International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 1, November-December 2021 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Evaluating Water Quality in the Oil and Gas Exploitation Regions within the Excravos River Catchment

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ABSTRACT

The physicochemical parameters and heavy metals in produced water effluent and receiving Ugborodo river in Escravos of the Niger Delta was evaluated. The sampling technique applied was purposive which was designed in descriptive statistical manner involving means and standard deviations, to ensure that all the parameters analysed were effectively recorded and presented accurately. Samples were collected at three points namely: produced water effluent at point of discharge, and Upstream and Downstream of the receiving river for comparisons. Findings revealed that pH (7.37), temperature (31ºC), total suspended solids (36mg/l) and biochemical oxygen demand (152mg/l) are within the permissible limit as regulated by Department of Petroleum Resources (DPR). The corresponding results of the upstream and downstream samples are also in line and therefore no considerable environmental concern to the ecosystem. However, salinity (9396mg/l), turbidity (50NTU), total dissolved solids (11409mg/l), chemical oxygen demand (215mg/l) and total hydrocarbon content (35mg/l) analyses results indicate slightly higher values than the permissible limits. These higher values could lead to environmental concerns over time; therefore, it is recommended that further treatment of the produced water to meet regulatory standards is necessary before discharging to the environment. There is therefore the need to improve treatment facilities, procedures, enforcing compliance and strict supervision to meet standards before discharging of produced water effluent into the environment. In conclusion, this study has created the awareness of the possible environmental impact that may arise from the continuous discharge of produced water effluent that is less than adequate in treatment and management into the Ugborodo river in Escravos, Delta State in the Niger delta.

KEYWORDS: *physicochemical, effluent, discharge, exploitation, environmental, produced-water*

How to cite this paper: Igonikon, Abariowua Chidiadi | S. A. Ngah | C. L. Eze "Evaluating Water Quality in the Oil and Gas Exploitation Regions within the Excravos River Catchment" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-1, December 2021, pp.179-190, URL: www.ijtsrd.com/papers/ijtsrd47758.pdf

IJTSRD47758

INTRODUCTION

Petroleum is a major source of energy and revenue for many countries today, and its production has been described as one of the most important industrial activities in the twenty-first century. According to the US Department of Energy (US Department of Energy, 2009). Since late 1850s when Edwin Drake drilled the first oil well, demand for petroleum has continued to rise. It is estimated that world daily petroleum consumption would increase from 85 million barrels in 2006 to 106.6 million barrels by 2030. Despite its significance, petroleum is produced with large volumes of waste, with wastewater accounting for more than 80% of liquid waste (Azetsu-Scott *et al.,* 2007) and as high as 95% in ageing oilfields. Generally, the oil/water volume ratio is 1:3 (Fakhru'l-Razi *et al*., 2009).

Produced water effluent which is also termed as an industrial wastewater is a term used in the oil and gas industry to describe water that is produced as a byproduct along with the oil and gas. Oil and gas reservoirs often have water as well as hydrocarbons, sometimes in a zone that lies under the hydrocarbons, and sometimes in the same zone with the oil and gas.

Oil wells sometimes produce large volumes of water with the oil, while gas wells tend to produce water in smaller proportion.

Produced Water which is natural water or formation water is always found together with petroleum in reservoirs. It is slightly acidic and sits below the hydrocarbons in porous reservoir media, (Reynolds, 2003). Extraction of oil and gas leads to a reduction in reservoir pressure, and additional water is usually injected into the reservoir water layer to maintain hydraulic pressure and enhance oil recovery.

Produced water has a complex composition, but its constituents can be broadly classified into organic and inorganic compounds including dissolved and dispersed oils, grease, heavy metals, radionuclides, treating chemicals, formation solids, salts, dissolved gases, scale products, waxes, microorganisms and dissolved oxygen, (Hayes and Arthur, 2004). Globally, ~250 million barrels of water are produced daily from both oil and gas fields, and more than 40% of this is discharged into the environment.

Oilfields are responsible for more than 60% of daily waste water effluent generated worldwide, (Fakhru'l-Razi *et al.,* 2009). The rate of oilfield produced water production is expected to increase as oilfield ages. Other factors have been reported to affect the quantity of produced water generated in an oilfield. This is because, Oil field operators are particularly interested in producing crude oil with little attention paid to the "necessary evil" (produced water) that comes with it. This produced water though field-dependent contains a variety of inorganic and organic compounds such as emulsified oil, organic compounds including dissolved hydrocarbons, organic acids, phenols and traces of chemicals added during production, inorganic compounds, suspended solids, dissolved solids and natural low-radioactive elements. As the reservoir matures injected produced water swipes through to the producing zone and water production increases with time which causes abandonment of the well. Oil field brine or produced water associated with hydrocarbon production is usually removed from the petroleum products before they can be transported and used. In the hydrocarbon producing area of the Nigerian Niger Delta, produced water volume has risen, because many of its oil and gas fields have declined in production with increased water cut.

