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HYDROLOGICAL PROCESSES AND TRENDS IN THE NIGER DELTA: EXPANDING THE DISCUSSION (PAPER II)

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Abstract: In recent years, increasing attention has been directed towards the adverse impact of water pollution on human health and the environment. Contaminated water, as a result of environmental pollution, has emerged as a pressing public concern, prompting the need for a deeper understanding of its consequences. Access to clean and safe drinking water is fundamental for human well-being and ecosystem health. This study delves into the multifaceted challenges posed by water contamination and the importance of upholding water quality standards. The significance of water quality standards cannot be overstated, as they serve as crucial benchmarks to assess and ensure the purity of surface waters. These standards, however, exhibit substantial variations owing to divergent environmental conditions. Concerns about water quality extend beyond the immediate human health implications to encompass broader ecological and economic dimensions. The cost of treating drinking water contaminated by pollutants presents a substantial financial burden. Furthermore, the ecological equilibrium of aquatic ecosystems is profoundly influenced by the presence of contaminants, underscoring the importance of maintaining clean water sources. To effectively monitor changes in water quality over time, the Water Quality Index (WQI) and other theoretical models are widely employed. These tools provide a systematic approach to evaluating water quality and help in decision-making processes related to water supply and management. Comprehensive assessments of water quality are indispensable for determining its suitability for various purposes, whether for drinking, industrial, or recreational use. In conclusion, this study underscores the paramount importance of water quality in safeguarding human health and the environment. Addressing the challenges posed by water contamination necessitates stringent adherence to quality standards, effective monitoring through tools like the WQI, and rigorous legislation. Ensuring clean and safe drinking water is not only a matter of public health but a fundamental requirement for sustainable development and the preservation of aquatic ecosystems.

Keywords: Water Quality, Water Pollution, Water Quality Index (WQI), Contaminated Water, Total Coliforms

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Introduction

The main public concern in recent years has been the damage to human health that is caused by contaminated water through environmental pollution [Sun et al 2013, [Quispe et al., 2012], [Shivaprakash et al., 2011]. Water is essential to the sustenance of life and access to safe drinkingwater is crucial for human health and wellbeing [Osei, et al., 2013]. The health and well-being of humans and ecosystems depend heavily on the quality of the water resources available through proper land use planning and enactment of robust legislation [Kolawole et al., 2011, Brands and Rajagopal, 2008]. Water quality standards for surface waters vary significantly due to different environmental conditions further concerns with water quality are the impacts of water pollution contamination on the ecosystem and the cost of drinking water treatment [Caniani, et al., 2013, Igos, et al., 2013]. The water quality index (WQI) and other theoretical models are used to monitor water quality changes in water supply over time [Divya and Mahadeva, 2013, Said, et al., 2004]. Assessments of water quality is very important for knowing its suitability for various purposes [APHA, 1985, Samarghandi, et al., 2007]. Water quality studies have been widely considered in literature [Monavari and Guieysse, 2007, Jeong et al., 2010]. Total coliforms are naturally found in both faecal and non-faecal environments, so they are commonly present in both surface water and groundwater under the direct influence of surface water sources. The guideline for total bacteria count is less than 100 $CFU\cdot mL^{-1}$ [CWQ, 2012].

LITERATURE REVIEW

Surface and groundwater quality assessment and management are major issues having profound impact on communities in the Niger Delta Region of Nigeria [NDR] [40]. Despite the region's abundance of water, water quality is threatened by deteriorating environmental conditions and water management that are not being sufficiently addressed [Shrestha and Kazama, 2007. World Bank, 1985]. It is well recognized that failure to protect water sources and inadequate water treatment are the primary reasons for drinking water contamination with bacteria [Pitkänen et al., 2011]. The aim of this study is to determine physico-chemical and bacteriological characterization of water in parts of the NDR and qualify them for various uses by affected communities. The objective of this study is proffer management strategy to reduce ingress of contaminants into the water resources available to communities.

Location and Geology of the Study Area

The area selected for this study is located in the southern flank of the Niger Delta Region of Nigeria (Fig. 1). The topography is generally low-lying with elevations ranging from below sea level in the southwestern flank of the region to about 40 m further inland. Most of the lowlying areas regularly experience perennial flooding. Thus, flooding and subsequent infiltration of water contaminants into water sources can be attributed to anthropogenic and natural causes [Sojinu, et al 2012, Mons, et al., 2013, Cooper and Lemckert, 2012]. Given that 75% of the NDR is wetland with an annual rainfall of 2000-3000mm, flooding may occur due to excessive rainfall, human manipulation of wetland, flood plains in particular and excessive release of water from Niger and Benue Rivers as reported early. This may result in the overflow of sewage and other contaminants into water courses. Soils are generally hydromorphic and poorly drained. The pristine vegetation has been reduced considerably in the area and replaced by mosaic of secondary re-growth due to agricultural activities and oil exploration [Ologunorisa, 2007]

