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(Research Article)

Spatial Variation of Physico-chemical and Microbial Parameters in Groundwater of Selected LGAs of Akwa-Ibom State, Nigeria

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Abstract

Physico-chemical and microbial parameters of groundwater are useful indicators in monitoring the progress of Goal 6.3 of Sustainable Development Goals (SDGs). The study evaluated the spatial variation of physico-chemical and microbial parameters in groundwater of selected LGAs of Akwa-Ibom State, Nigeria in line with SDGs. A total of twenty (20) groundwater samples were collected from boreholes at different locations within Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan Local Government Areas of Akwa-Ibom State. The boreholes were selected at random. Sterilized and pre-labelled water sampling bottles were used in collecting representative water samples to prevent contamination. Physico-chemical parameters sensitive to environmental changes such as temperature, pH and electrical conductivity were measured in-situ. Sampling and analysis followed guidelines specified by the American Public Health Association, (2012). Chemical analysis was carried out at the Geospectra Laboratory in Port Harcourt, Rivers State of Nigeria. Results showed that the groundwater condition ranged from acidic and slightly weakly acidic in Uyo and Ibiono Ibom but slightly alkaline in Itu. All the heavy metals analysed were within the permissible limits specified by WHO (2018) and NSDWQ (2015) in drinking water. The average values of total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), faecal coliform and total coliform in Uyo, Itu, Ibiono and Ibesikpo were 57.4 mg/L, 40.1 mg/L, 97.0 mg/L, 1032 and 1542.3 MPN/100ml, 54.3 mg/L, 51.6 mg/L, 110 and 47, 20.5 mg/L, 35.7 mg/L, 78.5 mg/L, 28.8 and 82.5 MPN/100ml, and 184 mg/L, 42.8 mg/L, 94.3 mg/L, 130 and 280 MPN/100ml respectively. The values of pH, BOD, COD, faecal and total coliforms were found to be above the permissible limits. Faecal and total coliforms, which indicate recent contamination, are high in Uyo and could be attributed to urbanisation with its consequent sewage management issues and increased animal droppings. There is a need for proper sewage management within the city.

Keywords: Spatial Variation; Physico-Chemical Parameters; Groundwater; Akwa-Ibom

1. Introduction

The importance of water cannot be overemphasized. As an indispensable natural resource, water seems to be the most defining factor for life, its quality and existence. The survival of man and other living things has been hinged on this important resource while good drinking water quality remains a necessity for life (Okere *et al.,* 2021; Udom *et al.,* 2018). Water plays a key role in the development of many other sectors of the economy including agriculture, health, industry and energy (Dimka, 2018; UN, 2018).

Groundwater is water stored, preserved and locked-up beneath the earth's surface and it constitutes over one-third of the water used either for domestic, agricultural or industrial purposes (Wu *et al.,* 2020). As one of the most refined forms of potable water that is available in nature, groundwater is useful for domestic use and other purposes. It seems that many people in the developing countries of the world have shown preference to groundwater as a reliable source of drinking water owing to its high quality and less vulnerability to pollution compared to surface water. Globally,

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groundwater is recognized as one of the most important natural resources and has remained a significant component of the global freshwater supply. It is an important source of freshwater particularly in regions where surface water is either not always sufficient or is polluted as with the case in Niger Delta region of Nigeria. Many cities and towns in Nigeria make use of groundwater for domestic, industrial and agricultural purposes (Udom *et al.,* 2018).

Over the years, groundwater quality has increasingly become an important issue of discussion as water pollution is now a serious environmental concern demanding for global attention (Bello *et al.,* 2019). Goal 6.3 of the Sustainable Development Goals (SDGs) is focused on improving the quality of water (UN, 2018). The progress of SDG 6.3 can be monitored by determining the proportion of the bodies of water that have good ambient water quality (UN, 2018). Pollution of groundwater increases the stress and difficulty involved in finding potable water for drinking and other purposes. Any modification in the chemical, biological and/or physical parameters of water which mostly originates from anthropogenic activities impairs the quality of water thereby making it unsafe for not only drinking but for any other use (Agarin *et al.,* 2019; Hwang *et al.*, 2017). It is on the basis of this that the assessment of spatial variation of physico-chemical groundwater parameters becomes important. Although many works have been carried out in years past on the same issue within the study area, faecal and total coliforms (indicators of recent pollution), biochemical oxygen demand and chemical oxygen demand (indicators of organic pollution) have not been considered. There is still need for periodical assessment of groundwater quality especially as industrialization, indiscriminate dumping of refuse and disposal of wastes that contain potential contaminants have become a norm in Akwa-Ibom State thereby limiting the potability of surface water. The strict monitoring, maintenance and assessment of water quality remain essential part of water resource management (Wizor *et al.,* 2019).

