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Abstract should highlight the main findings of their results which must add more value to the existing literature.

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The introduction should highlight those recent development in the area of problem studied and should highlight the gaps and justify why the present work is undertaken.

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Introduce and present results inform of frequency tables, pie charts, graphs and proceed to discuss them with literature.

4. Conclusion

In the conclusion section, besides wrapping up the research by reiterating the goal of the study and confirm the major results or outcomes and concrete recommendations be offered, some

limitations of the current study can be reported. The authors should discuss these limitations from which research directions for future studies may be offered.

5. References

1. References for research articles

A. N. Ikot, L. F. Obagboye, U. S. Okorie, E. P. Inyang, P. O. Amadi, I. B. Okon, Abdel-Haleem Abdel-Aty, *European Physical Journal Plus* 137(2022) 1370.

2. References for published/conference proceedings:

Kapitsaki GM. Reflecting user privacy preferences in context-aware Web Services. Department of Computer Science University of Cyprus Nicosia, Cyprus. In: Proceedings of the IEEE 20th International Conference on Web Services. 2013. <https://doi.org/10.1109/ICWS.2013.26>

3 References for Books

M. Abramowitz and I. A. Stegun, *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables* (Dover, New York, 1972). Pp. 23-37.

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Halpen-Felsher BL, Morrell HE. Preventing and reducing tobacco use. In: Berlan ED, Bravender T, editors. Adolescent medicine today: a guide to caring for the adolescent patient [Internet]. Singapore: World Scientific Publishing Co.; 2012 [cited 2019 Nov 3]. Chapter 18. Available from: https://doi.org/10.1142/9789814324496_0018

5 References for Internet source

Australian Medical Association [Internet]. Barton ACT: AMA; c1995-2012 . Junior doctors and medical students call for urgent solution to medical training crisis; 2012 Oct 22 [cited 2019 Nov 5]; [about 3 screens]. Retrieved on 4 April 2020 from: <https://ama.com.au/media/junior-doctors-and-medical-students-call-urgent-solution-medical-training-crisis>

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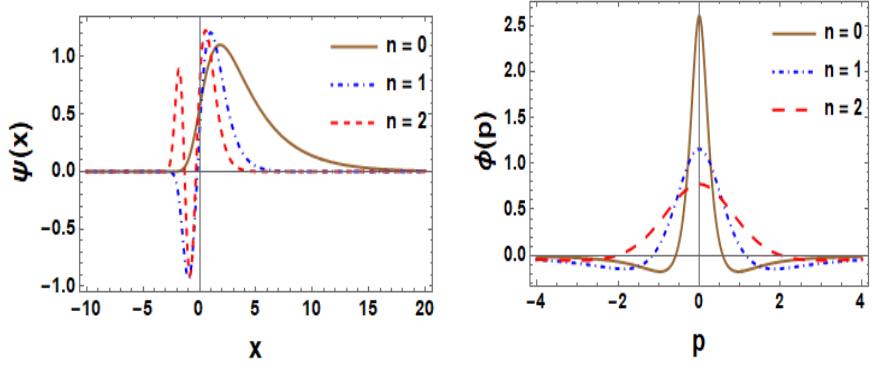


Figure 1: Wave function of the Position and Momentum spaces of shifted Morse Potential for ground, first and second excited states.

Table Guidelines

Tables should be included in the manuscript document and must be cited in the text. All tables should have a concise title and written as Table 1 as shown below:

Table 1: Numerical values of energy eigenvalues ($-E_n$) of shifted Morse Potential, where

$$A = 0.1, D_e = 0.02, \alpha = 0.8, m = 1.0, \hbar = 1.0$$

n	$A = 0.1, B = 1.0$	$A = 0.1, B = 1.5$	$A = 0.1, B = 2.0$
0	0.02396851613	0.02912952290	0.03235477070
1	0.5922741755	0.6103990945	0.6214088670
2	1.800579835	1.831668666	1.850462963
3	3.648885494	3.692938237	3.719517059
4	6.137191155	6.194207810	6.228571155
5	9.265496815	9.335477380	9.377625250
6	13.03380248	13.11674696	13.16667934
7	17.44210813	17.53801652	17.59573344
8	22.49041379	22.59928610	22.66478754
9	28.17871946	28.30055567	28.37384164
10	34.50702509	34.64182528	34.72289571

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Chaya leaf Extract Supplementation as Alternative to Antibiotics and Immunomodulating Agent in Broiler Chicken Nutrition.

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Abstract

A total of 180-day-old broiler chicks were used in this study that lasted for 8 weeks. The birds were weighed to determine their initial weight and assigned into 4 treatment groups, that were replicated 3 times with fifteen (15) birds per replicate in a Completely Randomized Design (CRD) experiment. The birds were fed formulated broiler starter and finisher diet together with the test ingredient (Aqueous chaya leaf extract), that was given to the birds via drinking water at varying levels of chaya leaf extract per 10 lit of water (20g CLE/10 lit, 40gCLE/10 lit and 60gCLE /10 lit) representing treatments (2, 3 and 4) that was later increased as the birds advanced in age and body weight. Birds in the dietary treatment groups (2,3 and 4) were raised and fed antibiotics free with aqueous chaya leaf extract (test ingredient) as alternative to antibiotics throughout the study period except the control group (T₁) that was given antibiotics and normal water. The results show that the inclusion of aqueous chaya leaf extract improved haematological parameters of broiler birds such as PCV, WBC, Hb, RBC and platelet. Aqueous chaya leaf extract influenced cytokine production as well as reduction in microbial load in the dietary groups compared to the control group. The result showed up-regulation and down-regulation of anti-inflammatory cytokine (Interleukin-10) in the dietary groups compared with the control which justify the immunomodulatory potentials of Chaya leaf extract to improve performance and health status of broiler birds.

Key words: Chaya leaf, antibiotics, broilers, alternative, cytokine and immunity.

Introduction

The chaya plant is both nutraceutical and phytobiotic in nature belonging to the Euphorbia family. It is a perennial green leafy vegetable plant which grows up to the height of about 3 to 6 meter tall. The chaya plant is a native of central and southern America (mexico) and also found growing in other tropical and subtropical regions of the world including Nigeria.

Over the years, the chaya plant has been used as food ingredient in the nutrition of broiler chicken as well as in human diet as ethno-medicine for prophylaxis and curative treatment of several ailments such as diabetes, obesity, high cholesterol, kidney stone, insomnia and hemorrhoids (oriental, 2018). However, as microorganisms are progressively becoming resistant due to the indiscriminate use of antibiotics and unrelented attack against the arsenal of antimicrobial agents. Hence the need for an alternative to antibiotics and a non-conventional means such as aqueous extract of chaya plant to address the growing medical problem associated with pathogen resistance cannot be over emphasized (Fernebro, 2011 and Akin-Osanoiyé *et al*, 2015).

Chaya plant contains protein, minerals and vitamins such as vitamins C and E. which are good source of antioxidants and used as feed additive and alternative to antibiotics in the nutrition and treatment of poultry and human diseases (Veronica *et al*, 2020 and Ndukwu *et al*, 2018).

Increase in public awareness on food safety has led to high demand of antibiotic free food products of poultry sources (Biswas *et al*, 2010). This single reason as well as direct and indirect actions has necessitated researchers to harness phytobiotic research such as chaya leaf extract as alternative to antibiotics for general health maintenance, immunomodulation, growth enhancement and therapeutic purposes (Diarra and malouin, 2014 and Ndukwu *et al*, 2018).

In this study, broiler birds in the dietary groups were raised and fed antibiotics free diet with aqueous chaya leaf extract through drinking water. The aim of this study was to investigate the immunomodulatory potentials of aqueous chaya leaf extract to stimulate cytokine production with the view to enhance the immune system of broiler chicken to overwhelm disease conditions as well as unfavorable environmental factors.

Materials and method

This study was conducted at the poultry section of the University of Port Harcourt Teaching and Research Farms, Choba, Rivers State. The area is located at latitude 4°N and longitude 7°E with an average temperature of 26.4°C and annual mean rainfall of 2708mm.

Identification of Chaya Plant (Test Ingredient).

The chaya plant (test ingredient) was properly identified and given a voucher number: UPHE 0586 at the Herbarium of the Department of Pharmacognosy and Phytotherapy, University of Port Harcourt by Dr. Suleimam M.

Collection and preparation of test diet

After harvest, the leaves of chaya plant were washed with clean water to get rid of dust, and sundried on a mat for 1 to 2 days. The chaya leaves used in this study were gotten from the surroundings of Mgbuoba, Port Harcourt and pharmaceutical garden, University of Port Harcourt, Rivers State, Nigeria. The leaves were later gathered and pounded in a mortar and a known quantity of the leaves were macerated with equal volume of water at 20 gram of chaya leaf extract/10lit of water (20gCLE/10lit, 40g CLE/10lit and

60g CLE/10Lit) that represents treatments 2, 3 and 4, which vary respectively in the concentration of aqueous leaf extract given to broiler chickens, except the control that was given equal volume of normal water. The quantity of leaves and volume of water used in the study were increased progressively on weekly basis as the birds increased in age and body weight. The birds in the dietary groups were raised without antibiotics, using only aqueous extract of chaya leaf that was given via drinking water together with formulated broiler starter and finisher diets.

Management of birds and experimental Design.

A total of 180 day-old broilers were weighed for their initial weight and assigned randomly into 4 treatment groups, that were replicated 3 times with fifteen (15) birds each in a Completely Randomized Design (CRD) experiment. The birds were fed formulated broiler starter and finisher diets together with

the test ingredient (aqueous chaya leaf extract) that was given through drinking water with varying levels of chaya leaf extract per 10 lit of water (20gCLE/10lit, 40gCLE/10lit and 60gCLE/10lit) representing treatments (2,3 and 4) while the control (T₁) was given equal volume of normal water. Birds in the dietary groups were raised without antibiotics, but were given only aqueous chaya leaf extract as alternative to antibiotics via drinking water.

At the end of the experiment, blood samples were collected from two birds in each replicate for laboratory analysis. EDTA bottles were used to collect blood samples. Blood plasma and spleen samples were used for haematological analysis and cytokine test respectively.

Data Collection

Data collection was done on the parameters studied in the experiment such as haematological analysis and cytokine test.

Table 1: Composition of experimental diet for Broiler Chicken

Ingredients	T ₁ (0g)	T ₂ (20g)	T ₃ (40g)	T ₄ (60g)
Maize	51.5	51.5	51.5	51.5
Soya bean	10	10	10	10
Groundnut cake	10	10	10	10
PKC	4.5	4.5	4.5	4.5
Fish meal	8.1	8.1	8.1	8.1
Wheat bran	4.7	4.7	4.7	4.7
Bone meal	3	3	3	3
Palm oil	4.4	4.4	4.4	4.4
Vitamin Pmx	2.5	2.5	2.5	2.5
Methionine	0.8	0.8	0.8	0.8
Lysine	0.2	0.2	0.2	0.2
Salt	0.3	0.3	0.3	0.3
Total	100	100	100	100
% Conc. of Chaya Leaf Extract	0	2.6	5.3	8
Nutrient Calculated				
CP		20.18	20.18	20.18
ME		3004.32	3004.32	3004.32
CCF		4	4	4

Oil	7.94	7.94	7.94
Lysine	1	1	1
Methionine	041	041	041
Calcium	1.65	1.65	1.65
Phosthorus	1.05	1.05	1.05

Test ingredient (Chaya Leaf Extract) in drinking water.

Contains in the following per kg: vitamin A: 23000000 IU, vitamin D: 1,100000vitamin E: 1800 IU, vitamin K: 800mg, vitamin B12: 6mg, niacin: 7500mg, folic acid: 450mg, pantothenic acid: 3000mg, biotin: 40mg, antioxidant: 3000mg, cobalt: 80mg, copper: 2000mg, iodine: 400mg, iron: 1200mg, manganese: 1800mg, selenium: 60mg and zinc: 14000mg.

Table 2: Volume of Water (Aqueous Chaya Leaf Extract) used as Test Ingredient for Broiler Starter phase during the Study

		T ₁ (0g)	T ₂ (20g)	T ₄ (40g)	T ₆ (60g)
Starter phase	1 st week	(0g) 7.5 lit	(0g) 7.5 lit	(0g) 7.5 lit	(0g) 7.5 lit
	2 nd week	(0g) 9.5 lit	(30g) 9.5 lit	(50g) 9.5 lit	(70g) 9.5 lit
	3 rd week	(0g) 10.5 lit	(40g) 10.5 lit	(60g) 10.5 lit	(80g) 10.5 lit
	4 th week	(0g) 12 lit	(50g) 12 lit	(70g) 12 lit	(90g) 12 lit

Table 3.5: Volume of Water (Aqueous Chaya Leaf Extract) used as Test Ingredient for Finisher phase during the Study

		T ₁ (0g)	T ₂ (60g)	T ₄ (80g)	T ₆ (100g)
Finisher Phase	5 th week	(0g) 13.5 lit	(60g) 13.5 lit	(80g) 13.5 lit	(100g) 13.5 lit
	6 th week	(0g) 15 lit	(70g) 15 lit	(90g) 15 lit	(110g) 15 lit
	7 th week	(0g) 16.5 lit	(80g) 16.5 lit	(100g) 16.5 lit	(120g) 16.5 lit
	8 th week	(0g) 18 lit	(90g) 18 lit	(110g) 18 lit	(130g) 18 lit

Cytokine Detection Technique

Cytokines are genes or hormone like proteins produced by immune cells to activate and regulates immune and inflammatory responses during invasion by pathogenic organisms or inflammation. The recently developed advanced molecular technologies such as Real-time Polymerase Chain Reaction Technology (RT-Time PCR) was used to determine cytokine during this study. This technique uses mRNA in cells and tissues where by mRNA transcript is converted to cDNA through the use of enzyme reverse transcriptase for cytokine level in RNA to be detected and quantified.

Quantitative phytochemical screening of chaya leaf extract.

Quantitative phytochemical screening reveals the quantity of the phytochemical composition of each of the bioactive constituent present in the extract (Jayashree and Gopukuma, 2018).

Quantitative estimation of sapomins

Water and methanolic extracts were dissolved in 80% methanol and 2ml of vanillin in ethanol was added, mixed well as the 2ml of 77% sulphuric solution was added, mixed well and heated on a water bath at 600°C for 10 minutes, absorbance was measured at 454nm against re agent blank. Diosgeninis was used as standard material and compared the assay with Diosglyin equivalents.

Test for Flavonoid

The flavonoid content was estimated by Aluminium chloride method using catechin as a standard. 1ml of the test sample and 4ml

of water were added to a volumetric flask (10ml volume). After 5 minutes 0.3 of 5% sodium nitrite, 0.3 ml of 10% Aluminum chloride was added. After 6 minutes incubation at room temperature, 2ml of 1 m sodium hydroxide was added to the reaction mixture. Immediately the final volume was made up to 10ml with diluted water. The absorbance of the reaction mixture was measured at 510nm against the blank spectrophotometrically equivalents (mg catechin/g dried extract).

Test for Alkaloids:

1 ml of plant extract was added to 5ml pH4.7 phosphate buffer together with 5ml BCG solution and shake in a mixture with 4 ml of chloroform. The extracts were collected in a 10-ml volumetric flask and then diluted to adjust volume with chloroform. The absorbance of the complex in chloroform was measured at 470nm against blank prepared as above but without extract. Atropine is used as a standard material and compared the assay with atropine equivalents.

Test for steroids

1 gain of the extract was macerated with 20ml of ethanol and filtered. To the filtrate, 2ml of chromagen solution was added as the solution left to stand for 30 minutes. The absorbance was read at 550nm.

Test for glycosides

1 grain of the extract was macerated with 50ml of distilled water and filtered. 4ml of alkaline pirate solution was added to the extract. The mixture was boiled for 5minutes and allowed to cool as the absorbance was read at 490nm.

Statistical Analysis

All data collected were subjected to Analysis of Variance Technique (ANOVA) in a Completely Randomized Design (CRD) using a Statistical Package for Social Science (SPSS version 23). Duncan multiple range test was used for separation of means among treatments with SPSS Software.

Statistical Model

$$Y_{ij} = \mu + B_i + e_{ij}$$

Where: Y_{ij} is the dependent variable; μ is the overall mean; B_i is the effect of dietary

treatment ($I = 1$ to 4); and e_{ij} is the random error associated with each record.

Result and Discussion

Quantitative screening of aqueous leaf extract of (*Cnidocolus aconitifolius*).

Quantitative Phytochemical screening revealed the amount (quantity) of secondary metabolites of plant in the extract

Table 2: Result of the quantitative phytochemical screening of chaya leaf aqueous extract

Phytochemical (mg/100g) components	Concentration Value
Saponin	1.97
Steroid	2.05
Flavonoid	3.90
Alkaloid	3.61
Glycoside	2.81

Quantitative screening of chaya leaf (*Cnidocolus aconitifolius*) extract.

Quantitative phytochemical investigation revealed and confirmed the amount of different secondary metabolites present in the extracts such as saponins, tannins, flavonoids, phenol, triterpenoid, alkaloids and cardiac glycosides. This result showed that chaya is a nutritious plant with high nutritional and medicinal values compared to ginger and garlic (Oni *et al*, 2018). Tannins are known for their wound healing and anti-inflammatory properties. Phenols are well implicated in the extract and are known for their antioxidants, antimicrobial, anti-allergic, anti-inflammatory, and anti-

carcinogenic properties (Alikwe and Owen, 2014 and Ivan Moises Sanchez *et al*, 2011). A similar report was made by (Oyagbemi *et al*, 2011) that phenols possessed antioxidants activity to prevent oxidative damage to biomolecules (DNA, lipids and proteins) of broiler chickens which play a major role as useful diagnostic tools in cancer and cardiovascular diseases. There was presence of flavonoids in the extract. Flavonoids have been implicated for their antioxidant activity, anti-microbial and anti-hyperglycemic properties (Iwuji *et al*, 2014 and Akin Osanaiye *et al*, 2015).

This result agrees with the findings of (Ivan-Moises sanchez *et al*, 2017) that flavonoids possessed antioxidants activity that can

neutralized free radicals and protect broiler birds from developing heart disease and cancer related cases. Cardiac glycosides were also implicated in the chaya leaf extract. They are known to possess antidepressant and anti-cholesterol properties. This report agrees with the findings of (Ndukwu *et al*, 2018) who made a similar report that cardiac glycoside has the potential to regulate blood chemistry such as the level of cholesterol and triglyceride in the blood of weaner rabbits which might have been harmful to normal function of the heart. Saponins are implicated in the extract. They are known for their high bioactivity profile such as anti-diabetic, antihyper cholesterol, hypotensive and

Haematology

The result showed that treatment3 had a higher PCV value followed by treatments 4 and 2. Treatment1 had the least PCV value. This result shows the potentials of chaya leaf aqueous extract to improve blood formation and normal function of the cells and tissues of broiler birds. The result from this study showed no significant difference ($P<0.05$) in the values obtained for PCV among the treatments. The values obtained for RBC, Hb and PCV falls within the range values ($2.05 \times 10^{12} L^{-1}$, $6.5-13.10 d L^{-1}$ and 22-43%) for RBC, Hb and PVC as reported by (Santoso *et al*, 2017). There is an increase in the RBC values in the dietary groups compared to control (T_1). This result confirms the capacity of chaya leaf aqueous extract to improve health status of broiler chicken. This result agrees with the findings of (Tend *et al*, 2014) who made a similar report that RBC enhance cardio-protective process by an endogenous cardio protective vascular cell signaling molecule which strengthen blood circulation. For the values obtained for WBC, treatment 3 had the best value followed by Treatments

cardiac depressant properties to prevent cardiac failure in broiler chicken (Iwuji *et al*, 2014 and Awoyinka *et al*, 2017). Saponins played a vital role as hemolytic agents to regulates blood profile of monogastric animals to inhibit bleeding and blood loss during injury. Alkaloids have been implicated for their antihypertension and detoxifying properties. (Mordi and Akanji, 2012). However, the nutritional and medicinal efficacies of chaya leaf extract have been justified as food for man, feed additive as well as alternative to antibiotics to improve nutrition, growth performance and health status of broiler birds

2,4 and 1. This result shows that birds in the dietary treatments had high immunity against pathogenic organisms and unfavourable environmental factors. This result aligns with the findings of (Oni *et al*, 2018) who reported best WBC counts values in birds fed with garlic, ginger and chaya leaf meal. This result also confirms the antimicrobial and immunomodulatory properties of chaya leaf aqueous extract which must have stimulated the ability of broilers in the dietary groups to perform their phagocytic function for optimum immunity and disease resistance (Fafiola *et al*, 2014). However, there was a significant difference ($P<0.05$) for platelet values obtained among the treatments. Treatment 3 had the highest values followed by Treatments 2, 1 and 4. The result further indicate the potentials of chaya leaf extract to enhance fibrinogenic activity to promote wound healing and inhibition of blood loss (bleeding) during injury. This result aligns with the findings of (Nse-Abaisi *et al*, 2013) that blood platelet is implicated in blood clotting as low platelet concentration suggest

the inability of the blood to stop excessive loss of blood during injury.