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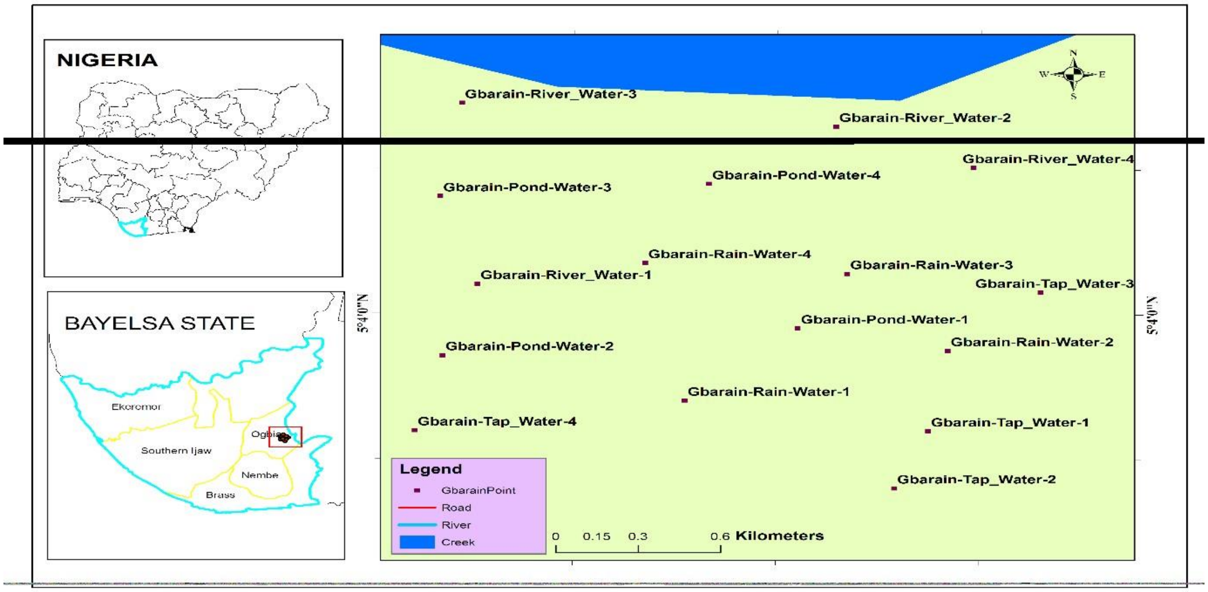

Figure 1: Map of the Niger Delta Region Showing the Study Location

The subsurface geology in the region reveals a three-fold lithostrati graphic subdivision, comprising an upper sandy Benin Formation, an intervening unit of alternating sandstone and shale named the Agbada Formation, and lower shale Akata Formation [Figure 2]. [Sojinu, et al., 2012], [Leton and Omotosho, 2004]. These three units cut across the whole NDR and each range in age from early Tertiary to recent [Sonibare and Ekweozor, 2004]. The Benin Formation consists predominantly of fresh water continental sands and gravel with intercalations of shale. This has unconfined aquifer properties and constitutes the most productive for water supply in the region. The hydraulic conductivity of the Benin Formation ranges from 4.6- 10.2 cm/s, while the annual water storage and recharge is estimated to be 6.16 -108 m^3. The Agbada formation comprises reservoir rocks while the Akata Formation contains the source rocks for crude oil formation and accumulation [Olobaniyi and Efe, 2007].

METHODOLOGY

Sample Collection

This study was conducted in 16 communities of the south-southern Niger delta Region of Nigeria (Fig. 3). Water samples comprising rainwater, river water, shallow drilled wells and subsurface drilled wells were collected. Triplicate samples were taken per each sampling and were later transported to the laboratory for analysis. One these samples was collected at its natural pH, in 2 l polyethylene bottles after rinsing several times with water from the point of collection for chemical and bacteriological analysis. Samples were transferred to the laboratory in coolers containing ice to reduce the degradation of samples before analysis.

Physico-Chemical Analysis

Recommended methods such as American Society for Testing and Materials (ASTM) and American Public Health Association (APHA) were employed (Table 1). Only analytical grade reagent and chemicals were used in preparing reagents and standards. Collected surface and groundwater samples were analyzed for pH, temperature, total dissolved solids (TDS), per standard methods [APHA, 1981, APHA/AWWA 1995]. Insitu measurements were carried out for the rain, surface and groundwater collected. Unstable field parameters namely pH, conductivity, total dissolved solids (TDS), and temperature were analyzed in the field and recorded. TDS was determined by using HACH TDS meter. pH and conductivity measurements were performed with a mercury-in-glass thermometer, portable Orion Model 290 pH meter and Oakton Model 35607 conductivity meter, respectively. Determination of total hardness was by Titrimetric Method. Chloride and Iron was determined using a portable data logging spectrophotometer (Atomic Absorption Spectrophotometer Hach DR/2010).The major cations were analyzed using the atomic absorption spectroscopy (AAS) [Ademoroti, 1996].Salinity was determined using Mohr's method. Turbidity was determined using the HACH turbidity. Nitrate was determined by Hach DR. 4000 spectrophotometer, using cadmium reduction method. The sulphate content of the sample was determined by turbidmetric method and bicarbonate was determined by titrimetric method [APHA, 1992].

Bacteriological Analysis

Quantitative bacteriological analysis was conducted to determine the total bacterial count, total coliforms and Escherichia coli. The standard plate counting (SPC) method was used to enumerate the total bacterial count [Edelstein, 1981, Edelstein, 1982]. Nutrient Agar was prepared and ethanol - sterilized for Escherichia coli assay. The plate was removed after 24hr and perfect circled colonies were identified as Escherichia coli (E. Coli) and other colonies together with E.coli were counted as the total coliform Total coliforms was detected and quantified with the use of Eosin methylene blue (EMB) agar and their incubation at 37 °C. Their counts were expressed in cfu/100mL of the water [WHO, 1997, APHA, 1981].