Ideally, the generated produced waters are usually pressurized, separated by gravitation, and enhanced by heat treatment or using de-emulsifiers before being re-injected down a well, either for disposal or enhanced recovery of hydrocarbons.

However, in the Niger Delta and some oil producing fields of the world, the produced water is discharged into coastal waters (Erakhrumen, 2015), thereby causing potential impacts on the coastal aquatic ecosystem.

According to Stephenson (1992), oil field brine or produced water is the most enormous waste effluent of the hydrocarbon production processes. It comprises several compounds such as dispersed oil, dissolved organic compounds which include aromatic hydrocarbons, phenols, organic acids, inorganic compounds, as well as relics of chemical substances derived during the separation process. The amounts of these associated compounds vary from one oil well to another in a field, and during the production span of the well. The polycyclic aromatic hydrocarbons (PAH), monocyclic aromatic hydrocarbons (benzene, toluene, ethyl benzene, and xylene—BTEX) and high-molecular-weight phenols have been observed to be the major pollutants from oil field brine. In addition, the studies of Sturve *et al.* (2006), Carls *et al.* (2008), observed that the polycyclic aromatic hydrocarbons (PAHs) and high-molecular-weight phenols could result to incomplete growth cycle in organisms as they usually have the potential to cause gene mutation and cancer. The high-molecular-weight phenols also have the potential to disrupt the endocrine development in organisms (Arukwe *et al.,* 2000). Benzene, toluene, ethyl benzene, and xylene, on the other hand, are highly volatile and relatively soluble in seawater, thereby increase the degree of toxicity with increasing molecular weight (Arukwe *et al.,* 2001).

Among the inorganic constituents, heavy metals are of environmental concern (OGP 2002). According to Mac-Donald *et al.* (1996), heavy metals can have deleterious effects on the environment and public health especially if present at levels above toxicity threshold. For example, the works of Miao *et al.* (2005) and Lin *et al.,* (2011) showed that copper (Cu) and zinc (Zn) (heavy metals) can be transported and deposited with the sea sediments and organisms. Greater concentrations of these metals in seawater according to Flemming and Trevors (1989) and Stohs and Bagchi (1995) have been known to cause growth imbalance to aquatic organisms. Such negative effects include reduction in the rates of reproduction, oxidation-level reduction, and death of cell, which eventually cause damage to organisms' gills, liver, kidneys, and nervous systems. In addition, at lower concentrations and greater exposure to sea or sediments contaminated with these metals, they can cause stunted growth, lower the rate of photosynthesis of plants, and change the abundance composition of animals (Morrisey *et al.,* 1996). Many other heavy metals such as chromium (Cr), cadmium (Cd), and lead (Pb) can cause various acute or chronic toxicities; and the bioaccumulation potential of these heavy metals enhances their environmental problems. This study therefore seeks to determine the physicochemical properties, heavy metals and hydrocarbon contents of produced water discharged into the Escravos River, Delta State.

Material and Methods

The Niger Delta region is situated in the Southern part of Nigeria and bordered to the South by the Atlantic Ocean and to the East by Cameroon. It occupies a surface area of about 112,300 square kilometers and represents 12% of Nigeria's total surface area. Its wetlands of 70,000km^2 which are the largest in Africa form basically sediment depositions. The Niger Delta has a well-endowed ecosystem containing one of the highest concentrations of biodiversity on the planet. Its arable terrain can sustain a wide variety of crops, lumber of agricultural trees and many species of fresh water fish than any ecosystem in Africa.

The Ugborodo River is a tributary of the Escravos River in southern Nigeria. "Escravos" is a Portuguese word meaning "slaves" and the area was one of the main conduits for slave trade between Nigeria and the United States in the 18th century. The Escravos river is a distributary of the Niger River, it flows for 57 kilometres (35 mi), ending at the Bight of Benin of the Gulf of Guinea where it flows into the Atlantic Ocean, a major US oil company, has its main Nigerian oil production facility at the mouth of the Escravos River. It lies within latitude 5°36'24.54"N and longitude 5°11'38.31"E of the delta.

