12	22.50	18.00	20.00	18.50	19.50	24.85	12.00
Alkalinity (mg/L as $CaCO_3$)	400	500		7.93	8.16	10.20	<0.001	5.85	6.30	5.20	10.85	7.00	6.65	4.85
Bicarbonate HCO^{3-} (mg/L)	150			4.75	4.89	6.11	<0.001	3.00	3.20	2.05	18.90	3.50	5.02	3.75
T/Hardness (mg.L as $CaCO_3$)	100	500		15.00	13.00	23.00	19.00	24.00	26.00	20.20	9.80	21.00	26.05	12.85
Calcium hardness (mg/L as $CaCO_3$)				7.00	6.00	11.00	9.00	13.00	12.00	11.20	9.10	10.00	13.85	5.80
Magnesium hardness (mg/L as $CaCO_3$)				8.00	7.00	12.00	10.00	11.00	14.00	10.00	2.00	11.00	12.20	7.05
Ca^{2+} (mg/L)		75	200	2.80	3.20	4.40	3.60	4.70	3.80	2.86	1.24	4.82	8.00	2.60
Mg^{2+} (mg/L)		30	150	1.95	1.71	2.93	2.40	2.50	2.98	2.40	1.56	3.05	6.25	1.80
Total coli form count MPN/100ml		0.05		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00
Lead (mg/L)		0.30		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium (mg/L)		0.01		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron (mg/L)	1	0.1	1	0.281	0.065	0.214	0.228	0.57	0.214	0.106	0.100	0.105	0.180	0.101
Zinc (mg/L)	1	5	15	0.125	0.143	0.281	0.305	0.62	0.200	0.200	0.200	0.200	0.100	0.112
Copper (mg/L)	1.5	0.5	1.5	0.013	0.008	0.042	0.054	0.041	0.021	0.021	0.018	0.02	0.040	0.012

The result of the hydro-physiochemical analysis carried out on the underground water sample (Well and Borehole water) in Delta Central Region of Delta State are summarized in the table below

Table 4: Description Statistics of Well Water

Parameters	Units	Max	Min	Mean	Medium	Std. Dev.	MAC
pH		6.23	5.03	5.77	5.85	0.39	6.5-8.5[a,b]
Temp	(^oC)	28.5	27.3	27.93	27.90	0.38	Ambient[b]
TDS	(mg/L)	518.00	48.00	210.90	148.20	180.60	500[a,b]
Conductivity	(µs/cm)	932.40	86.40	380.80	274.00	324.62	1000[b]
Turbidity	(N.T.U)	3.42	0.21	1.52	1.79	1.09	5.0[b]
TSS	(mg/L)	4.00	1.00	1.87	2.00	1.07	500[a,b]
DO	(mg/L)	6.70	5.60	6.21	6.40	0.41	6 – 8[a]
BOD_5	(mg/L)	3.40	2.10	2.93	3.20	0.48	6 - 9[a]
COD	(mg/L)	8.50	5.25	7.40	8.00	1.19	40[a]
Sulphate SO_4^{2-}	(mg/L)	6.17	1.15	3.81	3.85	1.85	250
Phosphate PO_4^{2-}	(mg/L)	2.90	0.71	1.57	1.22	1.86	5.0[a]
Nitrate	(mg/L)	20.00	0.26	3.37	0.48	7.34	45[a]
Chlorine	(mg/L)	64.05	5.80	30.09	28.60	18.85	250[a,b]
Alkalinity	(mg/L as $CaCO_3$)	24.00	8.91	17.26	18.29	5.14	500[a]
Bicarbonate HCO_3^-	(mg/L)	14.39	4.00	9.91	11.30	3.84	150[b]
T/Hardness	(mg/L as $CaCO_3$)	28.00	10.00	19.71	20.00	5.47	500[a]
Calcium hardness	(mg/L as $CaCO_3$)	11.00	4.00	9.14	10.00	2.48	NA
Magnesium hardness	(mg/L as $CaCO_3$)	17.00	6.00	10.27	10.00	3.55	NA
Ca^{2+}	(mg/L)	4.40	1.60	3.00	3.20	1.10	200[a]
Mg^{2+}	(mg/L)	4.15	1.47	2.83	2.98	0.88	150[a]
Total coli form count	MPN/100ml	2.00	0.00	0.27	0.00	0.76	0.05[a]
Lead	(mg/L)	0.03	0.02	0.02	0.02	0.01	0.30[a]
Cadmium	(mg/L)	ND	ND	NA	NA	NA	0. 01[a]