Table 5: Effect of Aqueous Leaf Extract of Chaya on Haematology of Broiler Chicken

Parameters (g)	T ₁ (0g)	T ₂ (20g)	T ₃ (40g)	T ₄ (60g)
PCV (%)	23.00 ±1.76	23.33 ±1.97	26. ±1.23	24.29 ±1.63
HB (g/l)	8.16 ±0.25	7.61±0.99	9.01±0.21	8.05±0.22
RBC (10 ⁶ /ul)	3.60 ±0.18	3.65±0.21	3.95 ±0.29	3.95±0.09
WBC (10 ³ /ul)	12.95±0.33	12.20±20.18	11.13±0.51	11.88±0.67
Platelet (10 ⁹)	226.67±4.42 ^b	234.16±9.45 ^a	241.50±8.00 ^a	213.83±3.11 ^b
Neutrophil (%)	43.16±0.44	40.16±0.60	38.83±2.80	43.16±1.30
Lymphocytes (%)	52.50±2.64	48.50±1.44	50.66±3.81	47.83±0.92
Eosinophil (%)	2.83±0.16	3.16±0.33	2.83±0.44	3.16±0.16
Monocytes (%)	5.83±0.44 ^b	7.66±0.33 ^a	5.50±0.50 ^b	6.50±0.86 ^{ab}

^{a,b,c} Means within each row bearing different superscript differ significantly (P<0.05).

Table 6: Effect of Chaya Leaf Extract on Cytokine Production, Immune System Stimulation and Microbial Reduction in Broiler Chicken

Parameters	T ₁ (0g)	T ₂ (20g)	T ₃ (40g)	T ₄ (60g)
Interleukin-10 (IL-10)	27.71 ±1.80 ^a	24.65±0.16 ^b	23.67 ±0.49 ^b	23.16 ^b ±0.26 ^b
Interferon – G (INF-G)	26.87±0.06	25.55±0.39	24.71±0.81	25.08 ±0.46
THB (10 ³)	288.16±33.71	262.17±71.57	253.2 ±16.83	269.00±2.89
TCC (10 ³)	203.00±15.50 ^b	267.16 ±77.92 ^a	112.67±51.41 ^c	142.50.±1.26 ^c

^{a,b,c} Means within each row bearing different superscript differ significantly (P<0.05).

Cytokine production, Immune system stimulation and Microbial load Reduction.

The result obtained for interleukin-10 (IL-10) showed upregulation and stabilization of interleukin-10 in the dietary groups compared with high interleukin-10 value obtained in the control group (T₁). However, high value (27.71 ± 1.38) of interleukin-10 observed in the control group was because of the interleukin-10 feedback negative control inflammatory characteristic mechanism that prevents interleukin-10 inhibiting activity against inflammatory stimulated responses caused by interferon (IFN- γ) production by nitrogen activated lymphocytes and increased Nitric oxide synthesis in lipopolysaccharide activated chicken bone marrow derived macrophages. The regulation of interleukin-10 (IL-10) level in the dietary Treatments 2,3 and 4 confirms the immunomodulatory and phytobioactivity potentials of chaya leaf extract to enhance cytokine production which stimulates the possible immunity and inflammatory responses in broiler birds. This result is in agreement with the findings of Oni *et al.*; (2018) and Saleria *et al.*, (2015) that chaya leaf contains vitamins C and E which are the major source of antioxidant that inhibits the activity of inflammatory enzymes in the body in order to reduce cellular damage to enhance the activity of thymus gland which activate the proliferation of the body T-cells and interleukin -2 (IL-2) which play a vital role in the function of immune system.

The values obtained for interferon-G (IFN-G) showed up regulation and down regulation of pro-inflammatory cytokine (Interferon G) in the control group (T₁) and dietary groups. Treatment1 had the highest value compared to the dietary groups (2,3 and 4). This result is in tandem with the findings of (Jannatara Ikhatun *et al.*; 2021) who reported that broiler chickens fed dietary combination of 0.025% L-arginine and 50-150mg/kg vitamin E caused a reduction of pro-inflammatory cytokines such as interferon (IFN-G) and Tumor necrotic factor alpha (TNF- σ). This report has further suggested that reduction in pro-inflammatory cytokine could be attributed to the immune modulatory effects of L-arginine and vitamin E likewise the aqueous chaya leaf extract that stimulates non-specific immunity by non-specifically neutralizing fungi, bacteria, tumor cells and parasites which automatically reduced the pathogenic load.

However, the values obtained for Total Heterotrophic Bacteria (THB) and Total Coliform Count showed a reduction in the values obtained in the dietary treatments (2,3 and 4) compared to control (T₁). Treatment3 had the least value (253.2 ± 11.83) followed by treatments (2 and 4). Treatment1 had the highest value of TBH (288.16 ± 33.71). For TCC, treatment 3 had the least value and followed treatments (4, 1 and 2). This result confirms the antimicrobial property and phytobioactivity potential of aqueous chaya leaf extract to improve growth performance and health status of broiler birds.

This result agrees with the findings of (Iwuji *et al.*, 2014) who reported that broiler chicken fed aqueous extract of chaya revealed high inhibition rate of some bacteria compared to standard drug (Chloramphenicol). It was observed that inhibition rate increases as the concentration of the extract increases. The result of this study also showed significant reduction in pathogen colonization in the dietary groups compared to the control group (T₁). However, E-coli, staphylococcus aureus, salmonella typhi, streptococcus Sp, Pseudomonas Sp, Bacillus Sp, Klebsiella and Proteus sp were

among the micro-organisms found in the colon excreta of broiler chicken which their colonies were reduced with aqueous leaf extract of chaya.

Conclusion

Aqueous chaya leaf extract has the potential to be used as alternative to antibiotics in broiler nutrition as its effects showed significant reduction in microbial colonization and rate of invasion by microbial organisms. This help to improve health status of broiler chicken. Also cytokine was stimulated to enhance the immune system of the birds to overcome disease conditions as well as unfavourable environmental factors.

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EVALUATION OF ANTIPLASMODIAL EFFECTS OF BLACK SEEDS, FENUGREEK AND CORIANDER SEEDS IN ALBINO MICE INFECTED WITH *Plasmodium berghei*.

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Abstract

Malaria remains a disease of public concern according to reports by the World Health Organization (WHO), which recommends diverse therapeutic approach including the use of plant derived products to combat drug resistance in malaria treated individuals. This study therefore, evaluates the antiplasmodial effects of black seeds, fenugreek and coriander seeds and their effects on packed cell volume and weight of experimental mice. Phytochemical analysis of the extract was conducted using Gas Chromatography-Mass Spectrometry analysis to establish the presence of antimalarial constituents. The plant extracts were screened for curative activities at dosages of 50mg/kg, 100mg/kg and 200mg/kg, in mice inoculated with *Plasmodium berghei* from donor mice. Chloroquine (6mg/kg body weight) was used as standard control drug. A 4-day curative assay was used to evaluate the antimalarial potentials of the plant extracts. Comparison between treated samples were analyzed using single factor analysis of variance at 95% confidence interval and 5% significance level ($P < 0.05$). The results obtained from this study revealed significant suppression rate at 50mg/kg for *Nigella sativa* (67.0%), 200mg/kg for *Trigonella foenum-graecum* (68.3%), and 200mg/kg for *Coriandrum sativum* (66.7%). Chloroquine (6mg/kg) showed a higher inhibitory performance at 86.6% on day 7 post treatment compared to the plant extracts. The packed cell volume increased in groups treated with chloroquine compared to the extract treated group while the weight of mice increased in all extract groups significantly compared to the chloroquine treated group. The results of the study were statistically significant at $P < 0.05$.

Key words: Antimalarials, *Plasmodium*, Phytochemicals.

Introduction

Malaria remains a disease of public concern according to reports by the World Health Organization (WHO). The WHO data infographics estimates about 241 million malaria cases and puts mortality cases as a result of malaria at 627,000 worldwide as at 2020, a high trend compared to reports accumulated in 2019 with 229 million cases of malaria and 409,000 deaths worldwide, largely attributed to bridges in the provision of malaria therapy as prevention, diagnosis and treatment measures during the pandemic era. Demographic statistics acknowledges pregnant women, children (<5years), infants and those infected with Acquired Immune Deficiency Syndrome (AIDS) as the most vulnerable to malaria disease.

Plants contain active or complementary compounds referred to as secondary metabolites which are useful for treatments (Pirintzos *et al.*, 2017; Hartmann, 2007). Natural products offer immense contribution in the control of malaria acting as substantial components in antimalarial drug production. For instance, quinine, a product of the Cinchona tree bark, is one of the earliest natural compounds manufactured for the treatment of malaria and a template for the production of derivatives such as chloroquine, mepacrine, primaquine, and mefloquine. (De Oliveira *et al.*, 2009).

Nigella sativa is a flowering plant, native to Asia, the Mediterranean and Africa. This plant is also known as black seed or cumin. These seeds have been found to contain potential phytochemicals, predominantly quinine compounds (thymoquinone) potent for antimalarial activities. The presence of thymoquinone in black cumin seeds is responsible for its therapeutic, anti-inflammatory and anti-cancerous potentials. (Tembhurne *et al.*, 2014). The antimalarial activity of black cumin can be confirmed in the research work of Promise *et al.*, 2014; Udu *et al.*, 2021 and Oreagba *et al.*, 2013. These researchers attest to the prophylactic, suppressive and curative potentials of these seeds and also identify the presence of metabolites referred to as phytochemicals (phenol, tannins, terpenoids, alkaloids, saponin, carbohydrate, flavonoids, anthraquinones, cardiac glycosides and proteins components etc.) in the seed extract.

Fenugreek is an annual plant, native to the Mediterranean, Europe and Asia region but is now cultivated in central and southern Europe, India and Northern Africa. The seeds of fenugreek contain polyphenol compounds such as rhapoticin and isovitexin, major bioactive compounds as reported by He *et al.*, 2015. A study by Palaniswamy *et al.* (2010) was conducted to analyze the anti-plasmodial activity of *Trigonella foenum graecum* L. in vitro with isolates of *Plasmodium falciparum* that have been modified for use in laboratories and are both sensitive and resistant to chloroquine. Multiple extracts (methanol, ethanol, butanol, chloroform, ethyl acetate) used for the study displayed potent antimalarial capabilities and revealed the existence of alkaloids, steroids, saponins, tannin-like phenolic compounds and flavonoids via phytochemical analysis.

Coriander is an annual herbal plant of the parsley family. These plants are native to the Mediterranean region. Gabriella and Dewi (2023) unveiled and identified the potency of *Coriandrum sativum* as repellent for malaria vector control by investigating its bioactive components in order to resolve the toxicity levels posed by N, N-diethyl-3-methylbenzamide (DEET) application. Results from the research identified two bio-active compounds; cyclododecanol and 2-Decenoic acid, capable of performing an inhibition at the specific sites of DEET-AgamOBP-1 binding. The inhibition of AgamOBP-1 prevents mosquitoes from taking blood from the host.

Research Objectives

The objectives of the research are to determine the phytochemical constituents of methanolic extracts of selected experimental herbal seeds (black seed, fenugreek and coriander seeds), evaluate their curative activity and investigate the extracts' impact on the packed cell volume and weight of study mice.

Materials and Methods:

Experimental animals

Sixty (60) albino mice weighing 20-30g bred in the animal house owned by the Department of Pharmacology, Faculty of Basic Medical Science, College of Medicine, University of Port Harcourt, were acclimatized for two (2) days prior to experimental procedures. The rodent malaria parasite purchased was sub-passage into three laboratory mice which served as the stock animals from which the infected inoculum was produced for infecting the experimental mice in each group. The experimental mice were housed in plastic cages containing wood shavings as beddings and covered using a wire gauze. The mice were equally fed using standard grower's mash.

Collection of plant materials (seeds)

Plant materials (seeds) used for this research was purchased from herbal stores (Jules and Deluxe organics herbal stores) located in Lagos, Nigeria. The seeds purchased were properly packaged, labelled and authenticated by a technologist in the department of pharmacy with total weight at 500g for each sample. The seeds were grounded and soaked in maceration jar containing 2000ml of Methanol (MeOH) solvent and allowed to stand for 72hrs. Continuous stirring was carried out in order to enhance the extraction of active constituents. The soaked seed samples were filtered and concentrated to dryness by mounting the filtrates on water bath regulated at a temperature set at 55°C so as not to denature the filtrate and to enable the residue come out properly for use.



Figure I: Thermostat water bath used for the evaporation of liquid from extract.

Phytochemical analysis of Plant extracts

Phytochemical analysis and profiling of methanol fractions of *Nigella sativa*, *Trigonella foenum-graecum* and *Coriandrum sativum* seeds were carried out by implementing the procedures described by Harborne (1973, 1998), and Trease and Evans (2002). Phytochemical screening of the plant seeds was carried out using an analytical technique referred to as Gas Chromatography-Mass Spectrometry (GC-MS), a tool for detecting volatile and semi-volatile organic molecules, fatty acids, steroids, hormones in liquid, gaseous or solid states, by picking up components of the compound as they separate into varying columns at different times referred to as the compound's retention time. The GC-MS analytical tool was used to determine the bioactive and phytochemical constituent of the extracts by compiling the relative percent amount of each constituent and by comparing the average peak area and also the retention time of each constituent. The identification of the constituents was achieved by determining the retention time/indices and interpretation of data using standard mass spectra presented in the NIST library. This analysis was carried out at Ebic Integrated Services, a laboratory located at Igbo-Etche Road, New Rumuokwurushi, Rivers State, Nigeria.

Research Design

In line with the objectives of the research, ten animal cages containing six mice each were established. The animals were inoculated with *Plasmodium berghei* (rodent malaria parasite) via intraperitoneal administration in order to establish parasitemia levels for a period of 72 hours (3days) before receiving doses of plant extract treatment and standard chloroquine drug to assess the curative activity of the treatments. The mice used for the experimental study was categorized as follows: Group 1-3 represents *Nigella sativa* extract at different doses of 50mg/kg, 100mg/kg and 200mg/kg respectively; Group 4-6 represents *Trigonella foenum-graecum* extract at different doses of 50mg/kg, 100mg/kg and 200mg/kg respectively; Group 7-9 represents *Coriandrum sativum* extract at different doses of 50mg/kg, 100mg/kg and 200mg/kg respectively, while Group 10 represents the standard reference drug Chloroquine considered the positive control group. To determine how many millilitres (ml) of extracts should be given to the mice, 1g of plant extract was dissolved in 10ml of distilled water while considering the average weight of the study mice. Also, 0.25g of chloroquine tablet was dissolved in 10ml of distilled water while considering the

weight of the study mice. The liquid formulation was determined at 0.01ml, 0.02ml and 0.05ml for 50mg/kg, 100mg/kg and 200mg/kg of extracts respectively and 0.3ml for standard chloroquine drug used as the positive control. The treatments were fed to the mice through oral administration using a syringe with measured calibration. Samples of blood were drawn from each group, 72hours post inoculation and before treatments in order to determine the initial mean parasitemia level. The treatment doses were administered for 3 days post inoculation of *Plasmodium berghei* parasite and blood samples withdrawn on day 4 and day 7 for analysis of parasitemia level to determine the extent of curative action of extract and standard chloroquine drug according to Rane's curative test procedure.



Figure II: 0.3ml inoculum injected into each mouse.

Sample and Sampling techniques

The chloroquine sensitive rodent malaria parasite *Plasmodium berghei* used for this study was obtained from the Nigerian Institute of Medical Research, Yaba, Lagos and was maintained by sub-passage into three laboratory mice which served as the donor mice. Sixty (60) albino mice were used to test the curative antimalarial activity of the plant extracts and standard Chloroquine drug. 2 ml of blood was withdrawn from the donor mice and dissolved in 20ml of physiological saline to produce the inoculum. Each study mouse was inoculated with 0.3ml of infected blood (inoculum) containing *Plasmodium berghei* parasitized erythrocytes intraperitoneally. Rane's curative test was used to analyze the schizonticidal activity of the extracts in inoculated mice with established parasitemia as described by Ryley and Peters, 1970. The experimental mice were left for 72 hours to develop malaria infection after inoculation. The plant extracts used for treatments in this study was prepared by dissolving 1.0g of each extract in 10ml of distilled water to required concentrations at 0.01ml, 0.02ml and 0.05ml to achieve the low, middle and high dose (Bahekar and Kale, 2016).

Standard Chloroquine tablets (0.25g) was dissolved in 10ml of distilled water to achieve a dosage of 0.3ml (6mg/kg) administered to the control group for the period of the experiment. The extracts

and standard chloroquine drug solution were administered orally to the mice. At the end of the 72 hours post-inoculation, blood samples were collected from each mouse by making a tail snip/incision and using a spreader to make a thin film on the microslide, which was allowed to air-dry before transporting to the laboratory for microscopic viewing (analysis). This sample was considered the basal/initial parasitemia (day 0). The study mice then received treatments for 3 days according to the measurement established for all groups. Blood samples for curative analysis were also collected on day 4 and day 7 post-treatment. The air-dried samples were stained with Giemsa (20%) at the laboratory before viewing under a microscope using the x100 oil immersion objective lens to reveal parasitized erythrocytes out of 500 random clear erythrocytes in fields of the microscope. (CDC.gov; 2016).

$$\text{Percentage parasitemia} = \frac{\text{Number of parasitized cells}}{\text{Total number of red blood cells}} \times 100$$

The mean percentage parasitemia inhibition was calculated using the formula: $100 - (a/b \times 100)$.

[Where a represents mean percentage parasitemia on treatment day, while b represents the mean percentage parasitemia on day 0] (Onyegbule *et al.*, 2019).

Packed cell volume and weight analysis

Samples of blood were collected from the experimental animals using a heparinized capillary tube on day 0, 3 and 7 in order to ascertain the packed cell volume of the mice. Three-quarter of the capillary tubes were filled with the blood of the mice and sealed at one end with a sealant. The filled capillary tubes were then placed in numbered slots of the haematocrit centrifuge and allowed to spin at 12,000 revolution per minute (RPM) for 10 mins, after which the packed cell volume was determined. The effects of the extracts and standard drug on the weight of the experimental mice was also monitored on day 0, 3 and 7 using the Golden-Mettler- U.S.A sensitive weighing balance scale.

Methods of Data analysis

Descriptive statistical analysis was adopted to analyze the data gotten from the experimental design. Mean and standard deviation were determined using Microsoft excel. Comparison between treated samples were analyzed using single factor analysis of variance (ANOVA) at 95% confidence interval and 5% significance level ($P < 0.05$), followed by Tukey's post-hoc test. Also, error bar charts were used for data presentation and analysis.

Results:

Table 1: Curative activity of *Nigella sativa*, *Trigonella foenum-graecum* and *Coriandrum sativum* at all doses and standard Chloroquine drug on Parasitemia level in percentage (%)

Group	Dose (mg.kg ⁻¹)	Percentage parasitemia level				
		Day 0 Basal parasitemia	Day 4 post- treatment	Day 7 post- treatment	% Inhibition Day 4 Day 7	
<i>Nigella sativa</i>						
1	50mg/kg	40.6±0.87 ^a	29.2±2.83 ^{ab}	13.4±0.74 ^a	28.1	67.0
2	100mg/kg	44.9±3.17 ^a	27.4±3.16 ^{ac}	20.4±1.96 ^a	39.1	54.7
3	200mg/kg	36.6±3.05 ^a	19.2±1.91 ^a	17.9±2.02 ^{ab}	47.5	51.1
<i>Trigonella foenum-graecum</i>						
4	50mg/kg	39.2±2.17 ^a	26.8±3.49 ^a	16.96±2.44 ^a	31.6	56.7
5	100mg/kg	43.4±2.76 ^a	35.8±4.52 ^a	18.2±2.88 ^a	17.5	58.1
6	200mg/kg	32.8±4.49 ^a	29.6±6.63 ^a	10.4±2.11 ^a	9.8	68.3
<i>Coriandrum sativum</i>						
7	50mg/kg	37.8±3.78 ^a	31.2±4.09 ^b	17.7±1.31 ^b	17.5	53.2
8	100mg/kg	42.2±2.93 ^a	25.6±3.24 ^b	15.1±1.18 ^b	39.3	64.2
9	200mg/kg	39.6±4.66 ^a	24.2±1.67 ^b	13.2±1.25 ^b	38.9	66.7
+ve control						
Chloroquine	6mg/kg	43.8±4.60 ^a	12.4±1.22 ^{ab}	5.85±1.09 ^a	71.7	86.6

Each value is a mean of six replicates expressed as mean ± S.D. Values in the same column with common superscript letters (a, b...) are significantly different at $p < 0.05$ when compared with one another. Statistical level of significance was determined by one-way Analysis of Variance (ANOVA).

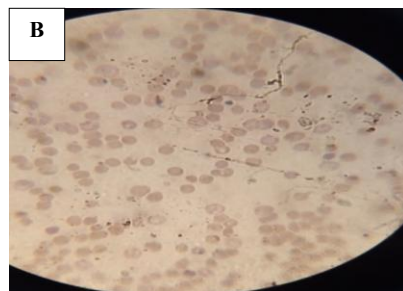
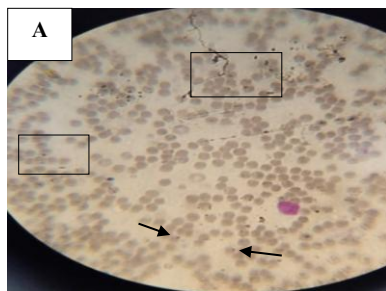


Figure III: Plate A (areas marked with squares and arrows indicate parasitemia presence) while Plate B is an indication of positive response to treatment from the extracts.

