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Geochemical Evaluation of Formation Water from Oil Wells in 'XYZ' Field, Southern Niger Delta, Nigeria

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ABSTRACT: The 'XYZ' field is located in the southern part of Niger Delta, specifically between south of latitudes 4° and 6°N and east of longitudes 3° and 9° E. The aim of this research is to ascertain the quality status of formation water from oil wells so as to justify its effects and possible environmental and health hazards on host communities close to the terminals. A total of twenty-five (25) formation water samples were collected from wells F2A, F9A, F29A, F6A and F4A located in the 'XYZ' field. These samples were subjected to laboratory analysis to obtain information on their quality status. Results of some physical and chemical parameters show average values of 6.98mg/l for p^H , 2210.12mg/l for TS, 34.3° C for temperature, 0.50ms/cm for resistivity, 192.64mg/l for TH, 261.8mg/l for TDS, 30.24 for SAR, 66.5mg/l for Ca^{2+} , 39.4mg/l for Mg^{2+} , 1248.5 for Na^+ , 7.00mg/l for K^+ , 0.62mg/l for Fe^{2+} , 219.7mg/l for HCO_3^- , 13.88mg/l for SO_4^{2-} , 7984.0mg/l for Cl^- and 47.02mg/l for oil and grease content present in the formation water. Statistical analysis using the Product Moment Coefficient Correlation method indicates negative correlations between TH and TDS ($\delta = -0.5$), Na^+ and Cl^- ($\delta = -0.04$), TDS and Resistivity ($\delta = -0.05$) and Ca^{2+} and HCO_3^- (-0.07) respectively. All paired parameters are inversely correlated. The TDS and TH ranges from 126.00g to 16940.00g and 88.00g to 325.00g respectively for all the varieties of water samples collected in 'XYZ' field. Sodium Absorption Ratio (SAR) for collected samples vary with slight difference ranging from 14.00 to 52.00. Results obtained from semilogarithm graph show that the distribution of ions is in the order of Cl^- , Na^+ , HCO_3^- , Ca^{2+} and CO_3^{2-} which can be related to their individual level of solubility and mobility in water. Major formation water types based on dominant ions in the 'XYZ' field are chloride-sodium water and chloride-bicarbonate-sodium water which can be linked to differences in solubility and mobility of these ions. Sodium Absorption Ratio of all the samples is very high which exceeds the permissible range of 10. Thus, capable of causing devastating effects and hazards on vegetations, soils and water bodies. It is therefore recommended that the environmental performance of production companies and multinationals should be assessed regularly as well as suggest reasonable measures of handling formation waters for adoption by production companies as a way of ameliorating the environmental effects of improper disposal of oil field formation water.

KEYWORDS: Formation water, Oilfield, Oil wells, Hazards, Environment

I. INTRODUCTION

Formation water otherwise known as 'oil field water' has become of great significance to the petroleum geologist whose focus during oil exploration and exploitation process is on how to get useful crude oil in commercial occurrence. Hence, the need to study critically all the various (physical, chemical and biological components) of the crude oil. Ordinarily, formation water is certainly not a type of hydrocarbon occurrence. However, it is nearly always associated with hydrocarbons in reservoirs. In many of the reservoirs particularly in the Niger Delta, water forms a sort of bottom seal. Seals can then occur in the forms of oil-water contact and gas -water contact as it is usually the case in most reservoirs. It is invariably produced along with hydrocarbons and is only separated at flow stations and then discarded by oil producing companies. The presence of formation water and its chemistry therefore, affects the properties of the different hydrocarbon types. Also, its presence at times aids oil recovery by way of water-drive recovery method. Studies have shown that the chemistry, nature and quality of formation water (oil field water) varies from field to field and even from well to well within the same field. Results obtained from different wells within 'XYZ' field has proved the wide range of variation in formation water chemistry.

Basically, formation water has got its own environmental health and acceptability problems based on concentration levels for certain chemical parameters (Freeze and Cherry,1979). It is therefore important to understand the toxicity, mobility and essentiality of chemical elements in formation water particularly Zinc (Zn), Copper (Cu), Magnesium (Mg), Lead (Pb) and Barium (Ba) whose occurrence in most naturally occurring water and formation water have been the major cause of scale,



hence being potentially toxic. It is therefore very important to understand formation water type, characteristics, flow patterns, distribution and chemistry in selected wells located within the ‘XYZ’ field (Lloyd, 1985).

Nearly all sedimentary rocks are deposited in layers and are therefore said to be water-wet. The water which is deposited with the sediments is called ‘Connate water’ and it is part of the sediment. With burial, compaction and induration, much of this water is squeezed out of the sediments and become diluted, displaced or even changed in composition. As oil and gas are formed, these also displace some of the free water in order to have space to occupy. However, the interstitial water which may occupy up to 30% of the total pore space cannot be displaced by the oil and gas. This interstitial water together with any free water present, constitute the formation or oil field water of the reservoir. Six types of formation waters depending on the dominant mineral ions present have been identified in this research namely Sulphate – Sodium, Bicarbonate-Sodium, Chloride- Sodium, Chloride-Bicarbonate Sodium, Chloride-Magnesium and Chloride-Calcium formation waters. Sea generally contains 35,000ppm of dissolved mineral species most of it being NaCl. However, most formation waters contain upwards of 300,000ppm of minerals in solution. Oil field waters containing over 100,000ppm are usually referred to as ‘Brines’.

II. STUDY AREA: LOCATION AND FIELD HISTORY

The study area is located in the Niger Delta which is in the southern part of Nigeria and found to exist geographically between latitudes 4° and 6° and longitudes 3°and 9°E. The study area lies within the swampy delta region which is well noted to host large numbers of producing oil wells being a giant oil field with huge economic significance. However, the study area nomenclatured the ‘XYZ’ field play host to quite a reasonable numbers of oil wells which are specifically located at about some 40km to the west of Port Harcourt in Rivers State, Niger Delta region of Nigeria.



Figure 1: Map of the study area showing its’ location in Nigeria and the various oil fields



The 'XYZ' field is situated in OML -77 in the swamp region of the Niger Delta, Nigeria. The first discovery was made in 1975 being the XYZ well 12A which found some 264ft NGS and 307ft NOS in 11 intervals. A total of five (5) wells have been drilled into the XYZ structure encountering 19 reservoirs between the depth of 7000 and 12000ft sandstones. Thirteen of these reservoirs are oil bearing reservoirs (E7.0, M5.0) are planned for further development. No hydrocarbon bearing reservoirs were logged in well 12A. There are seven (7) completed drainage points in 4 wells all producing under primary recovery technique. Total cumulative oil production as at 1st December, 2005 is 3.9mmstb as the areal extent of the 'XYZ' field is about 100km² from 3D survey carried out in 1966.

III. MATERIALS AND METHODS

Materials used for this research include pH meter, graduated cylinder, reference electrode, glass electrode, magnetic stirrer, analytical balance, burette, beakers and desiccators and reagents such as sulphuric acid (H₂SO₄), 0.10N, sodium carbonate approximately 0.05N. Research methods adopted preliminary/desk studies, collection of data involving the collection of formation water samples, laboratory analysis and interpretation of collected data. Having gotten approval from the Department of Petroleum Resources (DPR), Shell Petroleum Development Company availed me the opportunity to work with already stored samples of the formation waters collected from 'XYZ' field. For the purpose of this research, five samples from each well were collected and analysed. The wells considered are F12A, F9A, F29A, F6A and F4A all from the 'XYZ' field. In all a total of twenty-five (25) formation water samples were collected and stored in a half litre (1.5 litre) polyethylene bottles with cap stoppers (cocks) to prevent samples from pouring out as collection is needed for necessary laboratory analysis. Sample bottles were cleaned with metal-free nitric acid and then rinsed two or three times with distilled and deionized water. For every sample collected into the polyethylene bottles, labelling was ensured with respect to well nomenclature (F12A, F9A, F29A, F6A and F4A). One set of samples was filtered using 0.45um filter membrane while 3ml of concentrated nitric acid was added to the second so as to prevent precipitation of hydrous oxides and absorption. Treated sample bottles were clearly marked for the determination of anionic and cationic parameters. Samples were then kept in a cool place awaiting laboratory analysis. Physical parameters such as colour, odour and temperature were also determined.