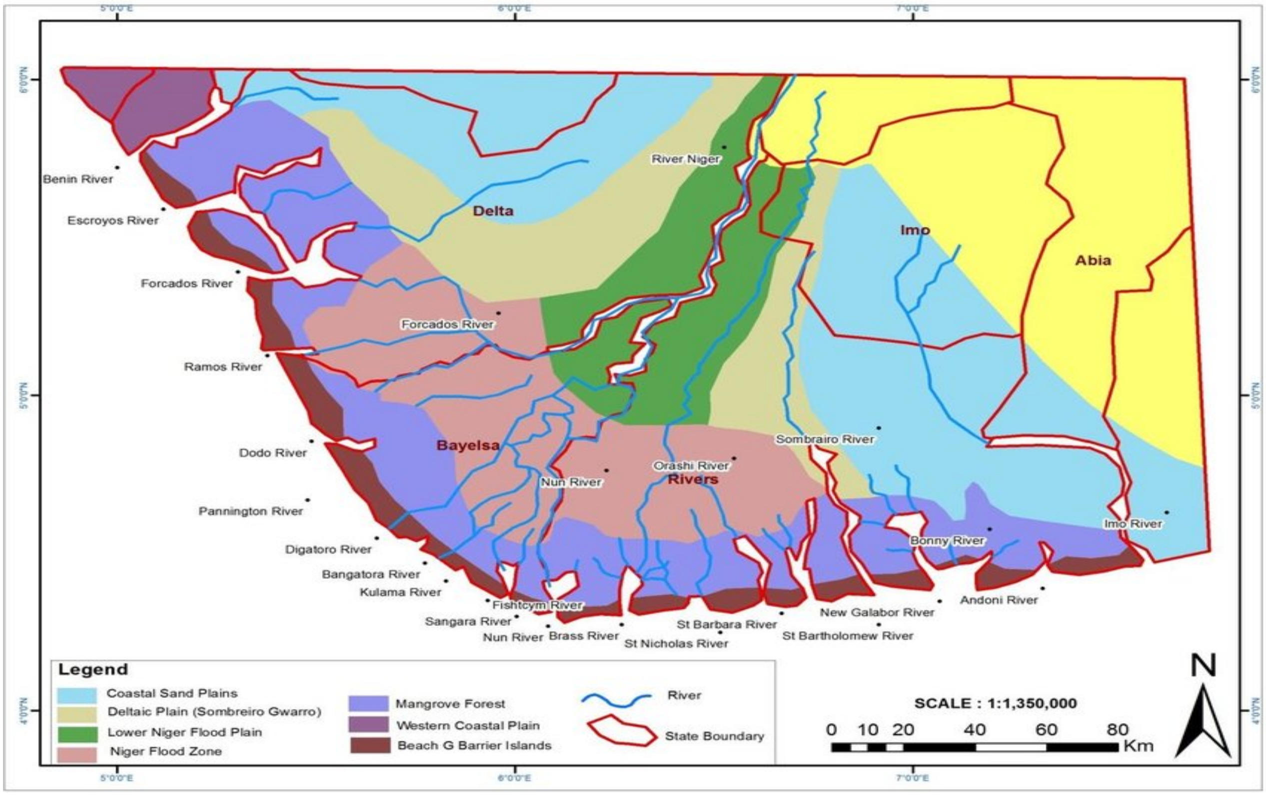

Fig. 1: Map of Niger Delta showing Escravos River, the Location of the Study Area

The hydrology of the Niger Delta is dependent primarily on the River Niger. The River Niger drains a large part of the West African sub region and discharges sediment laden water into the Atlantic Ocean through the Niger Delta. The delta is fan shaped in geometry with an apex located some 250 km from the Ocean at Onitsha. The River Niger bifurcates into two main distributaries, the Nun and Forcados rivers, some 100 km south of the apex creating a coastline spanning over 450 km. Water and sediments from the delta empty into the Atlantic Ocean through 11 major rivers namely: Imo river, Bonny river, San Bathelomeo river, Brass river, Nun river, Pennington river, Dodo river, Ramos river, Forcados river, Escravos river and the Benin river. Ugborodo river is a tributary of the Escravos river. These rivers which make up the main drainage outlet have fairly large river mouths of about 1.3 km to 5 km, opening into the Atlantic Ocean.

As a wave dominated delta, the fluvial influence on the development of the Niger delta is relatively weak. However, river forces have been responsible for the transport and deposition of sediments especially in areas where there have been accretion and significant land growth, and other phenomena such as the vegetation of previously bare land and waterbodies. This situation is quite evident in the section between Dodo and the

Escravos river. The development and disappearance of near offshore in the mouth of the San Bathelomeo river is also a possible consequence of sediment discharge into the Atlantic Ocean. Hence the nature of the River Niger system, and its main tributaries of the Nun and Forcados river is an important player in coastline dynamics,Abam, *et al.* (2004). Figure 3.1 shows map of the Niger Delta where Escravos river is situated.

The study adopted an experimental design and a Purposive Sampling Method in examining the produced water effluent discharged into the Ugborodo River froman oil terminal, Escravos, Delta State. Samples of produced water from the Point of Discharge, and Upstream and Downstream of the point of discharge of the receiving river were collected.. Samples were collected at three main points, Upstream, Point of Discharge and Downstream.

Table 1 Sampling Points and Coordinates

Sample Points:	Upstream	Produced Water	Downstream
	Latitude: 5°36'24.54"N	Latitude: 5°36'21.13"N	Latitude: 5°36'16.89"N
	Longitude: 5°11'26.88"E	Longitude: 5°11'32.04"E	Longitude: 5°11'38.31"E

The upstream and downstream sampling points are about 30 meters from the point of discharge of the produced water effluent into the Ugborodo River as shown in Fig. 1.