1.1. Study Area

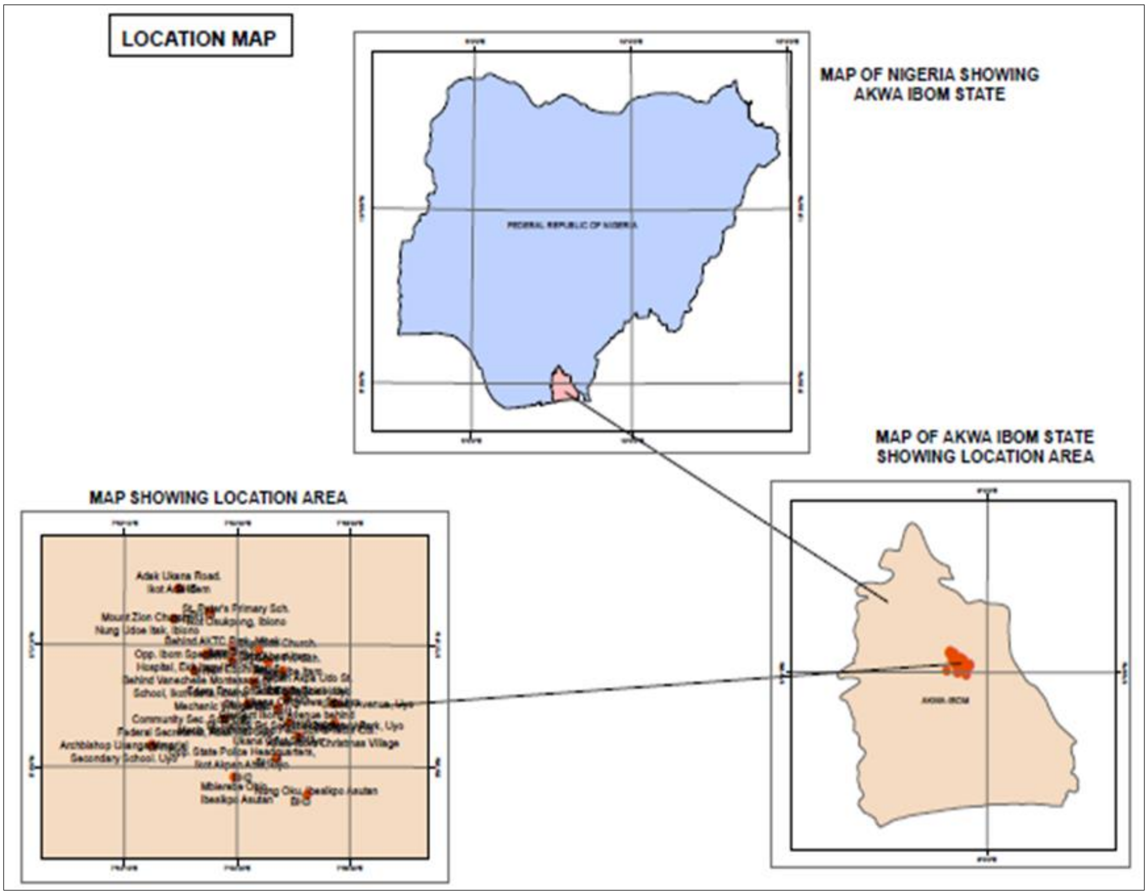

Figure 1 Location Map of the Study Area

This study was carried out within four (4) selected Local Government Areas of Akwa-Ibom State namely Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan. The study area lies in latitude 05° 01' 07.9'' N to 05° 03' 52.6'' N and longitude 007° 51' 24.4'' E to 007° 55' 57.2'' E (Figure 1). Akwa-Ibom State has a total land-mass of 6,900 km² and is drained by three major rivers namely the Cross River, the Imo River and the Qua Iboe River to the east, south west and south central part respectively. These three rivers together flow from the northern highlands of the state and flow into the Atlantic Ocean in the south. An ocean front forms part of Akwa-Ibom State, spanning a distance of about 129 km stretching from Ikot Abasi in the west to Oron in the south eastern part. Akwa-Ibom State is located within the Niger Delta region of Nigeria. January is the warmest month with an average temperature of 27.6 °C while August is the coldest month with a temperature averaging 25.5 °C. In a projection study of the changes in temperature and precipitation in the Niger Delta region, Agumagu & Agumagu (2018) showed an overall increasing trend in temperature and precipitation. The Niger Delta has a mean annual rainfall ranging from 2000 mm (inland) to over 4000 mm at the coast, and about 85 % of this occurs in the wet season. The high humidity (which decreases slightly in the dry season) alongside the long-wet season of about 6-10 months ensure adequate supply of water and moisture which promote the growth of perennial trees and shrubs (Abam & Nwankwoala, 2020). The water table depths in the area increase seawards, varying from about 5 m (inland) to 0.5 m at the coast. The high-water table in the Delta resulting from the high rainfall, swampy and flat topography of the area accounts for the high-water content of soil in the region.