Table 2: Percentage Packed Cell Volume of mice treated with *Nigella sativa*, *Trigonella foenum-graecum* and *Coriandrum sativum* at all doses and Standard Chloroquine drug

Group	Dose (mg.kg ⁻¹)	Percentage packed cell volume		
		Day 0	Day 3	Day 7
<i>Nigella sativa</i>				
1	50mg/kg	51.67±1.31 ^a	50.5±0.84 ^{ab}	38.6±1.59 ^a
2	100mg/kg	48.67±2.33 ^a	49.5±2.13 ^a	43.8±2.85 ^{ab}
3	200mg/kg	51.0±1.96 ^a	36.0±3.25 ^a	34.6±2.98 ^a
<i>Trigonella foenum-graecum</i>				
4	50mg/kg	52.33±0.47 ^a	36.0±2.12 ^b	32.3±2.84 ^b
5	100mg/kg	52.0±0.98 ^a	37.0±2.87 ^b	36.5±2.59 ^b
6	200mg/kg	48.67±1.57 ^a	34.6±1.72 ^b	34.2±2.19 ^b
<i>Coriandrum sativum</i>				
7	50mg/kg	50.5±2.62 ^b	35.5±2.08 ^a	33.0±1.94 ^a
8	100mg/kg	41.33±4.21 ^b	37.25±3.16 ^a	35.4±3.01 ^a
9	200mg/kg	50.0±1.36 ^b	36.42±2.98 ^a	36.23±3.4 ^a
+ve control				
Chloroquine	6mg/kg	43.67±1.27 ^a	48.67±2.25 ^a	46.56±2.02 ^a

Each value is a mean of six replicates expressed as mean ± S.D. Values in the same column with common superscript letters (a, b...) are significantly different at p < 0.05 when compared with one another. Statistical level of significance was determined by one-way Analysis of Variance (ANOVA).

Table 3: Weight of mice treated with *Nigella sativa*, *Trigonella foenum-graecum* and *Coriandrum sativum* at all doses and Standard Chloroquine drug

Group	Dose(mg.kg-1)	Weight (g)		
		Mice weight (g) on day 0	Mice weight (g) on day 3	Mice weight (g) on day 7
<i>Nigella sativa</i>				
1	50mg/kg	16.15±0.62 ^a	20.32±0.67 ^a	22.08±2.69 ^a
2	100mg/kg	23.47±2.23 ^a	21.58±2.52 ^a	23.58±2.42 ^a
3	200mg/kg	21.12±0.33 ^a	22.47±3.76 ^a	22.84±2.26 ^a
<i>Trigonella foenum-graecum</i>				
4	50mg/kg	18.10±0.89 ^b	22.25±1.01 ^a	23.02±1.40 ^a
5	100mg/kg	16.45±0.39 ^b	18.45±2.56 ^a	21.94±1.48 ^a
6	200mg/kg	18.90±0.73 ^b	19.48±0.38 ^a	21.90±0.99 ^a
<i>Coriandrum sativum</i>				
7	50mg/kg	18.90±1.93 ^a	19.48±2.41	21.90±2.15
8	100mg/kg	24.43±0.58 ^a	23.88±1.35	24.68±1.26
9	200mg/kg	25.82±1.32 ^a	25.10±0.9	28.18±1.40
+ve control				
Chloroquine	6mg/kg	32.70±3.12 ^a	29.57±2.71 ^a	29.82±2.25 ^a

Each value is a mean of six replicates expressed as mean ± S.D. Values in the same column with common superscript letters (a, b...) are significantly different at $p < 0.05$ when compared with one another. Statistical level of significance was determined by one-way Analysis of Variance (ANOVA).

Discussion of Findings

An identification of active principles in natural drug sources has been established as key to the development of drugs, synthetic and natural forms. In this study, rodent model of *Plasmodium* (the causative agent for malaria), *Plasmodium berghei* was used In-vivo for the evaluation of antimalarial agents of natural and synthetic formulations. The application of these drug formulations In-vivo revealed the effect of the extracts and standard drug.

The results obtained from the study showed significant decrease in mean parasitemia of *Plasmodium berghei* infected mice treated with methanolic extracts of *Nigella sativa*, *Trigonella foenum-graecum* and *Coriandrum sativum*. This result is in agreement with findings from Aschroft *et al.*, 2018 and Oreagba *et al.*, 2013 who also found out that higher doses of extract did not necessarily impose higher suppressive activity when compared to lower doses of *Nigella sativa* extract in curative activity. However, Higher dosages of *Trigonella foenum-graecum* at 200mg/kg exhibited greater chemosuppressive inhibitory performance (68.3%) on day 7 compared to dosages at 100mg/kg (58.1%) and 50mg/kg (56.7%) respectively. The same was observed in treatments using methanolic extracts of *Coriandrum sativum*, which indicated higher inhibitory performances at 200mg/kg at 66.7% compared to the 64.2% and 53.2% from those treated with 100mg/kg and 50mg/kg respectively. The phytochemical component thymol was identified in all samples of plant extract analyzed using GC-MS technique. Thymol is known for its active antimalarial potentials as seen in the work of Dell'Agli *et al.* (2012) who claimed that thymol-enriched oil fractions of plants had very active antiplasmodial effects on *Plasmodium falciparum* as the main components found in certain plants in Sardinia, a Mediterranean region. Thymol has been synthesized separately and also used as a synergetic drug in combination with antimalarial drugs (chloroquine) for the effective control of malaria parasitemia. Quinoline compounds identified in the analysis are known to block the digestion of haemoglobin in the blood feeding stages of the *Plasmodium* cycle. The synergistic effects of all the identified phytochemicals in each extract summed up to exert thorough antiplasmodial activity in the treated mice. A reduced level of parasitemia can also be attributed to the consistent administration of the extracts and control drug up until the fourth day of the Rane's curative analytic technique. Although the extracts showed moderate to good measure of curative activity in terms of mean parasitemia reduction, the standard drug chloroquine

was by far better indicating a higher chemosuppressive inhibitory performance at 86.6% on day 7 compared to the extracts at all doses.

Haematological indices are key factors in the analysis of parasitemia effect in malaria pathology (Maina *et al.*, 2010). Investigations carried out indicated an increase in packed cell volume of mice for groups treated with chloroquine as at day 7 compared to those treated with plant extracts, as doses administered were considered insufficient in the reversal of PCV levels. In the work of Kaur *et al.*, 2009, these effects were attributed to the presence of saponin, a bioactive component found in seed extracts which has been associated with the reduction of packed cell volume due to its haemolytic effect. In the work of Bissinger *et al.*, 2014, saponins, a naturally occurring glycoside in plants was associated with haemolysis and as well as triggering erythrocytic death. Asgary *et al.*, 2012 reported that *Nigella sativa* did not have any effects on haematological factors except for the increase of platelets. Contrary to reports from Asgary *et al.*, 2012, the extracts of the plants under study significantly increased packed cell volume in the reports of Ashcroft *et al.*, 2018 and Metung *et al.*, 2022. These variations may be attributed to the parasitic load inoculated in mice (hyperparasitemia), the parasite species, time of recovery, concentration of extracts and the presence of saponin as a bioactive compound in all tested extracts, which has been associated with decrease in PCV levels.

Body weight increase in experimental mice treated with methanolic extracts of *Nigella sativa*, *Trigonella foenum-graecum* and *Coriandrum sativum* were observed at all levels of treatment. Several researchers are in agreement with the research result on the body weight gain potential of *Nigella sativa* when consumed. Abdel-Magid *et al.*, 2007 claimed that supplementation of black seeds in animal feed ration helps in promoting the growth performance and feed conversion rate of animals. The increase in body weight of animals fed with supplementation of *Nigella sativa* has

been associated with the presence of essential fatty acids that cannot be synthesized such as oleic and linoleic acids. Mice treated with *Trigonella foenum-graecum* extracts also showed increase in body weight gain. This is in agreement with the work of Atta and John, 2012 who reported a significant increase in body weight gain when healthy female Wister albino rats were supplemented with fenugreek seed. The increment of body weight through extract feeding of Coriander aligns with the result established by Naemasa *et al.*, 2015 and Rahimi *et al.*, 2011. Contrary to the results from the three different extracts at all doses/level, mice given standard chloroquine drug at 6mg/kg, showed a significant decrease in body weight from 32.70g on day 0 to 29.82g on day 7. This can be attributed to weight control measures associated with the use of chloroquine drug and also conditions of low feed intake.

Conclusion:

This study provides insight on the relevance of ethnobotanicals/ethnopharmacological plants as proposed remedies for malaria diseases. Following the trends of resistance in malaria parasites, these plants have had a far-reaching effect as remedial cure for malaria as a result of biochemical components which are considered primary or secondary metabolites commonly referred to as phytochemicals, with potential antimalarial, anti-oxidant and anti-inflammatory properties. Etc. This research was able to identify the antimalarial potentials of black seeds, fenugreek and coriander seed, establish the effect of these plant extracts on the packed cell volume and weight of test animals and also confirm that plants possess certain compounds “phytochemicals” relevant for disease treatment.

Recommendation:

Based on established conclusions from this research, the following recommendations are forwarded:

1. More research should be carried out in order to determine the potentials of black seeds, coriander and fenugreek seeds for the treatment of malaria disease.
2. Proper experimental procedures should be carried out on plants via analytic techniques in order to determine phytochemicals and identify their parasite target potentials.

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CRUDE OIL PRICE INSTABILITY AND THE PERFORMANCE OF QUOTED ENERGY FIRMS ON THE NIGERIAN STOCK EXCHANGE

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ABSTRACT

Valuation of Companies operating in the energy sector is difficult due to the high volatility in crude oil and natural gas prices. The study examined the influence of oil price volatility, profitability, and capital structure on valuation of listed energy companies in Nigeria from 2005M01 to 2019M12. Secondary data series were sourced from the Organization for Petroleum Exporting Countries and selected energy companies in Nigeria databases. The Hausman and Heteroskedasticity tests were utilized at the 5% level of significance. The Heteroskedasticity test shows the evidence of unequal variance and thus prompted the use of GLS technique. The Hausman test showed that the Fixed Effect GLS technique is preferred. For the Fixed Effect Robust GLS, profitability is positive and significant to firm valuation. Though oil price volatility is positive, it is insignificant to firm valuation. However, capital structure is negative and significant to firm valuation. The study concluded that profitability and capital structure are the two primary determinants of valuation among listed energy companies in Nigeria. Thus, the study recommends that listed energy companies should explore the possibility of hedging against adverse crude oil price movement through the use of options, futures, swaps, and forward contracts in order to stabilize their market value. Also, management of publicly traded energy businesses should guarantee that their debts are used wisely while also limiting their intake because it impacts their valuation. Additionally, listed energy companies should continue to seek for ways to reduce operational expenses and litigation as this enhances their profitability and, as a result, their value.

Keywords: Energy, Volatility, Profitability.

Introduction

Oil's discovery in the 19th century has played a significant role in the global economy. Oil plays a significant role in the economies of many countries, accounting for more than 40% of government revenue in advanced nations and over 80% in some less developed nations (Babajide & Solie, 2020). The oil sector in Nigeria accounts for over 60% of the country's GDP, more than 85% of its export earnings, and over 70% of its government revenue (National Bureau of Statistics, 2010). The significant increase in oil prices during the 20th century's early years caused concern among policy makers, investors, and researchers due to its impact on macroeconomic variables. For instance, the West Texas Intermediate (WTI), a globally used reference price, rose from US\$12.23 per barrel in 1976 to US\$31.07 in 2003 (Chisadza, Dlamini, Gupta, & Modise, 2013). The price

of crude oil experienced a steady increase from US\$41.49 in 2004 to US\$100.06 in 2008, with a peak of US\$66 in 2006 (World Energy Report, 2011).

Numerous scholars have analyzed the economic importance of oil price shocks in both net oil importing and exporting economies (Asgari, 2013). Oil price fluctuations elicit diverse macroeconomic responses. A strong correlation has been established between rising oil prices and subsequent economic recessions in various economies. The impact of oil price shocks on economic activity is crucial to comprehend empirically due to its hindrance on effective policy making in many countries (Tweneboah & Adam, 2008). The impact of energy consumption on the environment differs across countries due to variations in economic structure, energy intensity, energy mix, and reliance on the global energy market (Akpan, 2009).

Energy companies have a substantial interest in forthcoming energy prices. The volatility of crude oil and natural gas prices poses a challenge for company valuation (Asche et al., n.d.). In recent years, there have been significant fluctuations and high volatility in crude oil prices. Oil price volatility has a disruptive impact on economic activity, affecting most countries as producers, consumers, or both. This is supported by ample evidence. Sharp increases affect economic growth and inflation in countries that import oil. Decreasing crude oil prices adversely affect the financial stability of oil-dependent governments, such as those in the MENA region. The fluctuation of crude oil prices presents a further incentive to reduce dependence on oil and its byproducts due to the potential hazard it poses to deferred investments of numerous investors and companies (Ojikutu et. al, 2017). The instability of energy prices encourages competition and motivates the adoption of alternative energy sources, particularly renewables, which are viewed as both environmentally friendly and financially secure.

Over the years, shale oil production has skyrocketed, while oil exports by OPEC nations, particularly Nigeria, have plummeted (Ebechidi et.al, 2017; lheanacho, 2016). A development that, according to Nigeria's Minister of Petroleum Resources and her fellow OPEC members, is of "grave concern."Nigeria has historically been an important oil supplier to the United States, but total Nigerian imports have decreased in recent years. Prior to 2012, the United States purchased between 9% and 11% of its crude oil from Nigeria (Salisu et. al, 2017).

In 2020, the United States bought an average of 193,000 barrels per day of crude oil from Nigeria, a decrease of more than 90% from the average volume imported in 2010 (Soyemi, et. al, 2017). Nigeria dropped from fifth largest foreign oil supplier to the US in 2011 to eleventh in 2015, accounting for less than 1% of US crude oil imports. The impact of crude oil prices on stock markets has continued to pique the interest of academics and investors from a variety of theoretical and empirical perspectives, including sectoral, country-specific, regional, and global evaluations (Dutta, Nikkinen & Rothovius, 2017). Crude oil is becoming increasingly important as a standard product in many areas of the global economy (Gourène & Mendy, 2018). Oil is a major fuel source, accounting for 39.9 percent of global fuel consumption (IEA, 2016); nonetheless, despite increased

efforts toward renewable and alternative energies, crude oil consumption remains unchanged (Gourène & Mendy, 2018).

Companies operating in the energy and oil industry possess a significant interest in forthcoming energy pricing. Moreover, the considerable instability of crude oil prices exerts a direct influence on the monetary market valuation of stocks (Asche et al., n.d.). The aforementioned concerns have been intensified by significant fluctuations in crude oil price volatility, particularly the worldwide oil price shocks that occurred in 2015 and 2019, which were centered on the US Shale revolution, as well as the COVID-19 pandemic that had a devastating impact on the entire globe (Dunn et al., 2020). Therefore, it is imperative for energy corporations to optimise their profits through the production and sale of energy products. The present study aims to examine the correlation between the assessment of publicly traded energy firms and crude oil prices in Nigeria across diverse market scenarios and economic cycles. Additionally, the study seeks to evaluate the susceptibility of energy companies listed in Nigeria to fluctuations in crude oil prices.

Numerous scholarly inquiries have been carried out on the relationship between energy consumption and economic growth, such as the works of Asche et al (n.d.), Erygit (2009), and Kumar et al (2012). However, the limited time available constrained the scope of several of these research studies. The research conducted by the primary author, as indicated above, was carried out within the United States and lacks clarity regarding the scope of offerings within Nigerian energy enterprises. As per the statement made by the second author, he refrained from furnishing any justifications for the aforementioned conduct that could have potentially enlightened investors, as per his research. Ultimately, the final author concluded that there was no significant correlation between the prices of crude oil and the values of company stocks. This study aimed to examine the impact of crude oil price shocks on the valuation of eight (8) energy companies listed in Nigeria. The research employed time series analysis to explore the correlation between the valuation of these companies and crude oil prices in Nigeria from 2005 to 2019. The specific objectives of the study were to assess the relationship between the valuation of listed energy companies and crude oil prices, as well as to determine the degree to which the profitability and capital structure of these companies affect their valuation in Nigeria from 2005 to 2020.

Literature Review

Abdelaziz et al. (2013) studied the relationship between oil prices, currency rates, and stock market performance in four Middle Eastern oil-exporting countries (Kuwait, Saudi Arabia, Egypt, and Oman). The preliminary findings of the empirical research reveal that there is no long-run co-integration between oil prices, stock prices, and the real exchange rate. However, after dividing the sample period to account for big oil price shocks, the analysis identified a long-run equilibrium relationship between Egyptian stock prices, real exchange rates, and oil prices. The findings in Kuwait point to the existence of a long-run equilibrium relationship between stock and oil prices.

An interesting aspect of this study is the introduction of oil price as a transmission channel through which exchange rate and stock prices were linked in all the four oil-exporting countries. They conclude that re-adjustment towards the long-run equilibrium in each country stock market occurs via changes in the oil price with shocks in Egypt and Saudi Arabia correcting itself in 17 and 14 months, respectively, while it takes 22 and 24 months in Oman and Kuwait.

Using monthly data and an autoregressive distributed lag technique, Jahan-Parvar and Mohammadi (2010) explored the link between oil prices and real exchange rates in a sample of 14 oil-exporting economies. The analytical results indicate a long-run steady link between the two variables in all nations analysed. The analysis of short-run dynamics reveals the existence of unidirectional causality from oil prices to exchange rates in four countries (Angola, Colombia, Norway, and Venezuela), bidirectional causality in two countries (Bolivia and Russia), and no causality in the remaining four countries (Gabon, Indonesia, Nigeria, and Saudi Arabia) (Algeria, Bahrain, Kuwait and Mexico). Nikbakht (2009) investigated the long run relationship between real oil price and real exchange rate using monthly data of seven OPEC member countries from January 2000 to December 2007. The results of the study show a long run and positive linkage between real oil prices and real exchange rates, suggesting that real exchange rate of OPEC members depends on oil price movements significantly.

Some empirical research in Nigeria have looked at the relationship between oil prices and Nigerian stock market performance. Adaramola (2012) used Johansen cointegration tests to examine the long-run and short-run dynamic effects of oil price volatility on Nigerian stock market behaviour from the first quarter of 1985 to the fourth quarter of 2009. The results of the study's bivariate model show a significant positive stock return to oil price shock in the short run and a significant negative stock return to oil price shock in the long run, with the Granger causality test indicating strong evidence that the causation runs from oil price shock to stock returns, explaining that variations in Nigerian stock market performance are explained by oil price movements. Asaolu and Ilo (2012) investigated the relationship between oil prices and stock market performance in Nigeria from 1984 to 2007 using Johansen cointegration and Vector Error Correction (VECM) analysis. The results of the study suggest a long run relationship between the two variables. Ogiri et al. (2013) considered the relationship between oil prices and stock market performance in Nigeria from 1980 to 2009 using a Vector Auto-Regressive (VAR) model. The results suggest that oil price volatility significantly explains stock price movements in the Nigerian stock market.

Babatunde et al. (2013) applied multivariate Vector Auto-Regressive (VAR) model, using the generalised impulse response function and the forecast variance decomposition error to investigate the interactive relationship between oil price shocks and the behaviour of the Nigerian stock market. According to the findings, Nigerian stock market returns respond positively but insignificantly to oil price shocks, then revert to negative effects over a period of time, depending on the type of the oil price shocks.

Aside from these researches on the relationship between oil prices and stock market performance in Nigeria, additional studies have looked into the relationship between oil prices and the Nigerian exchange rate. Englama et al. (2010) used monthly data from January 1999 to December 2009 to

analyse the effects of oil price volatility on the Nigerian currency rate. The study employed cointegration technique and vector error correction model (VECM) for the long-run and the short-run analysis, respectively. The results suggest that a 1.0 per cent increase in oil price at the international market increases Nigerian exchange rate with the US Dollar volatility by 0.54 per cent in the long-run, while in the short-run by 0.02 per cent.

Egbe (2015) used cointegration and the Error Correction method to analyse the influence of oil price volatility on the real exchange rate in Nigeria using quarterly data from the first quarter of 1981 to the fourth quarter of 2009. The study's findings reveal that the dynamic short-run impact of oil price volatility on currency rates does not hold, despite the fact that the majority of real exchange rate movements are related to long-run changes.

There has also been few research that look at the relationship between the exchange rate and stock market performance in Nigeria. Zubair (2013) employed cointegration to test for the possibility of long-run relationship and Granger causality to investigate the causal relationship between the Nigeria stock market index and exchange rate before and during the global financial crisis using monthly data over the period 2001 to 2011. The investigation's findings indicate the absence of a long-run association prior to and throughout the global financial crisis. The Granger causality test demonstrates that there is no causal relationship between the NSM All Share Index and the US Dollar exchange rate in both periods.

Umoru and Asekome (2013) used co-integration and the Granger causality approaches to investigate the dynamic relationship between stock prices and the Naira-US-Dollar exchange rate. The findings reveal that whenever the Naira-US Dollar exchange rate changes, stock values move in the same direction. The results provide evidence of a positive co-integration between the Naira-US Dollar exchange rate movement and the Nigerian stock market performance with bi-directional Granger causality found to exist between stock prices and exchange rate in Nigeria.