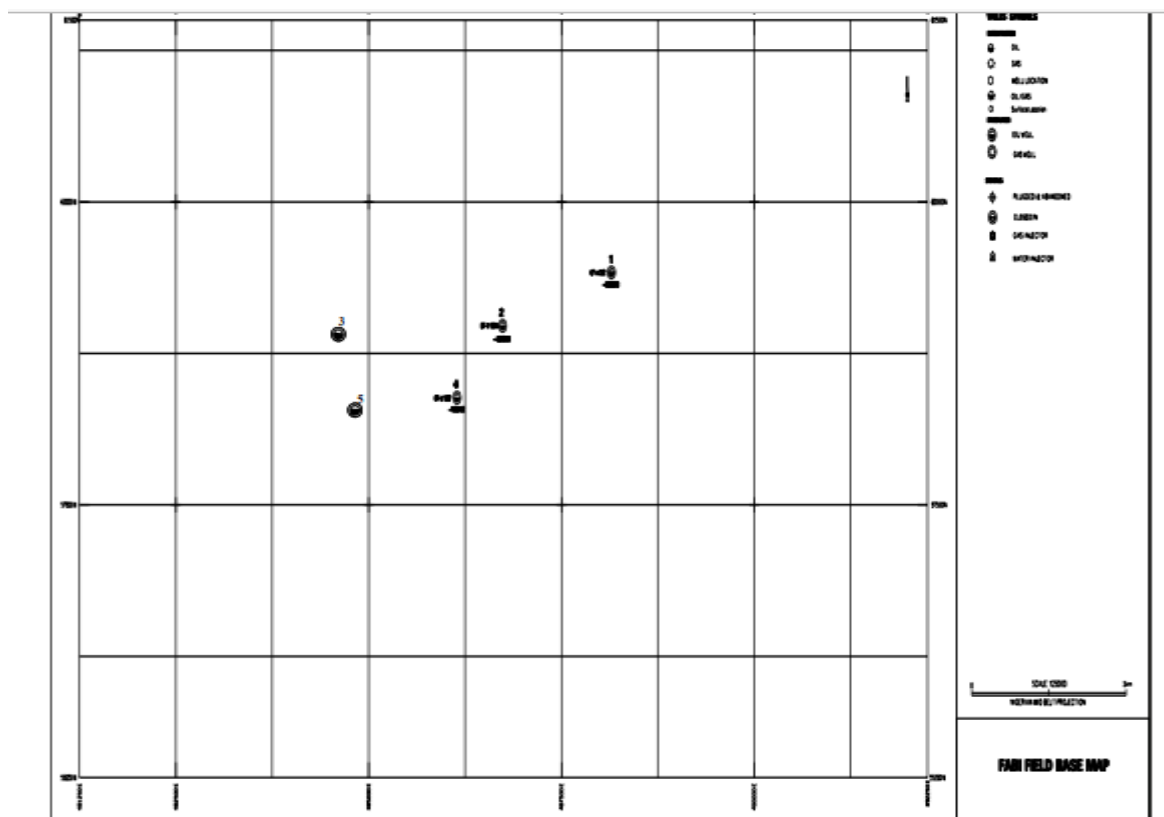


Figure 2: Base map of 'XYZ' field showing distribution of the wells

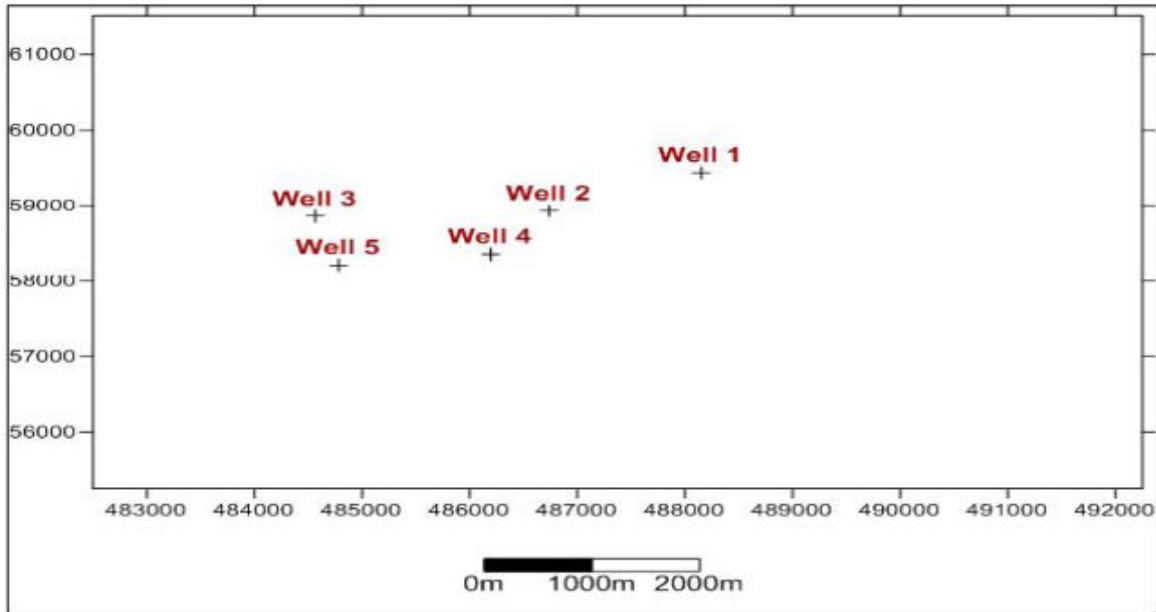


Figure 3: Map of 'XYZ' field showing well locations

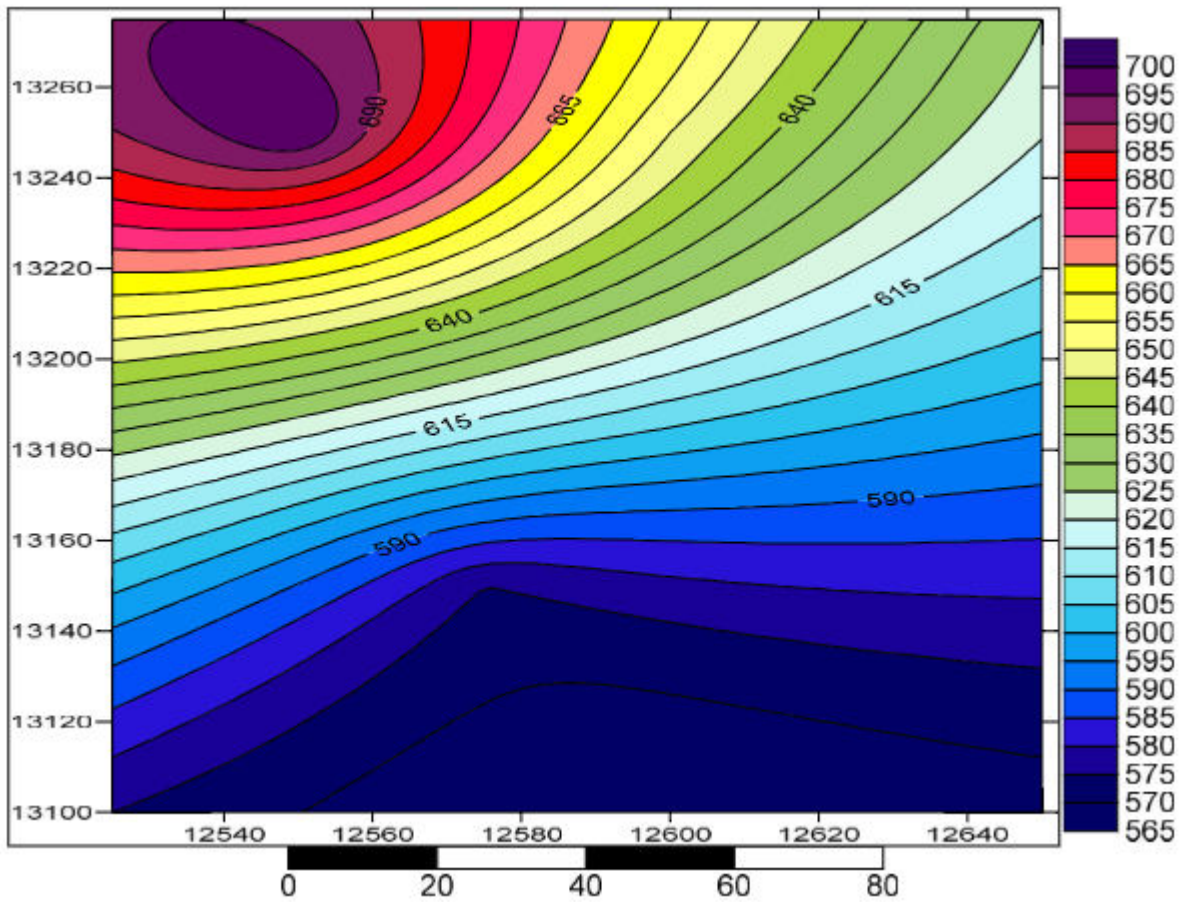


Figure 4: Thickness contour map for reservoirs across the five wells

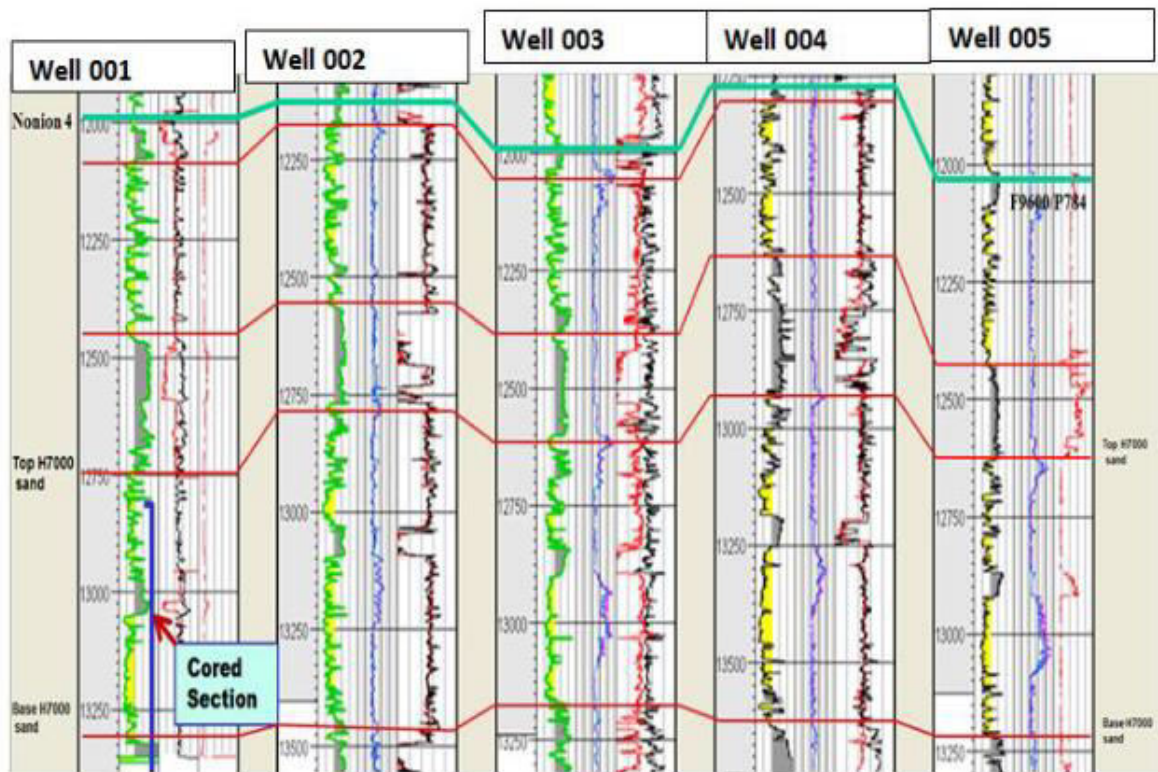


Figure 5: Well correlation panel for the five wells from seismic

IV. GEOLOGICAL SETTINGS: REGIONAL AND LOCAL GEOLOGY

Regional Geology of 'XYZ' field

The Niger delta is located in southern Nigeria between latitudes 4° and 6° and longitudes 3° and 9° E. It is bounded in the west by the Benin flank and in the east by the Calabar flank, a subsurface expression of the Oban Massif. It is bounded in the south by the Gulf of Guinea and on the north the older (Cretaceous) tectonic elements, such as the Anambra basin, Abakaliki Uplift and Afikpo Syncline. The delta covers an area in excess of 105,000 km² and constitutes the most important Cenozoic construction the south Atlantic. The Niger delta is the most important sedimentary basin in Nigeria from the point of both size and the thickness of sediments. It is also the most important from the economic point of view as its' petroleum reserves provide a large part of the country's foreign earnings. It is generally agreed that the modern Niger delta is built on an oceanic crust. Supporting arguments come from the pre-continental