The American Journal of Applied Sciences

ISSN 2689-0992 | Open Access

TYPE Original Research
PAGE NO. 10-24
DOI 10.37547/tajas/Volume07Issue08-02

Environmental Impact Assessment and Geological Evaluation of Non-Associated Gas Wells in Forcados-Yokri block, Burutu Area, Delta State, South-south Nigeria.

OPEN ACCESS

SUBMITED 19 July 2025
ACCEPTED 24 July 2025
PUBLISHED 01 August 2025
VOLUME Vol.07 Issue 08 2025

CITATION

Ibrahim Olanrewaju Ibrahim, Ngozi-Chika CS, Ashioba C, & Ibrahim Bilqees Damilola-Habeeb. (2025). Environmental Impact Assessment and Geological Evaluation of Non-Associated Gas Wells in Forcados-Yokri block, Burutu Area, Delta State, South-south Nigeria. The American Journal of Applied Sciences, 7(8), 10–24. https://doi.org/10.37547/tajas/Volume07Issue08-02

Ibrahim Olanrewaju Ibrahim.
Design and Hydrogeology units, Lower Niger River Basin Development Authority, Ilorin, Kwara state, Nigeria.

Ngozi-Chika CS
Department of Geology, Dennis Osadebay University, Asaba, Delta state, Nigeria

Ashioba C
Department of Geology, Dennis Osadebay University, Asaba, Delta state, Nigeria

Ibrahim Bilqees Damilola-Habeeb
Kulende study center, Force Education Unit, Ilorin, Kwara State, Nigeria

Abstract: Forcados-Yokri field is situated in Burutu area of Delta State. Its a large oil and gas province holding large volume of recoverable hydrocarbon. A Geological redevelopment was done to harness the abundant gas contained in it. There is urgent need for Nigeria to shift to cleaner source of alternative energy and reduce its carbon footprint, thus, the block was re-evaluated and re-developed for this gas deposit. The field was thus initiated to supplement gas production for domestic reserve and enhance the industrialization of the region and the country. The field has an expected STOIIP and GIIP (AG + NAG) of 2878 MMstb oil and 2298.7 Bscf of gas respectively. Cluster Jackets, 18" x 5.5km Oil Pipeline 12" x 6.4km Gas Pipeline, 33KV Power Cable Back-up, 8" Gas lift line (North Bank Gas Plant-Yokri Flowstation), new cluster jackets, 33kV Cable from North Bank Manifold, 700V Power Control Cable Ring were connected to the main Pipeline Phase 1. More importantly, 6" South Bank to Forcados Terminal fuel gas back-up Line, 8 km and 6" flow line were also connected to slug catcher at North Bank Gas Processing Facilities with the existing Associated Gas facilities at the CPF. Findings revealed feasible environmental space for gas production with phytoplankton distribution of Bacillariophyceae 52%, Cyanophyceae 33%, Euglenophyceae 7%, Dinophycea 5%, Chlorophyceae 3% with the zooplankton belonged to six (6) taxa; Copepoda, Hydrozoa, Mollusc larvae, Decapod larvae, Rotifera, and Chaetognatha. The study concluded the feasibility and viability of producing the hydrocarbon content of about 291MMstb of oil and 94 bscf of gas in the block area under the prevailing environmental condition.

Keywords: STOIIP= Stock Tank Oil Initially In Place, Zooplankton, AG is Associated Gas, NAG is Non-Associated Gas, CPF is Central Processing Facility and GIIP is Gas Initially In Place.

Introduction

1. Background

Forcados-Yokri field is situated in Burutu Area of Delta State. It is one of the largest oil fields in the area. A total of 152 wells have been drilled in the field till date. A redevelopment strategy for the Forcados Yokri Integrated block area was initiated to shore up the hydrocarbon reserve base. The scope of work included development of total expectation reserve target of 292MMstb (proved reserves of 201 MMstb) of oil and 92 bscf (proved reserves of 52 bscf) of gas. This is expected to reduce carbon emission and greenhouse gases, moreso, with the rolling out of compressed natural gas infrastructure (CNG) by Nigerian government in collaboration with Nigerian Midstream, Downstream Petroleum Regulatory Authority to convert vehicles from Premium Motor Spirit (PMS) based to gas based, cleaner, safer, cheaper and more environmental friendly fossil fuel. It is worthy of note that most oil producing companies in the area are expected to key into the real geoscientific dynamics shaping the world energy landscape. Climate change is real and can be partly traced to burning of oil and gas of which the gas can be converted to cleaner energy.

Before now, the associated gas is commonly flared with impunity in Niger Delta area and globally (Doust and Omatsola 1989 and 1990) which has serious consequential harm on the ecosystem with attendant serious public health implication on well-being of communities and the people. Gas utilization has increased tremendously in the day-to-day socio-economic activities in Nigeria as a cleaner fuel ranging from domestic cooking gas, alternative source of powering generators to generate electricity, abundant gas-powered stations, gas fired industries, compressed natural gas in our vehicles etc. These are due to new Technological and. Geoscientific innovations springing up globally to reduce carbon footprint and make the planet earth more habitable for man (Ibrahim et al 2023). The feasibility (ESIA) of producing the gas deposit was thus evaluated.

2. Location

Forcados Yokri field is bounded approximately around the co-ordinates of 319435mE - 335238mE and 158355mN - 141626mN with area coverage of 244.64sqKm (24464.0 hectares). The block area is composed of meandering creeks and mangrove swamps with dredge slots leading to well heads distributed over the area. The land terrain of the block area is covered by fresh water swamp

forest in the North Bank - Yokri axis and mangrove swamp forest in South Bank. Forcados-Yokri field is a brown field situated in the coastal swamp area straddling the mouth of the Forcados River in Burutu Local Government Area of Delta State (Fig. 1).