Javid, Sharif, and Alkhathlan (2018) examined the link between oil price volatility with bilateral trade between northeast Asian countries and GCC countries between 1980 and 2014. Oil price volatility was found to have a negative impact on exports of both groups of countries, and the real oil price was negatively associated with GCC exports but had a positive relationship with exports from northeast Asian countries. Nasir, Al-Emadi, Shahbaz, and Hammoudeh (2019) investigated the impact of oil price shocks showed a significant positive impact of oil price shocks on GDP growth, inflation, and trade balance in GCC countries. However, the GCC countries respond to these shocks differently: Saudi Arabia was found to be the most significantly affected by oil prices shock, whereas Bahrain was the least affected by oil price shocks. The impact of oil price shocks was also more persistent in Kuwait than in other GCC countries. Qatar and the UAE were the least impacted by oil price shocks, and any impact that did occur was strictly short term.

Methodology

We adopted a longitudinal research approach in this study. This is because our data collection includes repeated observations of the sampled variables (firm valuation - equity, oil price volatility, profitability, and capital structure) from 2005M01 to 2019M12. As a result, because the

data used in this study was obtained afterwards, we lack the opportunity to change it. The study is limited to the petroleum business; however, we intend to link it to other sectors of the Nigerian economy. The Organization for Petroleum Exporting Countries (OPEC) and the annual financial reports of the eight selected energy businesses provided data for the study. The sample for this study was obtained from eight energy related firms listed on the Nigerian Stock Exchange (NSE) from 2005 to 2019. The NSE Daily Official List was used to obtain monthly data on stock returns for each firm and the whole market. Monthly oil price data was also obtained from the Organization of Petroleum Exporting Countries (OPEC). We chose the sample to guarantee that each firm has data for all years within this time period. The study employed the Pooled OLS, Fixed OLS Effects model, Random effects model, Fixed Robust GLS, and Random Robust GLS techniques at the 95% confidence interval. This enabled us to study the behaviour of these organisations over time. As a result, the model used in this study is specified as:

$$FV_{i,t} = f(OPV_{i,t}, CS_{i,t}, Profit_{i,t}) \quad (1)$$

$$FV_{i,t} = \delta_i + \beta_1 OPV_{i,t} + \beta_2 CS_{i,t} + \beta_3 Profit_{i,t} + \varepsilon_{i,t} \quad (2)$$

On apriori, $\beta_1 < 0$; β_2 and $\beta_3 > 0$.

Where, $FV_{i,t}$ = Company/Firm Valuation, $OPV_{i,t}$ = Oil Price Volatility, $CS_{i,t}$ = Capital Structure/Leverage, $Profit_{i,t}$ = Profitability of firm, δ_i = Constant term (entity specific), β_i = Parameters to be estimated, $\varepsilon_{i,t}$ = Disturbances

Measurement of variables

For this study, we measure each of the variables as thus;

$FV_{i,t}$ = Company/Firm Valuation = Market Capitalization of firm

$OPV_{i,t}$ = Oil Price Volatility = To be calculated based on spot price of crude oil using Garch(1,1)

$CS_{i,t}$ = Capital Structure = Debt to Equity Ratio (DER) = $\frac{TotalDebt}{TotalEquity}$

$Profit_{i,t}$ = Profitability of firm = Return On Assets (ROA)
 $= \frac{NetIncomeAfterTax}{TotalAssets}$

Results and Discussions

Results

Table 4.1: Descriptive statistics Result

	FV	OPV	CS	PROFIT
Mean	4.42E+10	0.009241	0.049334	0.057965
Median	3.45E+10	0.006457	0.001066	0.060458
Maximum	4.21E+11	0.052018	2.888277	0.639424
Minimum	23884109	0.000691	8.25E-06	-0.552939
Std. Dev.	5.22E+10	0.008907	0.302982	0.145005
Skewness	2.924085	2.268440	7.017992	-1.066201
Kurtosis	14.87960	9.163725	52.95601	9.527362
Jarque-Bera Probability	10424.59 0.000000	3482.759 0.000000	160098.2 0.000000	2803.674 0.000000
Sum	6.31E+13	13.18745	70.39975	82.71569
Sum Sq. Dev.	3.88E+24	0.113121	130.9041	29.98365
Observations	1427	1427	1427	1427

Source: E-views Output

Table 4.1 shows that the average company valuation (FV), oil price volatility (OPV), capital structure (CS), and profitability (PROFIT) are 4.4210, 0.009241, 0.049334, and 0.057965, respectively. The large range between minimum and highest values in each of the valuation series in Table 4.1 indicates the presence of significant volatility. Furthermore, the skewness statistic shows that value is positive except for profitability, which is negatively skewed. In addition, the Kurtosis coefficients are big and highly significant, indicating that outliers are more likely than in a normal distribution. The kurtosis statistic, which compares the peakedness and tailedness of the probability distribution to that of a normally distributed series, demonstrates that all valuations display leptokurtic behaviour (i.e., their distributions have flatter tails than corresponding normal distributions). This implies that the existence of conditional heteroskedasticity should be evaluated for in each of the mean equations. Meanwhile, the Jarque–Bera statistic, which assesses distribution normality using both the skewness and kurtosis statistics, reveals that the distributions are not normal.

Table 4.2 Unit root Result

Variables	LLC T-Stat @ Level	P-value @ level	Order of Integration
PROF	-37.5001	0.0000	I(0)
CS	-2.02040	0.0217	I(0)
OPV	-14.9917	0.0000	I(0)

FV -30.2021 0.0000 I(0)

Source: E-views Output

According to the LLC stationarity test, all variables are static at the 5% level, as shown in the above table. Since all variables are integrated at level, they all have a consistent pattern and can be used for prediction and prospective prediction.

Table 4.3 Estimation Result

	(1)	(2)	(3)	(4)	(5)
Model	Pooled	Fixed	random	fixed_robust	random_robust
VARIABLES	FV(equity)	FV(equity)	FV(equity)	FV(equity)	FV(equity)
Opv	6.37211 (1.52111) 0.000***	6.23211 (1.20011) 0.000***	6.23411 (1.20111) 0.000***	6.23211 (5.34411) 0.282	6.23411 (5.34411) 0.243
Structure	-2.77810 (4.59709) 0.000***	-7.82109 (4.11409) 0.000***	-8.05009 (4.11009) 0.050*	-7.82109 (2.09209) 0.007***	-8.05009 (2.11209) 0.000***
Profitability	3.67710 (9.60209) 0.000***	3.70410 (8.53709) 0.000***	3.70710 (8.53009) 0.000***	3.70410 (1.07010) 0.011**	3.70710 (1.07910) 0.001***
Constant	3.75410 (2.01909) 0.000***	3.66710 (1.60209) 0.000***	3.70610 (1.11210) 0.000***	3.66710*** (5.32909) 0.000***	3.70610*** (1.07310) 0.001***
Observations	1,428	1,428	1,428	1,428	1,428
R-squared	0.041	0.032		0.032	
F-Stat.	20.08 (0.0000)	124.07(0.0000)	46.95(0.0000)	18.17(0.0011)	56.82(0.0000)
Number of panelid	8	8	8	8	8

Source: E-views Output

Standard errors in parentheses
 *** p<0.01, ** p<0.05, * p<0.1

The pooled OLS, fixed effects OLS, random effects, fixed robust GLS, and random robust GLS models are all estimated in the study. As a result, the results for each model are explained in turn.

Oil price volatility is positive (6.37211) and significant (0.000) to company valuation as judged by equity for the Pooled OLS result at the three levels of significance considered for this inquiry. This suggests that every unit rise in oil price volatility results in a 6.37211 unit increase in the value of Nigerian energy firms. Furthermore, at the defined substantial levels, Nigerian energy enterprises' profitability is positive (3.67710) and significant (0.000). This means that for every 1% increase in earnings, the firm's valuation will increase by 3.67710%. In this analysis, capital structure is negative (-2.77810) and statistically significant (0.000) at all levels of significance. This means that every unit increase in capital structure results in a 2.77810 unit fall in energy firm valuation. The F-statistic score of 20.08 indicates that the model as a whole is statistically significant.

Oil price volatility is positive (6.23211) and significant (0.000) to firm valuation as measured by equity at the three levels of significance examined for this analysis. This suggests that every unit increase in oil price volatility increases the market value of Nigerian energy businesses by 6.23211 units. Furthermore, at the defined substantial levels, Nigerian energy enterprises' profitability is positive (3.70410) and significant (0.000). This means that for every unit increase in profitability, the firm's valuation will increase by 3.70410 units. In this analysis, capital structure is negative (-7.82109) and statistically significant (0.000) at all levels of significance. This suggests that for every unit increase in capital structure, the valuation of energy firms falls by 7.82109 units. The model's statistical significance is confirmed by the F-statistic result (124.07).

We discovered that oil price volatility is positive (6.23411) and statistically significant (0.000) to the firm valuation of Nigerian energy companies using the Random Effects (GLS regression) approach. This suggests that a unit rise in oil price volatility has the potential to enhance the firm valuation of energy firms by 6.23411 unit. Similarly, profitability contributes positively (3.70610) and statistically significant (0.000) to the firm valuation of Nigerian energy enterprises. This suggests that a unit improvement in profitability has the potential to enhance the firm valuation of energy firms by 3.70610 unit. On the other hand, the capital structure of energy businesses is negative (-8.05009), but this is only relevant at the 10% level (0.050). This means that a unit increase in capital structure has the potential to reduce the worth of energy companies by 8.05009 unit. Given the F-statistic value of 46.95, the model is statistically significant as a whole.

Oil price volatility is positive (6.23211) but negligible (0.282) to company valuation as measured by equity for the Robust Fixed-Effects model outcome at the three levels of significance considered for this investigation. This means that a unit rise in oil price volatility will result in a 6.23211 unit increase in the capitalization of Nigerian energy companies. At the 1% and 5% levels, the profitability of Nigerian energy businesses is positive (3.70410) and substantial (0.011). This suggests that for every one-unit improvement in profitability, the firm's valuation will rise by 3.70410 unit. However, at the 1% and 5% levels, capital structure is negative (-7.82109) and statistically significant (0.011). This means that a unit increase in capital structure will result in a 7.82109 unit drop in the valuation of energy enterprises. The model as a whole is statistically significant based on the F-statistic value of 18.17.

Oil price volatility is positive (6.23411) but not significant (0.243) to firm valuation as measured by equity in the Robust Random-Effects model results at the three levels of significance considered for this investigation. This means that a unit rise in oil price volatility will result in a 6.23411 unit increase in the capitalization of Nigerian energy businesses. At all levels, the profitability of Nigerian energy businesses is positive (3.70710) and substantial (0.011). This suggests that for every one-unit improvement in profitability, the firm's valuation will rise by 3.70710 unit. Capital structure, on the other hand, is negative (-8.05009) and statistically significant (0.001) at all levels. This means that a unit increase in capital structure will result in an 8.05009 unit decrease in the

valuation of energy enterprises. We confirm that the model as a whole is statistically significant based on the F-statistic value of 56.82.

Table 4.4: Heteroskedasticity Test Result

Modified Wald test for groupwise Heteroskedasticity			
Chi2 (8)	69891.19	Prob>Chi2	0.0000

Source: E-view Output

Table 4.4 shows the joint p-value of the heteroscedasticity statistics as 0.0000 which is less than the 5% level chosen for this study. Therefore, the null hypothesis is rejected that the residual is not homoscedastic. The outcome of this result makes us to adopt the GLS regression model.

Table 4.5: Hausman Test Result

Correlated Random Effects - Hausman Test		
Test Summary	Chi-Sq. Stat.	Prob.
Cross-section random	288.70	0.0000

Source: E-views 10

Table 4.5 displays the results of the Hausman test for optimum model selection between Random and Fixed Effects Models. The table shows that the Hausman Test result favours the Fixed Effects model over the Random Effects model. On this basis, the fixed effect robust GLS model will be utilised in this study to conduct research, draw results, and provide recommendations. As a result, we test for the necessity to manage the time-effect, as shown below:

Table 4.6: Time-Effect Control Test Result

Time-effect Control Test	
Test Summary	
F(12, 1238)	1.72
Prob>F	0.057

Source: E-views10

Table 4.6 displays the results of the Time-effect control test for optimal model selection between controlling and non-controlling for time effect. Given that the Probability value above the 5% significant level utilised in this study, the outcome favours the use of no time-effect control. On this premise, we do not account for the temporal effect.

Discussion of Findings

Profitability is an important determinant of a company's stock valuation, hence raising it has the potential to increase the company's valuation. A gain in firm profitability should, in theory, lead

to an increase in firm valuation. Similarly, the Fixed Robust GLS technique's results show that profitability significantly increases business valuation by increasing the market value of stock. This is owing to high profit after tax, cheap production costs, high income, good corporate branding, and the availability of an existing market for the majority of Nigeria's energy businesses' products.

Using equity as a proxy, capital structure is a negative but substantial predictor of corporate valuation. This is because most energy companies' financial filings show a significant level of debt. This high level of debt reflects the significant level of risk that energy companies face, limiting their ability to undertake specific investments with positive net present value, which would have enhanced their worth. For example, financing institutions may put certain usage and sale constraints on energy enterprises' mobile and immovable assets, which can have a significant impact on their performance. Another cause could be that energy company management lacks the talent and aptitude to fully utilise debt financing, resulting in a constraining influence on firm valuation. We may also attribute it to the fact that the degree of debt utilised by most energy firms has above the optimal level, and so the negative impact has begun to harm Nigerian energy companies. This is consistent with the findings of Gjerde and Sættem (1999), Arouri and Fouquau (2009), and Ono (2011), who found that a firm's capital structure is inversely associated to stock market return. In contrast, Asaolu and Ilo (2012) and Effiong (2014) discovered a positive relationship between capital structure and market capitalisation.

Although oil price volatility is beneficial, it has no substantial impact on corporate valuation. In theory, oil price volatility is expected to reduce business valuation by lowering energy company profitability because forecasting into the future will become almost impossible due to the erratic nature of oil prices in the worldwide market. One possible explanation for the positive but small relationship between oil price volatility and firm valuation is that most of these Nigerian energy companies engage in hedging activities. Most energy companies are insulated from the risks of oil price volatility by hedging activities, but not for an extended period of time. This is consistent with the findings of Gjerde and Sættem (1999), Arouri and Fouquau (2009), Ono (2011), Faff et al. (2016), Sadorsky (2001), and Nandha and Faff (2008), all of whom discovered a positive relationship between oil price volatility and stock market returns. It does not, however, agree with Jones and Kaul (1996), Babatunde et al. (2012), Asaolu and Ilo (2012), Effiong (2014), and Sadorsky (1999), who all indicate a substantial negative relationship between oil price shocks and market capitalisation.

Conclusion and Recommendations

Conclusion

This study looked at the impact of crude oil price shocks on the valuation of eight Nigerian listed energy businesses from 2005M01 to 2019M012. Firm valuation proxy with equity, oil price volatility, profitability, and capital structure are the factors considered in the study. The study

primarily uses the Pooled OLS, Fixed effect OLS, Random effect OLS, Heteroskedasticity test, Hausman test, Random robust GLS, and Fixed robust GLS procedures at the 5% level in this analysis. According to Gjerde and Sættem (1999), Arouri and Fouquau (2009), and Ono (2010), the study indicated substantial support for profitability and capital structure as the key determinants of business valuation among listed energy companies in Nigeria (2011). Oil price volatility, on the other hand, is positive but not important to the company valuation of Nigerian listed energy companies. We attribute this to the hedging efforts of majority of Nigeria's oil corporations.

Recommendations

Based on the findings of this study, we proffer the following recommendations:

1. Given the finding that oil price volatility positively impacts firm valuation, it is recommended that listed energy companies should explore the possibility of hedging against adverse crude oil price movement through the use of options, futures, swaps, and forward contracts in order to stabilize their market value.
2. Each listed energy firm should be mindful of its optimal debt carrying capacity as well as efficient utilization of existing debts to mitigate (trade-off) the adverse impact of debt structure on firm valuation.
3. Listed energy companies should continue to seek for ways to reduce operational expenses and litigation as this enhances their profitability and, as a result, their value.

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EVALUATING THE POTENTIAL ROLES OF RENEWABLE ENERGY MINI GRIDS WITHIN THE NIGERIAN POWER SECTOR

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Abstract

This study explores Renewable Hybrid Mini Grid (RHMG) viability in Nigerian Electricity Supply Industry (NESI) via two major objectives which include: exploring various architectures and key factors for effective mini-grid development in Nigeria; and evaluation of the effective role that renewable hybrid mini-grid (RHMG) can play in supporting the main grid for improved power sector performance. The study is based on principles of decentralized power supply, renewable energy integration, economic feasibility, and electricity regulatory framework in Nigeria. This work employs Homer Pro software to model scenarios for Renewable Hybrid Microgrid (RHMG) incorporating Wind and Solar resources in standalone (SA) and grid-connected (GC) modes, alongside a RHMG-Embedded generation system. Six locations representing each of the six geopolitical zones in Nigeria were considered in this work. Their corresponding meteorological and load profile data alongside economic and financial data were used for the scenario modelling. The study finds that deploying Standalone Renewable Hybrid Microgrid (SA RHMG) and RHMG-Embedded systems is profitable under Nigeria's current regulatory framework. The study also identifies potential regulatory changes to support the profitable deployment of Grid-Connected RHMG (GC RHMG). Additionally, it proposes a two-way metering structure for electricity transactions to facilitate the development of GC RHMG projects in urban areas already connected to the national grid.

Keywords: Renewable Hybrid Mini Grids (RHMG); Levelized Cost of Energy (LCOE); Nigerian Electricity Supply Industry (NESI).

Introduction:

The Federal Government of Nigeria initiated the privatization of the electric power sector to address longstanding challenges within the vertically integrated monopoly structure of the Nigerian Electricity Supply Industry (NESI). However, post-privatization results have been disappointing. Ajenikoko et al. (2018) observed that deregulation did not improve the efficiency of the power sector. Persistent issues include poor electricity access, inadequate transmission and distribution capacity, technical constraints, idle generation assets amid high demand, stranded electricity, national grid blackouts, high technical and distribution (T&D) losses, outdated facilities, significant demand-supply gaps, cash flow problems, gas supply issues, and other

challenges (Abanihi et al., 2018; Awosope, 2014; Ezirim, Eke and Onuoha, 2016; IseOlorunkanmi, 2014; Latham & Watkins, 2016; Olukoju, 2004; Onuoha, 2010; Sambo et al., 2010; The Economist, 2016).

In seeking solutions to Nigeria's electricity situation, two very critical areas must be considered. The first area is the current National Grid (consisting of the grid connected generation plants, the transmission network managed by the Transmission Company of Nigeria (TCN) and the distribution networks managed by the 11 Distribution Companies - DISCOs) is plagued by insufficient capacity and unreliability as a result of the various challenges within the electricity value chain. Also, the issue of access to the grid is also poor as large portions of the Nigerian populace do not have access to the National Grid. Addressing these two areas will require adequate expansion, revamping, maintenance and strengthening of the National grid existing structures alongside extension of the grid to the numerous off grid areas in the country. The cost implications of all these are significantly too high for the government alone considering the current economic situation. The second critical area is the growing calls for sustainability and sustainable development globally. With the increased awareness and concerns regarding climate change, greenhouse gases (GHG) emissions and global warming, the need for increase in the share of renewable energy (RE) source within the energy mix of individual countries is becoming extremely glaring. Therefore, in keeping up with international regulatory frameworks for sustainability such as the Kyoto Protocol, the Paris Agreement and the UN SDG goals 7, 11 and 13, Nigeria must harness its RE resources to overcome the electric power issues within the country.

Nigeria is faced with the challenge of improving the current electricity situation in the face of financial constraints of the government and the need for sustainable development and environmental protection. The low utilization of renewable energy sources (RES) within our power sector increases the difficulty of dealing with this challenge. Considering that so much investment has gone into the power sector with very little resulting impact, there is need to explore a sustainable way forward for NESI to transform its current architecture to a more optimal infrastructure. Renewable energy adoption via mini grids can play a significant role towards achieving sustainability in the power sector landscape.

On the issue of mini grids, numerous studies on mini grids have been conducted on a variety of subjects, including demand side management (DSM), regulatory issues, socioeconomic effects,

business models, prospects and obstacles, technical and economic evaluation, and feasibility study (Adesanya and Schelly, 2019; Baneshi and Hadianfard, 2016; Bastholm and Fiedler, 2018; Bhattacharyya et al., 2019; Bidsha et al., 2014; Johannsen et al., 2020; Kaundinya et al., 2009; Knuckles, 2016; Moner-Girona et al., 2018; Mukhtaruddin et al., 2013; Oladigbolu et al., 2019; Panhwar et al., 2017; Pawar and Nema, 2018; Sharma et al., 2020; Tobnaghi, 2016; Vanadzina et al., 2019; Yanalem, 2020). While significant efforts have been dedicated to techno-economic modelling and optimization, limited attention has been directed towards Nigeria in existing research. Moreover, the predominant focus within Nigerian studies has been on stand-alone (SA) mini grids situated in rural areas, with minimal consideration given to grid-connected (GC) mini grids in urban settings. The literature also reveals a scarcity of comparative analyses concerning mini grids in both rural (SA modes) and urban (GC modes) environments in Nigeria. Consequently, this study aims to address these identified research gaps.

The main research questions addressed in this study are outlined below:

Q1: What architecture will be adequate for the incorporation of RE mini grids for a sustainable electricity supply system?

Q2: What roles will RE mini grids play in the development of a sustainable electricity supply system within NESI?