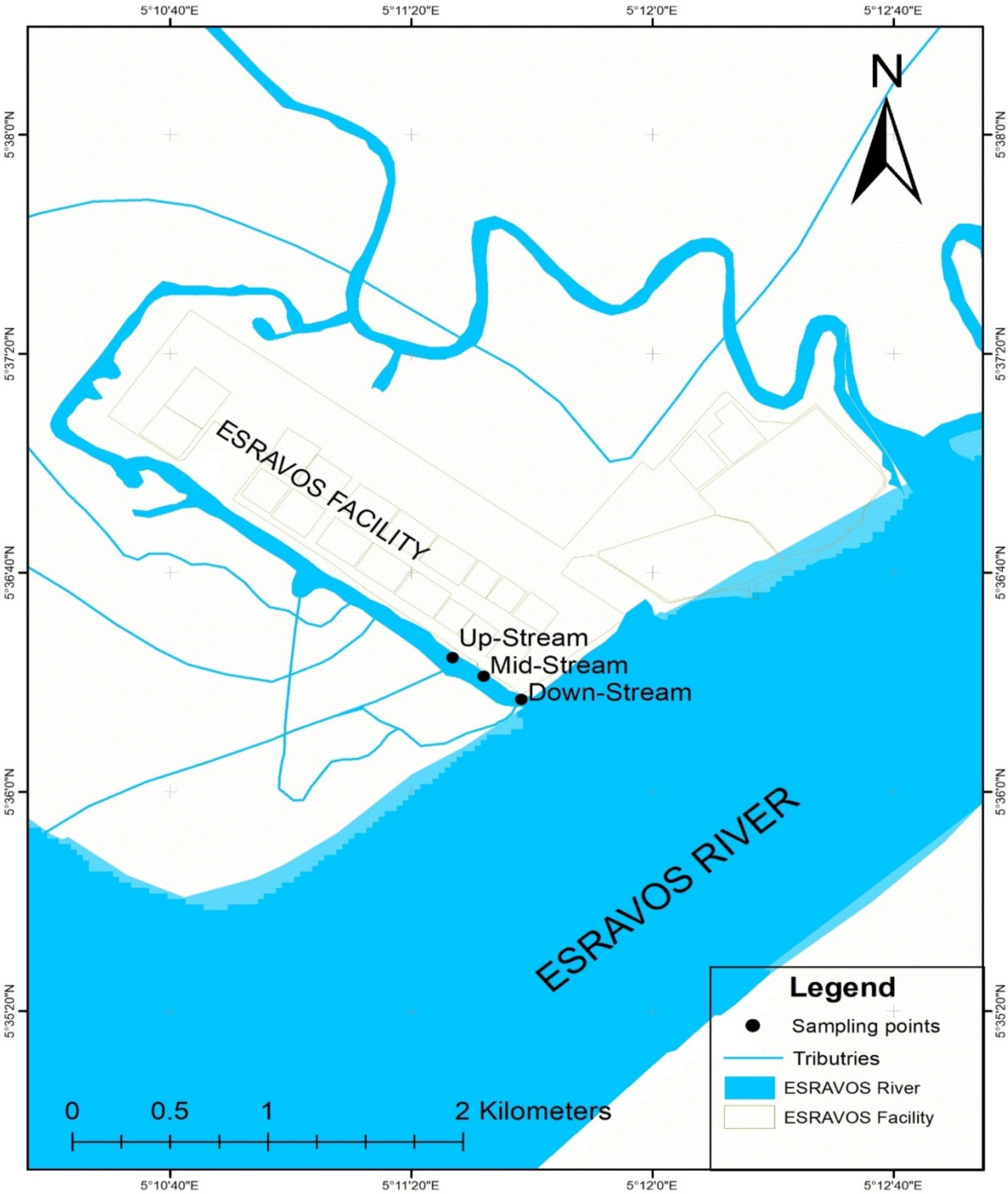

Fig. 2: A Map Showing Ugborodo River and Sampling Points

The collected samples were taken to End Point Laboratory, AGIP Estate, Port Harcourt for assessment and evaluation of their physicochemical properties and heavy metals to ascertain that discharged produced water meets the required standard.

Standard field methods were used in the samples collection at the sampling locations. Sample collection was done by dipping the sample bottles into the medium after rinsing the sample bottles with the same medium. It involves dipping a laboratory glass sampler bottle into the effluent at the point of discharge into the river, as midstream, where a representative sample was collected and also at the upstream and downstream of the point of discharge into the Escravos River. I obtained a sample that meets the requirements of the sampling program. Collected samples were taken to the Lab for analyses, however, proper handling of samples was ensured to avoid samples being deteriorated, contaminated or compromised before it is analyzed.I ensured that all sampling equipment were clean and free from contaminants.