drift reconstruction which indicates an important overlap of NE Brazil on the present Niger delta area from a series of geological and geophysical observations, for example the presence of series of linear subdued and alternatively positive and negative anomalies beneath the Niger delta interpreted as seafloor spreading lineations. Four (4) major cycles of sedimentation have been established in the Niger deltas well as the other parts of the southern Nigeria sedimentary basin. These include Albian to Cenomanian cycle (Oldest), Turonian to Santonian cycle, Campanian to Maastrichtian cycle and Paleocene/Lower Eocene to Recent. The fourth sedimentary cycle commencing in the Paleocene/Lower Eocene is responsible for the main part of delta's growth. The Niger delta oil province with its' commercial oil fields is confined to the area covered by a thick sequence of rocks belonging to the youngest (Tertiary) sedimentary cycle. Major structures in the Niger delta oil province are growth faults and roll over anticlines associated with these faults on their down thrown seaward sides (Merki, 1972).

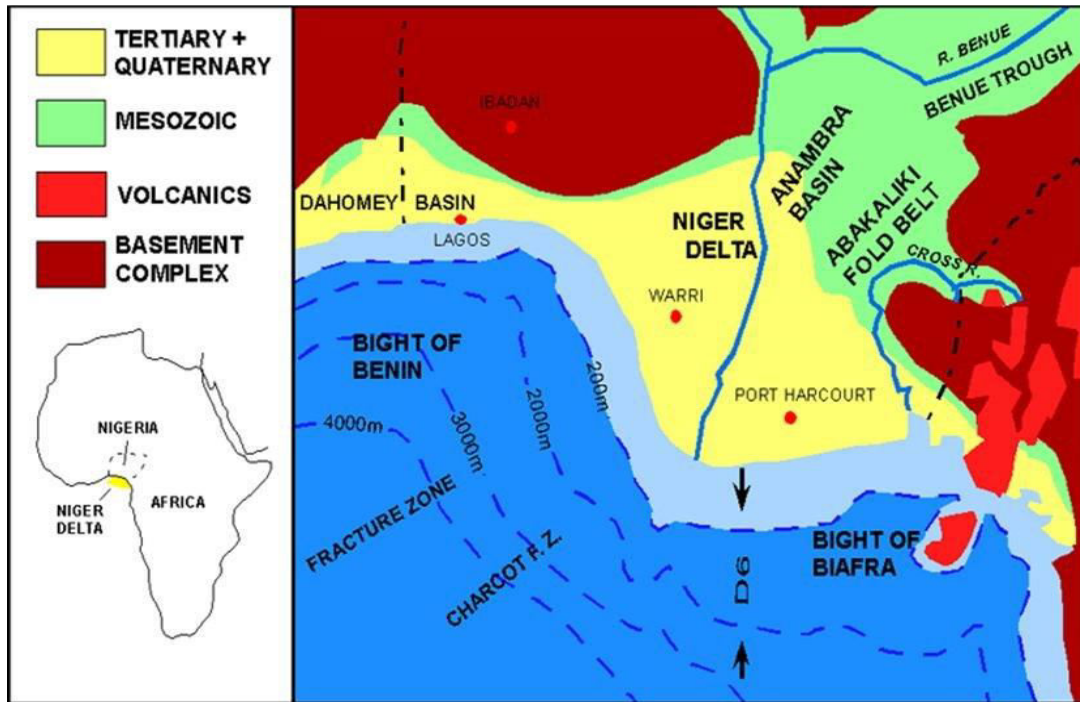


Figure 6: Geological Map of the Niger Delta Region (After Whiteman, 1982)

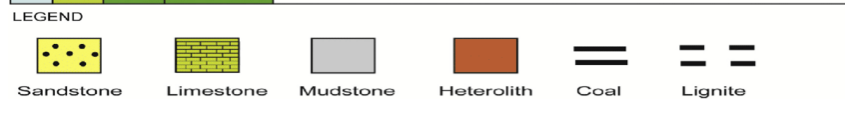
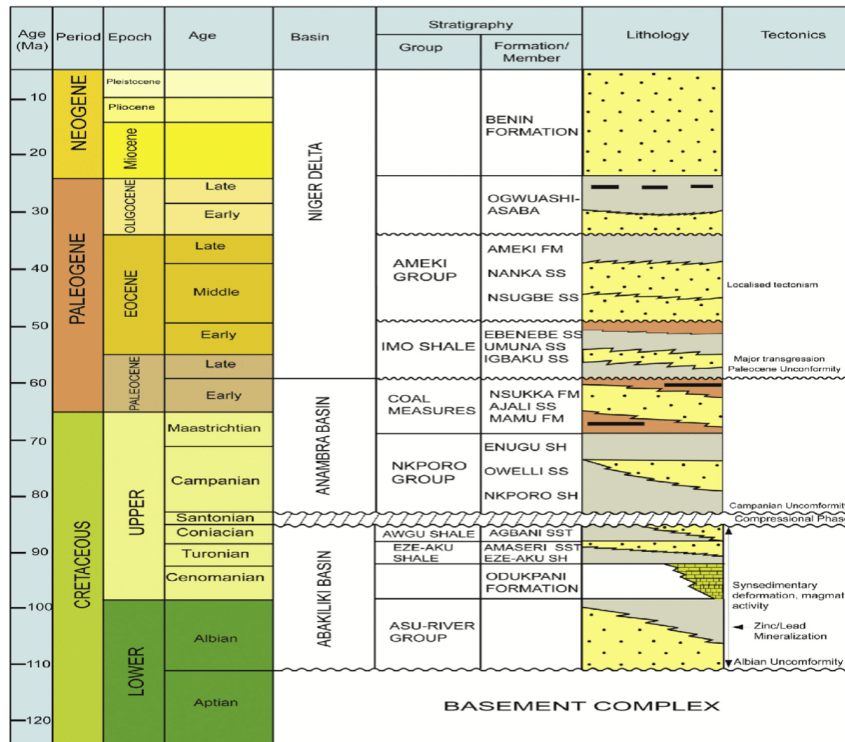


Figure 7: Schematic Cross section showing principal stratigraphic units of the tertiary Niger Delta (Ekweozor and Okoye, 1980).