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Iron	(mg/L)	0.29	0.01	0.19	0.10	0.10	1.00[a]
Zinc	(mg/L)	0.52	0.17	0.42	0.14	0.14	15[a]
Copper	(mg/L)	0.08	0.02	0.04	0.03	0.03	1.5[a]

[a]MAC = Maximum Acceptable Concentration by WHO (World Health Organization, 2022)

[b]MAC = Maximum Acceptable Concentration by SON (Standard Organization of Nigeria, 2017)

Table 5: Descriptive Statistics of Borehole Water

Parameters	Units	Max	Min	Mean	Median	Std. Dev.	MAC
pH		4.80	3.75	4.32	4.48	0.35	6.5-8.5[a,b]
Temp	(^oC)	28.60	26.50	27.97	28.00	0.57	Ambient[b]
TDS	(mg/L)	207.40	32.40	119.90	125.00	59.28	500[a,b]
Conductivity	(µs/cm)	207.40	58.30	169.20	154.00	85.31	1000[b]
Turbidity	(N.T.U)	2.20	58.30	1.31	1.27	0.72	5.0[b]
TSS	(mg/L)	2.00	0.18	1.47	1.40	0.51	500[a,b]
DO	(mg/L)	6.30	4.62	5.68	5.80	0.52	6 – 8[a]
BOD_5	(mg/L)	3.70	1.90	2.65	2.78	0.50	6 - 9[a]
COD	(mg/L)	8.70	4.75	6.78	7.05	1.16	40[a]
Sulphate SO_4^{2-}	(mg/L)	6.82	0.82	2.97	2.18	1,85	250
Phosphate PO_4^{2-}	(mg/L)	3.10	0.46	1.21	1.08	0.72	5.0[a]
Nitrate	(mg/L)	1.05	0.07	0.39	0.34	0.25	45[a]
Chlorine	(mg/L)	37.12	4.75	20.54	19.75	7.83	250[a,b]
Alkalinity	(mg/L as $CaCO_3$)	10.85	4.85	7.23	6.65	1.92	500[a]
Bicarbonate HCO_3^-	(mg/L)	18.90	2.05	5.37	3.93	4.62	150[b]
T/Hardness	(mg/L as $CaCO_3$)	27.00	9.80	18.56	19.60	6.83	500[a]
Calcium hardness	(mg/L as $CaCO_3$)	13.85	2.00	9.43	9.55	3.33	NA
Magnesium hardness	(mg/L as $CaCO_3$)	14.00	2.00	9.30	10.00	3.78	NA
Ca^{2+}	(mg/L)	8.00	0.81	3.62	3.60	1.73	200[a]

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Mg^{2+}	(mg/L)	6.25	0.49	2.60	2.40	1.34	150[a]
Total coli form count	MPN/100ml	4.00	0.00	0.29	0.00	1.07	0.05[a]
Lead	(mg/L)	NA	NA	NA	NA	NA	0.30[a]
Cadmium	(mg/L)	NA	NA	NA	NA	NA	0. 01[a]
Iron	(mg/L)	0.57	0.07	0.19	0.15	0.13	1.00[a]
Zinc	(mg/L)	0.62	0.10	0.23	0.20	0.13	15[a]
Copper	(mg/L)	0.06	0.01	0.03	0.03	0.02	1.5[a]