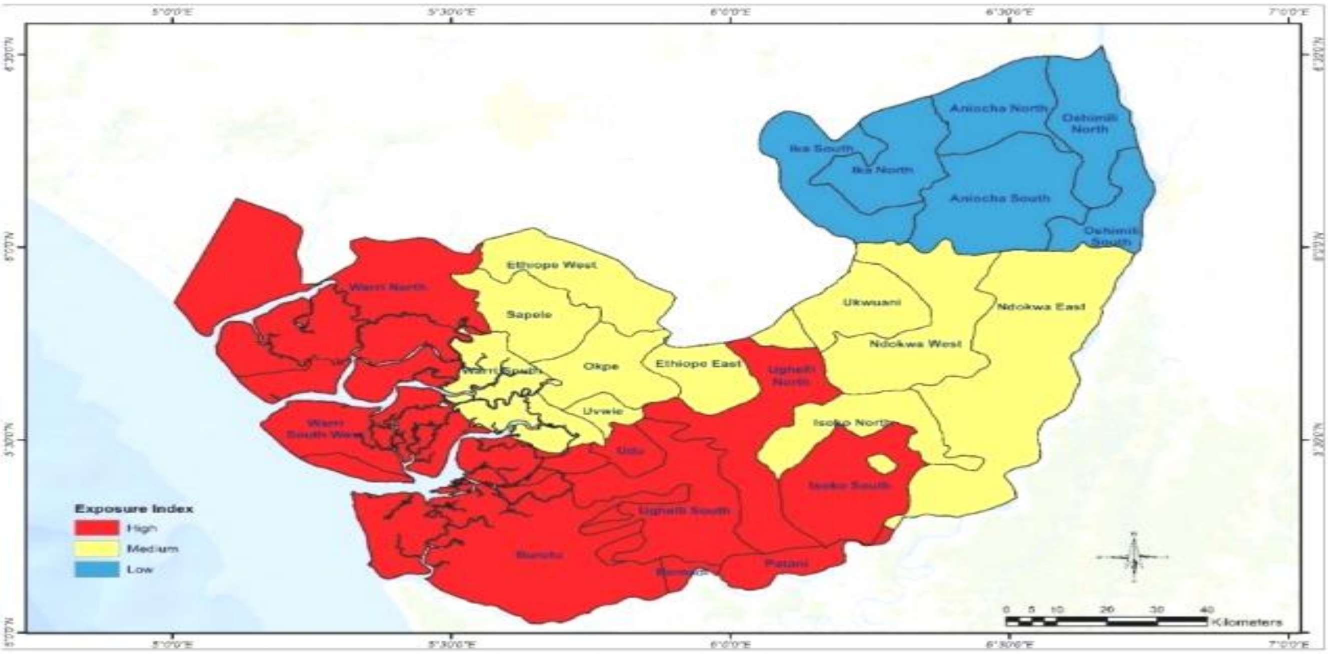

Fig. 1: Geological map of Delta study area, Nigeria

3. Sampling location and Statistical Analysis

The map showing the study area has shown an expensive area with vast potential to produce hydrocarbon in commercial quantity (Figs 1 and 2). The sampling points were geo-referenced by means of Global Positioning System (GPS). Purposive sampling was applied in the selection of study stations, taking into account tidal influence and regime. Control stations were located outside the spatial boundary. A number of statistical tools were employed; the student t-Test Paired Two Samples for means, and the single-factor (one-way) Analyses of Variance (ANOVA) adopted. The t-Test Paired Two Samples for Means was employed to compare two sets of data (study area and control) while the single factor ANOVA was eventually not used in this publication but reserved for an ongoing manuscript to be published soon.

Table 1: Sampling coordinates for Revalidation of Study block area

S/N	Sample codes	Point X	Point Y
1	AQ1	318722.4562	152599.6653
2	AQ2	318691.9888	151633.6733
3	AQ3	317941.3238	152105.6015
4	AQ4	319494.3507	152077.2955
5	AQC1	318799.9353	153637.2337
6	AQC2	318639.1922	150449.414
7	SW1	318722.4562	152599.6653
8	SW2	318691.9888	151633.6733
9	SW3	317941.3238	152105.6015
10	SW4	319494.3507	152077.2955

The objective was thus to determine statistically, environmental impacts of existing facilities (e.g flowstations, manifolds, pipelines and other associated facilities) on the environment, social and health components of the area. In essence, it can be vividly said that the block area in question had its environmental impact and social assessment to give some details of the area and allow for further mitigation planning. The sedimentological evaluation of the study area is typical of the Niger Delta and as described by previous workers (Ibrahim et al 2000).

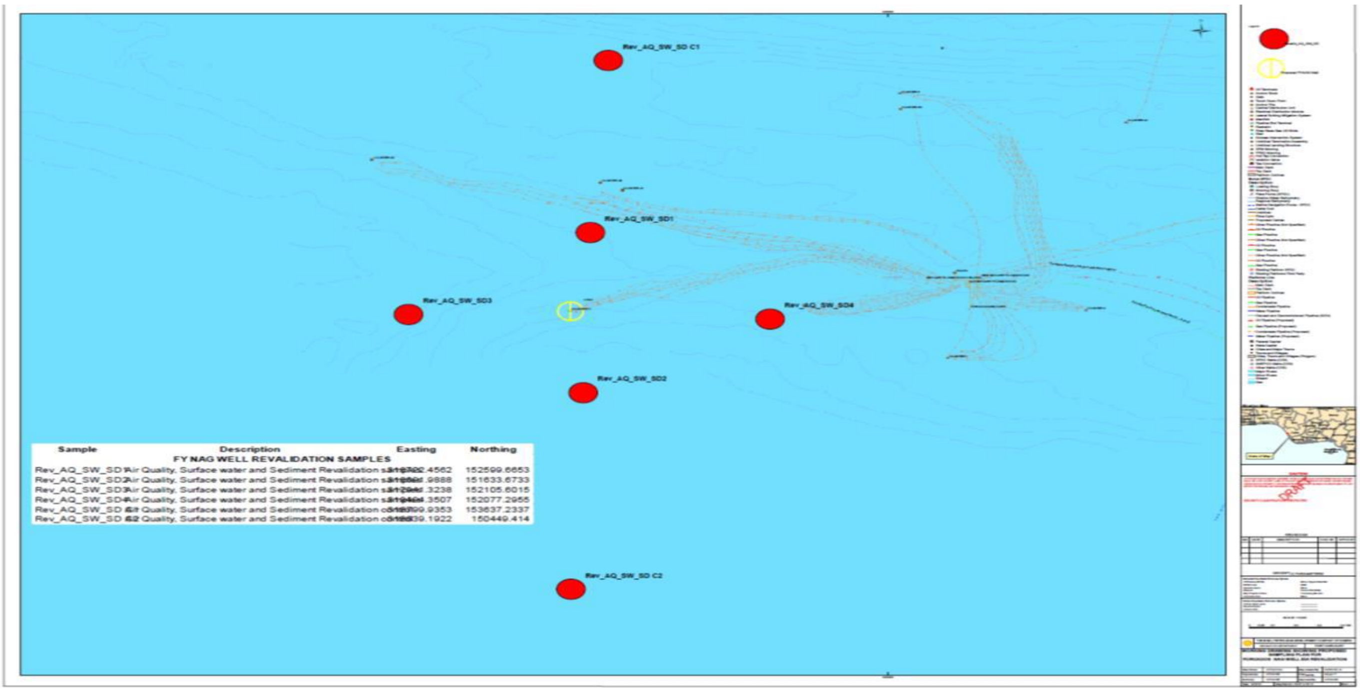

Fig. 2: Sampling points during the field work to the study area

4. Materials and Methodology

Materials for the work study included Pipeline Lay Barges, Drilling Rigs, Piling Rigs, Shuttle boat, Tugboats, Work barges, Welding Machines, Generator Barges, Power/Fibre optics, Subsea cable, Estuary flow station facilities, Cluster Jackets, 18" x 5.5km Oil Pipeline (New Estuary FS – South Bank), 12" x6.4km Gas Pipeline (New Estuary FS -South Bank), 33KV Power Cable Back-up (Forcados Terminal - CPF Ring), Construct 8" Gaslift line (North Bank Gas Plant - Yokri Flowstation), new cluster jackets, 33kV Cable from North Bank Manifold – CPF, 700V Power Control Cable Ring Main Pipeline Phase 1. More importantly, 6" South Bank to Forcados Terminal fuel gas back-up Line, 8 km and 6 " flow line to a slug catcher at North Bank Gas Processing Facilities and integrating the whole setup to the existing Associated Gas facilities at the CPF. For the Phase 2 pipeline: New gas flowline from NAG Well to CPF with 16'' Export Gas pipeline-34km 6'' Bulkline replacement-105km. Afremo pipeline repair works 8'' X 12.2km (Fig. 3).