1.2. Geology of the Study Area

The area of study lies within the Eastern part of the Niger Delta Basin. The origin of Niger Delta basin is traceable to the Cretaceous period during which the African plate broke off from the South American plate (Guiraud & Maurin, 1991). From the Eocene to the present, the delta has prograded south-westward, forming depo-belts that represent the most active portion of the delta at each stage of its development (Doust & Omatsola, 1989). Whiteman (1982) and Burke and Whiteman (1973) posited that rift faults bounded the north-western edge and north-eastern edge of the Niger Delta basin.

A total of five major depo-belts have been recognized in the Niger Delta basin which are Offshore, Coastal Swamp, Central Swamp, Greater Ughelli and Northern Delta (Obaje, 2009). The Central Swamp was re-classified by Doust and Omatsola (1989) into two smaller groups of Central Swamp I and Central Swamp II. These depobelts which are depositional points form one of the largest regressive deltas in the world with an area of some 300,000 km^2, a sediment volume of 500,000 km^3 and thickness of over 10 km in the centre of the basin (Kaplan *et al.,* 1994; Hospers, 1965; Kulke, 1995). According to Obaje (2009), the depo-belts represent a successive phase of grown delta having bands of thick sequences of deposits bounded by faults. The depositions of the Niger Delta resulted from the Paleocene-Eocene transgressive and regressive sequences. It is a body of transitional, continental and marine deposits formed by sediments supplied mainly by the Benue and Niger rivers in the Tertiary and Quaternary times.

The evolution of the Niger Delta is controlled by pre-and syn-sedimentary tectonics as described by Short & Stauble (1967), Weber & Daukoru (1975), Evamy *et al.,* (1978), Ejedawe (1989), Doust & Omatsola (1989), Stacher (1995) among others. The Tertiary Niger Delta is a sedimentary structure, of classic sediments, ranging in thickness from 9,000 to 12000 meters. The three main depositional environments typical of most deltaic environment (marine, mixed and continental) are observable in the Niger Delta and are represented by the three major lithostratigraphic units in the region. The grouping of sedimentary units of Niger Delta into three is based on lithostratigraphic units ratio of sands to shales in the deposits (Short & Stauble, 1967; Avbovbo, 1980). These lithostratigraphic units were named Benin Formation, Agbada Formation and Akata Formation by Evamy *et al.,* (1978). Niger Delta underlying the superficial soils and the Quaternary alluvial deposits from bottom to top the Akata, Agbada and Benin Formations respectively. Akpokodje (1989) grouped the Niger Delta region into five major geomorphologic units of dry flatlands and plains, deltaic plains with abundant fresh water back swamps, fresh water swamps, saltwater or mangrove swamps and active/abandoned coastal ridges, and active/abandoned coastal beaches. On the aquifers, Etu-Efeotor & Odigi (1983) and Etu-Efeotor & Akpokodje (1990) found that there are several irregular, lenticular and laterally discontinuous layers of clay aquitards which in most areas partially sub-divided the regular aquifers into units. The main aquifer system within the Niger Delta of Nigeria is the Benin Formation in which sands and sandstones constitute about 90 % of the lithology (Offodile, 2002).