[a]MAC = Maximum Acceptable Concentration by WHO (World Health Organization, 2022)

[b]MAC = Maximum Acceptable Concentration by SON (Standard Organization of Nigeria, 2017)

Table 6: Correlation matrix between various physical and chemical parameters for well water (bold correlation are significant at P<0.05)

Parameters	Temp (°C)	pH	TDS	Conductivity	Turbidity	TSS	DO	BOD_5	COD	SO_4^{2-}	PO_4^{2-}	NO_3^-	Cl	Alkalinity	HCO_3^-	TH	Ca H	Mg H	Ca^{2+}	Mg^{2+}	TCFC	Fe	Zn	Cu
Temp (°C)	**1.000**																							
Ph	0.145	**1.000**																						
TDS	-0.342	**-0.555**	**1.000**																					
Conductivity	0.112	-0.297	**0.670**	**1.000**																				
Turbidity	-0.329	**-0.547**	**0.811**	**0.517**	**1.000**																			
TSS	-0.265	-0.154	**0.680**	**07465**	0.310	**1.000**																		
DO	0.267	**0.653**	**-0.767**	-0.197	**-0.576**	-0.274	**1.000**																	
BOD_5	-0.204	**0.474**	-0.387	-0.438	-0.161	-0.242	**0.550**	**1.000**																
COD	-0.285	-0.040	-0.076	**-0.559**	-0.321	-0.084	-0.130	0.325	**1.000**															
SO_4^{2-}	0.229	0.014	0.339	0.440	0.098	**0.501**	-0.214	-0.250	-0.047	**1.000**														
PO_4^{2-}	0.324	0.228	0.084	0.286	-0.081	0.346	0.100	0.077	0.048	**0.914**	**1.000**													
NO_3^-	0.337	-0.150	0.254	**0.524**	-0.129	**0.457**	-0.220	-0.410	-0.186	0.442	0.297	**1.000**												
Cl	0.138	-0.314	**0.538**	**0.749**	0.335	**0.581**	-0.353	**-0625**	-0.379	**0.689**	**0.529**	0.444	**1.000**											
Alkalinity	**0.589**	-0.243	0.123	0.132	-0.061	-0.124	-0.357	**-0.715**	-0.120	-0.046	-0.232	0.253	0.194	**1.000**										

HCO_3^-	0.325	**-0.513**	0.263	-0.118	0.307	-0.357	**-0.523**	**-0.765**	0.013	-0.093	-0.260	-0.030	0.030	**0.765**	**1.000**									
TH	-0.333	0.3578	0.189	0.335	-0.082	**0.488**	0.100	-0.113	-0.005	0.402	0.334	0.232	0.375	-0.349	**-0.546**	**1.000**								
Ca H	-0.380	0.225	0.331	0.221	0.044	0.405	-0.180	-0.216	0.147	**0.464**	0.331	0.156	0.383	-0.161	-0.165	**0.921**	**1.000**							
Mg H	-0.313	0.386	0.109	0.3896	-0.125	**0.512**	0.250	-0.042	-0.101	0.297	0.268	0.245	0.332	-0.430	**-0.717**	**0.966**	**0.791**	**1.000**						
Ca^{2+}	-0.054	0.444	-0.122	0.118	-0.301	0.230	0.144	-0.176	-0.150	**0.546**	0.466	0.331	0.354	-0.245	-0.427	**0.802**	**0.738**	**0.753**	**1.000**					
Mg^{2+}	-0.184	0.351	-0.175	-0.018	-0.289	0.047	0.102	-0.263	**0.940**	0.369	0.237	0.165	0.290	-0.169	-0.262	**0.777**	**0.940**	**0.698**	**0.940**	**1.000**				
TCFC	0.014	0.230	-0.364	-0.025	-0.299	-0.276	**0.063**	-0.249	-0.145	0.320	0.235	-0.048	0.158	-0.101	-0.025	0.316	0.383	0.221	**0.730**	**0.818**	**1.000**			
Fe	0.024	0.362	0.076	0.139	-0.159	0.446	0.204	0.237	0.289	**0.645**	**0.723**	0.060	0.174	-0.144	-0.220	0.374	0.38	0.310	0.288	0.140	-0.016	**1.000**		
Zn	0.105	0.085	0.432	0.407	0.120	**0.600**	-0.105	0.106	0.291	**0.729**	**0.788**	0.256	0.442	**-0.074**	-0.112	0.314	0.360	0.238	0.108	-0.118	-0.287	**0.817**	**1.000**	
Cu	0.410	-0.282	0.176	**0.512**	0.059	0.329	-0.016	-0.389	-0.247	**0.630**	**0.609**	0.296	**0.678**	0.043	-0.116	0.015	-0.028	0.021	0.083	-0.017	0.124	0.292	0.438	**1.000**