With Gas lift pipeline 8" x 20km, Gas lift spur-line 4"x 20km were used, Old Estuary flow station (OEFS) pig launcher replacement and inter-connecting piping works with Non-Associated Gas (1 NAG) Well and 4 Oil well Development. Water based mud (bentonite) and pseudo oil-based mud (POBM) were used for the upper and lower sections of the holes respectively for rigidity to prevent caving. Spent muds and drilling fluids were generated during drilling and disposed off appropriately with no harm to the ecosystem. The POBM drill cuttings were transported to onshore and treated at the Thermal Desorption Unit (TDU) at Forcados Terminal. The unit eventually produced solids that are free of Pseudo Oil Based Mud (POBM). The treated solid is usually about 99.97% pure solid which is within regulatory limits of NUPRC and were shipped to deep offshore (depth of water greater than 200ft and distance greater than 12 nautical miles) and dumped. Drilling fluids and chemicals were continuously recycled/reused.

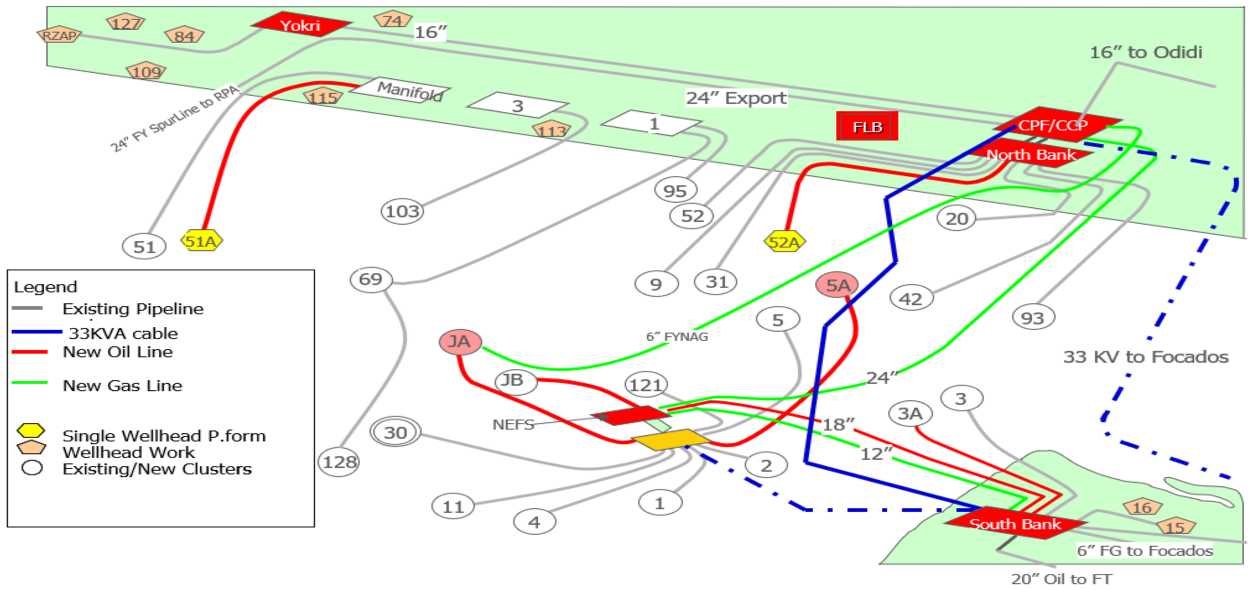

Fig. 3: Diagram showing Forcados Non-Associated Gas wells and clusters of hydrocarbon infrastructures.

5. Description of the Environmental condition of the area

The purpose of the data acquisition was to establish the status of the environmental condition of the study area before the intervention. Data obtained will be useful for adequate comparative study with previously obtained data and shall be used for adequate planning. This comparison provides us information on impacts of existing facilities such as flow stations, clusters, pipelines and manifolds on the environment in addition to determining future impact of proposed block activities on the environment to further improve on production. This network of pipelines was similarly advanced by previous workers, especially around the Sagbara gas flow station (Ibrahim et al 2023).

5.1 Climate and meteorology

The block area environment lies within tropical swamp belt of southern Nigeria characterized by heavy rain, frequent thunder storms, high relative humidity and relatively moderate temperatures. The rain occur mostly during the wet season from March to November of each year, with a monthly average of 199.58 mm reported for the area. Wind in the area is dominated by SW winds with speeds of 3.1-4.6 m/s measured during the study (Table 2). The climate of the study area is tropical and marked by the rainy and the dry seasons. The rainy season begins around March and lasts till November, while the dry season commences in December and lasts till February of each year. The annual rainfall is in the order of 2395 mm at an average of 199.58 mm per month. The relative humidity is typically lowest in January (69%) and highest in July and August (92% and 93% respectively). The mean relative humidity was 84.1%. The mean monthly air temperatures were similar and almost the same in some months as in February, May, July, August, September and October. The average monthly temperature is 27.6°C (Table 2). The lowest temperature was in July (26.3°C) and August and September and the highest was in February (29.3°C) and December. There are winds blowing from different directions during the year, namely; Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W), Northwest (NW) and North (N). The block area environment is dominated by South-west and North-east trade winds during the wet and the dry seasons respectively.

5.1.1 Micro-climatic Data

The average annual rainfall ranges from 3,000-3900 mm with a monthly mean of 270 mm. The mean annual maximum temperature is between 26.3-29.3°C, while the mean minimum temperature is between 22-23°C. Ambient temperature during the study ranged from 26.3°C- 29.3°C with an average value of 28.8°C. Wind speed in the study area ranged from 3.1 - 4.6 m/s with a mean value of 3.9 m/s. The South westerly (SW) wind was the dominant wind direction in the study area during the study.

Table 2: Micro-climate Measurement for the Area

Parameters	AQ1	AQ1	AQ1	AQ1	AQ1	AQ1
Temperature	29	29.3	28.3	28.6	27.2	26.3
Wind Speed (m/s)	4.2	4.6	3.2	3.6	3.5	3.1
Wind Direction	SW SW/SS	SW SW/SS	SW/SS	SW	SW	SW/SS

5.2 Air quality and Noise

There were no significant differences between the block area and control locations in noise and air quality conditions. Maximum noise levels at the project area was 69.6dB (A) which is within national regulatory limits set by NUPRC. However, an increasing trend in noise was observed when compared with previous data from the field. The increasing trend is attributed to increasing oil and gas operations as well as ship traffic in the area. Other air quality indicators including sulphur dioxide, nitrogen dioxide, volatile organic compounds and suspended particulate matter were low and within national regulatory limits of NUPRC. The particulate fractions SPM, 10.29 $\mu g/m^3$ and 17.49 $\mu g/m^3$ (Table 3) were also within stipulated limits of US Environmental Protection Agency limit. The increasing trend observed in SPM was attributed to the current particulate matter (black smoke) pollution in the Niger Delta area. In contrast to noise and SPM, VOC showed an apparent decreasing trend which was attributed to improved management of associated gas, in line with government's flare down policy.