2. Materials and Method

Field study was carried out in November, 2023. During field study, samples of groundwater were collected from boreholes. Guidelines specified by the American Public Health Association, APHA (2012) were followed in sampling and analysis of groundwater samples. A total of twenty (20) groundwater samples were collected from boreholes at different locations within the study area (Figure 1; Table 1). From Uyo main town, Itu, Ibiono Ibom and Ibesikpo Asutan, eleven, four, four and one groundwater samples were collected respectively. The boreholes were selected at random. Sterilized water sampling bottles were used in collecting representative water samples to prevent contamination. The sampling bottles were two 1-litre plastic containers and brown bottles. At each borehole location, the water sampling bottles were washed and rinsed thoroughly with the sample water before being sampled. Water samples were collected close to the well head to maintain the water integrity. The boreholes were allowed to flow for about 3 minutes to ensure stable conditions before collecting water samples. The sample bottles were filled to the brim with the sample water, and the lid immediately placed back to minimize oxygen contamination and escape of dissolved gases. Sampling was done using three sets of pre-labelled sampling bottles of one litre capacity for ionic, heavy metals and microbiological analysis respectively. Water samples for the determination of cations were stabilized by adding few drops of diluted HCl to them after collection. To maintain the integrity of the water samples, physico-chemical parameters sensitive to environmental changes such as temperature, pH and electrical conductivity were measured in-situ and recorded using portable digital meters. The coordinates of all the sampling locations were recorded using a Geographic Positioning System (GPS). The sampling date, names of sampling localities and other necessary description were recorded in the field notebook. Groundwater samples were temporally stored in a cooler with ice packs and later transported to the laboratory for chemical analysis. Water analysis was carried out at the Geospectra Laboratory in Port Harcourt, Rivers State of Nigeria.

Table 1 Locations for Groundwater Samples with their Coordinates

S/N	Locality	Longitudes	Latitudes
	UYO LGA		
1	Discovery Park, Udo Umana street	05 01 07.9	007 55 38.6
2	Clement Isong Avenue behind St Patrick's Primary School, Iboko Offot	05 01 36.4	007 54 51.0
3	Mechanic Workshop Opposite Federal Science and Technical College, Ukana Offot Street	05 01 19.6	007 55 08.3
4	Community Secondary School, opposite Federal Secretariat, Abak Road	05 01 12.2	007 53 18.0
5	Archbishop Usanga Memorial Secondary School	05 00 37.3	007 51 24.4
6	Mechanic Village	05 01 31.8	007 54 00.9
7	Golden Palace Hotels, Ukana Offot/Uwa Street	05 01 42.0	007 54 51.0
8	Akpan AKpa Udo street off Ikot Ebido	05 02 25.0	007 54 24.0
9	Edem Enua street, Ikot Ebido Oku	05 02 18.7	007 54 21.6
10	Library Avenue	05 01 29.9	007 55 57.2
11	Akwa-Ibom Christmas Village	05 00 32.3	007 55 27.6
	ITU LGA		
12	Government Primary School, Afara Ube Itam	05 02 34.5	007 54 07.7
13	Qua Iboe Church, Ikot Abasi Itam	05 02 53.2	007 53 40.8
14	Behind AKTC Park, Mbak Itam 3	05 03 00.5	007 53 26.7
15	Opposite Ibom Specialist Hospital, Ekit Itam II	05 02 50.1	007 52 48.4
	IBIONO IBOM LGA		
16	Behind Vanechelle Montessori School, Ikot Idaha	05 02 40.6	007 52 26.8
17	Beside Pristina Hotel Ikot Ambang	05 03 48.2	007 52 23.6
18	St Peter's Primary School, Ikot Osukpong	05 03 42.0	007 52 19.0
19	Mount Zion Church, Nung Udoe Itak	05 03 52.6	007 52 02.7
	IBESIKPO ASUTAN LGA		
20	Opposite State Police Headquarters, Ikot Akpan Abia	05 00 06.7	007 54 19.1