To answer the research questions, this paper is organized as follows: Section 2 presents the methodology of the study. Section 3 discusses the techno-economic, environmental, pricing and profitability performance of modelled scenarios for SA RHMG, GC RHMG and RHMG-Embedded generation systems; and the roles RHMG can play in Nigeria's power sector. Finally, section 4 provides the main conclusions and recommendations.

Materials and Methods

This study carries out the analysis in two parts: the techno-economic simulation of the six renewable energy (RE) mini grids modelled across each of the six geopolitical zones in Nigeria; and the alternate modelling of a 2.5MW grid tied RE generation system attached with a localized mini grid.

The first part consists of techno-economic analysis and modelling of a wind/solar based RE mini grid for six load profiles from a representative location in each of the six geopolitical zones in the country. The communities under consideration are: Mboke, Ihiagwa LGA, Imo state; Onye-

Okpon, Obubra LGA, Cross Rivers state; Iponrin, Ibadan, Oyo state; Gajiram, Nganzia LGA, Borno state; Giere, Dange Shuni LGA, Sokoto state; and Elebu, Moro LGA, Kwara state. For Mboke community modelling was done for both SA RHMg and GC RHMg, while for the other locations on SA RHMg modelling was done. Sensitivity analysis was done for the following factors: diesel price, discount rate, availability of government subsidy on capital costs, capacity shortage and inflation rates. Hybrid Optimization of Multiple Energy Resources (HOMER) Pro software was used for the techno-economic modelling.

The second part consists of an analysis of an alternate case in Mboke, Ihiagwa (LGA), Imo State RHMg-Embedded generation system which tested the feasibility of the NERC Regulations on Feed-In Tariff for Renewable Energy Sourced Electricity in Nigeria, 2015. The modelled RHMg-Embedded generation system consisted of a 2.5MW grid tied RE generation system attached with a localized mini grid, and was done using Homer pro Software.

The data used for the used for the techno-economic modelling was comprised of both primary and secondary data (Akinbulire and Oluseyi, 2014; Nouruddeen and Babangida, 2018; Oladeji and Sule, 2015; Oladigbolu, Ramil and Al-Turki, 2020; Ugwoke et. al., 2021). The input data are outlined below:

Table 2.1: Summary of Available RE Resources and Estimated Load data

	Giere	Onye-Okpon	Elebu	Iponrin	Mboke	Gajiram
Average Daily Radiation (kWh/m²/day)	5.95	4.74	5.16	4.91	4.71	5.99
Average Clearness Index	0.611	0.479	0.525	0.497	0.474	0.615
Average Wind Speed (m/s)	3.15	2.48	2.81	3.17	2.70	5.00
Average Daily Load (kWh/day)	5,424.66	18,082.20	754.07	361.83	3,712.50	4,789.40
Peak Load (kW)	707.04	2,165.74	73.21	33.53	392.70	694.94
Load Factor	0.32	0.35	0.43	0.45	0.39	0.29

Table 2.2: Costs and characteristics of system components.

System Components	Capita cost (\$/kW)	Replacement Cost (\$/kW)	Annual O&M Cost (\$/year)	Lifetime
--------------------------	----------------------------	---------------------------------	--------------------------------------	-----------------

PV module	1,210	1,077	10	25 years
Wind Turbine	1,8750	1,750	6	20 years
Battery (per Unit)	286	237	10	4 years
Converter	176	164	0	15 years
Diesel ICE	See Table 8	See Table 8	\$0.010/h	15,000 h

Source: Ugwoke et al., (2020); Nouruddeen and Babangida, (2018): Costs and characteristics of system components.

Table 2.4: Costs of diesel-ICE generators.

Size (kWe)	Capita cost (\$/kW)	Replacement Cost (\$/kW)
1000	183	152
750	130	108
500	137	114
400	211	175
300	162	134
250	139	115
200	171	142

Source: Ugwoke et al., (2020): Costs of diesel-ICE and biomass-CHP generators.

Table 2.5: Project Economics and fuel costs inputs.

Project Input	Values
Inflation rate (%)	15.5
Discount rate (%)	11.5
Annual Capacity shortage (%)	0
Project lifetime (years)	25
Diesel price (\$/L)	0.59
Exchange rate (USD to NGN)	1 : 500

Table 2.6: Sensitivity values

Sensitivity Variables	Values
Discount rate (%)	9.5, 11.5, 13.5, 15.5, 17.5
Annual Capacity shortage (%)	0, 2, 4, 6, 8, 10
Diesel price (\$/L)	0.49, 0.59, 0.69, 0.79, 0.89, 0.99
Government Subsidy (%)	5, 10, 15, 20, 25
Inflation rate (%)	13.5, 15.5, 17.5, 19.5, 20.5

Table 2.7: NERC FiT Regulations Assumption for Tariff Computation

Category	Unit	Solar PV	Wind
Capital Cost	\$/Kw	1500	1760
Fixed O&M Cost	\$/kW/yr	30.00	18.50
Variable O&M Cost	\$/mWh	0.06	1.48
Decline Rate of Price	%	5	5
FiT 2016 Capital Cost	\$/kWh	0.17695	0.12396
FiT 2016 O&M Cost	\$/kWh	0.00015	0.00151
FiT 2016 Total Cost	\$/kWh	0.1770	0.1255

Table 2.8: Component costing details for RHMG-Embedded Generation

Category	Unit	Total Solar	Wind
Capital Cost	\$/kW	1500	1760
Replacement cost	\$/kW	1425	1672
O&M	\$/yr	30.530	18.513
Capacity	kW	1500	1000
Life span	Yrs	25	20

Result/Discussions

The following results were gotten from HOMER Pro software for the modelling of the SA RHM system, GC RHM system, Sensitivity Analysis, RHM-Embedded Generation system. Also, the result for the comparison of the estimated electricity tariff against cost of using diesel generators is given below.

Table 3.1: RHM Tariff compared to Diesel COE

	Mboke GC	Mboke SA	Gajiram	Elebu	Iponrin	Giere	Onye-Okpon
HOMER LCOE (\$/kWh)	0.0426	0.131	0.0683	0.134	0.1437	0.103	0.165
Total COE (\$/kWh)	0.0581	0.2298	0.1198	0.2351	0.2521	0.1807	0.2895
End Use Tariff (\$/kWh)	0.0668	0.2643	0.1378	0.2704	0.2899	0.2078	0.3329
Average Diesel COE(\$/kWh)	0.33	0.33	0.33	0.33	0.33	0.33	0.33
RHM Tariff compared to Diesel COE (% Reduction)	80%	20%	58%	18%	12%	37%	-1%

Table 3.2: System Performance Metrics for the optimal RHM for the six communities.

System Performance		Local Cost						
System Metrics		Mboke GC	Mboke SA	Gajiram	Elebu	Iponrin	Giere	Onye-Okpon
Economic Metrics	Present Worth (\$)	407,271	5,044,325	8,949,140	1,368,369	1551,279	7,176,715	5,297,688
	Annual Worth (\$)	9,977	123,576	219,236	33,522	38,003	175,815	129,783
	NPC (\$)	2,413,706	7,247,815	4,876,100	1,505,115	774,752	8,328,022	44,494,770
	LCOE (\$/kWh)	0.0426	0.1310	0.0683	0.1340	0.1437	0.1030	0.1650
	Electricity Cost (US\$/KWe)	9303.8	28610.4	14916.7	29265.6	31384.0	22495.2	36036.0
	ROI (%)	-0.1	4.7	12.7	6.3	12.8	6.2	7.6
	IRR (%)	N/A	7.2	16.8	9.3	17.0	9.2	10.8
	Simple Payback (Year)	N/A	10.82	5.44	8.55	5.42	8.75	10.48
	Discounted Payback (Year)	24.08	9.35	4.92	7.02	4.96	7.47	8.54
Environmental Metrics	Renewable fraction (%)	38.2	66.0	83.9	71.7	85.8	71.2	65.5

Total Emission (KgCO ₂ e/year)	546,259	341,506	206,301	67,611	17,968	410,620	1,556,543
Electricity Produced (kWh/year)	1,422,909	2,136,399	6,112,884	473,294	307,719	3,594,032	11,820,139
Emission (KgCO ₂ e/year)	0.3839	0.1599	0.0337	0.1429	0.0380	0.1143	0.1317

Table 3.3: Homer sensitivity analysis results for the six communities RHMGS.

System Metric	Response to variation of Sensitivity Variable					
	Mboke	Gajiram	Elebu	Iponrin	Giere	Onye-Okpon
Discount Rate (10% Increase)						
Operating Cost (%)	5	5	4	5	6	3
NPC (%)	-11	-8	-10	-8	-10	-9
LCOE (%)	5	7	5	7	6	6
Inflation Rate						
Operating Cost (%)	-10	-8	-8	-11	-9	-4
NPC (%)	13	10	11	13	11	11
LCOE (%)	-11	-11	-9	-11	-9	-9
Fuel Price (10% Increase)						
Operating Cost (%)	0	4	3	3	5	5
NPC (%)	0	4	4	3	4	3
LCOE (%)	0	4	4	3	4	3
Capacity Shortage (10% Increase)						
Operating Cost (%)	0	0	0	-22	0	-32

NPC (%)	0	0	0	-13	0	-31
LCOE (%)	0	0	0	-6	0	-30
10% Capital Subsidy (Wind Turbine & Solar PV Module)						
Operating Cost (%)	-2	-1	-2	-1	-2	0
NPC (%)	-1	-2	-1	-2	-2	-1
LCOE (%)	-1	-2	-1	-2	-1	-1

Table 3.4: System Performance Metrics for the embedded generation – mini grid

System Performance		Local Cost		
System Metrics		GC RHMg	Embedded Generation (Optimal)	Embedded Generation (Wind Inclusive)
Economic Metrics	Present Worth (\$)	407,271	9,767,706	9,083,789
	Annual Worth (\$)	9,977	239,289	222,534
	NPC (\$)	2,413,706	(4,955,452)	(4,271,535)
	LCOE (\$/kWh)	0.0426	0.0404	0.0318
	Electricity Cost (US\$/KWe)	9303.8	8823.4	6945.1
	ROI (%)	-0.1	13.8	4.9
	IRR (%)	N/A	17.5	7.4
	Simple Payback (Year)	N/A	5.61	10.61
	Discounted Payback (Year)	24.08	5.04	8.88
Environmental Metrics	Renewable fraction (%)	38.2	77.5	83.2
	Total Emission (KgCO ₂ e /year)	546,259	430,465	351,760
	Electricity Produced (kWh/year)	1,422,909	3,002,873	3,286,223
	Emission (KgCO ₂ e /kWh)	0.3839	0.1434	0.1070

Emissions

Tables 3.2 and 3.4 shows how the modelled systems performed in terms of the economic and environmental aspects. Using the Emissions (KgCO₂e) per kWh metrics, Mboke GC RHMG had the highest value for Emission per kWh which was significantly higher than all the other modelled systems. An inverse relationship is observed between Renewable fraction (RF) and Emission per kWh, with Mboke GC RHMG having the lowest RF value of 38.2% with a high Emission value of 0.3839 KgCO₂e/kWh. Thus, increasing the RF fraction of an electricity generation system will yield savings in carbon emission.

Profitability

Positive economic measures like Internal Rate of Return (IRR), Return on Investment (ROI), and Payback Periods (PBs) witness to the viability of the modelled systems and aid in determining the profitability of the investments, particularly in the absence of capital incentives from the government. Besides Mboke GC RHMG system, all other modelled systems had positive ROI and IRR values with reasonable payback periods. This can be attributed to the fact that for the Mboke GC RHMG system, large quantity of electricity was purchased from the grid which significantly increased its operating cost. Given that no electricity sellback was done, the revenue generation was restricted, reducing the profitability of the system.

Tariff Structure

The computed tariff (Table 3.1) ranged from \$0.0668 - \$ 0.3329/kWh. Given that the typical distribution companies (DISCOs) electricity tariff in Nigeria ranges between \$0.051 – \$0.16/kWh (Ugwoke et al., 2020), Mboke GC and Gajiram SA RHMGs systems offer comparable tariffs to the DISCOs. While the other RHMGs charge higher rates than DISCOs tariff, Onye-Okpon charges a rate akin to what it would cost to power a diesel generator. Given the dependability of RHMG electricity and taking into account the country's active mini-grids' \$0.40–\$1.00/kWh pricing (Castalia, 2017, Ugwoke et al., 2020), the tariffs for the evaluated RHMGs for all the communities are still competitive. These findings give reason for optimism on attracting investments because these areas have previously been recognized as high-yielding opportunities (Ugwoke et al., 2020).

Sensitivity Analysis

The key design variables, or major sensitivity variables, are the cost of solar PV and wind turbines (reflected in government capital subsidies), discount rate, inflation rate, and fuel prices. Especially

for mapping revenue streams and cost structures, the information from the sensitivity analysis would be particularly helpful in creating and modifying viable business models.

Roles for RHMGS in NESI

From the study, five key roles RHM can play in improving the current grid architecture were discovered and are highlighted below:

1. Mini grids could improve the electricity access and availability, if included in the electricity architecture alongside the main grid.
2. By incorporation mini grids, Nigeria can generate more electricity at a substantially lower environmental cost.
3. Mini grids development can increase collaboration between the government and the private sector within NESI.
4. Given Nigeria's Renewable energy potential, mini grids can help improve the security of electricity supply in Nigeria.
5. Mini grids could be used to significantly reduce transmission and distribution (T&D) losses within the power sector.

Conclusion

This study focused on addressing the problem of Nigeria not yet effectively harnessing her RE potentials for sustainable development of the power sector. The ultimate aim of this study was to evaluate an effective role RE mini grids can play in supporting the main grid for improved power sector performance. The objectives focused on evaluating an architectural model within the electricity supply industry for the effective incorporation of RE mini-grids and the designatory roles of the RE mini-grids towards sustainable electricity supply. SA RHMGS, GC RHMGS and RHMGS-Embedded Generation systems provide various architecture options that can be deployed for the incorporation of mini grids within NESI, for improved power sector performance. The SA RHMGS and RHMGS-Embedded Generation systems can be profitably implemented under the current regulatory landscape of NESI, while the GC RHMGS will require active regulations on electricity sellback to the main grid for its successful implementation. These different RHMGS architecture have the potential for competitive and affordable tariff. It is important to note that factors such as inflation and discount rates, fuel price and cost of components (solar PV and wind

turbine), can significantly affect the profitability and affordability of RHMGs. The study limitations include: focus on only wind and solar resources were the RE resources for the simulation analysis within the study; demand side management (DSM) and electricity theft scenarios were not considered in the analysis; and secondary data was employed majorly throughout this study. The findings should be considered within the context of the reviewed literature and the limitations of the methodology.

Recommendations

From the analysis and results of this study the following recommendations are made:

1. To enable the sellback of excess electricity from mini-grids, a two-way metering system (net-metering) is needed. This system will allow electricity to flow from the main grid to mini-grid consumers when solar or other generation assets fall short and will enable the transfer of excess electricity from the mini-grid back to the main grid during peak generation times. Developing a net-metering policy to support electricity sellback from small GC RHMGs with capacities below 1MW and defining sellback rates would enhance the profitability of these systems.
2. Mini-grid developers should look towards exploiting the electricity market for urban communities through GC RHMGs and hybrid mini-grid – embedded generation systems. Under suitable regulatory environments, this market has good profit potentials.
3. The potential benefits of RHMGs to the power sector, environment and economy of the nation needs to be exploited. Therefore, there is a need for the Nigerian government to prioritize RHMGs development in Nigeria through partnering with both foreign and local investors.

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SELECTED PESTICIDES AND CUCUMBER RESIDUE LEVELS, GROWTH AND YIELD

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Abstract

This research delved into the impact of four pesticides-Diazinon, Endosulfan, Malathion, and Methoxychlor-on cucumber residue levels, growth, and yield, employing meticulous pre-planting preparation, pesticide application in a Randomized Complete Block Design, and detailed weekly monitoring of plant growth. Through Gas Chromatography Tandem Mass Spectrometry, the study quantifies pesticide residues, comparing them to the Maximum Residue Limits (MRLs) defined by the Codex Alimentarius. Findings reveal significant variations in residue levels; Diazinon residues ranged from 0.86 to 2.28 mg/kg, exceeding the MRL of 0.1 mg/kg, suggesting soil contamination. Endosulfan showed the least residue, from 0.44 to 1.75 mg/kg, within safe limits. Conversely, Malathion and Methoxychlor residues notably surpassed their MRLs, indicating potential safety concerns. The investigation further explores how pesticide concentrations influence cucumber development, identifying that while higher doses generally reduce plant height, certain moderate levels promote optimal growth, leaf size, and stem thickness. This highlights the importance of balanced pesticide application for effective pest control without detrimental effects on plant health. The research underscores the necessity of strict adherence to pesticide guidelines to ensure food safety and maintain agricultural productivity. The study makes a significant contribution towards fostering sustainable and health-conscious farming practices.

Keywords: Maximum Residue Limits (MRLs), Pesticide, Cucumber

1. Introduction

Fruits are essential in a balanced diet, primarily due to their rich fiber content, which is vital for the digestive system's optimal function. They serve as a key source of energy through their carbohydrates, mainly sugars that the body quickly absorbs, offering an immediate surge in energy. Consuming fruits contributes significantly to a healthy lifestyle by providing essential carbohydrates, fiber, and a variety of micronutrients necessary for the body's efficient functioning (Gaddafi *et al.*, 2022).

Comprising about 90 to 95 percent water, fruits play an essential role in maintaining hydration, regulating body temperature, and safeguarding organs and tissues. The cucumber (*Cucumis sativus*), a plant originating from South Asia and now widely cultivated across continents, including Africa, is an exemplary fruit known for its high-water content of 95%. In Nigeria, cucumber farming is prevalent in both northern and southern regions, offering health benefits such as hydration, vitamin K for blood coagulation and bone health, and vitamin A for immune system support and the functioning of critical organs.

However, the cultivation of cucumbers, like other crops, faces challenges from pests that can significantly impact crop yield and quality. In response, Nigerian farmers employ various pesticides, including herbicides, fungicides, and insecticides, to protect their crops. While these chemicals are crucial for controlling pests and diseases, their extensive use raises concern about environmental and human health impacts (Abubakar *et al.*, 2019).

According to (Mahmood *et al.*, 2016) research indicates that, although pesticides are beneficial for crop protection, they pose serious environmental threats and can accumulate in the food chain, affecting both non-target species and human health. Pesticides can accumulate in the body, leading to potential long-term health issues depending on their properties and interaction with biological systems (Kalyabina *et al.*, 2021).

This study aims to address the gap in knowledge regarding pesticide residue in cucumbers and the potential health risks from dietary exposure in Nigeria. By examining pesticide application, residue accumulation, and exposure levels, this research seeks to enhance food safety and public health measures. Additionally, it explores the direct effects of pesticides on plant health, including

potential phytotoxicity that can affect seed germination, plant growth, and crop yield, as well as the impact on soil microbial ecosystems and plant nutrient uptake.

The investigation into the retention of pesticides in cucumbers and their effects on growth and yield will offer insights into the consumption safety of these fruits at specific pesticide concentrations. This research is expected to inform safer agricultural practices and contribute to the development of effective pesticide management strategies, ultimately ensuring the health and quality of crops such as cucumbers.

2. Materials and methods

2.1 Study area

The study area covers an area of land measuring 35 meters long and 9 meters wide. It's situated within the agricultural research farm of the University of Port Harcourt in Choba, Rivers State, Nigeria.

2.2 Materials and apparatus

Diazinon, Endosulfan, Malathion, and Methoxychlor were selected as the pesticide treatments for this study. These pesticides, along with the cucumber seeds, were obtained from an Agro Allied shop located in Elioazu, Rivers State, Nigeria. The specific cucumber seeds used for planting were the Monalisa F1 hybrid variety. Additionally, a 15-liter knapsack sprayer was procured for the application of the pesticides.

2.3 Experimental site

Initial preparations for planting involved clearing the designated area, removing stumps, and constructing 48 raised planting beds, each measuring 1.2 meters square. These beds were organized into three groups of 16, with a 2-meter gap between groups and a 1-meter space between beds within each group.

Cucumber seeds were sown at intervals of 60 cm, creating nine planting spots per bed. To promote optimal growth, NPK fertilizer was applied to each bed a week before sowing the seeds. Seed germination began between 4 to 8 days after planting, achieving a 50% germination rate by August 8th, 2023. A subsequent germination check on August 13th, 2023, led to additional seeding in underperforming beds.

By the third week after seeds had sprouted, the crops were under attack by pests such as spotted cucumber beetles, flea beetles, and cabbage loopers. At this time, four pesticides—Diazinon, Endosulfan, Malathion, and Methoxychlor—were introduced, each at 20ml, 30ml, and 40ml concentrations, following a Randomized Complete Block Design (RCBD) and replicated three times. Each replicate was arranged into four rows, with each row receiving one of the pesticide concentrations or serving as a control, totaling 16 rows per group. Applications were made weekly in the early morning when pest activity was lowest.

Weeding was carried out by hand to prevent competition with the cucumbers, and poultry manure was applied in the sixth week to boost growth. The cucumbers began to bear fruit by September 13th, 2023, and were harvested on September 27th, 2023, for subsequent laboratory analysis of pesticide residues.

Throughout the growing period, data on plant growth such as leaf area, height, leaf count, and stem thickness were collected weekly post-pesticide application. At harvest, data were also gathered on fruit yield metrics including weight, width, and fruit count per pesticide concentration to evaluate the impact of the pesticides on yield. The harvested fruits were analyzed using Gas Chromatography Tandem Mass Spectrometry, and the findings were assessed against the Maximum Residue Limits (MRLs) set by the Codex Alimentarius.