Table 7: Correlation matrix between various physical and chemical parameters for borehole water (bold correlation are significant at $P<0.05$)

Parameters	Temp (ºC)	pH	TDS	Conductivity	Turbidity	TSS	DO	BOD_5	COD	SO_4^{2-}	PO_4^{2-}	NO_3^-	Cl	Alkalinity	HCO_3^-	TH	Ca H	Mg H	Ca^{2+}	Mg^{2+}	TCFC	Fe	Zn	Cu
Temp (ºC)	**1.000**																							
Ph	-0.337	**1.000**																						
TDS	0.270	0.280	**1.000**																					
Conductivity	-0.001	0.049	**0.614**	**1.000**																				
Turbidity	0.188	0.334	**0.800**	**0.884**	**1.000**																			
TSS	0.316	0.186	0.871	**0.873**	**0.969**	**1.000**																		
DO	**-0.629**	0.411	0.067	0.331	0.138	0.065	**1.000**																	
BOD_5	-0.527	**0.478**	0.163	0.390	0.266	0.166	**0.965**	**1.000**																
COD	-0.422	**0.476**	0.167	0.379	0.292	0.182	**0.911**	**0.986**	**1.000**															
SO_4^{2-}	-0.078	0.297	**0.562**	**0.869**	**0.909**	**0.821**	0.110	0.203	0.204	**1.000**														
PO_4^{2-}	-0.028	0.077	**0.564**	**0.981**	**0.881**	**0.859**	0.243	0.283	0.261	**0.920**	**1.000**													
NO_3^-	-0.192	**0.541**	0.012	0.398	**0.522**	0.451	0.005	-0.41	-0.108	**0.659**	**0.545**	**1.000**												