Samples for BOD was collected in amber glass bottles while samples for other physicochemical parameters were collected in plastic containers. Also, sample for hydrocarbon content analysis was collected in glass bottle. For measurements of heavy metal concentration levels, few drops of concentrated nitric acid was added to acidify the various samples.

The effluent samples were collected in plastic bottles. The bottles were made ready by first rinsing them with the same sample medium before collecting the samples to avoid contamination. Samples collection involves dipping the sampling bottles completely in the effluent at the point of discharge, and then upstream and downstream samples of the Ugborodo River and collected representative samples. The samples collected from the river are to serve as a baseline to determine the condition of the river as a result of the continuous discharge of produced water effluent into it. The collected samples were labelled properly, stored in ice-parked cooler and taken to the laboratory, End Point Laboratory, for physicochemical properties and heavy metals analyses. Each sample collected was further divided into three samples (Samples 1, 2 and 3) and analyzed accordingly to ascertain correctness of the analyses results.

Results and Discussion

The results obtained in this study are presented in Tables 4.1 – 4.6.

Physicochemical Parameters and Heavy Metals

Table 2: Levels of Physicochemical Parameters in Produced Water Effluent Sample

S/N	Parameters	Method (Code)	Sample 1	Sample 2	Sample 3	Average	SD(±)
1.	pH	APHA 4500-H⁺B	7.38	7.34	7.40	7.37	0.03
2.	Temperature(°C)	APHA 2550B	30.92	31	31	31	0.14
3.	Salinity(mg/l)	APHA 25208	9390	9397	9400	9396	5.13
4.	TDS(mg/l)	APHA 2540C	11408	11412	11406	11409	3.06
5.	Turbidity(NTU)	APHA 2130C	37	40	39	39	1.53
6.	TSS(mg/l)	APHA 2540D	42	46	43	44	2.08
7.	BOD5(mg/l)	APHA 5210B	152	148	157	152	4.51
8.	COD(mg/l)	APHA 5220C	210	216	220	215	5.03
9.	THC(mg/l)	API 45 & EPA 418.1/413.2	38	35	33	35	2.52

Table 3: Levels of Physicochemical Parameters in Upstream Water Sample

S/N	Parameters	Method (Code)	Sample 1	Sample 2	Sample 3	Average	SD(±)
1.	pH	APHA 4500-H⁺B	6.70	6.70	6.73	6.71	0.02
2.	Temperature(°C)	APHA 2550B	27.81	27.95	27.98	27.91	0.09
3.	Salinity(mg/l)	APHA 25208	7874	7880	7887	7880	6.51
4.	TDS(mg/l)	APHA 2540C	9455	9451	9452	9453	2.08
5.	Turbidity(NTU)	APHA 2130C	35	33	33	34	1.15
6.	TSS(mg/l)	APHA 2540D	26	28	25	26	1.53
7.	BOD5(mg/l)	APHA 5210B	98	95	92	95	3.00
8.	COD(mg/l)	APHA 5220C	140	145	142	142	2.52
9.	THC(mg/l)	API 45 & EPA 418.1/413.2	24	22	22	23	1.15

Table 4: Levels of Physicochemical Parameters in Downstream Water Sample

S/N	Parameters	Method (Code)	Sample 1	Sample 2	Sample 3	Average	SD(±)
1.	pH	APHA 4500-H^{+}B	7.33	7.35	7.30	7.33	0.03
2.	Temperature(°C)	APHA 2550B	28.56	28.50	28.10	28.39	0.25
3.	Salinity(mg/l)	APHA 25208	6240	6250	6242	6244	5.29
4.	TDS(mg/l)	APHA 2540C	7560	7556	7563	7560	3.51
5.	Turbidity(NTU)	APHA 2130C	56	45	49	50	5.57
6.	TSS(mg/l)	APHA 2540D	37	35	37	36	1.15
7.	BOD5(mg/l)	APHA 5210B	112	118	114	115	3.06
8.	COD(mg/l)	APHA 5220C	180	167	192	180	12.50
9.	THC(mg/l)	API 45 & EPA 418.1/413.2	35	30	33	33	2.52

Table 5: Concentrations of Heavy Metals in Produced Water Effluent Sample

S/N	Heavy Metals (mg/l)	Method (Code)	Sample 1	Sample 2	Sample 3	Average	SD(±)
1.	Cr	APHA 3111C	<0.005	<0.005	<0.005	<0.005	0.00
2.	Cu	APHA 3111C	<0.004	<0.004	<0.004	<0.004	0.00
3.	Cd	APHA 3111C	<0.0028	<0.0028	<0.0028	<0.0028	0.00
4.	Fe	APHA 3111C	0.705	0.712	0.696	0.704	0.01
5.	Pb	APHA 3111C	0.031	0.024	0.038	0.031	0.01
6.	Zn	APHA 3111C	0.116	0.121	0.130	0.122	0.01
7.	Ni	APHA 3111C	0.141	0.148	0.156	0.148	0.01
8.	Mg	APHA 3111C	1.647	1.650	1.638	1.645	0.01
9.	Na	APHA 3111C	1.927	1.938	1.930	1.932	0.01
10.	V	APHA 3111D	<0.12	<0.12	<0.12	<0.12	0.00