3. Results and Discussions

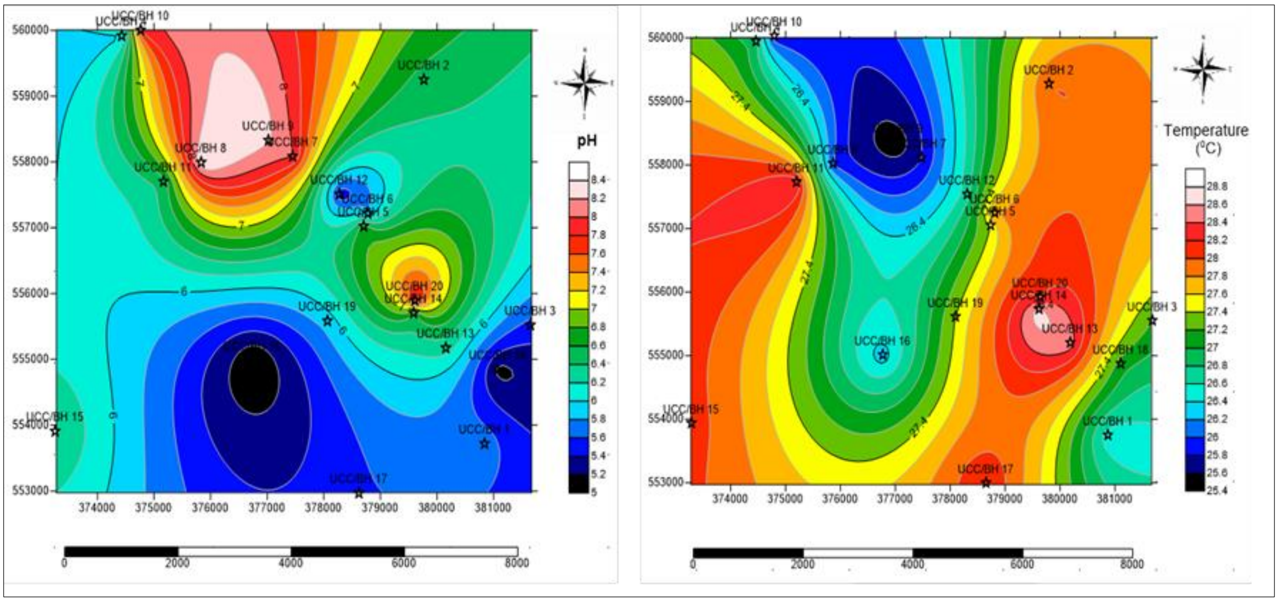

Figure 2 The Distribution of pH values and Temperature across the Study Area

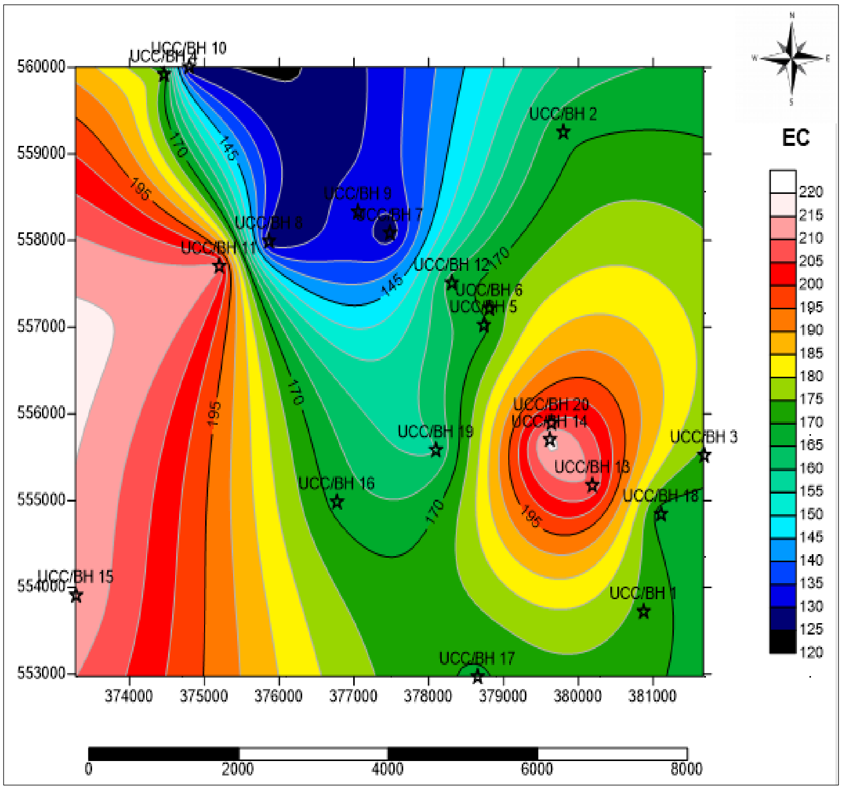

Figure 3 The Distribution of Electrical Conductivity across the Study Area

All the parameters analysed varied significantly. The minimum, maximum and average values of physico-chemical parameters, heavy metals and microbiological parameters in the groundwater samples are presented in Table 3. pH values ranged from 5.00 to 6.72, 7.90 to 8.40, 6.40 to 6.60 and 7.90 to 7.90 in Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan respectively. The pH values indicate groundwater condition of weakly acidic to neutral. Temperature values varied between 26.3 ^{0}C and 28.2 ^{0}C, 25.5 ^{0}C and 26.0 ^{0}C, 28.1 ^{0}C and 28.7 ^{0}C and, 28.2 ^{0}C in Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan respectively. Electrical conductivity (EC) ranged in values from 159.5 µS/cm to 175.0 µS/cm, 125.5 to 135.0

μS/cm, 207.2 μS/cm to 217.4 μS/cm and 205.1 respectively. The geospatial distribution of pH, temperature and EC across the study area is presented in Figures 2 and 3 respectively. Gibbs diagram of TDS and $Na^+(Na^++Ca^{2+})$ versus TDS and $Cl^-/(Cl^-+HCO_3^-)$ were used to determine the mechanism controlling groundwater hydrochemistry (Figure 4). The plots revealed that precipitation was the main controlling factor that governed the groundwater quality in the area, along with some contribution from chemical weathering of subsurface rocks. The groundwater flow direction is in north-west to south-east direction. This is in conformity to the regional groundwater flow of the Niger Delta of Nigeria.