RESULTS

Table 1: Physical Characterization of Water Resources in the Study Area

1	17.2	26.5	6.58	2100	1.13	0.52	1050
2	16.2	26.5	6.6	1980	1.08	0.48	990
3	16.9	26.6	6.62	2070	1.07	0.5	1035
4	16.2	26.5	6.65	1975	0.98	0.52	988
5	24.8	27.1	6.6	2620	2.69	9.65	1310
6	24.5	27.1	6.66	2580	2.48	8.48	1295
7	23.3	27.2	6.7	2460	1.2	9.4	1230
8	24.4	27.1	6.68	2580	1.71	8.5	1290
9	130.5	28.5	6.71	3042	1.32	0.3	1521
10	123.6	28.5	6.68	2880	1.28	0.29	1440
11	127.8	28.4	6.7	2980	1.23	0.29	1490
12	128.3	28.4	6.7	2990	1.26	0.31	1500
13	21.8	28.5	6.67	2310	1.22	2.4	1155
14	21.7	28.2	6.68	2292	1.16	2.5	1146
15	20.7	28.4	6.7	2185	1.17	2.49	1093
16	21.8	28.4	6.69	2300	1.15	2.5	1150

Table 2: Chemical Characterization of Water Resources in the Study Area

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Community water	NO_3 ppm	SO_4 ppm	Cl ppm	HCO_3 ppm	Na ppm	K ppm	Ca ppm	Mg ppm	Fe ppm	Mn ppm	TH ppm
1	0.35	3.52	43	24.1	30.7	18.46	14.8	7.3	0.18	0.01	307. 8
2	0.36	3.97	48. 5	13.3	27.4	15.7	12.6	6.5	0.2	0.02	304. 3
3	0.46	3.15	38. 7	13.9	25.5	12.6	10.8	6.3	0.16	0.01	291. 1
4	0.34	3.57	43. 7	13.4	26.4	12.8	11.2	7.4	0.16	0.02	283
5	3.4	15.5	35. 5	2.8	18.7	10.3	20.4	7.84	0.48	0.03	180
6	2.8	15.3	34. 9	2.9	18.6	10.7	19.8	6.8	0.36	0	180
7	1.36	14.6	33. 3	2.6	17.8	10.8	19.5	4.86	0.3	0.04	169
8	1.93	15.3	34. 9	2.8	18.5	11	20.3	5.4	0.32	0.06	177
9	0.46	9.57	116	12.7	56.6	48.8	68.7	54.6	0.28	0.03	455
10	0.44	9.62	117	10.1	65.4	46.8	65.8	50.7	0.26	0.02	430. 8
11	0.5	9.28	119	10.4	68.5	50.8	67.8	36.4	0.25	0.02	445. 8
12	0.52	9.82	120	10.5	70.4	60.5	60.7	36.5	0.24	0.03	447. 3
13	1.38	13.7	31. 3	2.5	12.2	7.8	18.6	6.7	0.34	0.02	158. 7
14	1.31	13.6	31. 3	2.5	13.3	7.5	18.7	6.5	0.54	0.03	157. 5
15	1.32	13	29. 6	2.4	12.8	7.7	17.9	7.2	0.5	0.2	150. 8
16	1.3	13.6	31. 6	2.5	12.6	7.6	18.5	6.8	0.38	0.02	158

Physico-Chemical Interpretation

Table 3: Descriptive Statistics for Physical Variables

Variables	Mean	Std. Deviation	Analysis N
EC	2459.0000	366.97702	16
salinity	1.3831	.49648	16
Turbidity	3.0706	3.65713	16
TDS	1230.1875	184.01892	16

Alkalinity	47.4813	47.84640	16
TH	268.5063	119.01064	16

Table 4: Correlation Matrix for Physical Variables

Variables		EC	salinity	Turbidity	TDS	Alkalinity	TH
EC		1.000	.317	.075	1.000	.867	.559
	salinity	.317	1.000	.739	.320	-.091	-.273
	Turbidity	.075	.739	1.000	.076	-.404	-.637
		1.000	.320	.076	1.000	.867	.558
TDS		.867	-.091	-.404	.867	1.000	.858
	Alkalinity	.559	-.273	-.637	.558	.858	1.000
	TH EC		.116	.391	.000	.000	.012
	salinity	.116		.001	.114	.369	.153
	Turbidity	.391	.001		.390	.060	.004
Sig. (1-tailed)		.000	.114	.390		.000	.012
TDS		.000	.369	.060	.000		.000
	Alkalinity	.012	.153	.004	.012	.000	
TH							

Table 5: Descriptive Statistics for Chemical Variables

	Mean	Std. Deviation	Analysis N
pH	6.6638	.04177	16
Nitrate	1.1395	.92227	16
Sulphate	10.4488	4.62751	16
Chloride	56.8750	37.05460	16
Bicarbonate	8.0875	6.43437	16
Sodium	30.9663	21.34207	16
Potassium	21.2463	18.61869	16
Calcium	29.1581	22.11915	16
Magnesium	16.1206	17.50782	16
Iron	.3094	.11897	16
Manganese	.0350	.04604	16

Table 6: Component Matrix for Chemical Variables

variables	Component		
	1	2	3
Sodium	.966	.163	-.077
Chloride	.950	.288	-.065
Potassium	.945	.267	-.063

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Magnesium	.885	.386	-.050
Calcium	.850	.507	-.093
Nitrate	-.689	.411	-.479
Sulphate	-.489	.817	-.237
pH	.226	.798	.298
Bicarbonate	.608	-.729	.079
Iron	-.599	.667	.023
Manganese	-.285	.389	.796