Table 6: Concentrations of Heavy Metals in Upstream Water Sample

S/N	Heavy Metals (mg/l)	Method (Code)	Sample 1	Sample 2	Sample 3	Average	SD(±)
1.	Cr	APHA 3111C	<0.005	<0.005	<0.005	<0.005	0.00
2.	Cu	APHA 3111C	<0.004	<0.004	<0.004	<0.004	0.00
3.	Cd	APHA 3111C	<0.0028	<0.0028	<0.0028	<0.0028	0.00
4.	Fe	APHA 3111C	0.503	0.386	0.365	0.418	0.07
5.	Pb	APHA 3111C	<0.012	<0.012	<0.012	<0.012	0.00
6.	Zn	APHA 3111C	0.011	0.015	0.018	0.015	0.00
7.	Ni	APHA 3111C	0.021	0.020	0.020	0.020	0.00
8.	Mg	APHA 3111C	1.821	1.822	1.816	1.820	0.00
9.	Na	APHA 3111C	2.609	2.776	2.104	2.496	0.35
10.	V	APHA 3111D	<0.12	<0.12	<0.12	<0.12	0.00

Table 7: Concentrations of Heavy Metals in Downstream Water Sample

S/N	Heavy Metals (mg/l)	Method (Code)	Sample 1	Sample 2	Sample 3	Average	SD(±)
1.	Cr	APHA 3111C	<0.005	<0.005	<0.005	<0.005	0.00
2.	Cu	APHA 3111C	<0.004	<0.004	<0.004	<0.004	0.00
3.	Cd	APHA 3111C	<0.0028	<0.0028	<0.0028	<0.0028	0.00
4.	Fe	APHA 3111C	0.355	0.376	0.397	0.376	0.02
5.	Pb	APHA 3111C	<0.012	<0.012	<0.012	<0.012	0.00
6.	Zn	APHA 3111C	0.164	0.192	0.173	0.176	0.01
7.	Ni	APHA 3111C	0.038	0.042	0.042	0.041	0.00
8.	Mg	APHA 3111C	1.985	1.947	1.909	1.947	0.04
9.	Na	APHA 3111C	2.497	2.613	2.497	2.536	0.07
10.	V	APHA 3111D	<0.12	<0.12	<0.12	<0.12	0.00

Physicochemical Properties

The analyses results obtained indicate that some physicochemical parameters have values that are negligible while others that have slightly higher values require further treatment of the produced water to meet regulatory standards is recommended before discharging to the environment as stated by the regulatory authority, Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) 2018 by the regulatory body, DPR as referenced.

pH

The pH analyses result of the produced water effluent was 7.37, this value is within the permissible limit of the regulatory authority, Department of Petroleum Resources (DPR) which ranges from pH value of 6.5 – 8.5 as an acceptable or permissible limit for produced water effluent to be discharged to the environment. The results obtained from the upstream and downstream samples (6.71 and 7.33 respectively) are also in line with the permissible limits and therefore no environmental concern.

Temperature (ºC)

Temperature is the degree of hotness or coldness of a body. The produced water temperature average value of 31ºC is within the permissible limit of the regulatory authority which ranged from 27°C – 31°C as an acceptable limit for produced water effluent to be discharged within inland and near shore environments according to the regulatory body (DPR). The results indicate that there will be no negative environmental impact.The analyses result of the upstream and downstream samples of 27.91ºC and 28.39ºC respectively also indicate no negative impact on the environment.

Salinity (mg/l)

The average salinity value for the produced water effluent analysis was 9396mg/l. The difference in values of upstream and downstream is as a result of dilution during the flooding processes. The obtained value is above the permissible limit of 600mg/l – 2000mg/l for inland and near shore environments from the regulatory authority, therefore environmental concern is expected.

High ion and chloride concentration results in water hardness and acidity of the surrounding waters which may be harmful for rural dwellers depending on the rivers and lakes around them for water supply for their daily survival. Meeting discharge regulatory specifications is the only way out of this harm that may befall human lives, aquatic lives and the ecosystem.

Turbidity (NTU)

The analysis result for turbidity was 50NTU, this value is above the permissible limit of <10 and <15 for inland and near shore environments and no limit for offshore environments by the regulatory body (DPR) as stated in the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN). Also, 34NTU and 50NTU which are values for the upstream and downstream processes respectively show that turbidity increased during the ebbing phase due to dissolved solids from inland.

Total Dissolved Solids (TDS)

The produced water effluent analyses result obtained for Total Dissolved Solids was 11409mg/l. This value is over two times greater than the permissible limit of 2000mg/l – 5000mg/l for inland and near shore environments respectively from the regulatory authority (DPR). This also affected the analyses results for upstream and downstream samples of 9453mg/l and 7560mg/l respectively, therefore negative environmental impact is a concern here.