2.4 Sample preparation for GC/MS analysis: Initially, a 20-gram sample was thoroughly mixed to achieve a consistent texture. A 10-gram portion of this mixture was then selected and spiked with isotopically labeled standards for enrichment. This portion was then mixed with anhydrous sodium sulfate to remove moisture, and the blend was left to dry for at least 30 minutes. After drying, the sample was subjected to a prolonged extraction process, often lasting from 18 to 24 hours, using methylene chloride in a Soxhlet apparatus. Following the extraction, the solvent was completely evaporated from the extract, and the remaining lipid content was precisely measured.

2.5 Procedure for pesticide analysis: The extracted samples were purified using a solvent mixture of methylene chloride and n-hexane in equal parts. A 40 μ L aliquot of these purified extracts was then injected into a gas chromatograph equipped with a fused silica capillary column, which could be either narrow or wide bore. The system included detection options like an electron capture detector (GC/ECD) or an electrolytic conductivity detector (GC/ELCD).

For GC-MS (Gas Chromatography-Mass Spectrometry) assessments, the setup featured an Agilent 6890 gas chromatograph linked to a 5973 MS detector. This configuration used a 30-meter capillary column with an internal diameter of either 0.25 mm or 0.32 mm, coated with SE-54 (or a DB-5 equivalent) with a film thickness of 1 μm . The temperature program started at 200 $^{\circ}\text{C}$ for one minute, increased to 230 $^{\circ}\text{C}$ at a rate of 1.5 $^{\circ}\text{C}$ per minute, and held at this final temperature for 10 minutes. The analysis operated in SCAN mode, covering an m/z range from 35 to 450, with nitrogen as the carrier gas flowing at 1 mL per minute and requiring manual injection of a 1 μL sample.

To quantify pesticide levels, an Agilent 6820 gas chromatograph with a similar 30-meter capillary column, internal diameters, SE-54 bonding, and film thickness was used. The temperature protocol matched the earlier description, with injector and detector temperatures set at 250 $^{\circ}\text{C}$ and 280 $^{\circ}\text{C}$, respectively. Nitrogen again served as the carrier gas at a 1 mL per minute flow rate, with a split ratio of 50:1, and a 1 μL sample volume was injected.

3. Data analysis

The data gathered were evaluated through the application of Analysis of Variance (ANOVA) using the IBM SPSS statistics software 25. Duncan Multiple Range Test (DMRT) was used in separating means of varying pesticide concentrations.

4. Results

The study findings on pesticide residue levels in cucumbers, varying according to different concentrations of four pesticides, diazinon, and residue levels were observed between 0.86 mg/kg at a 20ml dosage and 2.28 mg/kg at 40ml, with residues in the control group reaching 0.48 mg/kg. Notably, the residue levels in the control group were above the Maximum Residue Limit (MRL) of 0.1 mg/kg, indicating the possibility of soil contamination. Endosulfan showed the lowest residue levels among the studied pesticides, with levels ranging from 0.44 mg/kg at a 20ml dosage to 1.75 mg/kg at 40ml. The control sample's residue was 0.24 mg/kg, which is below the MRL of 1 mg/kg. This suggests that the use of Endosulfan, within the tested concentrations, might not breach the established residue limits. Residue levels of Malathion were notably high, ranging from 0.62 mg/kg at the minimum dosage to 2.74 mg/kg at the maximum, with the control sample showing 0.38 mg/kg. The residue levels for all samples treated with Malathion exceeded the MRL

of 0.2 mg/kg, which poses questions about its safety at these concentrations. Methoxychlor's residue levels were consistently near or above the MRL, increasing from 0.63 mg/kg at a 20ml dosage to 2.26 mg/kg at 40ml, with the control having 0.42 mg/kg. Given that the MRL for Methoxychlor is set at 0.01 mg/kg, its residues were over the permissible limits for all tested concentrations.

These findings underscore the varying impacts of pesticide concentrations on cucumber residue levels and highlight the importance of adhering to MRLs to ensure food safety.

Table 1 Pesticide Residue levels in sampled cucumber of different levels of concentrations.

Pesticide	20ml (mg/kg)	30ml (mg/kg)	40ml (mg/kg)	Control (mg/kg)	MRL (mg/kg)
Diazinon	0.86	1.65	2.28	0.48	0.1
Endosulfan	0.44	0.64	1.75	0.24	1
Malathion	0.62	1.77	2.74	0.38	0.2
Methoxychlor	0.63	1.53	2.26	0.42	0.01

In examining the impact of various pesticide concentrations on plant development across three-time intervals—21, 28, and 35 days as shown in Table 2, 3 and 4 the study revealed the following findings. In the initial stages of the study, 21 days post-germination, Endosulfan proved to be the most beneficial in terms of increasing plant height, while Methoxychlor showed only a slight enhancement in growth. As the study progressed to the 28-day mark, higher doses of both Malathion and Endosulfan, especially at 40ml for Endosulfan, resulted in significant growth, with Endosulfan leading in terms of plant height increase. In contrast, Methoxychlor and Diazinon reacted differently depending on the dose, with lower doses of Diazinon being more effective than higher ones. By day 35, a 30ml dosage of both Malathion and Diazinon indicated marked improvements in growth, particularly notable for Malathion's effectiveness at this concentration. However, increased doses of Methoxychlor and Malathion suggested the possibility of toxicity affecting the plants. The findings indicate that the most favorable growth outcomes were achieved with mid-level concentrations of Endosulfan and Malathion, underscoring the importance of finding a balance between using pesticides for effective pest control and maintaining plant health. The study also observed inconsistent effects from Methoxychlor and Diazinon, depending on the concentration and stage of growth.

Table 2 Effect of varying concentration of pesticide on plant height, leaf area, stem girth, and number of leaves after 21 days of planting

Duration	Pesticide	Conc	Plant Height	Leaf Area	No. of Leaves	Stem Girth
21 Days	Malathion	Ctrl	16.33 ± 1.26 ^a	38.50 ± 4.98 ^a	7.00 ± 2.65 ^a	0.60 ± 0.17 ^b
		20ml	12.67 ± 8.94 ^a	36.38 ± 14.01 ^a	7.00 ± 3.00 ^a	0.80 ± 0.17 ^{ab}
		30ml	19.17 ± 8.25 ^a	38.75 ± 15.45 ^a	7.67 ± 3.51 ^a	1.17 ± 0.28 ^a
		40ml	9.33 ± 2.36 ^a	24.25 ± 3.68 ^a	6.33 ± 2.31 ^a	1.13 ± 0.12 ^a
	Endosulfan	Ctrl	9.60 ± 6.00 ^a	24.52 ± 11.89 ^b	5.00 ± 0.00 ^a	0.80 ± 0.35 ^a
		20ml	18.17 ± 6.00 ^a	46.67 ± 5.34 ^{ab}	5.67 ± 2.52 ^a	0.90 ± 0.17 ^a
		30ml	22.33 ± 8.08 ^a	50.80 ± 2.10 ^{ab}	7.00 ± 2.00 ^a	1.20 ± 0.17 ^a
		40ml	23.17 ± 11.43 ^a	43.62 ± 19.99 ^a	7.33 ± 5.86 ^a	0.90 ± 0.35 ^a
	Methoxychlor	Ctrl	9.83 ± 1.15 ^a	22.14 ± 2.52 ^a	4.33 ± 0.58 ^a	0.77 ± 0.12 ^a
		20ml	15.33 ± 14.18 ^a	30.50 ± 18.31 ^a	5.67 ± 2.08 ^a	0.80 ± 0.17 ^a
		30ml	16.00 ± 9.34 ^a	28.50 ± 15.26 ^a	5.67 ± 2.52 ^a	0.90 ± 0.35 ^a
		40ml	16.67 ± 6.82 ^a	38.84 ± 19.20 ^a	5.67 ± 1.53 ^a	0.90 ± 0.17 ^a
Diazinon	Ctrl	24.83 ± 8.81 ^a	36.82 ± 10.86 ^{ab}	5.00 ± 1.00 ^b	0.90 ± 0.35 ^a	
	20ml	24.50 ± 8.76 ^a	45.25 ± 14.88 ^a	7.00 ± 1.00 ^a	1.10 ± 0.17 ^a	
	30ml	13.67 ± 5.51 ^{ab}	22.22 ± 4.84 ^b	4.67 ± 0.58 ^b	0.70 ± 0.00 ^a	

40ml 9.33 ± 2.47^b 22.67 ± 4.04^b 5.00 ± 1.00^b 0.90 ± 6.35^a

** Mean Values in the Same Column with different letters shows statistical significance at p<0.05

Table 3 Effect of varying concentration of pesticide on plant height, leaf area, stem girth, and number of leaves after 28 days of planting

Duration	Pesticide	Conc	Plant Height	Leaf Area	No. of Leaves	Stem Girth
28 Days	Malathion	Ctrl	32.67 ± 2.52 ^a	152.33 ± 18.52 ^a	14.33 ± 5.13 ^a	1.50 ± 0.00 ^b
		20ml	25.33 ± 17.90 ^a	143.67 ± 54.27 ^a	14.00 ± 6.55 ^a	1.83 ± 0.29 ^{ab}
		30ml	38.33 ± 16.50 ^a	155.00 ± 61.80 ^a	15.67 ± 6.51 ^a	2.33 ± 0.58 ^a
		40ml	18.67 ± 4.73 ^a	97.17 ± 18.07 ^a	12.67 ± 5.51 ^a	2.33 ± 0.29 ^a
	Endosulfan	Ctrl	19.17 ± 12.00 ^a	101.50 ± 44.08 ^b	10.33 ± 0.58 ^a	1.67 ± 0.58 ^a
		20ml	36.33 ± 12.01 ^a	186.67 ± 21.39 ^{ab}	1.83 ± 0.29 ^b	1.83 ± 0.29 ^a
		30ml	44.67 ± 16.17 ^a	208.60 ± 15.13 ^a	2.33 ± 0.29 ^b	2.33 ± 0.29 ^a
		40ml	46.33 ± 22.85 ^a	171.92 ± 79.28 ^{ab}	1.67 ± 0.29 ^b	1.83 ± 0.58 ^a
	Methoxychlor	Ctrl	19.67 ± 2.31 ^a	87.42 ± 14.21 ^a	4.33 ± 4.73 ^a	1.67 ± 0.29 ^a

	20ml	30.67 ± 28.36 ^a	128.50 ± 90.52 ^a	10.33 ± 5.77 ^a	1.67 ± 0.29 ^a
	30ml	32.00 ± 18.68 ^a	111.33 ± 57.27 ^a	11.67 ± 5.13 ^a	1.83 ± 0.58 ^a
	40ml	29.33 ± 13.65 ^a	153.67 ± 75.73 ^a	12.00 ± 3.61 ^a	1.83 ± 0.29 ^a
Diazinon	Ctrl	44.00 ± 7.20 ^a	155.25 ± 55.67 ^{ab}	9.67 ± 1.53 ^b	1.83 ± 0.58 ^{ab}
	20ml	49.00 ± 17.52 ^a	183.67 ± 63.52 ^a	14.00 ± 1.73 ^a	2.17 ± 0.29 ^a
	30ml	27.00 ± 11.27 ^{ab}	93.75 ± 14.81 ^b	9.33 ± 1.15 ^b	1.50 ± 0.00 ^b
	40ml	18.67 ± 4.93 ^b	100.00 ± 0.00 ^{ab}	9.33 ± 1.53 ^b	1.50 ± 0.00 ^b

** Mean Values in the Same Column with different letters shows statistical significance at p<0.05

Table 4 Effect of varying concentration of pesticide on plant height, leaf area, stem girth, and number of leaves after 35 days of planting

Duration	Pesticide	Conc	Plant Height	Leaf Area	No. of Leaves	Stem Girth
35 Days	Malathion	Ctrl	88.33 ± 12.58 ^a	183.33 ± 40.02 ^a	7.00 ± 4.00 ^{ab}	1.93 ± 0.15 ^{ab}
		20ml	106.67 ± 36.17 ^a	210.00 ± 14.00 ^a	7.00 ± 3.00 ^{ab}	2.23 ± 0.23 ^a
		30ml	116.67 ± 20.82 ^a	225.00 ± 15.00 ^a	15.00 ± 5.00 ^a	2.33 ± 0.29 ^a
		40ml	63.67 ± 43.32 ^a	136.67 ± 91.66 ^a	6.33 ± 4.73 ^b	1.47 ± 0.55 ^b

Endosulfan	Ctrl	85.33 ± 17.47 ^a	192.67 ± 56.58 ^a	25.33 ± 5.13 ^a	2.10 ± 0.20 ^a
	20ml	44.67 ± 31.34 ^b	89.33 ± 54.78 ^a	14.67 ± 7.57 ^b	1.33 ± 0.55 ^b
	30ml	103.33 ± 15.28 ^a	201.33 ± 60.18 ^a	19.00 ± 4.36 ^b	2.03 ± 0.11 ^a
	40ml	117.00 ± 14.73 ^a	212.33 ± 95.52 ^a	27.67 ± 2.52 ^a	2.27 ± 0.21 ^a
Methoxychlor	Ctrl	55.00 ± 21.79 ^{ab}	143.00 ± 75.01 ^{ab}	15.33 ± 5.51 ^{bc}	1.67 ± 0.49 ^{ab}
	20ml	123.33 ± 50.58 ^a	242.00 ± 57.42 ^a	32.67 ± 11.24 ^a	2.23 ± 0.31 ^a
	30ml	100.17 ± 7.46 ^{ab}	176.30 ± 56.20 ^{ab}	27.33 ± 6.43 ^{ab}	2.07 ± 0.25 ^a
	40ml	30.00 ± 17.32 ^a	60.67 ± 43.14 ^b	10.00 ± 5.00 ^c	1.10 ± 0.35 ^b
Diazinon	Ctrl	86.67 ± 30.55 ^a	182.50 ± 24.79 ^b	22.67 ± 7.57 ^a	2.00 ± 0.10 ^a
	20ml	120.00 ± 45.83 ^a	222.67 ± 70.44 ^a	24.00 ± 5.29 ^a	2.10 ± 0.35 ^a
	30ml	120.00 ± 18.03 ^a	215.33 ± 16.74 ^a	32.33 ± 6.81 ^b	2.30 ± 0.00 ^a
	40ml	76.67 ± 15.28 ^a	180.83 ± 32.41 ^a	25.33 ± 15.31 ^b	2.03 ± 0.23 ^a

** Mean Values in the Same Column with different letters shows statistical significance at p <0.05

Based on the provided statistical analysis as shown in Table 5 below, the efficacy of different pesticides on crop yield, measured through the number of fruits, fruit weight, and fruit width, can be interpreted as follows. Diazinon stands out significantly in its ability to boost fruit weight, especially noticeable at the 20ml dosage, showcasing its unmatched effectiveness in fostering fruit growth when compared with other pesticides in the study. Its influence on increasing fruit width is also prominent, indicating an overall enhancement in fruit dimensions. Endosulfan is particularly effective in boosting the fruit count, with its 20ml dosage highlighting its potential in enhancing fruit production quantity rather than size, demonstrating its advantage in maximizing harvest numbers. While Methoxychlor and Malathion have shown some effectiveness in improving various fruit metrics, they fail to consistently surpass Diazinon and Endosulfan in their areas of strength. Methoxychlor shows some level of improvement in fruit weight and width at certain dosages but doesn't dominate in any particular aspect. Malathion, on the other hand, appears least effective, particularly at the 40ml dosage for fruit weight, where it demonstrates negligible benefits compared to its control, suggesting a limit to its efficiency at higher concentrations.

In conclusion, Diazinon proves to be the superior choice for enhancing fruit size, with its most notable impact at lower concentrations. Endosulfan shines in its capacity to increase fruit numbers, making it ideal for goals focused on yield volume. These observations underscore the critical role of precise pesticide concentration selection in optimizing fruit yield, taking into account both the quality and quantity of the produce.

Table 5 Effect of the pesticides on crop yield

Pesticide	Concentration	Number of fruits	Fruit wight	Fruit Width
Malathion	Ctrl	6.00 ± 2.00 ^a	266.67 ± 76.38 ^a	16.33 ± 2.84 ^a
	20ml	4.97 ± 0.58 ^a	300.00 ± 100.00 ^a	14.66 ± 1.76 ^a
	30ml	8.00 ± 4.36 ^a	366.67 ± 104.08 ^a	15.43 ± 1.50 ^a
	40ml	5.33 ± 2.51 ^a	266.67 ± 76.38 ^a	16.63 ± 2.40 ^a
Endosulfan	Ctrl	5.67 ± 2.08 ^a	383.33 ± 104.08 ^a	18.00 ± 1.73 ^a
	20ml	10.00 ± 5.29 ^a	333.33 ± 104.08 ^a	17.40 ± 0.53 ^a
	30ml	9.00 ± 1.73 ^a	330.00 ± 86.60 ^a	17.37 ± 2.26 ^a
	40ml	9.3 ± 2.52 ^a	300.00 ± 5.00 ^a	15.90 ± 1.73 ^a
Diazinon	Ctrl	7.00 ± 5.00 ^a	216.67 ± 28.87 ^c	15.30 ± 3.48 ^a
	20ml	8.67 ± 2.89 ^a	483.33 ± 28.87 ^a	19.43 ± 0.819 ^a
	30ml	7.67 ± 2.52 ^a	333.33 ± 28.87 ^b	16.93 ± 0.67 ^a
	40ml	4.33 ± 1.15 ^a	283.33 ± 104.08 ^{bc}	15.37 ± 2.47 ^a
Methoxychlor	Ctrl	4.00 ± 1.00 ^a	266.67 ± 76.38 ^{ab}	16.00 ± 2.65 ^b
	20ml	6.67 ± 3.06 ^a	316.67 ± 57.74 ^a	16.27 ± 1.91 ^a
	30ml	6.33 ± 3.21 ^{ab}	350.00 ± 86.60 ^b	17.33 ± 1.01 ^a
	40ml	3.67 ± 1.53 ^b	300.00 ± 50.00 ^a	14.73 ± 1.03 ^a

** Mean Values in the Same Column with different letters shows statistical significance at $p < 0.05$

5. Discussion

The investigation into the prevalence of pesticide residues on fruits and vegetables globally has raised significant public health concerns. Research by Osaili et al. (2022) on fruit imports in the United Arab Emirates found that a vast majority (73.2%) of the 4513 fruit samples analyzed contained pesticide levels exceeding the Maximum Residue Limit (MRL), with 26.8% surpassing the limit considerably. This finding mirrors the results of our own study, which similarly identified high levels of pesticide residues in all cucumber samples tested, suggesting widespread regulatory and management deficiencies in pesticide application across the agricultural sector. The detection of pesticides such as Chlorpyrifos and cypermethrin in common fruits further emphasizes the urgency for improved oversight and practices.

The persistence of pesticide residues, including those not directly applied to crops, indicates environmental contamination as a significant source of agricultural produce contamination. Studies by Tudi et al. (2021) and Wang et al. (2021) illustrate how pesticides present in the soil can be absorbed and translocated into crops, highlighting the role of the soil-water partition coefficient in the uptake process. This phenomenon was observed in our control cucumber samples, suggesting residual soil pesticides as the likely source of contamination.

Furthermore, the detection of additional pesticide types in crops not treated with those chemicals, as supported by Froger et al. (2023), points to the environmental persistence of these substances and their ability to contaminate even untreated lands. The widespread presence of pesticides in

various environments, including organic farms, underscores the challenge of preventing unintended contamination of agricultural products.

This study's findings, coupled with the corroborative evidence from related research, underscore the pressing need for stringent pesticide application guidelines, enhanced monitoring, and adoption of sustainable agricultural practices to mitigate the risks of exceeding MRLs and ensure food safety. While certain pesticides have been shown to improve plant growth and yield by protecting against pests and diseases, the potential environmental and health risks associated with their use cannot be overlooked. The balance between the benefits of pest control and the adverse impacts on ecosystem health and plant vigor necessitates careful consideration and management of pesticide use in agriculture. The nuanced responses of cucumber plants to various pesticide concentrations in this study highlight the importance of precision in pesticide application for optimal agricultural outcomes and the sustainability of food production systems.

6. Conclusion

This study clearly shows the complex relationship between the use of pesticides, the growth of cucumbers and the overall goal of keeping agriculture environmentally sustainable. It finds that although pesticides eradicate pests, the residue left behind can often be more than what is considered safe, leading to serious concerns for health. The research highlights how pesticides impact crop growth and yield. The urgent need for careful planning in how pesticides are used, calls for methods that manage pests effectively while also looking after the environment and keeping farming practices sustainable. Achieving this balance is essential for future agricultural practices, as it ensures food security while preserving ecological integrity and minimizing potential risks to human health and the environment.

7. Recommendations

The following are recommendations for the study;

1. Farmers should consider the use of biopesticides as alternatives. This will lower the risk of pesticide accumulation and minimize contamination.
2. Integrated Pest Management should be implement into agriculture this will help balance pest management with reduced chemical dependence.

3. Regular monitoring of soil health, pesticide residue levels, should be conducted to help detect early signs of contamination and timely corrective measures should be conducted.
4. Policies that enforce limits on pesticide residues in agriculture should be implemented to maintain food safety and environmental health.
5. Training programs should be conducted to help farmers understand the ecological impact of pesticides and adopt safer pest management practices, this will contribute to long-term soil health and sustainable crop production.