Table 3: Air quality measurement result

Parameters	AQ1	AQ2	AQ3	AQ4	AQC1	AQC2	P-value	NUPRC Limit
Noise (dB(A)	66.9	68.2	62.4	69.6	69.6	62.1	0.765	80-100
NH_4 (ppm)	0.84	1.22	1.42	1.32	1.14	0.25	0.691	NS
SO_2 (ppm)	<0.01	0.01	<0.01	0.13	0.02	0.01	0.5	0.01
NO_2 (ppm)	0.02	0.02	0.01	0.01	0.12	0.01	0.563	0.08
VOC (ppm)	0.86	1.86	1.77	1.6	1.28	0.56	0.699	NS
SPM ($\mu g/m^3$)	10.29	17.49	14.63	14.23	13.99	10.59	0.813	60-90
H_2S (ppm)	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	NS

Air quality parameters monitored included sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), Ammonia (NH_4), Volatile Organic Compounds (VOC), Hydrogen Sulphide (H_2S) and Suspended Particulate Matter (SPM). Sulphur dioxide levels ranged from <0.01-0.13 ppm and showed no significant difference between levels at study area and those of the control stations. All evaluated samples showed SO_2 levels lower than NUPRC standard of 0.01 ppm except AQC1 and AQC2 of the control stations. Nitrogen dioxide concentrations ranged from 0.01-0.12ppm. There was no significant difference between values at the study area and the control stations of AQC1 and AQC2. All values were within NUPRC recommended limits. Volatile Organic Carbon (VOC) values ranged from 0.56 – 1.86 ppm (Table 3). There was no significant difference between values at the study area and control. All stations showed VOC levels were high both within the tolerant limit of 0,09 ppm. Ammonia (NH_4) ranged from 0.25-1.42 ppm with no significant difference between block area and control station, while H_2S were not detected in the study area, except for sample AQ1 with 0.01 ppm (Table 3).

5.3 Sediments

Sediments varied from sandy to sand-clay texture indicating a low affinity for micropollutants including heavy metals and petroleum hydrocarbons. Sediment pH was mildly acidic which is related to that of overlying surface waters. Total organic carbon level was measured to be <1% signifying absence of organic pollution. Redox conditions were generally positive, a sign of conducive environment for microbial degradation of organic matter. Nitrate levels were low particularly around the proposed project area, indicating active microbial assimilation associated with organic matter degradation. Levels of heavy metals in sediments were low and within recommended sediment quality guidelines. Cadmium concentration (0.97-1.85 mg/kg) was, however, higher than sediment guideline of 0.99 mg/kg but within historical levels of BDL to 8 mg/kg for the Niger Delta. The highest cadmium level of 1.85 mg/kg was obtained at the control indicating the widespread problem of cadmium pollution in the area. BTEX were not detected in the sediments indicating absence of recent petroleum pollution. PAH was also not detected in the sediments. TPH (5.03-44.03 mg/kg) was significantly higher around the proposed project area than control indicating low level contamination around the area, but all levels were below sediment guideline of 50 mg/kg indicating absence of petroleum pollution. Microbial counts were generally low compared with normal counts in unpolluted sediments. This conform to earlier published figures (McDonald et al 2000).

Total fungi was marginally higher around the project area while hydrocarbon utilizing fungi was only found in the project area indicating greater microbial activity around the project area capable of degrading organic matter including oil. Trending of sediment parameters showed decrease in pH possibly linked to discharge of acidic sediments from mangrove swamp forests into the coastal waters. Similarly, TOC showed decreasing trend possibly linked to erosion of organic matter deficient sediments from coastal areas into the water. Exchangeable cations showed increasing trends which may be attributed to variations in tidal conditions during sampling. Heavy metals showed increasing trends. Although the levels of heavy metals were within recommended sediment guidelines (except cadmium), increasing trends in heavy metal is a course for concern because of their persistence and toxicity and adequate attention should be paid to pollution control measures particularly during the proposed NAG well drilling. Total petroleum hydrocarbons showed increasing trend with significantly higher levels around the project area compared to control indicating local sources of contamination.

5.4 Phytoplankton:

Phytoplankton diversity and density were generally high (Fig. 4). The phytoplankton followed the order of dominance: Bacillariophyceae > Cyanophyceae > Euglenophyceae > Dynophyceae > Chlorophyceae in the project study area. The dominance of the phytoplankton by bacillariophytes (diatoms) is usually considered an indicator of unpolluted environment. There were no significant differences between the project location and control in phytoplankton diversity indices including the Shannon index. Shannon index was generally above 3 indicating unpolluted water shows the distribution of major phytoplankton taxa in the study project area and control. The phytoplankton was represented by five major families namely: Bacillariophyta, Cyanophyta, Chlorophyta, Dinophyta and Euglenophyta which conforms with other reports in Nigerian water (Akoma and Opute, 2010). Similar results was obtained (DeLaune 2009) in a study of the phytoplankton.

Baccillariophyta was the most dominant taxon constituting 52% of the total phytoplankton density in the study area and 55% in the control. Diatom dominance in phytoplankton of Nigerian waters is widely reported. The major species of Bacillariophyta include Pleurosigma angulatum (3.28%), Pinnularia interrupta (2.25%), Thalassiosira sp. (1.23%), Cymbella ovals (1.94%) and Cyclotella meneghianina (1.86%). The dominance of diatoms is usually considered an indication of unpolluted waters. Cyanophyta was the next dominant family after Bacillariophyta, with 28 species making up 33% of phytoplankton in the project area and 28% in the control. The Cyanophyta was dominated by Oscillatoria pseudominma. (2.05%), Oscillatoria limosa (2.02%), Oscillatoria princeps (2.00%), Phormidium forseolarum (1.92%), isocystis planktonica (1.92%), Oscillatoria terebriformis (1.61%) and Merismopedia elegans (1.59%). The spatial variation in total phytoplankton density and species count are presented in Fig 4.25. Phytoplankton density varied between 1932 cells/l in station SW 2 to 2347 cells/ml in SW 4 at the project area and from 2373-3224 cells/l at the control. A total of eighty-seven (87) species of phytoplankton were recorded in the study area ranging from 56 species in station SW3 to 64 species in SW4 with no significant difference between project study location and control.

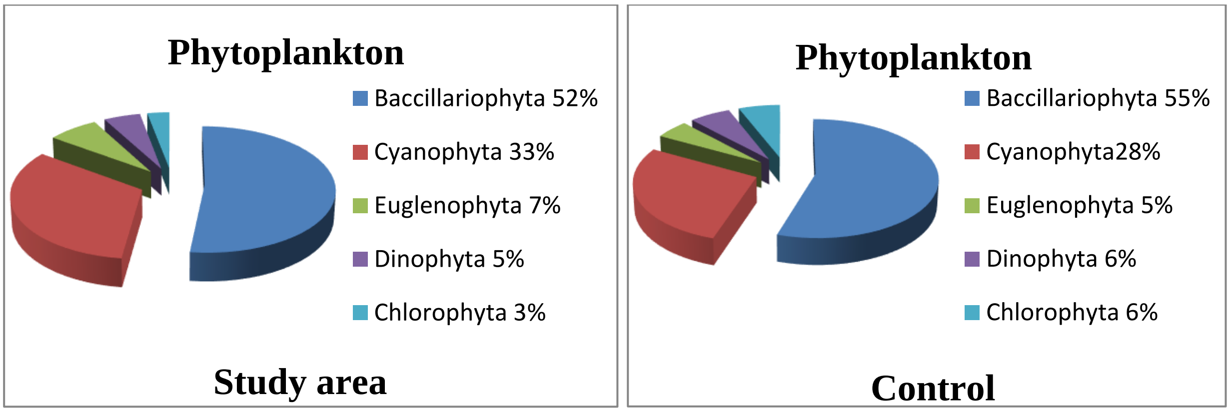

Fig. 4: Phytoplankton population distribution enumerated in the study Forcados area