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Cl	-0.043	-0.036	**0.692**	**0.753**	**0.664**	0.677	0.394	**0.508**	**0.526**	**0.547**	**0.635**	-0.155	**1.000**											
Alkalinity	**-0.681**	-0.127	0.007	0.089	-0.214	-0.184	**0.659**	**0.551**	0.452	-0.170	-0.001	-0.337	0.432	**1.000**										
HCO_3^-	**-0.520**	-0.278	-0.005	0.120	-0.205	-0.164	**0.619**	**0.553**	**0.491**	-0.206	-0.006	**-0.539**	**0.532**	**0.960**	**1.000**									
TH	**0.652**	-0.113	0.139	-0.001	0.027	0.169	0.032	0.012	0.045	-0.301	-0.067	-0.151	-0.124	-0.280	-0.189	**1.000**								
Ca H	**0.779**	-0.269	0.135	-0.044	0.029	0.203	-0.392	-0.442	-0.431	-0.209	-0.030	-0.073	-0.317	**-0.512**	**-0.468**	**0.864**	**1.000**							
Mg H	**0.460**	0.013	0.120	0.029	0.021	0.119	0.322	0.329	0.370	-0.317	0.082	-0.283	0.031	-0.074	0.036	**0.936**	**0.633**	**1.000**						
Ca^{2+}	0.392	**-0.474**	0.178	0.221	0.003	0.191	0.236	0.164	0.148	-0.262	0.109	-0.384	0.256	0.256	0.373	**0.786**	**0.613**	**0.783**	**1.000**					
Mg^{2+}	0.357	0.116	0.189	0.014	-0.040	0.144	0.118	-0.017	-0.075	-0.294	-0.012	0.057	-0.162	0.012	-0.016	**0.852**	**0.814**	**0.744**	**0.792**	**1.000**				
TCFC	-0.033	0.162	-0.220	-0.354	-0.417	-0.358	**0.517**	0.429	0.407	**-0.633**	-0.441	-0.303	-0.259	0.252	0.252	**0.668**	**0.330**	**0.798**	**0.562**	**0.662**	**1.000**			
Fe	0.023	-0.158	0.397	**0.744**	**0.592**	**0.555**	0.366	**0.511**	**0.570**	**0.536**	**0.629**	-0.247	**0.895**	0.265	0.436	-0.092	-0.322	**0.082**	0.236	-0.298	-0.272	**1.000**		
Zn	0.179	**0.528**	**0.451**	**0.595**	**0.823**	**0.708**	-0.071	0.063	0.111	**0.844**	**0.671**	**0.733**	0.186	**-0.604**	**-0.639**	-0.062	0.036	-0.120	-0.376	-0.212	**-0.463**	0.242	**1.000**	
Cu	**0.584**	0.027	0.374	**0.761**	**0.557**	**0.560**	**0.696**	**0.742**	**0.751**	0.413	**0.648**	-0.051	**0.707**	0.323	0.428	0.350	0.012	**0.531**	**0.584**	0.250	0.251	**0.776**	0.206	**1.000**

DISCUSSION OF RESULTS

The results of the physical and chemical parameters given in Table 2 and 3 with the range(5.03 – 6.23), mean ± standard deviation(5.85 ± 0.39) of pH for wells water and range (3.75-4.80), mean ± standard deviation (4.32 ± 0.35) of pHforboreholes water. Generally, the aquifer in South Southern Nigeria is noted for low pH and the acidity of the groundwater has been attributed to gas flaring in the area or may be associated with the oxidation of dissolved ferrous iron or the presence of organic matter in the soil. Petroleum exploration processes release gasses that combine with atmospheric precipitation which recharges various water bodies including groundwater through infiltration (MacDonald *et al*., 2021). The standard pH value for healthy water ranges from 6.8 to 8.5 (WHO, 2022). The result of the pH value reveals that the groundwater of the area is acidic to slightly acidic and this is in agreement with the result that was reported to range from acidic to slightly acidic in their respective study (Udom and Acra, 2006, Okuo*et al.*, 2007; Gordon and Eyinaya, 2012 and Egbai*et al.,* 2013, Oseji *et al.*, 2020).

The temperature of well water ranges from (27.3 to 28.5°C), with a mean ± standard deviation of (27.93±0.39°C), while the borehole water temperature varies from 26.5 to 28.6°C, with a mean ± standard deviation of 27.97 ± 0.58°C. These groundwater temperatures in the area reflect the local physiographical conditions.

Total Dissolve Solids (TDS) values range from (48 -518 mg/L) and (32.4 – 207.4 mg/L) with mean ± standard deviation of (210.90±180.60 mg/L) and (119.90±59.28mg/L) for sampled wells and boreholes water respectively. These values are low and below WHO (2006), FEPA (1991), and SON (2007) standards of 1000mg/L.TDS above 1000mg/L shows salt water. The Perth Groundwater Atlas (2004) has recommended categories for TDS of natural groundwater:fresh 0-500 mg/L, marginal 501-1000 mg/L, brackish 1001 – 5000 mg/L, and saline>5001 mg/L. Groundwater in the study area may therefore be fresh and marginal.