Total Suspended Solids (TSS)

The Total Suspended Solids value for the produced water effluent of 44mg/l is within the permissible limit of <30mg/l - <50mg/l for inland and near shore ecosystem respectively from DPR. Upstream and downstream samples results are (26mg/l and 36mg/l) respectively are also in line with the permissible limit, therefore, there is no environmental concern.

Total suspended solids exceeding required limit present in produced water as well as oil and grease content would result in discharge of oily water into the environment, polluting the environment and destroying the ecosystem and aquatic habitat. These could be very harmful because the important component in the marine and aquatic food web (phytoplankton, periphyton, sphergiral and zooplankton) would be destroyed. Respiration of aquatic animals would be hampered by the sealing caused by large oil droplets in aquatic habitats. This results in suffocation of aquatic animals.

Biochemical Oxygen Demand (BOD)

The produced water effluent analyses average value for Biochemical Oxygen Demand is 152ml/g. This value is within the permissible limit of 140mg/l – 313mg/l for inland and near shore ecosystem respectively as regulated by DPR. The values for the upstream and downstream samples analyses results (95mg/l and 115mg/l) were lower than that of the produced water as a result dilution from the receiving river. Therefore, there is no environmental concern or negative impact on the environment.

Chemical Oxygen Demand (COD)

Chemical Oxygen Demand is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions. The produced water effluent value for COD was 215mg/l. This value is slightly higher than the permissible limit of 125mg/l for inland and near shore environments and no limit for offshore environments as regulated by DPR as stated in Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN). The upstream and downstream analyses results of 142mg/l and 180mg/l show increase in value above the regulated value. Concentration levels of chemical oxygen demand of the produced water effluent is higher than that of the receiving river, environment will be impacted in the long run.

Total Hydrocarbon Content (THC)

The Total Hydrocarbon Content analysis result obtained for the produced water effluent was 35mg/l. The obtained value is slightly higher than the permissible limit of 20mg/l by the regulatory authority for inland and near shore environments and no limit for offshore environments. The upstream and downstream samples values of 23mg/l and 33mg/l is an indication of dilution during the flooding and ebbing process of the receiving Ugborodo river.

Heavy Metals

Ten (10) out of twenty-one (21) heavy metals that were considered to be common in other sited works in produced water were analyzed. In addition, a few metals are of particular environmental concern because their concentrations may be high enough to cause bioaccumulation and toxicity (Ray and Rainer, 1992). Heavy metals are very harmful because of their ability to accumulate in the bodies of fishes and sea foods, this leads to Bioaccumulation (the gradual accumulation of substances, such as pesticides or other chemicals such as contaminants in an organism). Such fishes and sea foods when consumed by man and other animals will lead to the accumulation of heavy metals in different parts of the body. Heavy metals are non-degradable in nature and have long biological half-lives because bioaccumulation occurs when an organism absorbs a substance at a rate faster than that at which the substance is lost or eliminated by catabolism and excretion. Though, they are essential components in metabolism, they are also toxic when present in high concentration and over a long period of time. The quantities of heavy metals in produced water can vary from different formations, and they vary depending on the age and geology of the formation from which the oil and gas are produced. The results of the heavy metals analyzed were presented in Table 2 – 7 representing produced water effluent, upstream and downstream samples and results discussed as follows:

Chromium (Cr)

The mean Chromium concentration in the produced water effluent sample analysis was < 0.005mg/l. This value of < 0.005mg/l is slightly higher than the permissible limit of 0.0mg/l of the regulatory authority (DPR). The upstream and downstream samples analyses value was also the same as that of the produced water effluent which is < 0.005mg/l. Therefore, environmental concern over a period of time is expected.

Lead (Pb)

The mean Lead concentration in produced water effluent analyses value was 0.031mg/l. Though this value is slightly higher but is negligible going by the allowable or permissible limit of 0.0mg/l and no limit for inland and near shore by the regulatory authority (DPR). Also, the upstream and downstream analyses values are same as <0.012 is lower than that of the produced water. Therefore, environmental concern over a period of time is expected.

Nickel (Ni)

Nickel's mean concentration level value of the produced water effluent was 0.148mg/l and the permissible limit is 0.0mg/l. The analysis value is slightly higher than the permissible value though negligible. Also, upstream and downstream samples analyses values of 0.020mg/l and 0.041mg/l respectively are smaller than that of the produced water sample value. Therefore, environmental concern over a period of time is expected.

Zinc (Zn)

Mean concentration level of Zinc in the produced water effluent analysis was 0.122mg/l. This value is considered negligible compared to the value of the allowable limit of 1.0mg/l – 5.0mg/l by the regulator (DPR) for inland and near shore environments respectively is far more than the obtained value. The upstream and downstream samples values are 0.015mg/l and 0.176mg/l respectively. Environmental issue is not a concern here.