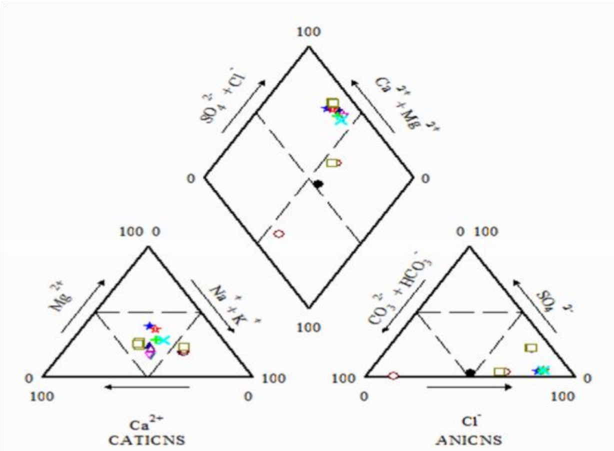

Figure 2: Piper Diagram for Ground Water in the Study Area

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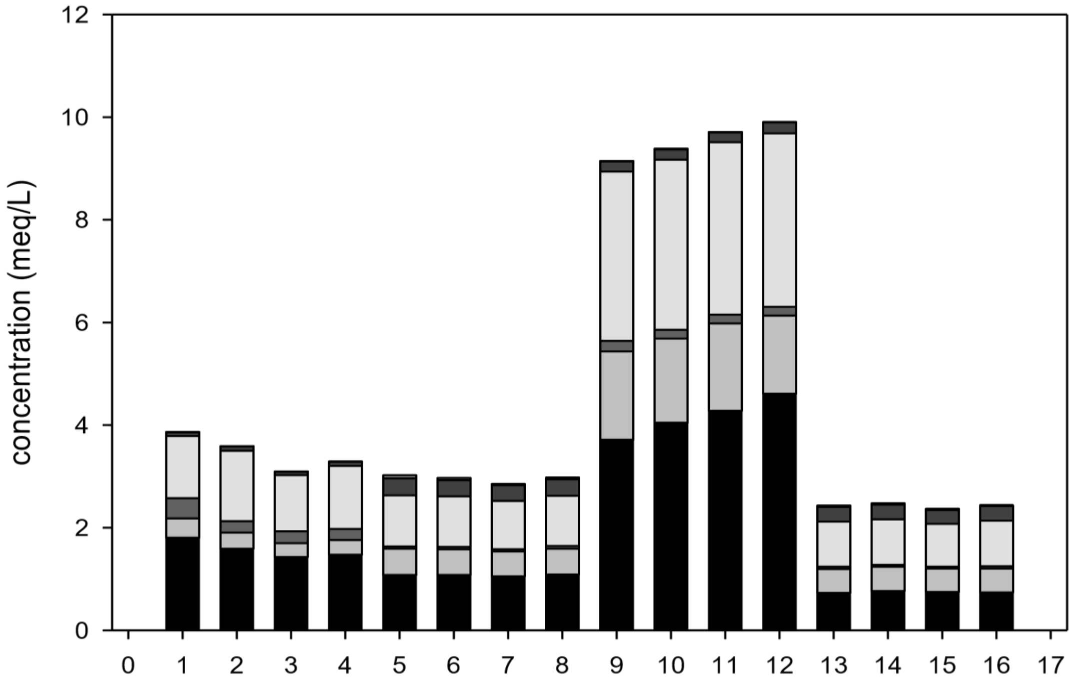

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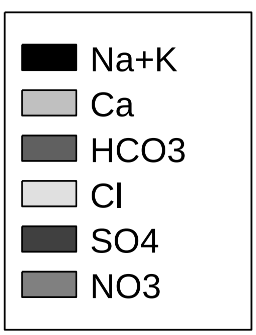

Figure 3: Collins Diagram

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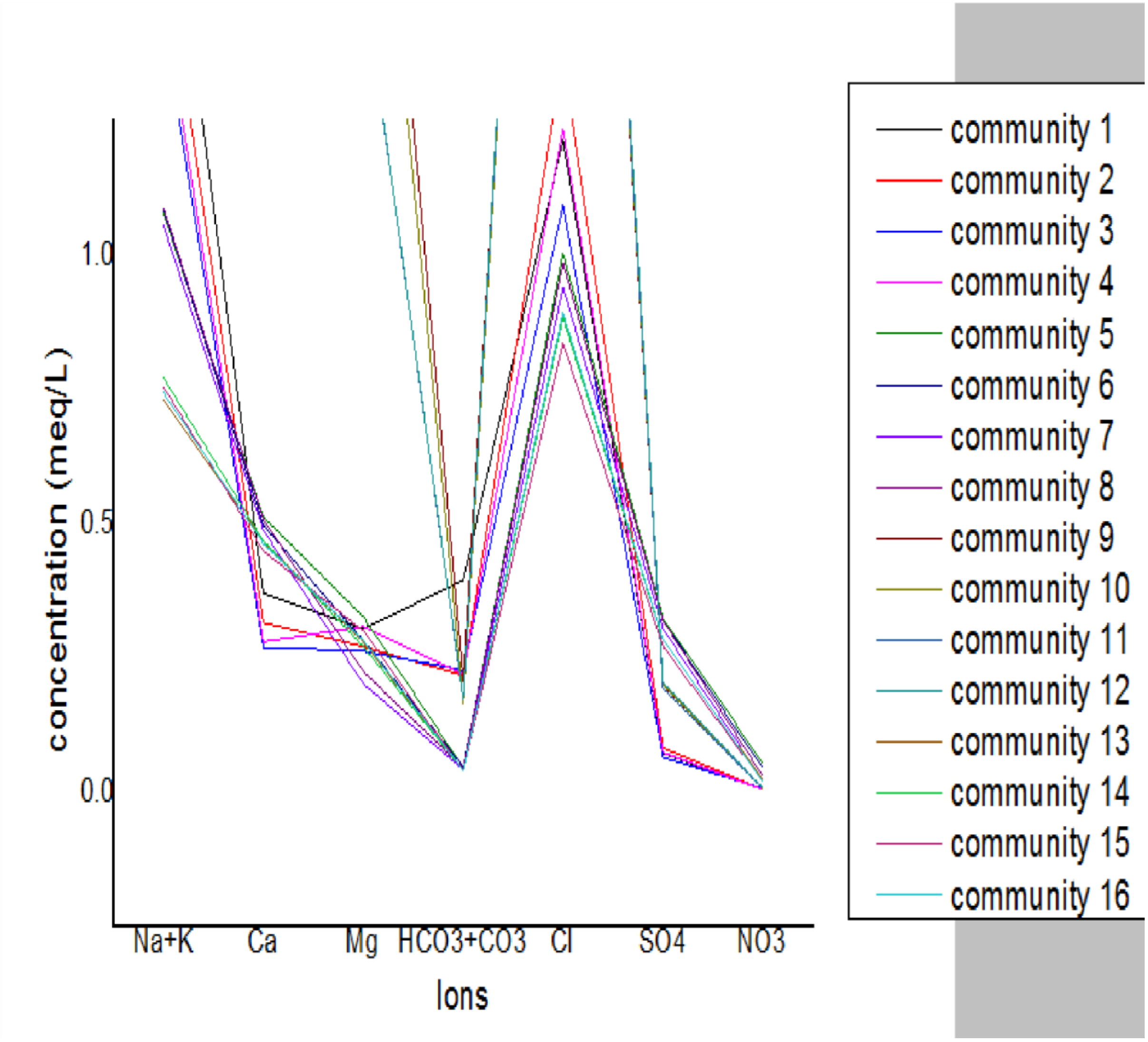