5.5 Zooplankton:

The zooplankton belonged to six taxa including copepods, hyrozoa, molluscs, decapods, rotifers and chaetognths. Zooplankton of the area (Fig. 5) was dominated by rotifers followed by copepods in the and control with no significant difference between study area and control in the diversity indices. Dominance of rotifers and copepods is usually associated with unpolluted environments. Shannon index ranged from 2.7 to 3.1 in the project study area and above 3 in the control indicating moderately polluted conditions in the project study area (Fig 5). The percentage composition of zooplankton taxa has revealed Rotifera were the most dominant with 12 species accounting for 33% of the zooplankton in the project area and 29% in the control. Most dominant members of the rotifers included Lecane climacois (6.14%), Kelicottia longispina (4.78%), Monomaratta longiseta (4.02%), Euchlanis dilatata (3. 56%) and Keratella testudo (3.11%). Copepods were the second in dominance with 14 species representing 33% in this study and 32% as control. They include Cycopina longicornis (5.91%) Scaphacalanus magus (5.08%), Calanus finmarchicus (3.49%), Copila mirabilis (2.96%) and Euchaeta marina (2.89%). Hydrozoa was measured to be 13% in this study and 20% in control. More importantly Mollusca L, Decapod L and Chaetognatha all recorded 7%, 7% and 4% respectively in this assessment (Fig. 5).

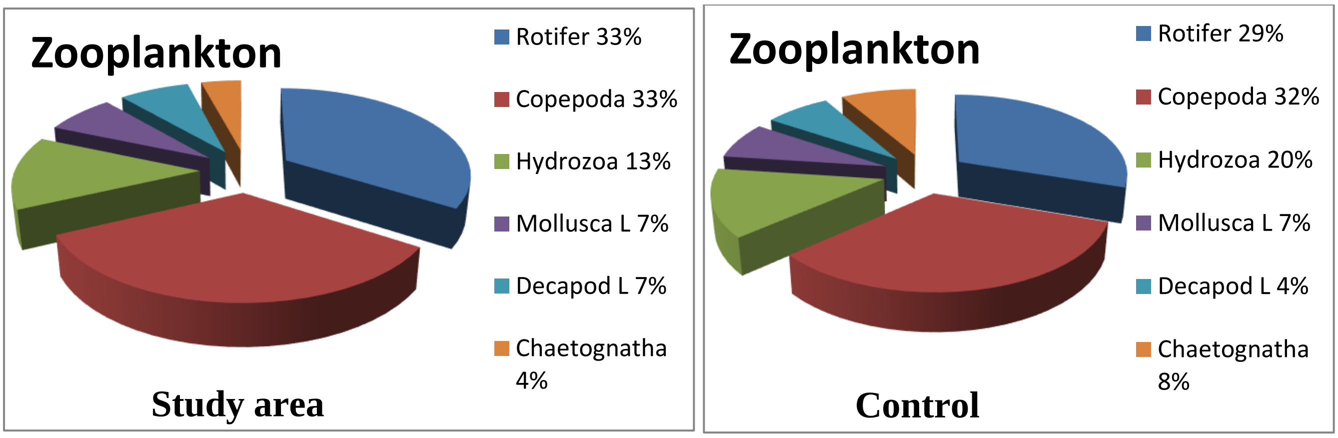

Fig. 5: Zooplankton population distribution enumerated in the study Forcados area

5.6 The Benthics

The benthics of the study area was evaluated to be a total of fifty-four (54) organisms in the project study area and 27 organisms in the control. Paleontologic benthic fauna were largely larval forms including, polychaetes, crustaceans, gastropod and bivalve molluscs. The polychaetes with a relative abundance of 52% were the most dominant in the area and while crustaceans with an abundance of 41% were dominant in the control (Fig 6). Dean (2009) has reviewed the use of polychaetes as indicators of pollution in aquatic environment and has shown that they are very important indicators of organic enrichment, heavy metals and hydrocarbons. Their dominance in the project study area is an indication of a relatively more polluted sediment conditions compared to the control. Polycheata, Bivalves, Gastropods and Crustaceans all recorded values of 52%, 9%, 11% and 28% respectively in this study compared to the control station that recorded 28%, 1%, 30% and 41% respectively (Fig. 6).

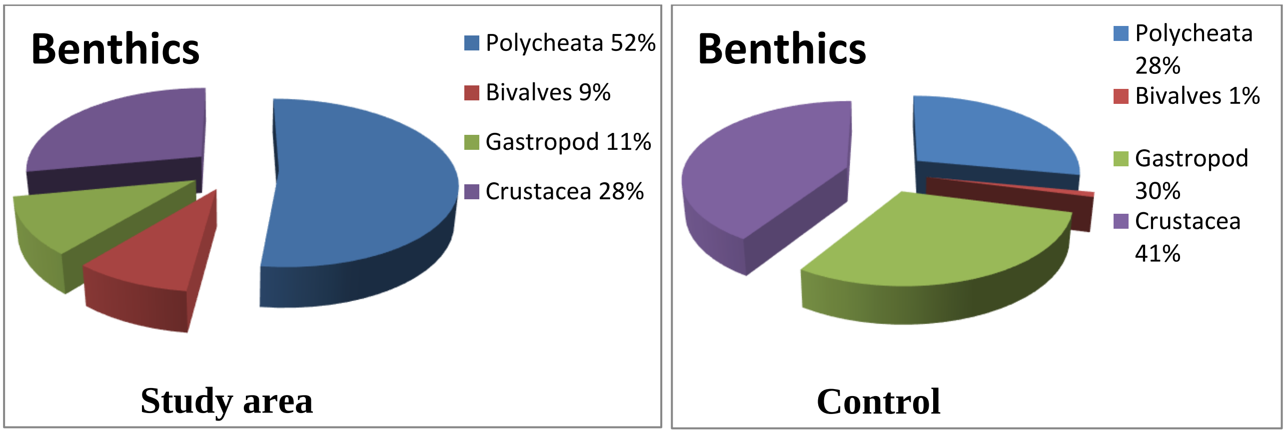

Fig. 6: Recorded Benthics in the study area of Forcados, Delta area

5.7 Fisheries:

Fishes of the study area included both fin and shell fishes. The shellfishes include the crustaceans namely, blue swimming crab (Callinectes spp.), the mangrove swamp crabs (Cardiosoma sp and Sesarma sp), the shrimps (Penaeus notialis, Parapaeneopsis atlantica and Palaemonetes africanus) and prawns (Macrobrachium spp. and Nematopalaemon hastatus). The molluscs include cockles (Senilia senilis), whelks (Thais sp.), oysters (Crassostrea gasar) and the periwinkles (Tympanotonus fuscatus and Pachymelania aurita). The fin fishes include bonga fish, croakers, gobies, groupers, grunts, snappers, sole, shad, mullets and tilapias. Fishes such as the bonga-Ethmalosa fimbriata migrate along the nearshore-inshore axis in relation to changes in salinity, food availability and age. Fishing gears of the area are many and varied, but commonly include gillnets, tow nets, cast nets, beach seines, lift nets, traps, hooks and lines, fences and stakes. Fishes are processed for preservation by gutting or merely washed in water for smoke-drying (DeLaune 1999**)**.