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NATURAL GAS UTILIZATION FOR SUSTAINABLE GROWTH: AN ANALYSIS OF GAS INFRASTRUCTURE DEVELOPMENT

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Abstract

With growing global concerns about climate change and increasing energy demand, the importance of natural gas, the cleanest fossil fuel, cannot be over emphasised. Nigeria, with its vast proven gas reserves, must capitalize on this opportunity. Currently, gas is treated as a by-product of oil activities due to limited markets, however, with a population of around 200 million, enhancing domestic gas use can drive sustainable development. Using the Ordinary Least Square, the study examined the Economic Effect of Gas Infrastructure, finding a significant positive relationship between natural gas utilization (domestic) and gas infrastructure development, leading to improved economic performance, especially in the industrial sector. The results suggest that greater domestic gas utilization correlates with greater economic growth, though Nigeria's gas utilization remains low due to inadequate infrastructure. Hence the need to develop gas infrastructure especially transmission and distribution pipelines to industrial hubs and city centres. The study recommends revising Nigeria's domestic gas utilization policy to create a clear regulatory framework that promotes private investment in gas infrastructure. It also calls for enforceable contracts to attract foreign direct investment (FDI) and highlights the critical role of gas infrastructure development in reducing flaring, boosting gas utilization, creating jobs, and fostering economic growth.

Keywords: Natural gas utilization, Sustainable growth, Infrastructure Development

INTRODUCTION

The Nigerian economy has undergone significant transformations over the years, shaped by historical events (civil war, great depression, economic recession), global economic dynamics (credit creation, local and international trade, exchange rates, inflation, etc.) political unrest among all other social and economic calamities. Prior to the over dependence on crude oil, the economy was a primarily agrarian and manufacturing based. Agriculture and local trade played crucial roles in sustaining communities. This period saw the government's economic policies dictated by the agricultural and manufacturing sectors.

However, the subsequent discovery of crude oil led to shift towards exploration and production and massive investment in the industry was seen during the oil boom era. By the 1970s, Nigeria's economy became heavily oil-dependent significantly affecting the value of the naira. Despite contributions from the service, agricultural, and manufacturing sectors, crude oil still dominates the Nigerian economy, accounting for 8% to 10% of the country's GDP. Crude oil exports constitute about 90% of Nigeria's total exports.

Oil dependence has high impact on the country's economy as fluctuations in global oil prices directly affect Nigeria's economic growth. The country's economic growth is closely tied to oil export earnings, as petroleum revenue funds a substantial portion of the government fiscal budget. High oil prices lead to a favourable trade balance, increased foreign reserves, a stronger naira, and economic growth. While low oil prices lead to declining foreign reserves, budget deficits, slower economic growth, and a weaker naira.

Energy plays a key role in the economic growth and development, including poverty eradication and security of a nation. Energy is a key factor in all the sectors of any country's economy. Uninterrupted energy supply is a critical issue for all nations today. Economic growth in the future borders on the long-term availability of energy that is affordable, accessible, and environmentally friendly. It is worthy to note that the standard of living of a country can be directly linked to the per capita energy consumption.

Energy also fuels activities like manufacturing, agriculture, commerce, industry, and mining. Inaccessibility of energy contributes to poverty, furthermore, economic decline. Energy, poverty eradication and socioeconomic development, such as productivity, income growth, education, and health (Nnaji et al, 2010) which are major KPI's in the economy, are closely related.

Nigeria is blessed with numerous energy resources; it is a gas province known for producing oil. It accounts for 2.5% of the world's gas reserve (Egila et al., 2013). As at end of 2018, NNPC estimated Nigeria's gas reserve to be 200.90 TCF which is almost twice the oil reserve of 36,971.91MMbbls. Nigeria has one of the top largest natural gas reserves in the world; it is amongst the top 10 countries. This makes it the highest oil and gas producer in Africa (Atoyebi and Olatunbosun, 2012).

Despite the abundance of natural resources, crude oil and natural gas alike, Nigeria is plagued with epileptic power supply. Its electrical power consumption as at 2014 is 144.5kWh per capita (Worlds bank, 2019) with a population of over 180 million people and only about 40% having access, this can be said to be very poor. IEA reports that in 2017, out of the 32,223GWh of electricity produced 26,670GWh was produced from natural gas. Despite almost 83% of the country's electricity been generated from natural gas, its shortage is still accorded the key reason for inadequate electricity generation. Even with the shortage, Nigeria is still amongst the highest gas flaring countries in the world, it is ranked 7th all over the world. In Nigeria, poor electricity supply one of the greatest infrastructural problems challenging the business sector. This has a huge

cost implication on the firm rising from idle capacity (workers and some equipment), spoiled materials, lost output, and damaged equipment. The general implication is to increase business uncertainty and lower returns on investment. This has really undermined attractiveness of the economy to external investors and Nigeria's growth potential.

Nigeria faces a significant challenge related to gas flaring, which results in the loss of a considerable quantity of natural gas during oil production. This is as a result of a number of oil wells lacking the necessary infrastructure to efficiently separate and process the associated natural gas (natural gas produced alongside oil). In 2014, approximately 10.73 billion cubic meters (m³) of natural gas were lost due to gas flaring in Nigeria. This loss accounts for about 12% of the total oil production in the country. Nigeria ranks as the fifth-highest gas flaring nation globally, contributing to approximately 8% of the total gas burned worldwide (WEC, 2013; BUR1, 2018).

Despite the ongoing challenge, there has been progress in reducing gas flaring. Over the past decade, the quantity of natural gas flared has decreased by more than 50% (BUR1, 2018). This reduction is a positive development, although the country still flares a significant fraction of its total natural gas. While still ranked fifth in the world, this represents a significant improvement from its second-place ranking in 2011.

Nigeria Gas Policy, NGP (2017) termed Nigeria a gas player and not an oil player having the 9th largest gas reserve in the world. But the country has not embarked on any exploration for gas, the gas reserve discovered were by chance. As of 2015, 29% of oil produced was gas (most of the produced gas are associated gas).

Alawode and Omisakin (2011); in their paper titled "Monetizing Natural Gas Reserves: Global Trend, Nigeria's Achievements, and Future Possibilities," highlighted that the discovery of natural gas in Nigeria dates back as far as the discovery of oil. However, natural gas received less attention. The authors reviewed global natural gas monetization technologies and projects, assessed Nigeria's achievements in monetizing natural gas, and proposed future possibilities. It is crucial and fitting for Nigeria to tap into its extensive natural gas reserves to benefit its economy, enhance regional cooperation, and meet the growing demand in various global markets.

During the early exploration and exploitation of crude oil, natural gas was regarded as an unwanted product from crude oil production which was the most sort after but as global development grows, natural gas and its derivative products has developed to be a more sorted for globally. Research has proved now that natural gas utilization is gaining predominance as the primary energy requirements of the world. This development has been recorded in only a few years with the increased availability of the gas resources from different countries (Ikoku, 1992). The total global annual gas consumption is estimated to rise to 2.9 trillion cubic meters by 2015 accounting for approximately 27% of the total primary energy supply (Patel, 2005).

Agbonifo (2016) stated in his paper that Nigeria can harness natural gas for social and economic development like most developed countries if it has a clear insight into natural gas infrastructural

development. Odumubgo (2010) view it from the point that natural gas infrastructure is relevant in environmental management which will in turn spur socioeconomic development for the local population. Sonibare and Akeredolu (2004) argued that projects emanating from natural gas utilization are the backbone to eliminating the threat to the wellbeing of the local population.

The Nigerian domestic gas market is controlled by the National Gas Company (NGC). The NGC supplies gas to some power generating for power generation and also some manufacturing companies as feedstock. The gas demand is increasing on a daily base implying that that there is a potential large market for investors. Presently, domestic gas demand is about 400 MMSCFD which is low when compared to the country's gas resource and population. The low demand domestically is attributed to inadequate gas infrastructure (transmission and distribution) and low level of industrialization. Even with the expected growth in the power sector, the sector accounts for about 90% of gas sales in the country.

To encourage domestic gas utilization, the government gave Domestic Gas Supply Obligations to operators in the industry as instructed by the Nigerian Domestic Gas Supply and Pricing Regulations (NDGSR), 2005.

Even with the obligation, there is still a supply shortfall from operator due to lack of commitment by Gas Producers, preference for export market by producers, slippage in project execution, budget constraints, inadequate pipeline infrastructure, non-readiness of off-take plants, failure of swap deals and failure of commercial negotiations (DPR Oil and Gas Industry Report, 2014).

Due to the recent global out cry for gas flaring reduction, international organizations, Government and big International Oil Companies have started to pay attention to routine gas flaring and process of flare down (Kaldany, 2001, Ishisone, 2004). For example, the World Bank Group in partnership with the Government of Norway started a project (Global Gas Flaring Reduction Initiative, GGFR), to enact common guidelines and standards for gas venting and flaring on a global basis. The project aims to advance the legal and regulatory framework for flaring reductions not just for its environmental unfriendliness but also for destroying valuable natural resources.

Developing Nigeria's gas reserves holds promise for reducing dependence on oil. Currently, oil constitutes more than 90% of Nigeria's foreign exchange earnings. Nigeria possesses substantial natural gas reserves, comparable to its oil reserves. The rising global demand for gas presents an opportunity to diversify revenue streams.

Asikhia and Orugboh (2011) emphasized the cost efficiency of natural gas and its significant implications for the Nigerian economy.

Reduced Production Costs: Cheaper energy derived from natural gas can lead to a decrease in production costs, as a result decreasing the price of goods for consumers.

Investment and job Opportunities: the money saved by utilizing natural gas can be redirected toward plant expansion, thereby creating additional job opportunities within the economy.

Increased Productivity: access to affordable fuel (natural gas) can lead to higher capacity utilization in industries, which would translate to greater productivity.

In summary, leveraging natural gas efficiently can drive economic growth, cost savings, and employment generation in Nigeria.

Nigeria faces a number of socio-economic problems. Over the years, these problems range from low-income levels, high inflation, growing unemployment, to high level of poverty have worsened. Oil and gas industry has been a major contributor of income to Nigeria's economy for decades namely 65% of the government's revenue and 88% of the country's foreign exchange earnings (KPMG, 2019) excluding the effects of direct and indirect employment generation that accompanies the setting up of different Exploration and Producing (E & P) companies in Nigeria and beyond.

The major drivers of gas utilization globally is the increasing demand for clean and affordable energy. Furthermore, Nigeria is in dire need to increase power supply which is the driving force for economic activities, and also move away from over dependency on oil. Nigeria being a developing/expanding economy is blessed with enormous natural gas reserve that is not taken advantage of. With the country's commitment to sustainable development and economic growth one would expect utilization of natural gas by key sectors of its economy, like the industrial sector but this is not the case. To achieve increase in natural utilization, gas infrastructure should be developed as an increase in gas infrastructure development will drive gas commercialization to create open and competitive access to gas.

The necessity of diversifying Nigeria's economy through investments in gas infrastructure should be considered paramount in this study. From the foregoing, our problem is over reliance on oil and this situation exposes Nigeria to shocks and other difficult economic effects. For example, in recent times, oil price sank and was exchanged at negative values during the pandemic while natural gas prices didn't collapse. Granted natural gas does not have much political intrigues and other possession and control issues associated as seen in oil reserves. Hence it is imperative that serious and intentional actions be channelled towards harnessing gas for economic development.

MATERIALS AND METHODS

In this study, empirical techniques will be employed in examining the casual relationships. In order to establish objectivity of findings we shall adopt the quasi-experimental design which embodies the use Ordinary least squares (OLS) regression technique to test specified hypotheses we established in chapter one. The essence of using the OLS is for the purpose of its BLUE (best linear unbiased estimator) in nature.

Model Specification

The model that will guide the empirical analysis for this study was specified. The model will enable the establishment of the hypotheses stated in the study. Natural Gas Utilized (Domestic and Export) would be used as a proxy to model gas infrastructure because natural gas can be an input in production also, a system cannot produce more output than its level of development. In this line therefore, total utilized gas shall serve as a proxy for gas infrastructure development. The model was specified to demonstrate the behaviour of the different variables that were practicably involved in the domestic gas utilization commercially. The model was fashioned to cater for some other error terms that are peculiar to the challenges faced Nigeria oil and gas industry. This model was specified to take care of some peculiar issues affecting both supply and demand of natural gas in Nigeria.

Gas infrastructure development obviously, has a huge impact on the performance of the national economy. In this regard, we shall measure economic performance using the Real Gross Domestic Product (RGDP). It should be noted that Gross domestic product (GDP) is a measure of total goods and services produced within a national geographical confine, this is measured in monetary terms.

In presenting this in a model format, RGDP shall serve as our dependent variable while the gas development variables shall serve as our independent variables. The model is presented in both mathematical and econometric formats as follows:

$$RGDP = f(DNGU, ENGU, NGF, NGPRI) \text{ ----- (1a)}$$

Transforming equation 1 into an econometric format gives;

$$RGDP = \beta_0 + \beta_1 DNGU + \beta_2 ENGU + \beta_3 NGF + \beta_4 NGPRI + U_i$$

Taking the log transformations of equation 1 above gives

$$RGDP = \beta_0 + \beta_1 \text{Log}DNGU + \beta_2 \text{Log}ENGU + \beta_3 \text{Log}NGF + \beta_4 \text{Log}NGPRI + U_i \text{..... (1b)}$$

The essence of the log transformation is to enhance the validity of the estimates Ahmad et al (2015).

Where:

RGDP = Real Gross Domestic Product

DNGS = Domestic Natural Gas Utilized

ENGU = Export Natural Gas Utilised

NGF = Natural Gas Flared

NGPRI = Natural Gas Price

$\beta_1 - \beta_4$ = Estimated parameters.

U_i = error term

Apriori theoretical expectations

$$\frac{RGDP}{\partial DNGU} > 0, \frac{RGDP}{\partial ENGU} > 0, \frac{RGDP}{\partial NGPRI} > 0 \text{ and } \frac{RGDP}{\partial NGF} < 0$$

Data sources

The data source used for this study is secondary (time series) data. It was elicited from the Statistical Bulletin of the World Bank's World Development Indicators (WDI, 2017), Nigerian National Petroleum Corporation Annual Statistical Bulletin, Department of Petroleum Resources Oil and Gas Reports, Central Bank of Nigeria (CBN) and Annual Abstract of Statistics of the National Bureau of Statistics (NBS), Organization of Petroleum Exporting Countries Annual Statistical bulletin and any other reliable and accurate source for oil and gas data. The study evaluates the impact of an analysis of gas infrastructure development on sustainable economic growth. The data series are yearly observation from 1989 to 2018, a total of 29 observations. This period is informed by the fact that the period witnessed strategic policies that have tended to heighten the process of economic growth. Some of them are the Sustainable Development Goals of 2015; set by the United Nations General Assembly among others. The period and the frequency of the selected dataset adopted for the investigation is based on data availability.

Unit-root test.

It is applied to evaluate the behaviour of a series over time and how the series responds to shock. Unit root testing ensures that variables used in regression models exhibit the necessary statistical properties for reliable analysis. A variable is valid in the regression model if it has a constant mean (the average value of the variable remains stable over time), constant variance (the spread of the variable's values remains consistent) and constant covariance (the relationship between the variable and other variables remains stable). Meaning it is stationary. Unit root testing helps identify whether variables are stationary, ensuring the validity of your regression model. The unit root test to be used for this model testing is Augmented Dickey Fuller (ADF) unit root test.

Co-integration test

This test is carried-out to determine whether the variables under investigation have long-run relationship.

In this study, the Bounds co-integration test was be used, it will be applied to the specified modelled variables that allows for more than one co-integrating relationship and the rejection of the null hypothesis of no co-integration will provide basis for estimating the Error Correction Model (ECM). The choice of this approach is informed by the nature of integration obtained in

Table 3. As noted by Ahmad et al (2015), The Bounds test method for Co-integration is most suitable when there is different order of integration within a model specifically, if the variables are integrated at I(0) and I(1) i.e integrated at levels and at first difference. Ahmad et al's assertion is further corroborated by the works of Pesaran et al. (2001).

Error Correction Model

Error correction models (ECMs) are a type of time series model designed for analyzing data where variables exhibit a long-run stochastic trend (co-integration). Error Correction Model (ECM) will be used to estimate the short-run coefficients of the lagged explanatory variables regressors added to the model and the speed at which the model converges to equilibrium that is, dependent variable returns to equilibrium after a change in other variables. In the case of this study, ARDL ECM method will be used to correct the error models since Johansen's co-integration test method is used. The ECM model is presented below:

$$\Delta Y_t = \alpha_0 + \alpha_1 \Delta X_t + \alpha_2 U_{t-1} + \varepsilon_t$$

Where;

α_2 is the degree of adjustment or rate of adjustments

Y_t is the dependent variable

X_t is the explanatory variable(s).

U_{t-1} is the Error Correction term

ε_t is the model's error term

RESULTS AND DISCUSSION

Descriptive statistics

The statistical analysis of the data series on E-VIEWS 9 in Table 1 shows the mean, standard deviation, minimum, maximum, skewness, and kurtosis. We use the linear form of the dataset to compare the moments of the distribution of the data series. The mean value for RGDP is =N= 38.73 million. While that of DNGU, ENGU and NGF are 242,000,000, 507,000,000 and 705,000,000 MSCF respectively. And also that of NGPRI \$3.69. The low standard deviation values show that there is a lower deviation of the series from the mean. The time series of RGDP, DNGU, ENGU, and NGF mirrors a normal distribution, their values are close to the zero threshold, while the NGPRI has a long-right tail (positive skewness). The kurtosis for RGDP, DNGU, ENGU and NGF is platykurtic. That is to say they have negative kurtosis (flat-curved) as they are all lower than the values of three (being the normal distribution mark). This means the series will have lower

values below its sample mean. While that of NGPRI is leptokurtic that is it has positive kurtosis (peak-curved), it has a value higher than three.

Table 1: Descriptive Statistics

Variables	RGDP =N='m	DNGU Bscf	ENGU Bscf	NGF Bscf	NGPRI \$
Mean	38.73	242	507	705	3.688354
Std. Dev.	19.12	113	478	227	2.022547
Minimum	17.29	103	0	289	1.467500
Maximum	69.80	445	1200	1000	8.860000
Skewness	0.458409	0.420338	0.228973	-0.599234	1.184347
Kurtosis	1.632194	1.801481	1.407701	1.882504	3.614511

Source: Authors

Model Analysis for Gas Infrastructure Development and Nigeria's Economic Growth

This model measures the impact of Gas infrastructure on Nigeria's sustainable economic growth. On this wise, the measure of economic development Nigeria's Real gross domestic product is used while various Gas development measures such as Domestic Natural Gas Utilised, Export Natural Gas Utilised, Natural Gas flared and Natural Gas Price were proxies for gas infrastructures development. The following test shall be executed:

ADF Unit Root Test

The Unit root results presented in Table 2 indicates the unit root output for each variable. Specifically, the output shows that four of the variables are stationary after first-differencing they are Log(RGDP), Log(ENGU), Log(NGF) and Log(NGPRI) while Log(DNGU) is stationary at levels.

From the foregoing, the result indicates that there are just two order of integration for the variables in our model.

Table 2: Unit root test for each of the variables

Variable	ADF Statistics	Critical Value (1%)	Critical Value (5%)	Probability Value	Order of Integration
Log(RGDP)	-2.976347	-3.689194	-2.971853	0.0495	I(1)
Log(DNGU)	-4.544923	-4.356068	-3.595026	0.0066	I(0)
Log(ENGU)	-8.596035	-3.857386	-3.040391	0.0000	I(1)
Log(NGF)	-3.930529	-3.699871	-2.976263	0.0058	I(1)

Log(NGPRI)	-6.798959	-3.699871	-2.976263	0.0000	I(1)
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Source: Authors

ARDL Bounds Co-integration Test

Having obtained the order of integration for we shall proceed to test whether the variables in our model possess a long-run equilibrium relationship or not, this is also referred to as test for Co-integration. We shall adopt the Bounds Test method to establish this. The choice of this approach is informed by the nature of integration obtained in Table 3. As noted by Ahmad et al (2015), The Bounds test method for Co-integration is most suitable when there is different order of integration within a model specifically, if the variables are integrated at I(0) and I(1) i.e integrated at levels and at first difference. Ahmad et al's assertion is further corroborated by the works of Pesaran, Shin and Smith (2001).

Table 3 shows the results for the ARDL Bounds Test for the presence of co-integration within the study's model. Usually, the hypothesis is stated in null format as such, the decision rule follows that:

- (i) Accept null hypothesis if f-statistics is less than Upper Bounds value at 5 percent level of significance
- (ii) Fail to accept null hypothesis if Bounds F-statistics value is greater than Upper Bounds at 5 per cent level of significance.

From the results shown in Table 3 it is established that we could safely reject the null hypothesis. This is because; the F-statistics of 8.146756 is greater than the Upper Bounds value at 5 percent critical value of 4.01. It therefore, confirms there is long-run equilibrium relationship in our study model.

Table 3: ARDL Bounds Test for Co-integration

Model	F-statistics	
Log(RGDP) = f (LogDNGU, LogENGU, LogNGF, LogNGPRI)	8.146756	
Critical values	Lower Bounds	Upper Bound
10 %	2.45	3.52
5%	2.86	4.01

1%	3.74	5.06
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Source: Authors

Error Correction Model

Since we had established the presence of long run relationship in the model, we have to test the ability of the model to restore to equilibrium relationship when there is a short run distortion this leads to the short run and long run model displayed in Table 4 and 5.