Local Geology of ‘XYZ’ field

The ‘XYZ’ field is an elongated rollover anticline bounded to the north by a major growth fault and with some collapse type crestal faulting in the downthrown block. The ‘XYZ’ field structure is a large collapsed crest rollover trending east-west. Bounded to the north by the major xx boundary fault, its’ former part of the larger Baristo structural trend. The hydrocarbons found at shallow depths are trapped against the southern -most antithetic fault while at deep levels, the hydrocarbons are dip closed in footwall of this same antithetic fault. The field is made off stacks of sedimentologically similar reservoir sand bodies called barrier bar type by an earlier worker which is now interpreted as splay or mouth bar. For the sedimentology of the ‘XYZ’ field, the reservoir sands are mainly stacking of similar reservoir sands which trend east-west. The sands are usually thickest near the growth fault and the growth faults are thin in the southwestern direction.

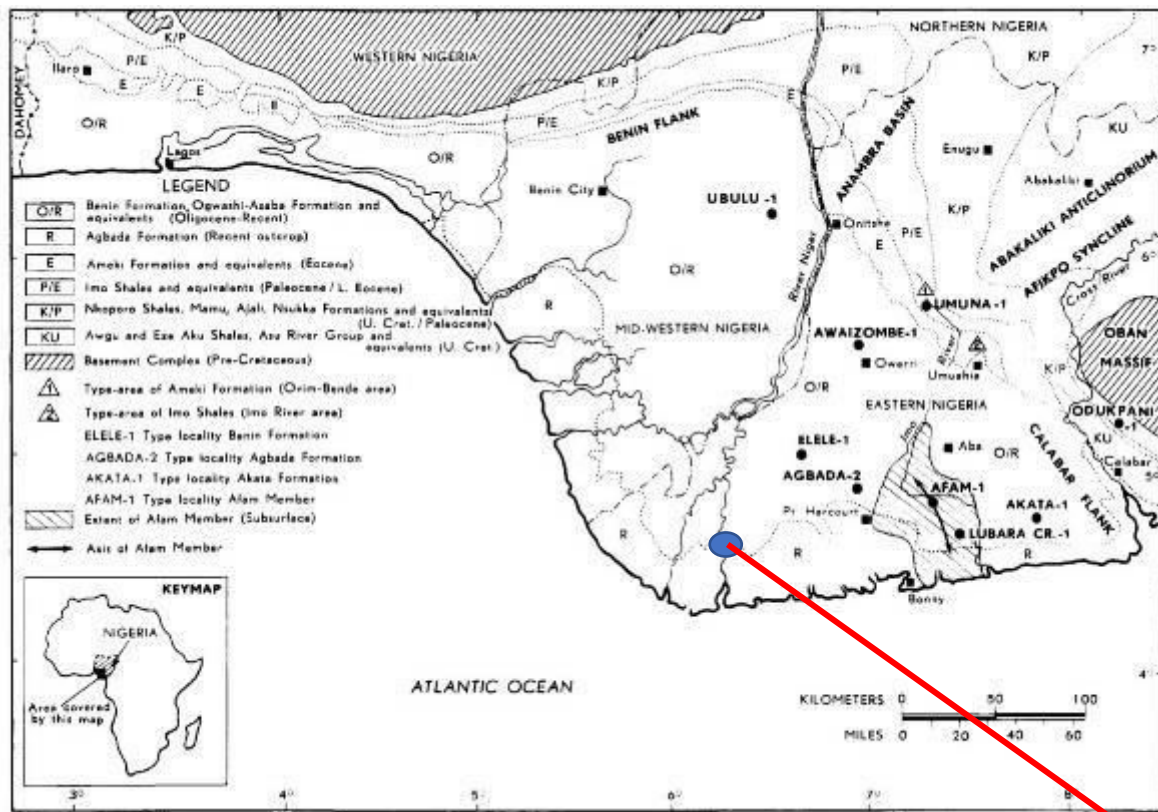


Figure 8: Geologic Map of the Niger Delta region showing the study area (After Short and Stauble, 1967)

Study Area

V. RESULTS AND DISCUSSIONS

Table 1 below present the results of the physical parameters analysed in the formation water sampled from five (5) oil wells in ‘XYZ’ field located in the southern coastal swamp of the Niger delta. The physical parameters tested for include temperature, colour and odour. These results were obtained in-situ from the oil wells with the readings being the actual data acquired as at the time of collecting the formation waters at the well site. A total of twenty-five (25) formation water samples were retrieved from all the five oil wells, which implied that five (5) samples were collected from each oil well at various depth downhole. Well number F12A has an elevation of about -12988 with formation waters retrieved at a depth ranging between 11325-11725ft. Well F9A is located on an elevation of about -12870 with its formation waters retrieved at a depth ranging between 11825-12225ft. While F29A, F6A and F4A all have their formation waters collected at a depth range of 12325-12725ft, 12825-13225ft and 13325-13725ft in that order



downhole. However, all the samples were observed to be colourless but exhibit offensive odours. The offensive odour could be traced to the presence of sulphur contents in the well formation during the formation of the crude oil.

Table 1: Physical parameters analysis for formation water samples obtained from oil wells

S/NO	Well Name	Well Elevation	Sample No	Temp(°C)	Colour	Odour	Depth (FT)
1	F12A	-12988	1	24	Colourless	Offensive	11325
			2	24.5	Colourless	Offensive	11425
			3	25	Colourless	Offensive	11525
			4	26	Colourless	Offensive	11625
			5	26.2	Colourless	Offensive	11725
2	F9A	-12870	6	26.9	Colourless	Offensive	11825
			7	27.5	Colourless	Offensive	11925
			8	28.8	Colourless	Offensive	12025
			9	28.8	Colourless	Offensive	12125
			10	29.5	Colourless	Offensive	12225
3	F29A	-12869	11	29.5	Colourless	Offensive	12325
			12	29.5	Colourless	Offensive	12425
			13	30.2	Colourless	Offensive	12525
			14	30.9	Colourless	Offensive	12625
			15	32.3	Colourless	Offensive	12725
4	F6A	-12912	16	32.9	Colourless	Offensive	12825
			17	33.4	Colourless	Offensive	12925
			18	33.6	Colourless	Offensive	13025
			19	34.7	Colourless	Offensive	13125
			20	35.4	Colourless	Offensive	13225
5	F4A	-12868	21	35.9	Colourless	Offensive	13325
			22	36.4	Colourless	Offensive	13425
			23	36.9	Colourless	Offensive	13525
			24	37.7	Colourless	Offensive	13625
			25	39.6	Colourless	Offensive	13725

The data for physical and chemical parameters of the formation waters collected from wells F12A, F9A, F29A, F6A and F4A in ‘XYZ’ field are presented in tables 2a and 2b below. The percentage composition of each chemical parameter which include anions and cations per sample are presented in table 2b with each results summarized using bar charts (Figures 9-17). The summary of the various parameters in terms of their mean values are however compared to those of the 1984 DPR standard (Table 12) From the results obtained, the pH values range from 6.00 - 8.31 and temperature varies between 25.00°C to 45.50° C respectively. Resistivity ranges between 0.21ms/cm to 0.84ms/cm which was generally seen to be low. Results were also obtained for Total Hardness (TH), Total Solid (TS), Total Dissolved Solids (TDS) and Total Suspended Solids (TSS). Total Hardness ranges between 88.00 – 325.00g. Total Solids range between 126.00 to 16940.00g. Total Dissolved Solids range between 86.0mg/l and Total Suspended Solids range between 54.0mg/l to 182.0mg/l. For the anions, chloride (Cl⁻) is the most abundant while bicarbonate and hydroxyl ion (OH⁻) all occur in small but rather appreciable amounts. The formation water types dominant in the ‘XYZ’ field are Chloride- Sodium and Chloride-Bicarbonate-Sodium respectively. For the cations, the most abundant cation contents in the formation waters are two namely the alkaline earth elements which includes Ca²⁺ and Mg²⁺ with the alkalis which included Na⁺ and K⁺. The alkalis potassium occurs in less abundant amounts than sodium. Oil and



grease content of the formation waters in the wells are greater than the potassium, sulphates, copper, lead, cadmium, zinc, iron and nickel contents.