Figure 4: Schoeller Diagram

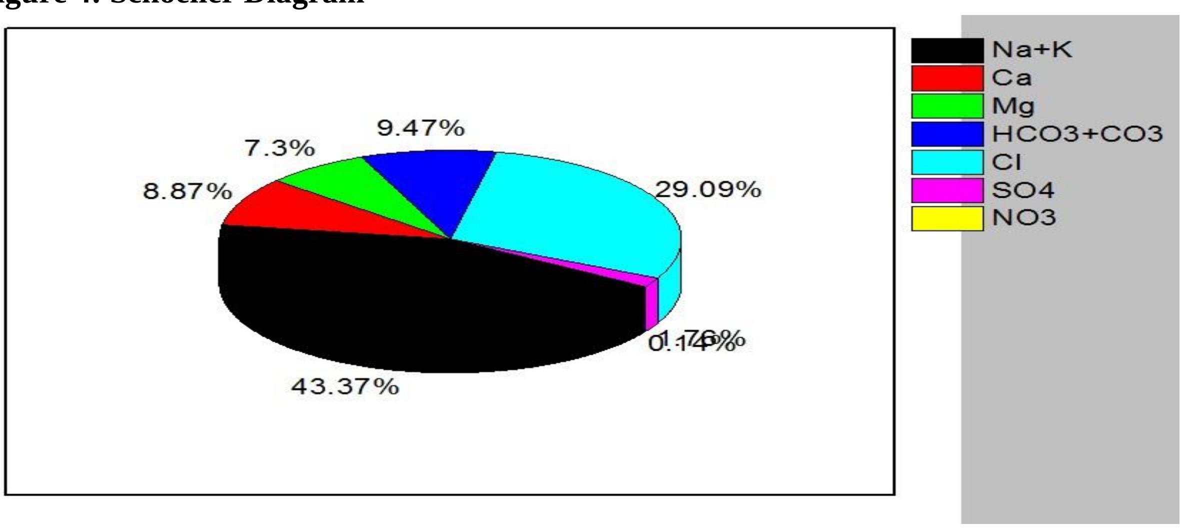

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Figure 5: Pie Diagram for Pond Water in the Study Area