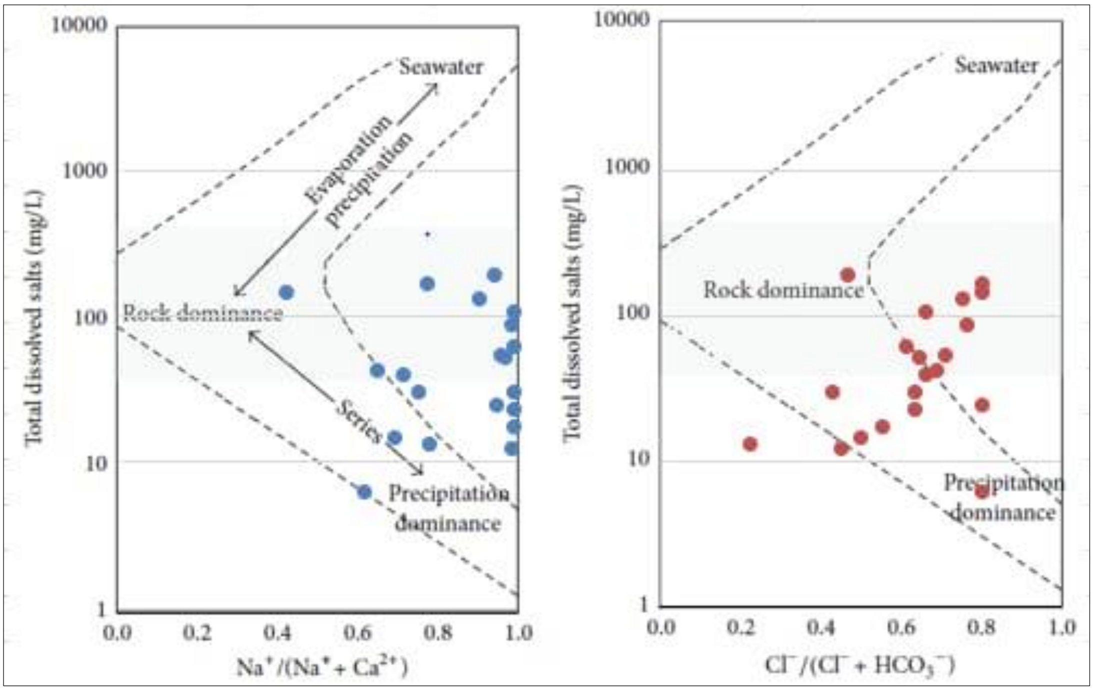

Figure 4 Gibbs Diagram showing Plots of TDS versus Na^+ and Cl^-

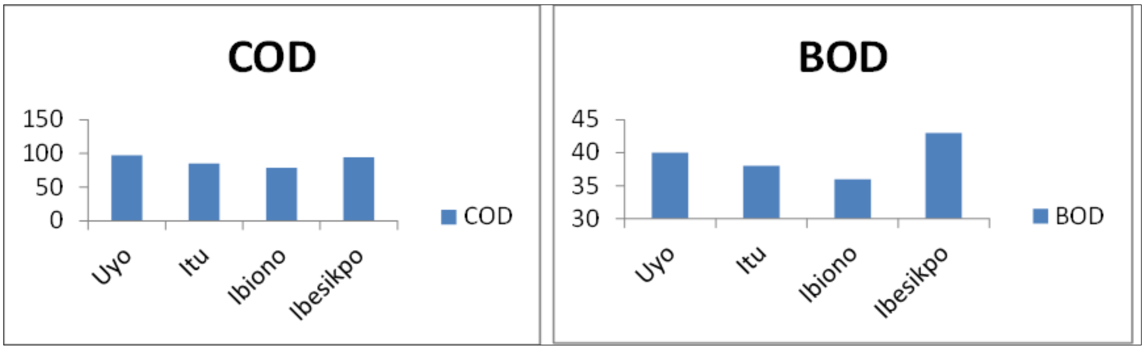

Figure 5 Distribution of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) across the Study Area

Table 2 The Minimum, Maximum and Average Values of Parameters in Groundwater Samples