5.8 Vegetation

Vegetation characteristics reflect a typical fresh water and mangrove swamp forests that extends from Yakri to Sikebolon, Ogbotobo and Forcados. The physiognomy of the fresh water swamp is at different stages of re-growth with vegetation cover of 75 – 85% with an average ranged between 20 – 26m. The mean tree density was 900 trees/ha. A total of 33 plant species belonging to 23 families was recorded in the study area, common tree species in the swamp forest include Elaeis guineensis, Alstonia boonei, Ceiba pentandra, lophira alata, Pycnanthus angolensis among others. Microphanerophyes and Nanophanerophytes constituted 70 and 80% of the vegetation respectively. Common plant diseases in the study area include leaf spot and mosaic virus caused mostly by Aspergillus, Fusarium spp and Curalaria spp. The plant tissues analysis indicated that

the mean concentration of Fe, Zn, Cu and Mn, Cd, Ni, and Pb were 110.34, 44.82, 4.4 and 90.19, <0.01, 0.06 and 0.14 mg/kg respectively. The results indicate that there was no toxicity in the plant tissues in the study area.

5.9 Mangrove Vegetation

This kind of vegetation cover is observed mostly west of the Forcados tank farm. Mangroves are naturally near homogenous vegetation systems. They are adapted to the hostile environmental conditions characterized by variable salinity, hypoxia (oxygen deficient), waterlogged soil strata, tidal pressures, strong winds and sea waves. Such adaptations include possession of Stilt roots for

anchorage; prop roots, and root pneumatophores for dealing with anaerobic mud conditions, and lenticels on the bark to aid aeration; high water retention in succulent leaves to keep salt levels diluted; rhizofilteration to exclude salt during uptake of water; possession of salt glands for secretion/excretion of salt onto their leaf surfaces, or bark, or accumulating salt in older leaves which are discarded as leaf abscission takes place (Dean, 2009). The combination of these mechanisms differs from one species to another. Mangroves (Chinda et al 2007) are among the most productive terrestrial ecosystems, sustain a huge hydrobiological system and play a very important role in stemming coastal erosion and land formation; as well as providing the quiet back waters for spawning of many marine species.

6.0 Physicochemical properties of surface water in the area

The results of physicochemical measurements in surface waters of the Field area are presented.

6.1 Temperature

Temperature ranged from 27.8 to 29.7oC with no significant difference between the project location and control. The measured temperatures are normal for tropical coastal waters.

Table 4: Summary of results of Physicochemical measurements in surface water of the study area

Parameters	Proposed project area			Control			P values
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	
Temperature ('C)	27.8	28.8	28.35	29.2	29.7	29.4	0.156
pH	7.5	7.9	7.75	12040	23250	17645	0
Electrical Conductivity, µS/cm	13650	42157	26752	12040	23250	17645	0.37
Salinity, ‰	9,9	32.1	20.03	8.2	16.6	12.4	0.18
Total Dissolved Solids (TDS), mg/l	7234	22260	14156	6301	12332	9312	0.37
Turbidity, NTU	13.4	81.7	37.1	16.5	19.1	17.8	0.01
Total Suspended solids (TSS), mg/l	19.8	34.6	27.9	6301	12322	9312	0.655
Colour, Pt.Co.	25	50	36	40	40	40	0.317
Redox potential (±mV)	135.5	184.7	172.3	184.8	186.1	185.45	0.18
Dissolved Oxygen, mg/l	5.4	5.43	5.42	5.38	5.38	5.38	0.18
Biological Oxygen Demand (BOD),mg/l	4.11	8.31	6.01	6.27	6.27	6.27	0.18

6.2 pH, Conductivity, Salinity, Total Dissolved Solids (TDS)

Hydrogen ion concentration (pH) varied between 7.5 and 7.9 with no significant difference between proposed project location and control. The pH is normal for tropical marine waters. According to CWT (2004), the pH of seawater is usually between 7.5 and 8.4. A study (Emere 2007) reported that the pH of marine waters is similar to that of estuarine waters and is usually stable between 7.5 and 8.5 worldwide. NNPC (1985) reported a range of 3.1-8.6 for surface waters of the Niger Delta. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5. Electrical conductivity, Salinity and Total Dissolved Solids are interrelated parameters of salt concentration. Electrical conductivity ranged from 12040 to 42157 µS/cm with significantly higher ($P<0.05$) values around the project location compared to control. The fact that conductivity was higher around the proposed project area than further offshore at SWC2 may indicate local influence of saline conditions due to tides or effluent discharges. The observed conductivity values are typical of brackish waters. Estuaries usually have electrical conductivity typically from >1500 to 51,500 µS/cm with values increasing as salinity increases (NSW, 2010).

The levels of salinity (8,2-32.1 ppt) and TDS (6301-22260 mg/l) are also characteristic of brackish waters. Dissolved oxygen (DO), Oxidation-Reduction Potential (EH), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) The levels of DO, EH, COD and BOD are all indicators of the redox conditions in the environment. Dissolved oxygen concentrations ranged from 5.38-5.43 mg/l with no significant difference between study locations and control. According to Chapman (1996) DO concentrations in unpolluted freshwaters are usually close to, but less than, 10 mg/l. Concentrations below 5 mg/l may adversely affect the functioning and survival of biological Community while levels below 2 mg/l may lead to the death of most fishes. The observed DO levels are normal in brackish tropical waters. The moderately lower values may be attributed to the effect of salinity because the amount of oxygen that can dissolve in water, decreases as salinity increases (NOAA, 2017). NNPC/RPI previously reported a range of 2 to 9 mg/l for the Niger Delta area. The present concentrations are normal for the study area. The redox potential (EH) ranged from 135.5 to 186.1 mV with no significant difference between project location and control. According to previous workers, (Chapman 1996) surface water containing dissolved oxygen are usually characterized by a range of EH values between +100 mV and +500 mV. The observed EH values are in tandem with the levels of DO in the water.

Chemical Oxygen Demand varied between 9.58 and 18.2 mg/l while BOD ranged from 4.11-8.31 mg/l with no significant difference between facility location and control. According to Chapman (1996) the concentrations of COD observed in surface waters can reach up to 20 mg/l in unpolluted waters indicating that the waters were unpolluted by organic matter. Also, NNPC/RPI (1985) reported a range of 1.9 to 2460 mg/l in the Niger Delta waters indicating that the observed values are usual for the study area. The BOD values were also within levels that do not indicate organic pollution. Typical natural water has a BOD from 0.8 to 5 mg/l.

6.3 Alkalinity

Surface water alkalinity ranged from 220-460 mg/l. Alkalinity is the measurement of the water's ability to neutralize acids. It represents the buffering capacity of water and its ability to resist a change in pH. According to previous workers, alkalinity of seawater averages 116 mg/l to 127 mg/l with lower values in brackish water.

6.4 Turbidity and Total Suspended Solids (TSS)

Turbidity and TSS are related parameters indicating particulates load in water. Turbidity ranged from 13.4 to 81.7 NTU while TSS ranged from 24.2 to 34.6 mg/l (Table 4). The USEPA guidelines on suspended solids for the protection of fisheries resources prescribes values below 25 mg/l as indication of no harmful effects (Emere and Nasiru, 2007). In Estuaries, turbidity less than 10 NTU is considered healthy while poor water quality is indicated by levels above 20 NTU. For most surface waters, turbidity is usually between 1 NTU and 50 NTU with possibility of higher values after heavy rains when the water levels are high while lower values can be expected in still water where suspended particles have settled. The observed levels of turbidity and TSS are indicative of poor water quality but such levels are commonly encountered in natural tidal waters due to tide-induced re-suspension of sediments (Chapman, (1996).