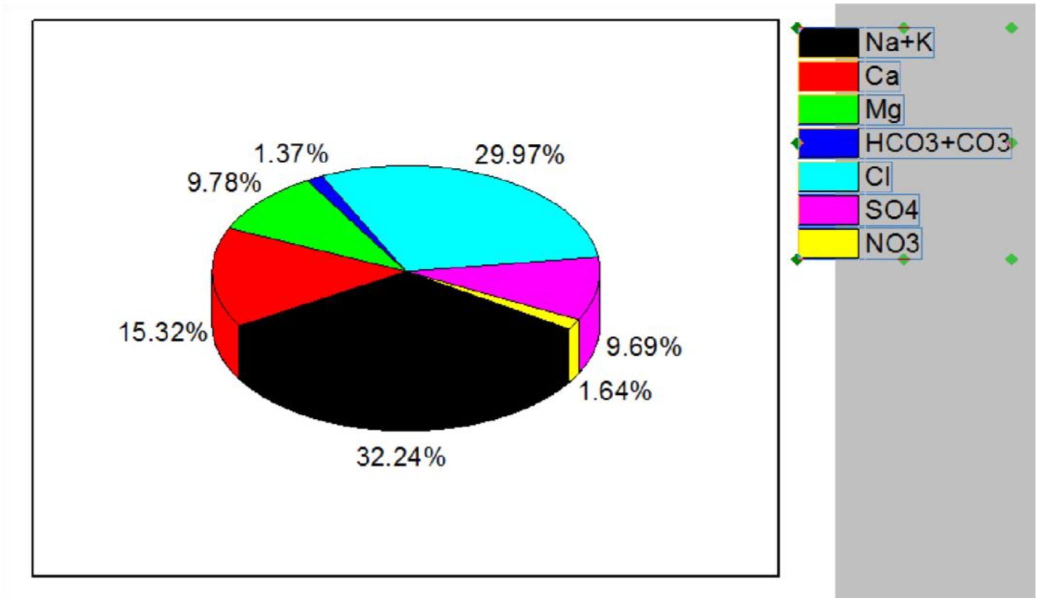

Figure 6: Pie Diagram for River Water in the Study Area

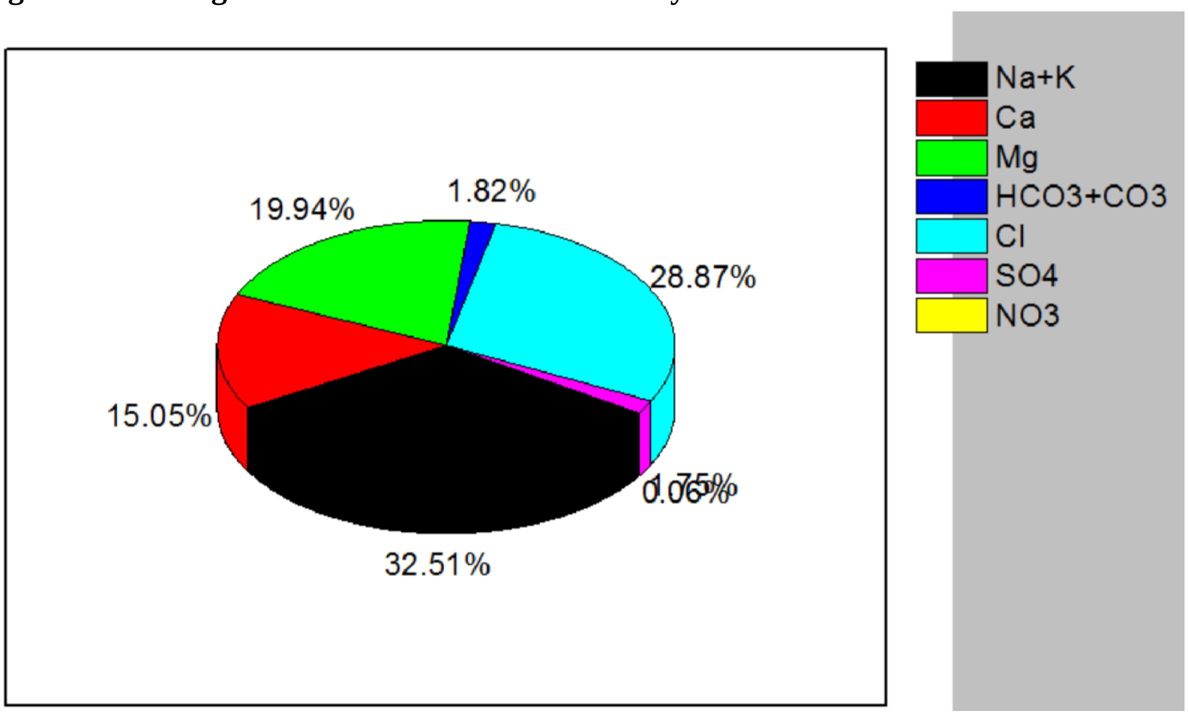

Figure 7: Pie Diagram for Rain Water in the Study Area

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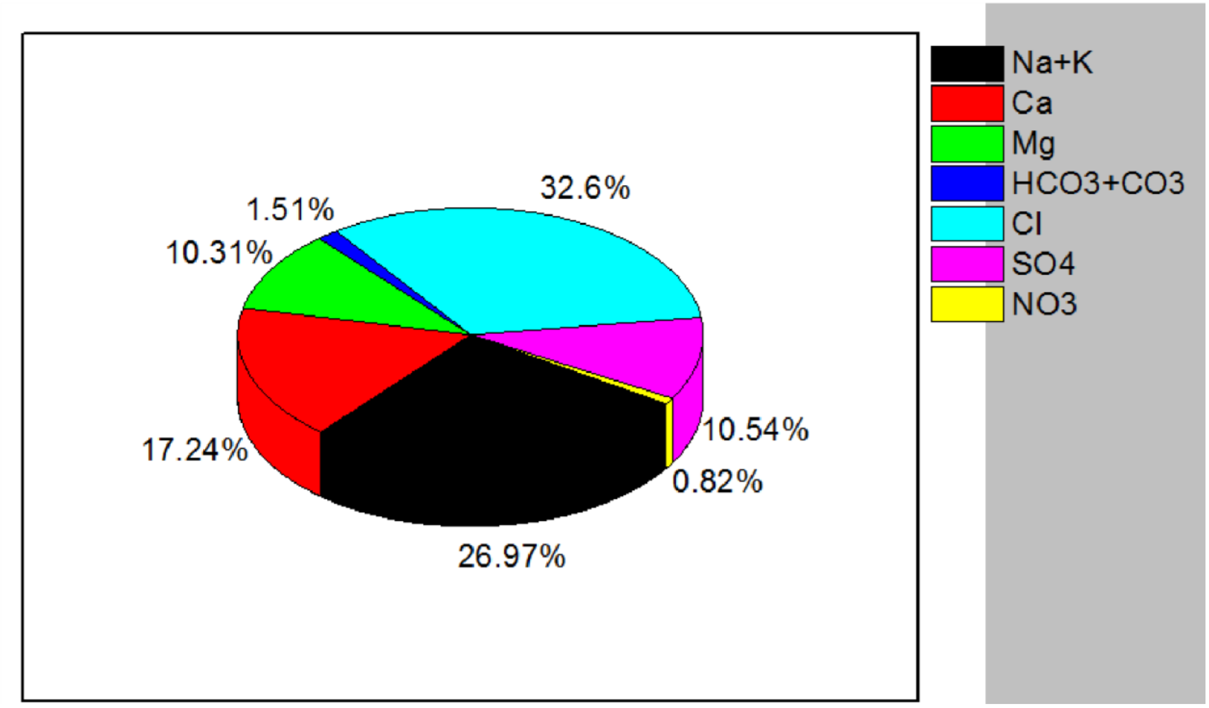

Figure 8: Pie Diagram for Ground Water in the Study Area

Table 7: Matrix of the Bacteriology of Water Supply in the Study Area

Community water	E. coli	T. coli	TBC	Comments
1	1	1	2	Not acceptable
2	2	4	6	Not acceptable
3	2	2	4	Not acceptable
4	4	3	6	Not Acceptable
5	3	5	8	Not Acceptable
6	2	4	6	Not Acceptable
7	5	4	9	Not acceptable
8	6	10	16	Not acceptable
9	ND	ND	ND	Acceptable
10	ND	ND	ND	Acceptable
11	ND	ND	ND	Acceptable
12	ND	ND	ND	acceptable
13	1	4	5	Not acceptable
14	1	1	2	Not Acceptable
15	2	4	6	Not Acceptable
16	2	3	5	Not Acceptable

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In this section of the report ND means not detected.