Conductivity and TDS almost go together. The mean + standard deviation values for conductivity are

380.80±324.62(µs/cm) for wells water and 169.20±85.31(µs/cm) for boreholes water. The low values of Electrical Conductivity (E.C), is an indication that the water samples are fresh. These values were however far below the WHO limits for drinking waterof 1200 (µs/cm). This is in consonance with the TDS value recorded. A higher TDS means that there are more cations and anions in the water with more ions in the water, the water becomes saline and increases the electrical conductivity.

The mean ± standard deviation values for Total Suspended Solid (TSS) are (1.87±1.07 mg/L) and (1.49±0.51 mg/L) for both well and borehole water respectively.

The dissolved oxygen (DO) values are within the permissible limits of 6-8 mg/L. The mean + standard deviation value is 6.21±0.41 mg/L for wells water and 5.69±0.52 mg/L for boreholes water.

The Biochemical Oxygen Demand (BOD) is reported to be a fair measure of cleanliness of any water on the basis that values less than 1-2mg/L are considered clean. 2-3mg/L fairly clean, 5mg.L doubtful, and 10mg/L definitely bad and polluted (Moore and Moore, 1976). The mean ± standard deviation values for wells and boreholes water are 2.93±0.48 mg/L and 2.65±0.50 mg/L respectively. This shows that the overall quality of groundwater in the study area is fairly clean.

The Chemical Oxygen Demand (COD)is an indication of organic matter susceptible to oxidation by chemical oxidants. A large value of COD (>100 mg/L) indicates high organic pollution, moderate COD value (50 – 100 mg/L) indicates moderate organic pollution and low COD value (< 40 mg/L) is generally considered safe. The COD values in the sampled area are generally below 40 md/L. The COD/BOD ratio of water samples from the study area are (> 1.5 mg/L) indicating that the water body will be in oxidative stress. The mean ± standard deviation value of COD in both wells and boreholes water in the studied area is (7.40±1.19 mg/L) and (6.78±1.16 mg/L) respectively. The COD values recorded are below the WHO-accepted limits.

Sulphate (SO_4^{2-}) has an elevated concentration with a mean + standard deviation value of 3.81±1.85 mg/L for wells water and 2.97±1.85 mg/L for boreholes water. This is high compared to the WHO permissible limit of 0.05mg/L. the outcome of the elevated concentration could be attributed to the Deltaic plain that is a sequence of sands and clays. The dissolution of sulphides such as pyrite from the interstratified materials by percolating water produces SO_4^{2-} ions in water. SO_4^{2-} ion occurrence could also be related to increasing traffic flow and petroleum activities in the study area. Gaseous emissions from vehicles contain a significant amount of sulfur-rich gases. The gas flares in the area are also major contributors of sulfur-rich gases into the atmosphere. According to (Oghenejobor, 2005; Olobaniyi and Owoyemi, 2006) the relatively calm atmosphere coupled with constant rainfall and high temperature in the area ensures that much of the emitted substances are not carried far from the vicinity before they are scavenged out of the atmosphere as acid and recharges the aquifer. Recent studies on the nearby Niger Delta community show that SO_4^{2-} ions contribution to free acidity could be high as 76% (Ogunkoya and Efi, 2003).

The phosphate ion (PO_4^{2-} in mg/L) recorded a mean ± standard deviation value of 1.57±0.86 mg/L for well water and 1.21±0.72 mg/L for boreholes water. The values are within the acceptable limit of 0-5 mg/L set by the WHO.

Nitrate (NO_3^- in mg/L) recorded a mean ± standard deviation value of 0.80 ±0.61 mg/L for wells water and 0.30±0.24 mg/L for borehole water. These values are within the acceptable limit for drinking water. Normally, nitrate pollution is associated with septic systems and agricultural activities. The mean ± standard deviation value for chloride is 30.09±18.85 mg/L for well water and 20.55±7.83 mg/L for borehole water.