Parameters	Uyo			Itu			Ibiono Ibom			Ibesikpo Asutan			Standard	
Parameters	**Min**	**Max**	**Av**	**Min**	**Max**	**Av**	**Min**	**Max**	**Av**	**Min**	**Max**	**Av**	**WHO (2018)**	**NSDWQ (2015)**
Temperature	26.3	28.2	27.2	25.5	26.0	25.6	28.1	28.7	28.4	28.2	28.2	28.2	ambient	ambient
pH	5.00	6.72	5.76	7.90	8.40	8.13	6.40	6.60	6.45	7.9	7.9	7.9	6.5-8.5	6.5-8.5
EC (μS/cm)	159.5	175.0	169.4	125.5	135.0	128.2	209.2	217.4	213.0	205.1	205.1	205.1	500	1000
TDS (mg/L)	6.0	162.0	66.5	24.0	83.0	54.3	14.0	29.0	20.5	184	184	184	1000	500
Cl^- (mg/L)	5.0	25.0	14.0	11.0	20.0	15.3	4.0	7.0	5.5	7.00	7.00	7.00	250	-
HCO_3^-	4.0	42.0	9.5	4.0	8.0	6.0	4.0	8.0	4.0	8.00	8.00	8.00	600	-
BOD (mg/L)	36.6	44.4	40.1	36.2	41.0	38.3	34.8	36.9	35.7	42.8	42.8	42.8	-	2-5.0
COD (mg/L)	80.5	97.7	97.0	81.3	90.3	84.6	76.4	81.3	78.5	94.3	94.3	94.3	-	2-5.0
NO_3^- (mg/L)	<0.001	44.3	17.7	12.5	26.4	18.5	0.919	3.76	2.49	2.70	2.70	2.70	50	50
Faecal coli	17	>1,600	1,032	17	110	44.3	21.0	38.0	28.8	130	130	130	-	0
Total coli	39	>1600	1,542.3	27	280	112.8	40.0	170.0	82.5	280	280	280	-	10
Ni (mg/L)	<0.008	0.043	0.012	<0.008	0.043	0.027	<0.008	0.014	0.0095	<0.008	<0.008	<0.008	0.07	0.02
Ca (mg/L)	<0.004	9.89	1.99	<0.0042	0.356	0.124	<0.0042	0.822	0.324	<0.0042	<0.0042	<0.0042	200	250
Zn (mg/L)	<0.003	0.106	0.024	<0.003	0.031	0.010	<0.003	0.019	0.007	<0.003	<0.003	<0.003	3	3
Cu (mg/L)	<0.004	0.055	0.006	<0.004	0.080	0.024	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	2	1
Mg (mg/L)	0.148	1.34	1.31	0.068	0.358	0.200	<0.0018	0.329	0.141	<0.0018	<0.0018	<0.0018	200	150
Fe (mg/L)	<0.0046	0.055	0.024	<0.0046	0.0046	0.005	<0.005	<0.005	<0.005	0.179	0.179	0.179	0.3	0.3
K (mg/L)	<0.001	3.46	2.34	0.341	2.63	1.386	<0.001	0.514	0.137	0.001	0.001	0.001	200	-
Na (mg/L)	0.911	8.14	5.30	5.53	7.77	6.80	1.08	2.57	1.94	2.11	2.11	2.11	200	200
Al (mg/L)	<0.03	<0.03	<0.03	<0.03	0.455	0.136	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.1	0.2
SO_4^{2-} (mg/L)	<0.001	8.28	1.98	0.032	2.57	1.141	<0.001	1.51	0.386	0.931	0.931	0.931	250	100

The values of pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), faecal and total coliforms were found to be above the permissible limits of Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) and World Health Organization (WHO, 2018) for drinking water. The highest and lowest values of BOD and COD were obtained in Ibesikpo Asutan and Ibiono Ibom respectively (Figure 5). Total and faecal coliforms were highest in Uyo and lowest in Ibiono Ibom (Figure 6). The ranges of values (and average) of TDS, BOD, COD, faecal coliform and total coliform were 12.0 mg/L – 284.0 mg/L (119.3 mg/L), 12.0 mg/L – 162.0 mg/L (57.4 mg/L), 36.6 mg/L – 44.4 mg/L (40.1 mg/L), 80.5 mg/L – 97.7 mg/L (97.0 mg/L), 17 - >1600 (1032) and 39 - >1600 (1542.3 MPN/100ml) in Uyo. In Itu, the ranges of values (and average) of TDS, BOD, COD, faecal coliform and total coliform were 24 mg/L – 83 mg/L (54.3 mg/L), 36.2 mg/L – 90.3 mg/L (51.6 mg/L), 37.3 mg/L – 85.4 mg/L (71.3 mg/L), 17 – 280 (110 MPN/100ml) and 17 – 110 (47 MPN/100ml) respectively. In Ibiono Ibom, The ranges of values (and average) values of TDS, BOD, COD, faecal coliform and total coliform were 14 mg/L – 29 mg/L (20.5 mg/L), 34.8 mg/L – 36.9 mg/L (35.7 mg/L), 76.4 mg/L – 81.3 mg/L (78.5 mg/L), 21 – 38 (28.8) and 40 – 170 (82.5 MPN/100ml) respectively. In Ibesikpo Asutan, the values were 184 mg/L, 42.8 mg/L, 94.3 mg/L, 130 and 280 MPN/100ml for TDS, BOD, COD, faecal coliform and total coliform respectively.