Table 8: Ph versus Phreeqc Saturation Index of Some Mineral Species

Community water	pH	SI			
		Pyrolusite	Manganite	Hausmannite	Dolomite
1	6.58	-11.44	-6.78	-16.11	-3.36
2	6.6	-1.80	0.42	3.03	0.75
3	6.62	-2.05	0.13	2.18	0.72
4	6.65	-1.84	0.39	2.94	0.72
5	6.6	2.03	3.26	10.83	0.48
6	6.66	2.10	3.30	11	0.43
7	6.7	2.13	3.36	11.16	0.20
8	6.68	2.34	3.57	11.75	0.32
9	6.71	4.69	4.99	15.64	-0.02
10	6.68	3.90	4.37	13.92	2.28
11	6.7	4.07	4.50	14.23	2.21
12	6.7	4.25	4.67	14.75	2.21
13	6.67	1.73	2.84	10.00	0.28
14	6.68	1.87	3.03	10.48	0.26
15	6.68	1.87	3.03	10.48	0.26
16	6.69	1.72	2.85	9.99	0.28

Table 9: Data Summary of Canadian Water Quality Index in the Study Area

Data Summary	**Overall**	**Drinking**	**Aquatic**	**Recreation**	**Irrigation**	**Livestock**
CWQI	**65**	**64**	**68**	**100**	**80**	**79**
Categorization	**Fair**	**Marginal**	**Fair**	**Excellent**	**Good**	**Fair**
F1 (Scope)	50	50	50	0	33	25
F2 (Frequency)	22	25	22	0	8	23
F3 (Amplitude)	25	29	8	0	1	12
Minimal Dataset Requirement of 4 Variables	Met	Met	Not Met	Not Met	Not Met	Met
Contaminant Analysis of Last Sample	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested

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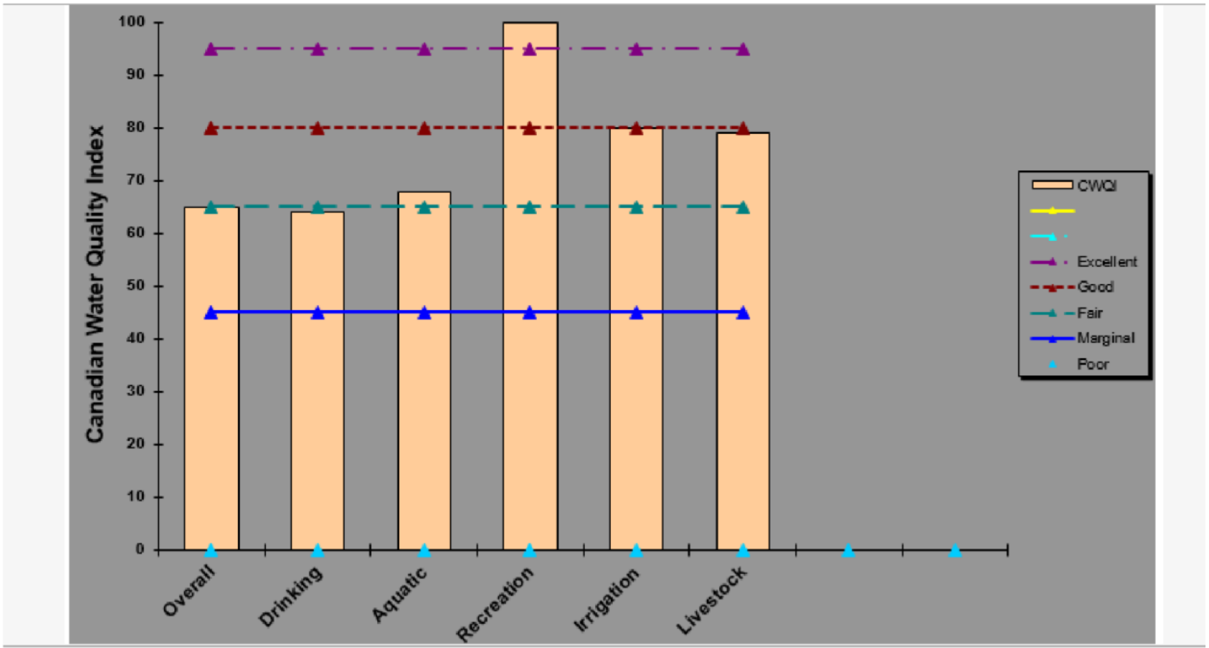

Figure 9: Canadian Water Quality Index for Water Supply in the Study Area

Table 10: Sodium Adsorption Ratio (Sar), Residual Sodium Carbonate (Rsc) And

Community water	Na (meq/L)	Ca (meq/L)	Mg) meq/L	SAR(meq/L)	RSC	LSI
1	0.65	0.495	0.4	3.95	0.66	-2.6
2	0.630435	0.47	0.43	4.06	0.60	-2.9
3	0.6	0.49	0.39	4.16	0.57	-2.9
4	0.63	0.46	0.39	3.90	0.55	-2.9
5	0.57	0.46	0.36	1.93	-0.025	-3.4
6	0.58	0.46	0.36	2.07	0.02	-3.44
7	0.59	0.48	0.33	2.25	0.086	-3.47
8	0.6	0.46	0.34	2.19	0.07	-3.44
9	0.55	0.36	0.32	1.23	-1.53	-1.93
10	0.58	0.36	0.28	1.51	-0.91	-2.10
11	0.55	0.38	0.32	1.85	-0.23	-2.05
12	0.56	0.38	0.31	2.01	0.02	-2.04
13	0.55	0.435	0.27	1.42	-0.21	-1.50
14	0.56	0.43	0.266667	1.56	-0.16	-1.50
15	0.55	0.43	0.27	1.48	-0.19	-1.52
16	0.55	0.42	0.28	1.46	-0.19	-1.58