Alkalinity is not pollution. It is a total measure of the substance in water that has acid-neutralization ability. It

protects or a buffer against pH changes that is, keeps the pH fairly constant and makes water less vulnerable to acid rain (Gordon and Enyinaya, 2012). The mean ± standard deviation value for Alkalinity is 17.26±5.14 (mg/L as $CaCO_3$) for well water (table 4) and 7.23±1.92 (mg/L as $CaCO_3$) for boreholes water (table 5). The implication for these values is that there are geological formations that have carbonate, bicarbonate, and hydroxide compounds.

Bicarbonate also records a mean ± standard deviation value of 9.91±3.84 mg/L with minimum and maximum values of 4 and 14.39 mg/L respectively for well water and 5.37±4.62 mg/L with minimum and maximum values of 2.05 mg/L and 18.9mg/L respectively for boreholes water. The type of soil and atmospheric carbon dioxide (CO_2), carbonate, and oxidation of organic materials may be responsible for the value obtained (Back and Custodio 1995)

Calcium and magnesium ions in water are responsible for total hardness (TH). Total hardness is an important criterion for determining the suitability of water for domestic, drinking, and industrial supplies (Karanth, 1987). TH varied from 10-20, with a mean ± standard deviation value of 19.71±5.47 (mg/L as $CaCO_3$) for the well water sample and 9.8-27 (mg/L as $CaCO_3$) with a mean ± standard deviation value of 18.56±6.83 (mg/L as $CaCO_3$) for the boreholes water.

According to Freeze and Cherry (1977), total hardness can be classified as soft, if it is between 0 and 60 mg/L. Thus, the groundwater in the study area is soft.

The inorganic chemical constituents obtained in the study are in the normal range permissible by WHO. The constituents have been categorized into three categories. Major constituents which are cations include calcium and magnesium while anions include bicarbonate, sulphate, and chloride.

The secondary category with a permissible concentration range of 0.01-10 (mg/L) which is cation is iron (Fe).

The third category is trace elements. The cations in this group include lead (Pb), Cadmium (Cd), Zinc (Zn) and Copper (Cu).

Calcium ion in wells water range from 1.6 - 4.4 mg/L with mean ± standard deviation value of 13.00±1.10 mg/L for well water (table 4) and 0.8 - 8.0mg/L with mean ± standard deviation value of 3.62±1.73 mg/L for boreholes water (table 5). Calcium salt and calcium ion are among the most commonly occurring inorganic chemicals in nature. Though the human body requires approximately 0.7 – 2.0g of calcium per day as a food element, excessive amounts can lead to the formation of kidney or gallbladder stones. Calcium toxicity is rare, but overconsumption may lead to the deposit of calcium phosphate in the soft tissue of the body (Gordon *and Enyinaya*, 2012). Calcium toxicity causes depression.

Other secondary constituents of groundwater found in the analysis are magnesium ion and iron ion. Mg^{2+} has a mean ± standard deviation value of 2.83±0.88 mg/L for well water and 2.60±1.34 mg/L for boreholes water while iron ion (Fe^{2+}) 0.19±0.13mg/L for boreholes water and 0.70±0.10 mg/L for well water. The min and max values are (0.065 and 0.57 mg/L) and (0.01 and 0.294 mg/L) for wells and boreholes water respectively (table 4 and 5). Iron exposure at high levels has been shown to result in vomiting, diarrhea, abnormal pain, seizures, shock, low blood glucose, liver damage, convulsions, coins and possibly death after 12-48 hours of ingesting toxic levels of iron (Nwuidu*et al.*, 2008). Death may also occur if children ingest sufficient iron to exceed the body's iron-binding capacity (Yuen and Becker, 2019).