6.5 Nitrates

Nitrate ranged from 0.5-0.6 mg/l with no significant difference between project location and control (Table 5). Nitrate levels above 22 mg/l in natural water normally indicates man made pollution (Chapman, 1996). In marine environments, levels of 0.44 to 0.89 mg/l are considered ideal (Alken Murray, 2006) indicating that the water was unpolluted with regards to nitrates. Nitrites ranged from 0.1-0.3 mg/l with no significant difference between project location compared to control. Nitrites occur in water as an intermediate product in the biological breakdown of organic nitrogen, their presence may infer recent input of organic wastes. According to notable researchers (Hem, (1985) the level of nitrite considered ideal for marine fish is between 0.04 and 0.15 mg/l. The observed levels should be expected because of multiple sources of organic matter inputs including tidal export from associated mangrove swamps. Phosphate ranged from 0.013 to 0.09 mg/l with no significant difference between project area and control. According to Chapman (1996), phosphorus ranges from 0.02 to 0.06 mg/l (Table 5) in most natural waters. A study by previous researchers (NNPC research group, 1985) gave a range of 0.049 to 0.584 mg/l for phosphate in rivers of southern Nigeria. Present values are therefore normal for the Niger Delta (Omiema and Ideriah, 2012).

Table 5: Major Cation and Anion result with control data of the study area

Parameters	Proposed project area			Control			P values
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	
Chemical Oxygen Demand (COD), mg/l	9.58	18.2	14.35	12.55	12.55	12.92	0.18
Alkalinity, mg/l	400	460	430	220	420	320	0
Bicarbonate (CO_3^{2-}) mg/l	488 5	561.2	524.6	268.4	512.4	390.4	0.05
Nitrate, mg/l	0.5	0.6	0.56	0.53	0.57	0.55	0.317
Nitrite (NO^{2-}), mg/l	0.01	0.03	0.02	0.02	0.02	0.02	1
Phosphorus, mg/l	0.02	0.09	0.05	0.013	0.029	0.021	0.655
Phenol, mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
Chloride (Cl^-), mg/l	4.33	9235	3478.6	4.254	53.18	28.72	0
Sulphate (SO_4^{2-}), mg/l	25.08	49.71	34.94	15.97	24.63	20.3	0.043
Na^{2+}, mg/l	3546	8461	5929	1953	4333	3143	0
K^+, mg/l	188.58	443.7	321.6	118.82	223.89	171.36	0
$Ca^{2+,}$ mg/l	70.74	109.37	90.95	64.78	87.43	76.11	0.213
$Mg^{2+,}$ mg/l	359.11	1280	822.5	287.34	355.39	321.37	0

7.0 Major Anions and Cations

Chloride ranged from 4.25 to 9235 mg/l (Table 5), while sulphate ranged from 15.97 to 49.71 mg/l with significantly higher levels at the project location compared to control. Chloride and sulphate are major anions which contribute to the salinity of marine waters. For typical ocean waters, average concentration of chloride is 19,345 mg/l and that of sulphate is 2,701 mg/l (Anderson, 2008). These typical ocean levels are usually diluted in estuaries and in the vicinity of large rivers discharging into the sea as is typical of the present study area (Mouth of Forcados River) (Garrison, 2005). It is worthy of note that (RPI/NNPC 1985) previous workers reported values of 3 to 18,648 mg/l for chloride and BDL to 2,796 mg/l for sulphate in waters of southern Nigeria. The values of chloride and sulphate obtained are normal for the study area. However, the observation of higher values of chloride and sulphate within the proposed project study area compared to control (SWC2) which is further offshore may indicate local saline intrusion due to tides or saline discharges. Sodium, potassium, calcium and magnesium are major cations that contribute to the salinity of marine waters.

Sodium ranged from 1953 mg/l to 8461 mg/l, potassium ranged from 118.82 to 443.7 mg/l, calcium ranged from 64.78 to 109.37 mg/l and magnesium ranged from 2.72 to 2.83 mg/l (Table 5)with significantly higher values at project location compared to control. Levels of major cations in sea water (Hem, 1985) average 105 mg/l for sodium, 380 mg/l for potassium, 410 mg/l for calcium and 1350 mg/l for magnesium. Concentrations of major cations were within normal levels for nearshore waters. Lower values compared to average sea water is associated with riverine dilution. Although SWC2 is the farthest offshore location and should naturally show the highest levels of major cations, concentrations at SW2 and SW3 within the study area were the highest. A similar trend was found in conductivity, chloride and sulphate levels. This may be attributed to variations in tidal conditions during sampling or saline effluents from variable marine operations in the area.

8.0 Heavy metals:

Trends in sediment heavy metals generally followed those of zinc (Table 5) as observed in the trends of copper and chromium (Table 5). Heavy metal levels in sediments increased markedly in a previous study following an initial decrease from baseline to 2012. Since there were no significant differences in heavy metal levels in sediment between the study location and control, the observed increasing trend cannot be linked to operations in the study area. Although the levels of heavy metals were within recommended sediment guidelines (except cadmium), increasing trends in heavy metal is a cause for concern because of their persistence and toxicity and adequate attention was paid to pollution control during well drilling.

Table 6: Heavy metal and control result of the study area

Parameters	Proposed Project area			Control			P- values
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	
Cadmium, (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	1
Zinc, (mg/l)	0.55	0.62	0.6	0.544	0.57	0.544	0.655
Iron, (mg/l)	0.45	3.68	1.431	0.5	0.64	0.5	0.655
Copper, (mg/l)	0.02	0.04	0.03	0.029	0.032	0.031	0.18
Chromium, (mg/l)	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001	1
Nickel, (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	1
Lead, (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	1
Vanadium, (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Arsenic, (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Mercury, (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Barium, (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Magnesium, (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Silver, (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	-

9.0 Organics:

Total Petroleum Hydrocarbon was characterized and measured to have a mean of 0.109 mg/l at the study area (Table 7). This was computed from the maximum and minimum values of 0.006 mg/l and 0.212 mg/l respectively. A slightly higher value was obtained as control (0.361mg/l). THC ie Total Hydrocarbon Content was averagely measured to be 0.193mg/l. Oil and grease measurement was moderate (Table 7). BTEX was evaluated to be <0.001 throughout the study area. The present EIA study has showed significantly higher levels in the Non Associated gas content kin the study area compared to control indicating possible impact from ongoing operations around the well area. Such operations may include discharge of deck/ballast effluents from vessels as well as operational effluents from existing oil and gas facilities in the area. Although the present levels of TPH were within sediment quality guidelines, the increasing trend calls for close attention to pollution control measures in the area particularly during the proposed Non associated gas well drilling. Aliphatic Hydrocarbon measurement recorded 0.241 maximum values and <0.031mg/l.. This is in variance with what is abtainable with previous workers (Massoud et al 1999) in the Kuwait oil slik.

Table 7: Organic Petroleum and control results obtained from the area

Parameters	Project study area			Control			P- values
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	
Total Petroleum Hydrocarbon (TPH), (mg/l)	0.006	0.212	0.109	0.361	0.361	0.361	0.18
Total Hydrocarbon Content (THC), (mg/l)l	0.118	0.241	0.193	0.29	0.61	0.45±	0.18
Oil and grease (O&G), (mg/l)	0.112	0.24	0.187	0.261	0.27	0.266	0.18
BTEX, (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
PAH, (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-

Aliphatic Hydrocarbon, (mg/l)	<0.031	0.241	0.124	<0.031	0.305	0.305	0.18

10.0 Mitigation measures:

The following mitigation measures will need be adopted for negative and adverse impacts on the ecosystem.