Cupper (Cu)

The mean concentration level of Cupper in the produced water effluent was < 0.004mg/l for all the samples. The concentration of cupper as indicated is of no environmental concern. Also, the permissible limit as prescribed by DPR for inland and near shore locations are 2mg/l and no limit respectively, which is higher than the obtained analysis result. The same result of 0.004mg/l was obtained for upstream and downstream samples also. Therefore, no environmental concern of any sort is expected.

Cadmium (Cd)

The mean concentration level of Cadmium in the produced water effluent was < 0.0028mg/l Same concentration level was obtained in the upstream and downstream samples. No permissible limit was giving by the regulators. Therefore, no consequences to the environment.

Iron (Fe)

Iron's mean concentration level according to the analysis result in the produced water effluent was 0.704. This value is lower than the permissible limit value of 1.0mg/l and no limit for inland and near shore by the regulator (DPR).The values for the upstream and downstream samples of 0.418mg/l and 0.376mg/l respectively are also lower than that of the produced water effluent, therefore, no threat to the environment is envisaged.

Magnesium (Mg)

The mean level of Magnesium concentration in the produced water effluent as per the analysis report was 1.645mg/l, this concentration value is lower than that of the values of the upstream and downstream samples of 1.820mg/l and 1.947mg/l respectively. No permissible limit from the regulatory authority. This lower value in the produced water effluent compared to the receiving river indicates no harm to the environment.

Sodium (Na)

Produced water sample analysis of Sodium mean concentration level was 1.932mg/l. This has the highest concentration of all the heavy metals analyzed and is lower than the values of the upstream and downstream samples results of 2.496mg/l and 2.532mg/l respectively obtained. These higher values are attributable to the fact that salt water contains sodium naturally as expected. However, no environmental consequence.

Vanadium (V)

The mean concentration level of Vanadium in the produced water effluent as analysed was < 0.12mg/l. This value is the same for upstream and downstream samples concentration. It is therefore negligible and of no environmental concern of any kind going by the allowable limit of 0.0mg/l by the regulatory authority (DPR). From the samples analyses reports as indicated, most of the heavy metals except chromium, lead and nickel, have values that are lower than the permissible limits by the regulatory authority (DPR). This means that the environment may not be severely affected in the short while but will be affected in the long run.

This work is supported by studies carried out by Oboh *et al.* (2009), in the Niger Delta which noted that discharged produced waters had high metal ions and total hydrocarbon concentrations, THC. Okoro (2010), on the other hand, demonstrated that produced water discharges in near shore environment in the Niger Delta led to substantial accumulation of hydrocarbons and microorganisms up to 500m from discharge points. Isehunwa and Onovae (2011) observed that the produced water discharged into the environment had high levels of oil and grease as well as TDS and TSS. Recent environmental impact assessments show that contrary to the trend in the Niger Delta, North Sea and Gulf of Mexico have continued to review their effluent limits pursuant to ZERO effluent discharge. This contrasts sharply with the Niger Delta which has maintained its effluent discharge limits for a long time without review. This has left the region with discharged effluents that may fall short of the needed environmental friendliness level (Adaobi and Omowumi, 2016).

Environmental Impact

The environmental impact caused by discharging untreated or poorly treated produced water effluent to surface or coastal waters causes degradation of the ecosystem and the environment at large. Therefore, safely disposing of this highly saline water and mitigating the effect of past disposal practices is a national concern for environmental officials, land managers, petroleum companies, and land owners. Within the oil and gas production industry there is an increased focus on the discharge of produced waters to the environment. That there is no universally agreed standard for oil-in-water discharge quality is partly an indication of the different capacities of receiving waters to absorb the pollutants. It is, however, compounded by a lack of any universally agreed methods even on how to measure oil-in-water, which in extreme cases leads to varying results by orders of magnitude according to the actual methods used.

Treating produced water properly before disposal ensures elimination of the harms done to the environment by the oil and gas industry. This study indicates that produced water effluent discharged into the Ugborodo river can be treated further to improve on the recommended permissible limits and continued monitoring and supervision by the regulatory authorities cannot be over emphasized.

Conclusion

The evaluation of produced water effluent discharged into the Ugborodo River, Escravos indicates that Some of the physicochemical properties and heavy metals analyzed such as pH, temperature, total suspended solids (TSS) and biochemical oxygen demand (BOD) other physicochemical properties such as salinity, turbidity, total dissolved solids (TDS), chemical oxygen demand (COD) and total hydrocarbon content (THC) whose values were slightly higher than the permissible limits are recommended for further treatment and management before being discharged to meet regulatory requirement or standard by the Department of

Petroleum Resources (DPR) in the protection of the ecosystem and the environment in general.

Recommendations

The regulatory agencies should adopt strict compliance measures by routine monitoring and supervision of samples of produced water effluent to be discharged and treatment facilities used for produced water treatment and further treatment of the produced water should meet regulatory standards as recommended before discharging to the environment.

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