The mean ± standard deviation value of Zn concentration is 0.36±0.14 mg/L for well (Table 4) and 0.23±0.13 mg/L for borehole water (Table 5). The value is within the maximum tolerance limit set at 0-5mg.L by WHO (Table 3).

Copper mean ± standard deviation value is 0.05±0.03 mg/L for well and 0.03±0.02 mg/L for boreholes water. These values are within the acceptable limit of the WHO as shown in (Table 3 and 4). The rest of Cadmium (Cd) Lead (Pb) was more or less not detected except for samples SW1 and SW2 with lead concentrations of 0.031mg/L and 0.015mg/L respectively. This portends some health hazards as the accumulative effect of these levels may possibly lead to Pb poisoning (Ara and Wani, 2015).

The descriptive statistics of the well and borehole water are shown in Table 4 and 5 the TDS, EC, turbidity, TSS, DO, BOD, COD, SO_4^{2-}, PO_4^{2-} NO_3^-, alkalinity, HCO_3^-, T/hardness, Ca^{2+}, Mg^{2+}, Pb, Fe, Zn, and Cu concentration are below the MAC in drinking water. The concentration of TDS was found to be greater than 500 mg/L in 1 out of 21 locations sampled. The correlation between various physical and chemical parameters analyzed between the different locations at 5% level of significance ($p<0.05$) shows a significant correlation between the various parameters and are indicated with bold numerical values (Table 6 and 7). The borehole water shows a negative correlation between DO and Temperature, HCO_3^- and temperature, alkalinity and temperature, Ca^{2+} and pH, HCO_3^- and NO_3^-, Zn and HCO_3^-, Zn and Mg^{2+}. Also negative correlation exists between TDS and pH, turbidity and pH, HCO_3^- and pH, DO and TDS, COD and EC, DO and turbidity, DO and HCO_3^-, BOD and alkalinity, HCO_3^- and TH, HCO_3^- and CaH in well water. These negative correlations indicated that an assumed dependence of the parameters were opposite to what exists. The borehole water correlation matrix in Table 7 shows a positive correlation coefficient between Cu and Fe with r= 0.776, this strong correlation coefficient indicates that the two elements have the same source of pollution. This also applies to Zn and Fe in water with r= 0.817. The source of these heavy metals level in water samples is prone to leachate contamination from refused dump sites.

CONCLUSION AND RECOMMENDATION

Water quality assessment was carried out in major communities of the eight local government areas that made up the Delta Central region of Delta State. Water samples were collected from 7 hand dug wells and 14 boreholes evenly distributed within the region. pH, temperature, TDS, EC, turbidity, and TSS which characterized the physical parameters and the chemical parameters which include the DO, BOD, COD, SO_4^{2-}, PO_4^{2-}, NO_3^-, Cl^-, Alkalinity, HCO_3^-, total hardness, Ca^{2+}, Mg^{2+}, total coli form count, Pb, Cd, Fe, Zn, and Cu.

The concentration values of the various parameters determined for each of the water samples are relatively below WHO, 2022 standard for domestic uses. The pH results obtained showed that the water samples from the boreholes are acidic (3.75 to 4.70), while those from the well are slightly acidic (pH 5.52 to 6.23) and lower than WHO specified standard except for the total coli form count which is higher than the WHO permissible limits in two sample locations (SW2 and SW20) this high level of total coli form reflect the increasing impact of anthropogenic pollution and contamination. The water sample from the various wells and boreholes are therefore not fit for domestic, agricultural; and industrial purposes. It is therefore recommended that water abstracted from this region should be treated before consumption, borehole should be made far away from any possible contaminant sources like waste dump sites and septic tanks, regular pollution monitoring has to be undertaken to asses environmental status and water treatment plant should be established. This study should be replicated for comprehensive data development on the suitability of water resources in the Delta Central region of Delta State.

Conflict of interest

The authors declare that there is no conflict of interest.

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