Table 2: Physical parameters analysed in formation waters from oil wells in 'XYZ' field

S/N	Well	Elevation	Depth (Ft)	Sample No	pH value	Temp(°C)	Resistivity (ms/cm)	TH (mg/l)	TS(g)	SAR (mg/l)	TDS (mg/l)	TSS (mg/l)
1	F12A	-12988	11325	1	6.6	25	0.41	88	13056	30	150.5	104
			11425	2	6.5	26	0.37	160	1066	35	510.2	138
			11525	3	6	26.6	0.42	120	870	45	204	125
			11625	4	6.82	27.8	0.35	128	1084	28	525	160
			11725	5	6.73	32.5	0.62	138	2740	45.2	645.2	130
2	F9A	-12870	11825	6	7.2	26	0.61	242	352	16	125.5	104
			11925	7	8.31	28.5	0.42	150	16940	14	425.5	95
			12025	8	6.04	28.9	0.57	174	340	32	86	84
			12125	9	6.09	32.5	0.82	325	390	30	94.05	89
			12225	10	7	36.5	0.66	185	126	52	52	135
3	F29A	-12869	12325	11	7.2	35.5	0.84	245	208	27	75	75
			12425	12	6.52	36.5	0.43	150	812	35	195	89
			12525	13	7.55	38.5	0.44	162	1206	24	234	82
			12625	14	8.00	39.5	0.53	172	825	18	326	64.5
			12725	15	8.25	40.5	0.62	198	1044	20	520	72.5
4	F6A	-12912	12825	16	6.3	30	0.84	153	1020	42	410	79.2
			12925	17	6.45	32	0.37	165	1500	14.24	324	54.0
			13025	18	7.25	34	0.21	195	1820	36.28	350	65.0
			13125	19	8.00	37	0.34	220	1040	20.45	205	173
			13225	20	8.01	39.5	0.42	242	1050	14.5	95	64.5
5	F4A	-12868	13325	21	6.42	38.5	0.38	189	1230	41.25	99	182
			13425	22	6.89	39.5	0.25	200	1856	34.5	420	150
			13525	23	7.04	40.5	0.42	245	1430	38.5	182.5	134
			13625	24	6.82	42.5	0.60	280	1520	29.2	130.2	135
			13725	25	6.70	45.5	0.72	290	1728	34	162	165

Table 3: Chemical parameters analysed in formation waters from oil wells in 'XYZ' field

Well	Elevation	Depth(ft)	Sample	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	SO ₄ ²⁻	OGC	Cu ²⁺	Pb ²⁺	Cd ²⁺	Zn ²⁺	Fe ²⁺	Ba ⁺	Ni ⁺	OH ⁻	CO ₃ ²⁺	Cl ⁻	HCO ₃ ⁻
			1	65	36	680	10	30	35	0.05	0.04	0.02	0.01	0.25	5	0.1	0.01	300	1050	245
			2	75	32	7	5	15	34	0.04	90	0.01	0.02	0.25	12	1.25	0	240	1005	125
			3	82	42	686	5	5	125	0.01	0.41	0.04	0.01	0.25	20	1.5	0.03	125	0	155
			4	45	60	1	10	15	23	0.02	0.04	0.01	0.03	0.15	15	0.3	0.4	100	8250	300
			5	102	12	615	5	20	132	0.20	0.05	0.02	0.04	0.2	10	0.4	0.03	120	1004	200
						3													9055	
						501														
						7														
						428														



F9A	-12870	6	94	36	655	10	10	130	0.50	ND	0.01	ND	0.2	10	0.05	0.02	85	1055	150	
		7	82.0	40	204	5	10	28.0	0.10	0.02	0.05	0.02	0.25	6	2	0	120	0	420	
		8	54	30	42.3	10	10	22.5	0.10	0.01	0.06	0.01	0.25	11	0.3	0	220	1200	125	
		9	42	36	505	5	10	20	0.40	0.03	0.1	0.03	1.0	10	2.2	0	144	4	520	
		10	71	40	280	10	20	18	0.20	ND	0.09	0.03	2	15	1.5	0.01	108	5080	235	
																		3042	1502	5
F29A	-	11	66	30	325	5	5	25	0.10	0.2	0.1	ND	0.25	8	0.6	0.02	120	1000	200	
		12	92.5	86	265	5	10	30	0.25	0.01	ND	ND	0.25	7.	1.2	0.02	100	5	535	
		13	84	14.5	108	108	10	25	0.50	0.02	0.02	0.01	0.15	5	0.25	0.01	55	1205	150	
		14	109	36.4	125	12	15	23	0.40	0.03	0.01	ND	0.2	10	0.2	0.01	50	0	180	
		15	106	17	145	2	11	22	0.10	0.04	0.05	0.04	0.58	14	3.05	0.02	30	7282.	150	
													12				5	5035	2520	
F6A	-12912	12825	16	85.2	70.4	625	10	27	30	0.20	0.02	0.06	0.02	0.59	10	2.5	0.02	20	7250	180
			17	74.5	45	420	3	15	32.5	0.30	ND	0.07	0.03	0.25	16	0.42	0	25	1507	230
			18	53.6	69	350	5	5	25	0.25	0.01	0.04	0.01	0.26	8	0.5	0	15	2	120
			19	23.2	30	620	10	25	26	0.10	0.1	0.05	0.03	0.25	10	ND	0	20	6042	240
			20	48	36	208	5	15	32	0.01	0.25	0.1	0.02	0.25	12	0.5	0.15	250	3040	125
																		3080		
F4A	-12868	13325	21	14.4	40	65	4	10	35	0.20	0.21	0.12	ND	0.20	10	0.1	0.12	130	2500	100
			22	44.8	44.8	12	5	12	30	0.40	ND	0.4	0.01	2.50	5	0.8	0.50	300	300	120
			23	49.6	49.6	60	6	15	32	0.50	0.10	ND	0.01	2.20	6	2.0	0.20	250	250	4
			24	45.6	24	45.6	8	12	135	0.40	ND	0.15	0.02	0.09	12	1.2	0.20	200	0.2	152
			25																	

Table 4: Percentage Composition of ions in Sample 1

Ions	%
Ca ²⁺	0.76
Mg ²⁺	0.42
Na ⁺	79
K ⁺	0.12
SO ₄ ²⁻	0.35
OGC	0.41
Cu ²⁺	0.001
Pb ²⁺	0.001
Cd ⁺	0.0002



Zn ²⁺	0.0001
Fe ²⁺	0.003
Ba	0.06
Ni	0.0012
OH ⁻	0.00012
CO ₃ ²⁺	3.5
Cl ⁻	12.2
HCO ₃ ⁻	2.85

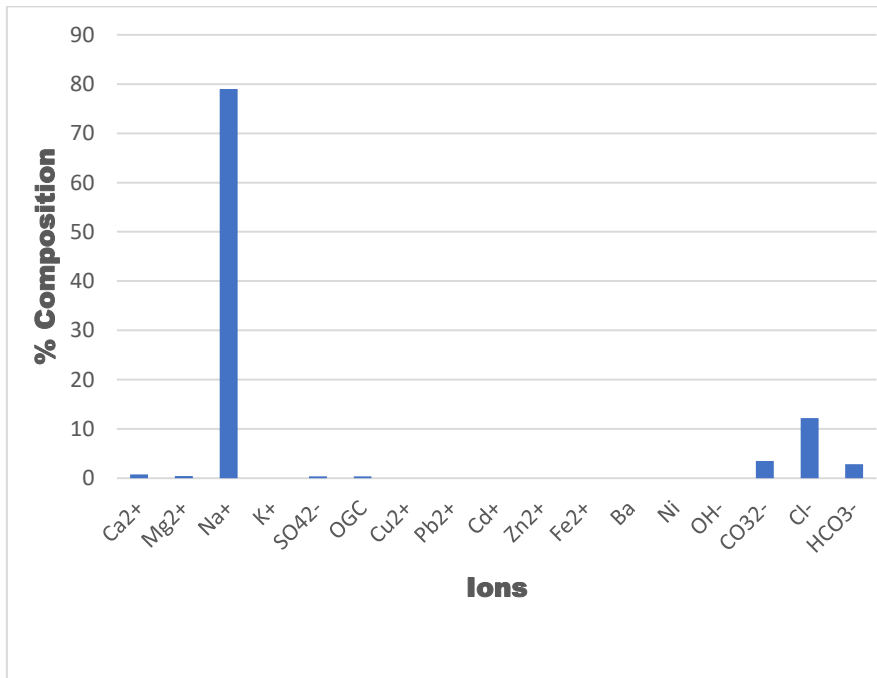


Figure 9: Bar chart showing percentage composition of ions in sample 1

Table 5: Percentage Composition of ions in Sample 2

Ions	%
Ca ²⁺	0.43
Mg ²⁺	0.18
Na ⁺	39.3
K ⁺	0.03
SO ₄ ²⁻	0.006
OGC	0.19
Cu ²⁺	0.0002
Pb ²⁺	0.005



Cd ⁺	0.00005
Zn ²⁺	0.0001
Fe ²⁺	0.0014
Ba	0.07
Ni	0.007
OH ⁻	0
CO ₃ ²⁺	1.4
Cl ⁻	57.6
HCO ₃ ⁻	0.72