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Langelier Saturation Index (Lsi) Of Community Waters

DISCUSSION

Physico-Chemical Characterization

All physical characteristics of water resources fall with the recommended guide level for portable water supply (Table 1 and 2).The pH mean is 6.6638 mg/L. Therefore, it is within the acceptable limits for drinking water... The nitrate mean is 1.1395 mg/L and the calcium mean is 29.1581 mg/L. These all fall within the recommended guide level for portable water supply. The sodium mean is 30.9663 mg/L and the iron mean is .3094 mg/L. The iron content is above recommended guidelines for portable, domestic and industrial water supplies. Chemical and bacteriological characterization as recorded in the NDR may be attributed to regional variation in anthropogenic and natural sources of water contaminants in the region.

Physico-Chemical Interpretation

Principal component analysis (PCA) analysis was performed by the extraction method. (Tables 3-6). The communalities for all of the variables included on the components were greater than .5 and had simple structures. Cumulative % of component explains the values of the total variance in variables which are included on the component. The result of PCA indicates four main controlling factors underlying the physical characterization of the water in the study area (Table 6). Whilst component 2 of the physical characterization explains 93% of the total variance and includes a strong loading of EC component 3 explains 91.281%, of the total variance and it includes a strong loading of sulfate ions. Their strong correlation suggests a common source of these ions. According to the classifications of the Piper diagram, (Figs.2) the water facies in these communities consist of minimal Ca-HCO_3 waters typical of shallow fresh ground waters and essentially Na-Cl waters typical of marine and deep ancient ground waters. These waters are mixed resulting in mild water contamination. Schoeller diagram revealed water quality with similar finger prints with peaks of Cl and a common trough for HCO_3. Collins diagram revealed a TDS for communities 9-12. These are surface water and ground water respectively (Fig. 3-4).

Pie diagrams revealed highest percentage of Na+K ions, followed by Mg for the cations, and chloride followed by SO_4 for the anions (Fig7 and 8). Variations of Na+K, Chloride, TDS from pie diagrams and Collins diagram indicate sea water intrusion on the water supply in the study area. There is an indication of Na+K cations dominating other cations and chloride anion dominating other anions in the studied area (Fig 5-8). The number of Escherichia coli and total coliforms seen per 100ml of some of the water samples are provided (Table 7) and exceeds the recommended international and regional limits of 0 per 100ml of sample. Therefore some of these water supplies in these communities do not meet the drinking water standards set by regulators. Water sources have influenced the bacterial contamination significantly ($p < 0.01$). Bacterial contamination was common with surface water and ground water from unconfined aquifer. Bacterial and other forms of contamination may be attributed to wellhead does not extend high enough above the ground surface. Also, this could be due to broken or removed well heads and wells without housing. Moreover, the bacterial contamination was serious in unprotected wells or wellhead below ground level. Therefore, there is need for proper land use planning and firm enactment and implementation of environmental laws in this region, to effect robust surface and ground water resource management.

Aqueous chemical speciation and mineral saturation calculations were performed using PHREEQ (Table 8). Pyrolusite, mangarite, hausmanite and dolomite were readily saturated in some of the groundwater and under saturated in the surface waters. There was the absence of siderite and calcite, indicating potential dissolution of these minerals. Therefore, rain water harvesting can readily substitute for ground water exploration.

The overall water quality based on the Canadian water Quality Index (CWQI) is fair. Lowering of water quality is attributed to drinking and aquatic water criteria. The water quality is excellent for recreational and irrigation purposes and good for livestock utilization (Table 10 and Figure 9). All sodium adsorption ratios were <10 indicating community water safe for irrigation with no structural deterioration (Table 10). However, salt-sensitive plants may be affected. Residual sodium carbonate values for all community water revealed negative values indicating water is unlikely to cause structural degradation. Langelier Saturation Index for all community water showed negative indicating no likelihood pf scaling but strong risk of corrosion [Igos, et al., 2013].

CONCLUSIONS

Various theoretical models and graphical interpretations have been employed in the assessment of community water quality in the South-southern Niger Delta Region of Nigeria. These community waters have been subjected to international regulatory standards and found to be fair for drinking (where the Escherichia coli and total coliforms do not exceed the international and regional recommended limits of 0 per 100ml of sample). The community water in the studied area is poor for aquatic life, good for livestock and excellent for both recreational and irrigation purposes. The application of principal component analytical techniques has been used to establish the nature of physicochemical variables. These reflect contamination activities from a common source. Possible sources of community water contamination include: domestic, soil erosion, vegetal effects and soil–groundwater interaction. It is recommended that well heads be properly built above ground level and provided with well cap. In addition, rain water harvesting may be a good alternative to ground water exploration due to the high annual rainfall in the studied area.

ACKNOWLEDGEMENTS

The authors are grateful to the management of Niger Delta University for the release of academic staff research allowances. These monies were used for this research work. The data supporting the conclusions can be obtained from the references and tables included in the text.

Competing financial interest declaration

The authors do not have any conflicting financial interest concerning this project. This project has been funded from academic staff allowances provided by the University to the authors.

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