• use of wet scrubbers for all emission sources

• use of mufflers for vehicle exhaust.

• ensure that the cluster is located outside the border of the navigation fairway in

keeping with government regulations requiring the fairway to be kept free and open

to water transport traffic

• ensure that Vessel/boat operators observe recommended speed limits

• ensure effective consultation with stakeholders

• ensure commitment and transparent adherence to P-GMoU programmes.

• identify and address legacy issues promptly

• support skills acquisition and empowerment schemes to facilitate occupational

proficiency, productivity and sustainability

11.0 Conclusions

The study concludes on a favorable climatic condition in the area with adequate technological tools and greater scientific skills capable to produce the gas deposit for deeper and better utilization as alternative fuel in Nigeria and diaspora market to reduce global carbon footprint. The Environmental Impact Assessment has thus also provided great opportunities for skilled and unskilled job creation in the area. All identified adverse effects most especially the severe pollution of the air are short-term and will need be mitigated as outlined and can be reduced or controlled.

More importantly, this assessment will guide the operators and inhabitants on the need to protect the environment as much as possible during such intervention to add value to the community and lastly, restoration of all sites from oil spill during production phase will need be attended to in the area to prevent contamination of the soil, water, air and other vital ecosystem components that will strengthen the public health of inhabitants.

Acknowledgements

The authors sincerely thank friends and well wishers for the encouragement during the most tedious part of this work. Special thanks to support staffs and Industrial Training Geoscience students of 2024 and 2025 sets at Lower Niger River Basin development Authority, Ilorin, Kwara State for the support in compiling articles and useful data.

Funding

No external funding has been received during the preparation, typesetting, compilation and review of manuscripts or publication of these findings.

Conflict of Interest

No conflict of Interest has been established in the work.

References

1. **Akoma, O. C. and Opute, F. I. (2010).** Phytoplankton species from Imo river estuary, Nigeria 1: pennate diatoms (Diatomaceae, Eunotiaceae and Naviculaceae). Nigerian Journal of Botany 23(2): 343-354.
2. **Awosika L.F., and Folorunsho R. (2002).** An outline of the different Geomorphology of the Niger Delta in shelf circulation patterns, observed from Davis Drifter off the Eastern Niger Delta in the Gulf of Guinea., 29: 209-218
3. **Billig P, Bendahmane D, Swindale A (1999).** Water and sanitation indicators measurement guide.Washington DC. Food and Nutrition Technical Assistance Project, Academy for Educational Development: 7–18.
4. **Chapman, D. (Ed.) (1996).** Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring -Second Edition. United Nations Educational, Scientific and Cultural Organization. World Health Organization, United Nations Environment Programme. UNESCO/WHO/UNEP
5. **Chindah AC, Braide SA, Amakiri J, Onokurhefe J (2007).** Effect of crude oil on mangrove (Rhizophora

Mangle L.) seedlings from the Niger Delta, Nigeria.Revista UDO Agricola; 7 (1): 181 – 194.

6. **Davies O.A., Abowei, J.F.N and Tawari, C.C. (2009).** Phytoplankton Community of Elechi Creek, Niger Delta, Nigeria-A Nutrient-Polluted Tropical Creek. American Journal of Applied Sciences 6 (6): 1143-1152.
7. **Dean, H. K. (2009).** The use of polychaetes (Annelida) as indicator species of marine pollution: a review. Rev. Biol. Trop. 56 (4): 11-38.
8. **DeLaune, R. D., Lindau, C. W. and Gambrel, R. P. (1999).** Effect of Produced-Water Discharge on Bottom Sediment Chemistry Final Report. OCS Study, MMS 99-0060. U.S. Department of the Interior. Minerals Management Service Coastal Marine Institute Gulf of Mexico OCS Region
9. **Doust H. (1989).** The Niger delta: Hydrocarbon potential of a major Tertiary delta province, in coastal lowlands, geology and geotechnology, in Proceedings of the Kon. Nederl. Geol. Mijnb. Genootschap, pp. 203-212.
10. **Doust, H., and Omatsola, E. (1990).** Petroleum Geology of the Niger Delta. Geochemical Society, London, Special Publications. 50, pp.365.
11. **Emere, M. C. and Nasiru, C. E. (2007):** Macroinvertebrates as indicators of the water quality of an urbanized stream, Kaduna, Nigeria. Journal of Fisheries International: 2 (2); 152-157. Federal Ministry of Health (Nigeria) (FMOH, 2004). 2003 National HIV/AIDS and Reproductive Health Survey. Federal Ministry of Health Abuja, Nigeria.
12. **Ejedawe, J.E. Coker, S.J.L., Lambert-Aikhionbare, D.O. Alofe, K.B., and Adoh, F.O. (1984).** Evolution of oilgenerative window and oil and gas occurrence in Tertiary Niger Delta Basin. American Association of Petroleum Geologists, 68: 1744 -1751
13. **Ekwe, A.C. Onuoha, K.M., and Osayande, N. (2012).** Fluid and lithology discrimination using rock physics modelling and Lambdamurh inversion as an example from onshore Niger Delta Nigeria, 64: 12-18.
14. **Hem, J. D. (1985).** Study and interpretation of the chemical characteristics of natural water 3rd edition, US Geological survey Paper 2254, University of Virginia, Chalottesville 263p Hydrochemistry and plankton dynamics of Kuramo lagoon. Life Science Journal. 5 (3): 50 – 55
15. **Ibrahim, O.I, Adekeye, O.A, Bale R.B., Babatunde, W.S (2020).** Sedimentological, Depositional environment and Sequence stratigraphic studies of OML AB field, Southeastern Niger Delta, Nigeria. Centerpoint journal (science edition).Vol. 25(1) pp. 181-196.
16. **Ibrahim, O. Ibrahim, Ibrahim B. D**, **Ngozi-Chika, C.S**, **Adeoye, A.S and Shaibu S (2024).** Hydrocarbon prospectivity of selected block wells, Southern Niger-delta, Nigeria. Discovery nature of Discovery Scientific Society Journal. eldn 1003. 1: Pp 1-10
17. **Ibrahim, O.I Ngozi-Chika C.S Okanigboan, P.N Abdulraheem, K.K and Bilqees, D (2023).** Mothballing, Manifold, Pipeline installation and Impact Assessment in existing Saghara Gas solution Flowstation Facility, Warri, Niger Delta, Nigeria. Nigerian Journal of Engineering Science Research (NIJESR). 6(02), pp.9-23. ISSN: 2636-7114
18. **Massoud, M. S. , Al-Abdalib, F., Al-Ghadbanb, A. N. and Al-Sarawia, M. (1996).** Bottom sediments of the Arabian Gulf--II. TPH and TOC contents as indicators of oil pollution and implications for the effect and fate of the Kuwait oil slick. Elsevier
19. **McDonald, D. D., Ingersoll, C. G. and Berger, T. A. (2000).** TEC Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31
20. **Omiema, S. D. and Ideriah T. J. K. (2012).** Distribution of microorganisms in water and sediment along Abonnema shoreline, Eastern Niger Delta, Nigeria. Journal of Chemical, biological and physical sciences.2 (4): 2114-2122