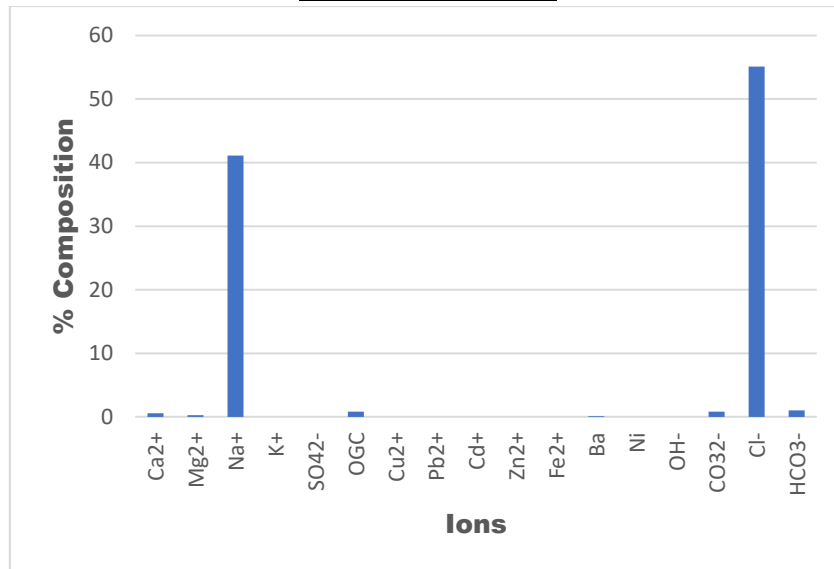


Figure 10: Bar chart showing percentage composition of ions in sample 2

Table 6: Percentage Composition of ions in Sample 3

Ions	%
Ca ²⁺	0.55
Mg ²⁺	0.28
Na ⁺	41.1
K ⁺	0.03
SO ₄ ²⁻	0.03
OGC	0.84
Cu ²⁺	0
Pb ²⁺	0.003
Cd ⁺	0
Zn ²⁺	0



Fe ²⁺	0.002
Ba	0.13
Ni	0.01
OH ⁻	0
CO ₃ ²⁺	0.84
Cl ⁻	55.1
HCO ₃ ⁻	1.04

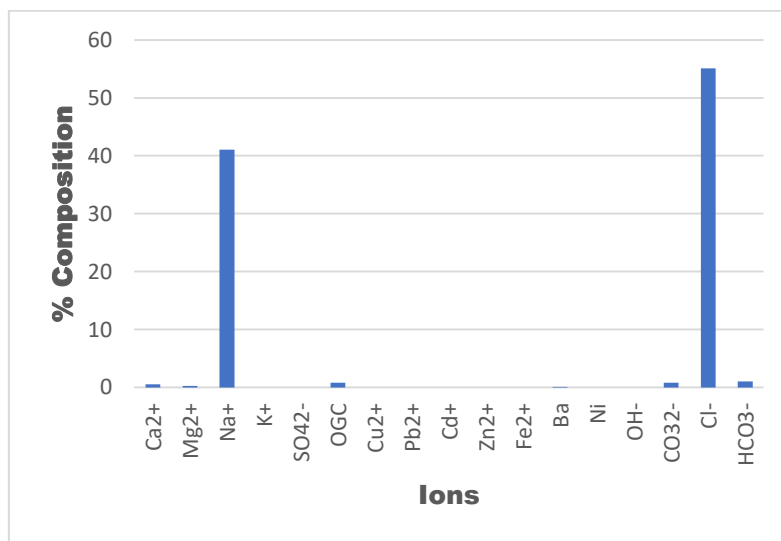


Figure 11: Bar chart showing percentage composition of ions in sample 3

Table 7: Percentage Composition of ions in Sample 4

Ions	%
Ca ²⁺	0.68
Mg ²⁺	0.91
Na ⁺	76.1
K ⁺	0.15
SO ₄ ²⁻	0.23
OGC	0.35
Cu ²⁺	0.0003
Pb ²⁺	0.0006
Cd ⁺	0
Zn ²⁺	0
Fe ²⁺	0
Ba	0.23



Ni	0.0004
OH ⁻	0.006
CO ₃ ²⁺	0.02
Cl ⁻	15.2
HCO ₃ ⁻	4.55

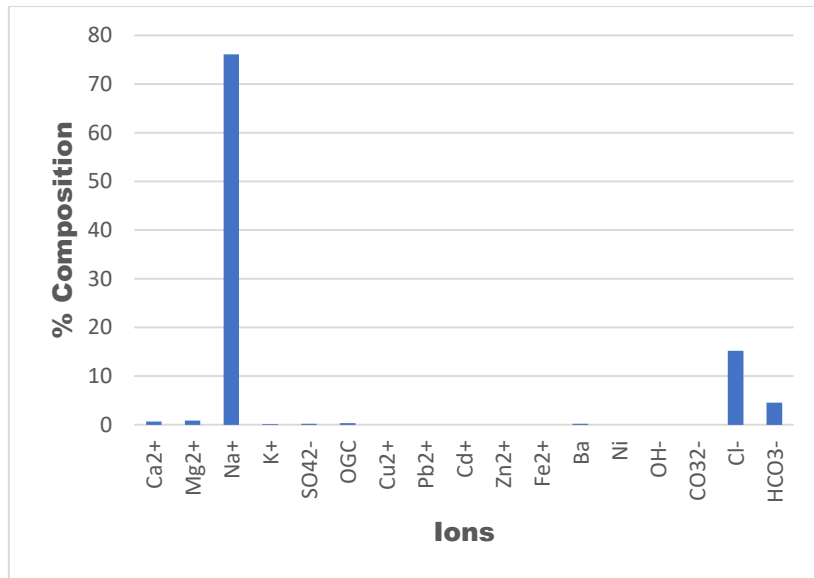


Figure 12: Bar chart showing percentage composition of ions in sample 4

Table 8: Percentage Composition of ions in Sample 5

Ions	%
Ca ²⁺	1.01
Mg ²⁺	0.12
Na ⁺	4.23
K ⁺	0.05
SO ₄ ²⁻	0.2
OGC	1.31
Cu ²⁺	0.002
Pb ²⁺	0.0005
Cd ⁺	0.0002
Zn ²⁺	0.0004
Fe ²⁺	0.002
Ba	0.01
Ni	0.004
OH ⁻	0.0003



CO_3^{2+}	1.19
Cl^-	89.8
HCO_3^-	1.98

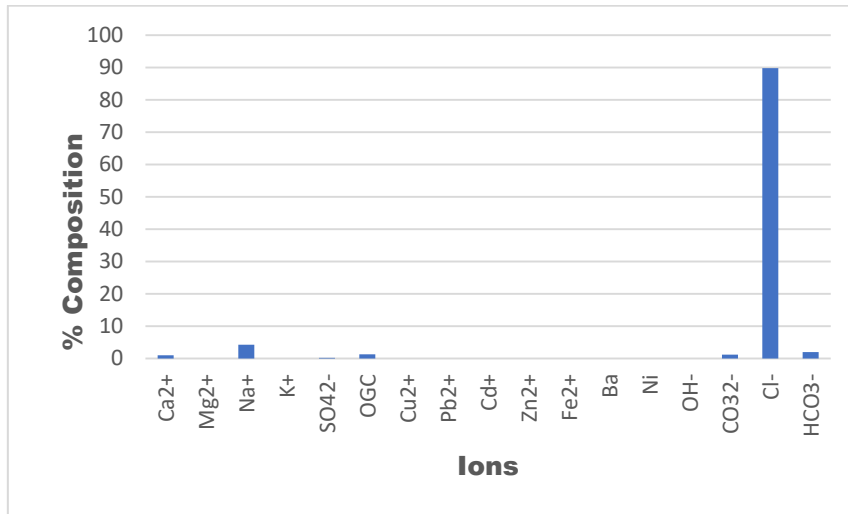


Figure 13: Bar chart showing percentage composition of ions in sample 5

Table 9: Percentage Composition of ions in Sample 10

Ions	%
Ca ²⁺	0.45
Mg ²⁺	0.25
Na ⁺	1.78
K ⁺	0.06
SO ₄ ²⁻	0.13
OGC	0.11
Cu ²⁺	0.0013
Pb ²⁺	ND
Cd ⁺	0.0006
Zn ²⁺	0.0002
Fe ²⁺	0.013
Ba	0.09
Ni	0.009
OH ⁻	0