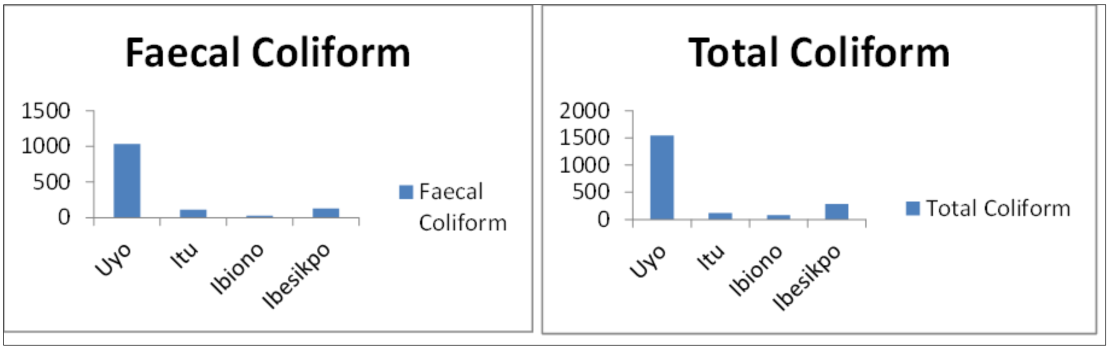

Figure 6 Distribution of Faecal Coliform and Total Coliform across the Study Area

Findings of the study showed that the groundwater ranged from acidic and slightly weakly acidic in Uyo and Ibiono Ibom but slightly alkaline in Itu. This is similar to the chemical analysis carried out by Beka and Udom (2014) where slightly acidic and slightly basic conditions of groundwater were reported for Uyo, Ibiono Ibom, Itu and other parts of Akwa-Ibom State. Recent work on groundwater assessment within Uyo by Umana (2022) revealed that groundwater of Uyo is acidic. The numerical values of pH obtained from this study do not vary significantly from 3.19 – 5.18 in Uyoby Adedeji *et al.,* (2010), 6.3 in Ibiono Ibom and 8.3 in Itu by Beka *et al.,* (2015), 4.2 -8.9 in all LGAs of Akwa-Ibom State by Beka and Udom (2014) and 3.24- 6.77 in all parts of the state by Umoh *et al.,* (2020). All the heavy metals analysed for were within the permissible limits specified by WHO (2018) and NSDWQ (2015) in drinking water. This result agrees with Umana (2022) who assessed the quality of groundwater around Aka-Offot Industrial Layout in Uyo and found that the mean values of iron, lead, zinc, chromium and cobalt did not exceed recommended values. Similar results have been reported by Udom *et al.,* (2002), Beka and Udom (2014), Beka *et al.,* (2015), Adedeji *et al.,* (2010) and Umoh *et al.,* (2020). Although Beka and Udom (2014) and Beka *et al.,* (2015) agreeably maintained that total coliform exceeded the values recommended by WHO in drinking water, the values obtained in this study are in excess of 1,600. This could be attributed to urbanization with its consequent sewage management issues and increased animal droppings.

4. Conclusion

The study showed groundwater condition which ranged from acidic and slightly weakly acidic in Uyo and Ibiono Ibom but slightly alkaline in Itu. The pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), faecal and total coliforms exceeded the permissible limits of Nigerian Standard for Drinking Water Quality and World Health Organization for drinking water. This could be attributed to urbanization with its consequent sewage management issues and increased animal droppings. High values of faecal and total coliforms which indicate recent pollution are potential for pathogenic organisms. High BOD values imply organic pollution. All the parameters analysed were found to vary significantly. It was found that precipitation was the main controlling factor that governed the groundwater quality in the area, along with some contribution from chemical weathering of subsurface rocks. The groundwater flow direction is in north-west to south-east direction which conformed to the regional groundwater flow of the Niger Delta of Nigeria.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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