CO ₃ ²⁺	0.68
Cl ⁻	94.9
HCO ₃ ⁻	1.48

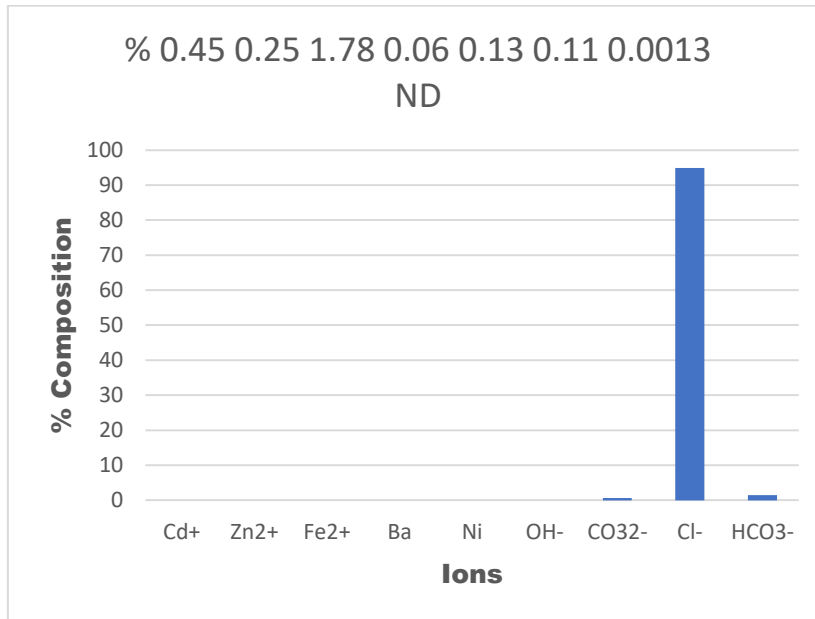


Figure 14: Bar chart showing percentage composition of ions in sample 10

Table 10: Percentage Composition of ions in Sample 15

Ions	%
Ca ²⁺	3.5
Mg ²⁺	0.56
Na ⁺	4.8
K ⁺	0.067
SO ₄ ²⁻	0.36
OGC	0.72
Cu ²⁺	0.003
Pb ²⁺	0.0013
Cd ⁺	0.002
Zn ²⁺	0.0013
Fe ²⁺	0.02
Ba	0.39
Ni	0.1
OH ⁻	0.0006



CO ₃ ²⁺	0.99
Cl ⁻	83.5
HCO ₃ ⁻	4.96

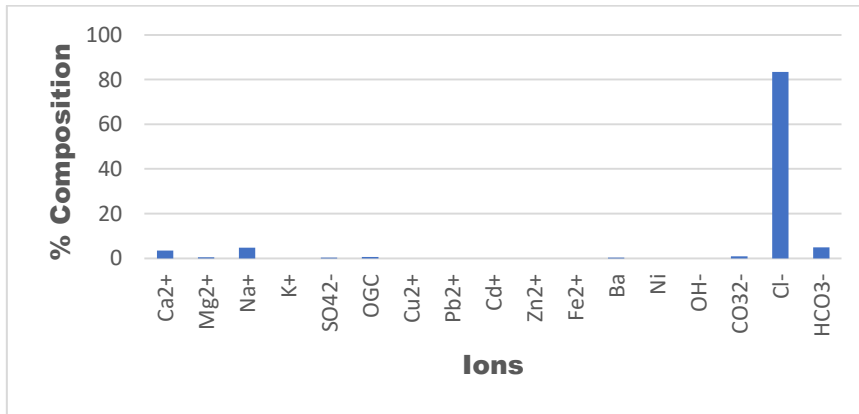


Figure 15: Bar chart showing percentage composition of ions in sample 15

Table 11: Percentage Composition of ions in Sample 20

Ions	%
Ca ²⁺	1.23
Mg ²⁺	0.94
Na ⁺	5.45
K ⁺	0.13
SO ₄ ²⁻	0.39
OGC	0.84
Cu ²⁺	0.0003
Pb ²⁺	0.007
Cd ⁺	0.003
Zn ²⁺	0.0005
Fe ²⁺	0.006
Ba	0.31
Ni	0.003
OH ⁻	0.004
CO ₃ ²⁺	6.5
Cl ⁻	80.8
HCO ₃ ⁻	3.28

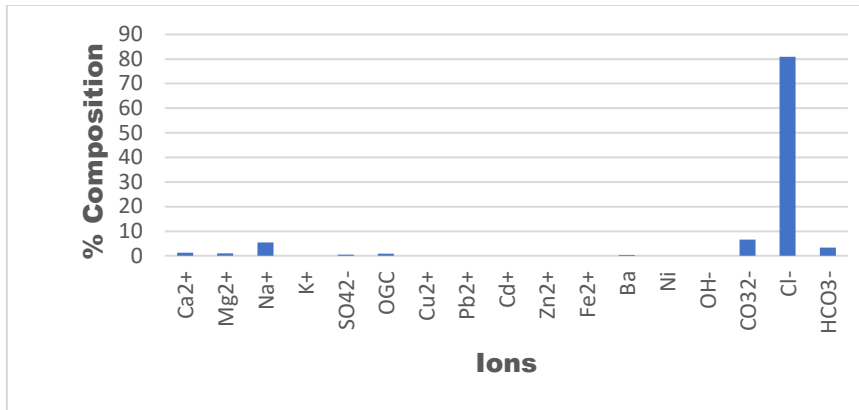


Figure 16: Bar chart showing percentage composition of ions in sample 20

Table 12: Percentage Composition of ions in Sample 25

Ions	%
Ca ²⁺	0.47
Mg ²⁺	0.28
Na ⁺	2.19
K ⁺	0.08
SO ₄ ²⁻	0.13
OGC	0.92
Cu ²⁺	0.004
Pb ²⁺	0.003
Cd ⁺	0.002
Zn ²⁺	0.004
Fe ²⁺	0.022
Ba	0.13
Ni	0.002
OH ⁻	0.004
CO ₃ ²⁻	1.32
Cl ⁻	92.2
HCO ₃ ⁻	2.19

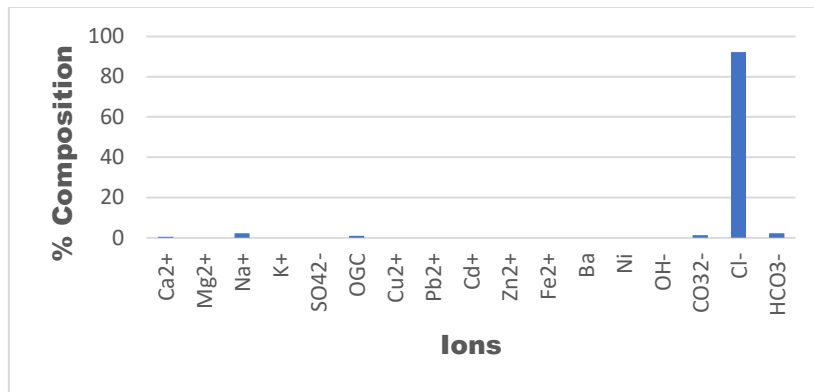


Figure 17: Bar chart showing percentage composition of ions in sample 25

Table 13: Permissible Range for Physico-chemical parameters associated with formation waters (DPR, 1984)

Parameters	Undesirable Effects	Highest Desirable Level	Maximum Permissible Level
A.Physical			
Colour	Discolorations	5	50
Odour	Odours	Unobjectionable	Unobjectionable
Taste	Taste	Unobjectionable	Unobjectionable
Total Solid (mg/l)	Gastrointestinal irritation	500	1500
Suspended Matter	Gastrointestinal irritation	5	25
B.Chemical			
P ^H (Unit)	Taste	7.0 to 8.5	6.5 to 9.2
Calcium (mg/l)	Corrosion		
Chloride(mg/l)	Excessive Scale Formation	75	200
	Taste	200	600
	Corrosion in hot water systems		
Total Hardness of CaCO ₃ in mineral oil	Excess scale formation Taste Odour	100	500
C.Trace Elements			
Arsenic (mg/l)	Toxic		
Copper(mg/l)	Astringent Taste Discolorations of fittings and Utensils	0.5 0.1	0.05 1.5
Cyanide (mg/l)	Toxic taste, Discolorations, Deposits in pipes		1.0
Zinc (mg/l)	Turbidity Astringent	5.0	15.0

When physico-chemical parameters are analysed in formation waters and their percentage compositions and contents exceed maximum permissible level, they have the potential to cause scale formation. Scale is the hard deposit of the inorganic mineral constituent of water which precipitates from the water. Scale may adhere to metal and other surfaces in the oil and gas production system or may be deposited as sludge. The resultant effect of the presence of scale formation caused by formation waters in the oil and gas sectors may include reduced oil production, well plugging, reduction in pipe carrying capacity, impedance of heat transfer, increase in operational safety hazards, localization of corrosion attack and increased operational cost. In production operations, scale problems may be encountered whenever water is produced with oil and gas due to the destabilization of water caused by changes as the fluids pass



through the production processing equipment. The scale species common in oil and gas production system include calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate and iron deposits. In comparison of the physical and chemical parameters analysed in the formation waters with the DPR 1984 standard which identifies the contents and composition of the parameters whether they fall within permissible range or not (Table 13).

Table 14: Summary of Physical and Chemical Characteristics of Formation Water Samples and DPR (1984) Standard

S/NO	Measured Parameter	Mean Value	DPR Standard	Remark
1	pH	6.98	4.0 - 9.2	Permissible
2	Temp(°C)	34.3	24.4 – 29.00	Not Permissible
3	Resistivity (mg/l)	0.50	6.00 - 1272	Permissible
4	TH (mg/l)	192.64	Max. 100	Not Permissible
5	TS (mg/l)	2210.12	Max.1500	Not Permissible
6	TDS (mg/l)	261.8	Max. 100	Permissible
7	SAR	30.24	Max. 410	Not Permissible
8	Ca ²⁺ (mg/l)	66.5	Max. 200	Permissible
9	Mg ²⁺ (mg/l)	39.4	Max. 150	Permissible
10	Na ⁺ (mg/l)	1248.5	Max. 200	Not Permissible
11	Zn ²⁺ (mg/l)	0.036	Max. 5.0	Permissible
12	K ⁺ (mg/l)	7.00	Max. 50	Permissible
13	Pb ²⁺	0.11	Max. 5.0	Permissible
14	Fe (Total Iron)	0.62	Max.1.00	Permissible
15	Ba ⁺	10.80	Max. 5.0	Not Permissible
16	HCO ₃ ⁻	219.7	Max. 500	Permissible
17	Cl ⁻	7984.9	Max. 500	Not Permissible
18	SO ₄ ²⁻	13.88	Max. 200	Permissible
19	CO ₃ ²⁺	131.0	Max. 20	Not Permissible

S/N	Parameter	Range	Mean Value	Percentage Composition
1	Ca ²⁺	23.20-109.00	66.5	0.68
2	Mg ²⁺	12.00-86.00	39.4	0.40
3	Na ⁺	65.00-6861.2	1248.5	12.80
4	K ⁺	2.00-12.00	7.00	0.07
5	SO ₄ ²⁺	5.00-30.00	13.88	0.14
6	OGC	18.00-135.00	47.03	0.48
7	Cu ²⁺	0.01-0.50	0.23	0.0023
8	Pb ²⁺	0.01-0.90	0.11	0.001
9	Cd ⁺	0.01-0.20	0.07	0.0007
10	Zn ²⁺	0.01-0.50	0.04	0.0004
11	Fe ²⁺	0.09-2.55	0.62	0.006
12	Ba ⁺	5.00-20.00	10.8	0.11
13	Ni ⁺	0.05-3.05	0.92	0.009
14	OH ⁻	0.00-0.50	0.09	0.0009
15	CO ₃ ²⁺	15.00-300.00	131.0	1.34
16	Cl ⁻	1004.0-15250	7984.9	81.7
17	HCO ₃ ⁻	100-535.00	219.7	2.25

Since the chemical character of any water determines its' quality and utilization, the quality is a function of the physical, chemical and biological parameters and could be subjective since it depends on a particular intended use (Tijani, 1994). Fe⁺ and Cl⁻ occurrence in these formation waters can be highly attributed to geological influence. The extent of laterites and lateritic soils might well suggest an answer to the total Fe levels. The Fe level are possibly derived from minerals such as hematite (FeO₃), limonite(2Fe₂O₃(3H₂O), siderite (Fe₂CO₃) and mainly Goethite



(Fe(OH)₄) in which most Fe are suspected to exist in these waters especially in colloidal form. HCO₃⁻ ions are attributed to minerals like calcite and siderite, however, its content in formation waters may be greatly influenced by biota through bacteria activities within the reservoirs. Chemical parameters such as Ca²⁺, Mg²⁺, K⁺, Fe, SO₄²⁻ all fall within acceptable limits. High chloride and carbonate content in the formation waters are responsible for its unpleasant taste making it unfit for consumption (Carroll, 1962). Water containing SAR(0-10mg/l) can be applicable on all agricultural soils while waters containing SAR (18-26mg/l) can produce harmful effects which requires good soil management. Formation waters with SAR (26-100mg/l) is unsuitable for irrigational purposes. Based on the above, formation waters (Oil field water) collected from the study area contains SAR ranging from 14.00 - 52.00 with a mean value of 30.24mg/l. This is far above the maximum permissible range, thus very high and harmful to all kinds of soils, vegetations and organisms (aquatic or terrestrial). High SAR values in formation waters from wells in ‘XYZ’ field is a factor capable of reducing permeability of soils exposed to discarded formation water contents. Hence, cannot be used for irrigation, agricultural and domestic uses.

Physical parameters such as PH and TDS all fall within acceptable limits (DPR, 1984). Other parameters such as SAR, Temp, TH and TS do not fall within acceptable range. Thus, capable of influencing excessive scale formation with the capacity to form excessive scales hence, causing corrosion in oil pipes.

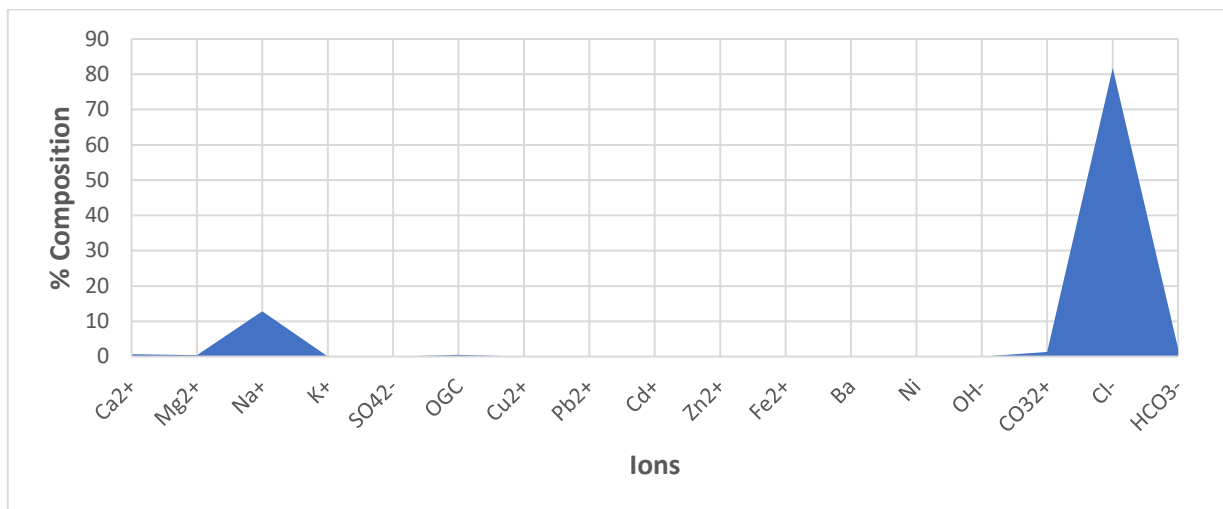


Figure 18: Semilogarithm graph showing percentage distribution of ions in formation waters

Statistical Analysis

The need for statistical analysis involving statistical correlations between some pairs of physical and chemical parameters was aimed at ascertaining the possibility of a strong or weak correlation between pairs of analysed parameters. Hence, the use of Product Moment Coefficient of Correlation method was considered. The pair of variables used include TH and TDS, Na⁺ and Cl⁻, TDS and RES, Ca²⁺ and HCO₃⁻ in that order. Using formulae, the Product Moment Coefficient of Correlation is mathematically expressed as:

$$\delta = \frac{\text{Cov}}{S_1 S_2}$$

Where δ = Computational Variance

Cov = Covariance of X₁ and X₂

S₁S₂ = Standard Deviation of S₁ and S₂ respectively

Note For the purpose of computation refer to tables showing results of physical and chemical parameters analysed from the formation waters (Tables 2 and 3). Such that values of paired variables are represented as X₁ and X₂ respectively.

Hence, results of coefficient of correlation values obtained from formulae for TH and TDS ($\delta = -0.5$), Na⁺ and Cl⁻ ($\delta = -0.04$), TDS and RES ($\delta = -0.05$), Ca²⁺ and HCO₃⁻ ($\delta = -0.07$). From results obtained it is therefore deduced that all the paired variables showed significantly that they exhibit a negative weak strong correlation which geologically implied that they belong to heterogenous geogenic sources.



VI. CONCLUSION AND RECOMMENDATIONS

Results from formation water chemical analysis as obtained from 'XYZ' field shows that the presence of Na^+ , Cl^- and HCO_3^- as the dominant ions has been the basis for the classification of formation water types in the study area. The relationship between the bedrock geology and chemistry of formation water is quite strong and is reflected on the extent of chemical perturbations. Since results of SAR obtained from the formation waters exceeds permissible limit it is assumed to be capable of causing much havoc on soils, vegetations and water bodies. Hence formation waters should be properly discarded. It is therefore recommended that oil producing companies should be properly enlightened on the proper disposal of produced formation waters while stringent environmental laws and policies should be well spelt out as defaulters of such promulgated laws should be sanctioned.

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Authors Contribution

The correspondence author initiated the research solely by collecting required data from the Department of Petroleum Resources (DPR) and embarked on the analyses using standard laboratory. The samples were moved to the laboratory while results were interpreted by the correspondence author. Manuscript writing was done by the correspondence author.

Competing/Conflict of Interest

There is no competing or any form of conflict of interest since the research was initiated and executed by the corresponding author. Hence, it is absolutely the interest of the corresponding author to submit the full manuscript of the outcome of this research to your journal for publishing without any objection.

Data Availability Declaration

Data acquired for the purpose of this research will only be made available to a third party at the discretion of the corresponding author.

Data Availability Declaration

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