The study's short run model along-side associated explanatory variables which are Domestic Natural Gas Utilized (DNGU), Export Natural Gas Utilized (ENGU), Natural Gas Flared (NGF) and Natural Gas Price by the Industrial Sector. Specifically, the error correction substance or ECT shows a parameter value of 0.107883 meaning that any short-run disruption in the system would take an average speed of 11 per cent to restore normalcy in the system. This speed of adjustment which appears weak indicates that shocks in the Nigerian economy could take longer time for the Gas infrastructure system to restore equilibrium.

For Table 5 which shows the estimated coefficient of long-run relationship for the model which deals on the impact of Gas infrastructure development on the performance of the Nigerian Economic growth. The results among others shows that Domestic natural gas utilized has a positive and significant influence on the performance of Nigeria's gas infrastructure at 5 per cent level of significance. Specifically, the result implies that a unit increase in domestic gas utilized would lead to a 0.9 unit improvements in the Nigerian Economic performance. Export Natural Gas Utilised has a negative and significant impact on the performance of the Nigerian economy in the long term. Specifically, a unit increase in ENGU would lead to a 2.325459 units decrease in Nigerian economic output. Natural Gas flared has a negative and significant impact on the performance of the Nigerian economy. It shows that a unit increase in NGF would lead to a 0.86 unit decrease in the level of national output. Natural Gas Price has a negative and significant impact on the performance of the Nigerian economy. It shows that a unit increase in NGPRI would lead to a 0.024 unit decrease in the level of national output.

Table 4: Short-Run Error Correction Model Representation for ARDL (1, 1, 0, 0, 0)

Regressors	Coefficient	T-statistics	Probability Value
D(LogDNGU)	-0.044083	-1.609464	0.1315
D(LogENGU)	0.250878	0.987384	0.3415
D(LogNGF)	0.092550	1.803918	0.0945

D(LogNGPRI)	0.002619	0.080882	0.9368
ECT(-1)	0.107883	1.603143	0.1329

Source: Authors

Table 5: Long-Run Error Correction Model Representation for Selected ARDL Model (1, 1, 0, 0, 0)

Regressor(s)	Coefficients	t-statistics	Prob.value
Log(DNGU)	0.965311	1.929554	0.0758
Log(ENGU)	-2.325459	-0.663021	0.5189
Log(NGF)	-0.857870	-2.228999	0.0441
Log(NGPRI)	-0.024279	-0.080300	0.9372
C	22.594255	1.572351	0.1399

Source: Authors

Discussion of findings

The general study in energy economics debates that increase in gas infrastructure development, in this case proxied by domestic natural gas utilization and export natural gas utilization, will benefit the economy while and increase in natural gas flared will have an adverse effect on the economy. Among others, the following are apparent from the empirical results of the model, they are as follows;

(i) Domestic Natural Gas Utilised has a positive and significant influence on the performance of Real Gross Domestic Product at 5 per cent level of significance. Specifically, the result implies that a percentage increase (decrease) in DNGU would lead to a 0.965311 percent improvements (deterioration) in the performance of the Nigerian Economy.

(ii) Export Natural Gas Utilised has a negative and insignificant impact on the development of the Nigerian economy. Specifically, a percentage increase (decrease) in NGU would lead to a 0.857870 percent (decrease) increase in Nigerian economy.

(iii) Natural Gas flared has a negative and significant impact on the performance of the Nigerian economy. It shows that a percentage increase (decrease) in NGF would lead to a 0.857870 percent decrease (increase) in the level of national output.

(iv) Natural Gas Price has a negative and significant influence on the performance of Real Gross Domestic Product at 5 per cent level of significance. Specifically, the result implies that a percentage increase (decrease) in NGPRI would lead to a 0.024279 percent increase (decrease) in the performance of the Nigerian Economy.

(v) The R2 value shows that the explanatory variables explain 99.8 per cent of total changes in the dependent variable.

(vi) DNGU and NGF satisfies apriori expectation while ENGU, NGPRI does not.

CONCLUSION

The study explains the effect of gas infrastructure development on the economy through the analysis of gas utilization for the period covering from year 1989 to 2018 in this study using the E-Views, an econometric modelling analytical tool for time-series forecasting of the modelled Ordinary Least Squares Equations (OLE), the result shows that there is significant and positive relationship between the natural gas utilized and development of Nigeria's gas infrastructure, as the number of gas infrastructure increases the volume of gas sold also increases. Domestic Natural Gas Utilization equally displayed that on the long term it contributes positively to the building/development of the nation's gas infrastructure and the performance of the Nigerian economy. It could be proven to be healthy and that there is positive effect of the domestic natural gas utilization on the nation's economy if there is adequate gas infrastructure to process produced gas. The study also showed that Export Natural Gas Utilized and Natural Gas Price has a negatively impacts on the performance of the Nigerian economy, this can be as a result of gas making inroad to our energy stream. On the other hand, the effect of flaring natural gas has negative implication on the national economy as revealed by the Economic Effect of Gas Infrastructure result obtained from the analysis in terms of its effect on the GDP. It is essential to understand the macroeconomic framework of an economy before implementing policies that can effectively mitigate the adverse effect of deficit gas infrastructure.

RECOMMENDATION

To give solution to gas infrastructure deficit is in Nigeria, we recommend that

- Exiting policy on domestic gas utilization should be revised and the policy and regulatory framework for the development/upgrade of gas fields, infrastructures and distribution should be economically feasible for the investors to partake in the industry. The policies should not be vague, there should be specific detailed features such as legislation, regulation, industry structure, developing gas resources, national human resources and gas markets, infrastructure, communications strategy and a roadmap and action plan. The revised Policy should mandate the legislative and commercial framework in place, so that private sector drives the development of the gas sector. There should be specific detailed features such as legislation, regulation, industry structure, developing gas resources, infrastructure, building gas markets, developing national human resources, communications strategy and a roadmap and action plan. The Policy could be

planned to capture the envisioned short term, medium term and long term framework to grow the country's gas sector.

- The Government should ensure that terms of contract are précised and on their own part, they should be committed to the conditions defined in the contracts that is to say the contracts should be enforceable as this will encourage more Foreign Direct Investments.
- Looking at the correlation between the gas price and export gas being negative, it stands to reason that the positive correlation exhibited by other countries is as result of them having adequate gas infrastructure that enhances gas utilization. Hence it is also appropriate that Nigeria develops its gas infrastructure in other to have a positive correlation. The funding of the new projects should also be encouraged especially gas transmission infrastructure to accommodate gases not utilized that are to be flared. This would foster job creation for the teeming youths thereby spurring socioeconomic growth.

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ENZYME EXPRESSION: A SUROGATE TO HALOPHYTE SENSITIVITY IN HYDROCARBON IMPACTED SALINE WETLAND.

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ABSTRACT

Plants immobility especially during times of acute stress and danger has led to the formation of strong antioxidant systems. Halophytes have the ability to thrive in stressed condition primarily high salinity. The enzymatic expressions of these halophytes; *Paspalum vaginatum*, *Rhynchospora corymbosa* and *Fimbristylis littoralis* present in their natural saline habitat and those in the natural habitats exposed to hydrocarbon pollution were considered in this study. Soil and plant samples were obtained from Bodo Creeks during the wet and dry season, and analyzed for their Total Hydrocarbon Content (THC) as well as plant stress enzymes, Catalase, Superoxide Diamutase, PolyPhenoloxidase, Peroxidase and Malondoaldehyde. Also, bioaccumulation factor was calculated. The results obtained were subjected to statistical analysis revealing significant differences ($P > 0.05$). Higher and varying enzymatic expressions in plants exposed to saline stress and those exposed to both saline and hydrocarbon stresses were recorded. It was deduced that each plant expressed each enzyme differently. Consequently, an increase or decrease in bioaccumulation factor of THC in each respective plant did not receive a corresponding increase or decrease in enzymatic expressions of all the enzymes which could be as a result of other factors propelling the production of certain enzymes in plants.

KEYWORDS: Halophytes, *Paspalum vaginatum*, *Rhynchospora corymbosa*, *Fimbristylis littoralis*, Catalase, Superoxide Diamutase, PolyPhenoloxidase, Peroxidase, Malondialdehyde, THC, Pollution, Salinity.

Introduction:

Presently, changes in soil saline concentrations is one of the world's greatest challenges especially in agriculture and this has led to a decline in plant productivity and microbial community. This has further led to a depletion of the vegetation around the globe which impacts the environment and the human population because a large number of plant species are sensitive to increased salinity (Mishra & Tanna, 2017). In the face of these changes, certain plant species are naturally adapted to flourishing in their habitat under highly stressed environment. These plant species known as Halophytes are known to thrive in environments of high salinity and are considered to be salt resistant and tolerant with their ability to complete their life cycle in such environment (Flowers

& Colmer, 2008). Salinity stress is known to cause secondary stress in plants which could be portrayed as osmotic and/ or oxidative stress which if not managed by the plants can lead to osmotic and ionic imbalance, functional and structural protein damage as well as membrane injury (Das & Strasser, 2013; Rajput et al., 2021).

The ability of halophytes to be salt tolerant in their environment can be linked to Reactive Oxygen Species (ROS) generation and detoxification pathways amongst other mechanisms which focuses on the activities of antioxidative enzymes which are critical in the rummaging or scouting of toxic radicals within the plant system thereby aiding in detoxification and cell integrity (Das & Strasser, 2013).

Pollution known as the introduction of external, foreign and harmful substances into an environment that changes and influences the natural state of the environment and the organism's residual therein. One of the biggest problems facing growing and developed industrial nations is environmental pollution brought about by rising human activity (Edwin-Wosu & Nkong, 2015; Fanaei et al., 2020). This alteration forces the organisms to simulate mechanisms to strive within this environment and thrive or die.

The metabolic processes of species, particularly sessile creatures, have been found to be impacted by hydrocarbon pollution in diverse ecosystems ranging from freshwater swamp, tropical rain forests, and mangrove forest which are rich in unique biological diversity (Anejonu et al., 2015) However, a significant challenge to the saline coasts has been the contamination caused by hydrocarbons, particularly to the halophytes that are flourishing in such natural habitats (Gao et al., 2022).

Glycophytes categorized as salt sensitive plants have been studied to reveal their tolerance and adaptation to environmental stress like hydrocarbon pollution within their environment (Alam and Sharma, 2017). However, there is little information on the sensitivity of halophytes to such hydrocarbon stressed and other toxic environmental stresses beside the saline stress. Studies have recorded the use of enzyme technology in remediation technology (Whiteley and Bee, 2006; Edwin-Wosu & Nkang, 2015). Enzymes are substances that function as catalysts in living things, controlling the speed at which chemical processes happen without undergoing any changes to themselves (Britannica, 2023). In plants, some enzymes are known to break down free radicals

that are released under stress conditions. For instance, Catalase breaks down hydrogen peroxide (H_2O_2) to water (H_2O).

This study was aimed at revealing the sensitivity responses predicated on enzymatic expression of three halophyte species in parts of Bodo Creek under hydrocarbon pollution. Furthermore, it seeks to compare the differences in variation between the enzyme expressions in plants species present in hydrocarbon polluted and unpolluted sites to ascertain the varying enzymatic expressions. The significance of this study promotes the evaluation of enzymatic activities in halophytes as a surrogate to their response to exposure to stress conditions.

Methodology:

Description of Study Site:

This study was conducted within March 2021 and July 2021 for the dry and the wet season respectively. Several documented reports have described the study area (Rivers state) in line with national context, thus revealing its geographical location (Fig. 1) and neighboring states in parts of Northern, Eastern, Western and Southern Nigeria (Edwin-Wosu & Edu, 2013; Mojuetan & Edwin-Wosu, 2022), types or vegetation complex and environmental condition (Izah, 2018; Mojuetan & Edwin-Wosu, 2022).

The state houses 23 local government council including the study location – Gokana (Fig. 2), there in the study site, Bodo community and the sampled site- Bodo creek is situated. Bodo creek accommodates a large expanse of swamp land, expansive mangrove ecosystem and salt marshes approximately spanning 9,230 hectares with canals permitting the influx and outflux of salt water (Pegg & Zabbey, 2013; Zabbey & Babatunde, 2015; Gbaa & Tanee, 2020).

Some parts of the wetland in Bodo Creeks have been impacted by hydrocarbon pollution. Selection of study locations were based on the resilience and prevalence of some halophyte species as well as their abundance within the hydrocarbon impacted sites and the unimpacted sites.

Flora Sample Collection:

Based on the patchy and random distribution of halophytes, the species were randomly sampled from both the impacted and non-impacted sites. Three halophyte species at their individual points were georeferenced at the coordinates in Table 1 using a handheld GPS for cartographic expression and imagery of study area, location and sites indicated in Figures 1-3.

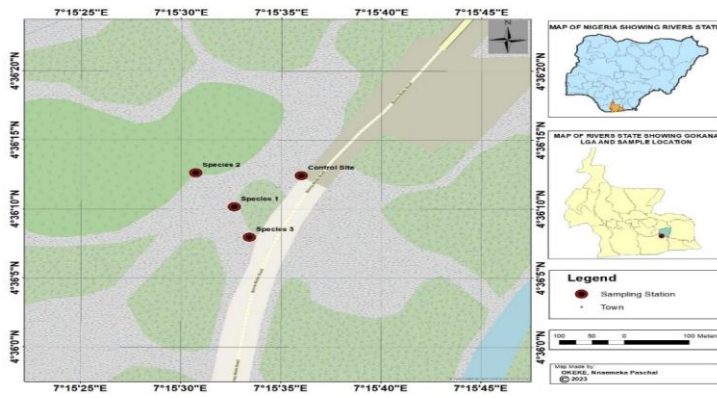


FIGURE 3: STUDY SITE (BODO – BONNY BRIDGE) INDICATING SAMPLE SITE PARTS OF BODO CREEK.
 TABLE 1: Coordinates Of Species Sampled Points

PLANTS	IMPACTED SITE	NON-IMPACTED SITE
<i>Paspalum vaginatum</i> (Sp 1)	04.60286° N 007.25911° E	04.60345° N 007.26004° E
<i>Rhynchospora corymbosa</i> (Sp2)	04.60353° N 007.25852° E	04.60345° 007.26004° E
<i>Fimbristylis littoralis</i> (Sp3)	04.60242° N 007.25936° E	04.60345° N 007.26004° E

Laboratory Analysis:

At the laboratory, the following enzymes were analyzed:

Catalase (CAT): The reagents KH_2PO_4 (0.7ml) in 50 ml and Na_2HPO_4 (0.87ml) in 50 ml water) were incubated at 370°C. In a test tube, 4ml of (0.036%) H_2O_2 was added. 100µl of the sample was pipetted. At 0, 30 seconds, and 1 minute, measurements were read. An increase or decrease in absorbance at 240 nm was observed and recorded (Aebi , 1984).

The change in catalase activity was calculated as: (Change in Absorbance per Minute or per Unit of Time) = $[(\Delta A_{240\text{nm}} / \Delta t)]$ Where: $\Delta A_{240\text{nm}}$ = Change in absorbance at the specified wavelength (240 nm) during the time interval. Δt = the time interval in minutes or seconds for which the change in absorbance is measured

PolyPhenol Oxidase (PPO): A known quantity of 1g of the sample was homogenized at 4 °C in 2 ml of 0.1 M sodium phosphate buffer (pH 6.5) and centrifuged at 20,000 rpm for 15 minutes. Polyphenol oxidase activity was measured using the supernatant as an enzyme source. The reaction mixture included 200ml of the enzyme extract and 1.5 ml of 0.1 M sodium phosphate buffer (pH 6.5). 200ml of 0.1M catechol was added to begin the reaction, and the activity was measured as a change in absorbance at 495nm over the course of three minutes at 30secs intervals. Changes in absorbance $\text{min}^{-1}/\text{mg}^{-1}$ of protein were used to express the enzyme activity (Mayer et al., 1965).

PPO Activity (Changes in Absorbance per Minute per mg of Protein) = $(\Delta A_{495\text{nm}}) / \Delta t] / (\text{mg of Protein})$

Where: $\Delta A_{495\text{nm}}$ = the change in absorbance at 495 nm during the specified time interval.

Δt = the time interval in minutes for which the change in absorbance is measured

mg of Protein = the amount of protein in the enzyme extract used in the assay.

Superoxide Diamutase (SOD): A known quantity of 4ml of Carbonate buffer was measured into test tube. 100 μl of sample mix was pipetted and incubated at 37°C. The reaction was started by pipetting 100 μl of adrenalin. Readings were taken at 0, 30 secs and 1minute at 480nm (Misra and Fridovich, 1972).

SOD Activity = $[(\text{Blank Absorbance} - \text{Sample Absorbance}) / \text{Blank Absorbance}] \times \text{Dilution Factor}$

Where: Blank Absorbance = the absorbance of the blank solution (containing 4 ml carbonate buffer, 100 μl sample, and 100 μl adrenaline) at 480 nm after the specified incubation time (30 seconds). Sample Absorbance = absorbance of the sample solution (containing 4 ml carbonate buffer, 100 μl sample, and 100 μl adrenaline) at 480 nm after the specified incubation time.

Dilution Factor = any dilution that may have occurred during the procedure.

Peroxidase (POD): The plant's homogenate (10%) was made in 0.1M phosphate buffer (pH 6.5), clarified by centrifugation, and the assay was conducted using the supernatant. 0.1ml of the

enzyme extract was added to 3.0ml of pyrogallol solution after the spectrophotometer was set to read zero at 430 nm. 0.5ml of H₂O₂ was added to the test cuvette and stirred. A spectrophotometer was used to record the change in absorbance every 30 seconds for up to 3 minutes. The change in absorbance per minute at 430 nm is used to measure peroxidase activity (Chance & Maehly, 1995).

POD Activity = (Change in Absorbance per Minute at 430 nm) = (ΔA_{430nm}) / Δt

Where: ΔA_{430nm} = the change in absorbance at 430 nm during the specified time interval.

Δt = the time interval in minutes for which the change in absorbance is measured

Malondialdehyde (MDA): A known quantity of 1% of Thiobarbituric Acid, 15% of Trichloroacetic Acid and 4% of Sulphosalicylic Acid were prepared in 100ml of 0.25N HCl (2.03ml HCl in 100ml distilled water). 0.5 ml sample was added to 3 ml of working reagent. It was boiled for 15 minutes to 20 minutes, centrifuged for 15 minutes and read at 532nm (Sharma and Krishna, 1968).

Lipid Peroxidation (Malondialdehyde) = [(Sample Absorbance - Blank Absorbance) / Working Reagent Volume] \times Dilution Factor

Where: Sample Absorbance = the absorbance of the sample at 532 nm after the reaction. Blank Absorbance = the absorbance of the blank solution (0.5 ml sample + 3 ml working reagent) at 532 nm after the reaction. Working Reagent Volume = the volume of the working reagent used (3 ml). Dilution Factor = any dilution that may have occurred during the procedure.

Total Hydrocarbon Content: A 500 ml separatory funnel was filled with 2g of the sample. After adding 20 ml of solvent, it was shaken vigorously for two-minute. The solvent layer was allowed to settle and then it was separated. After capturing contaminants and water using filter paper and sodium sulfate, a portion of the solvent layer was transferred to a sterile, volumetric flask and placed into a dry 10 mm photometer cell. To obtain a reading at 420 nm wavelength, the photometer's cell was moved to the AAS. Before the sample measurement, the photometer was calibrated and a blank reference was also recorded (Note: the cell contained a solvent as blank). The calibration data was used to determine the concentration of total hydrocarbon content. It was calculated by measuring the concentration of the sample extract using sample photometer reading on reference calibration curve.

BIOACCUMULATION FACTOR: This was calculated as: $BCF = C_{PLANT} / C_{SOIL}$

C_{PLANT} = concentration of THC in plant; C_{SOIL} = concentration of THC in soil. (Laadislav et al., 2012).

Statistical Analysis: The results obtained were subjected for statistical analysis using Duncan Multiple Range Test and Least significant difference to test for their levels of significance.

RESULT:

The result of enzyme activity expression as presented in Table 2 has revealed seasonal variation among the halophytic species under polluted and controlled conditions.

The catalase activity was expressively significant ($P < 0.05$) among species with *P.vaginatum* under pollution recording the highest activity of 536 ± 32.70^a u/g and 581 ± 34.10^a u/g respectively in dry and wet seasons. *R.corymbosa* under pollution and *P.vaginatum* not under pollution recording the least activity of 345 ± 26.30^b u/g and 271 ± 23.3^b u/g in dry and wet seasons respectively.

The Polyphenoloxidase activity was expressively significant ($P < 0.05$) among species with *P.vaginatum* under pollution recording maximum activity in the dry and wet seasons, respectively, at 4.7 ± 1.2^a min/g and 1.3 ± 0.9^{ab} min/g. *Fimbristylis littoralis* under pollution recorded the least activity of 0.67 ± 0.2^{ab} min/g in the dry season while *R. corymbosa* (under pollution) and *F. littoralis* (controlled) recording the least activity of 0.4 ± 0.2^{ab} min/g during the wet season.

The Malondialdehyde activity was expressively significant ($P < 0.05$) among species with *Rhynchospora corymbosa* recording the highest activity of 26 ± 7.3^{ab} nmol/g and 35 ± 8.4^a nmol/g in dry and wet seasons respectively. *Fimbristylis littoralis* (controlled) recording the lowest activity of 22 ± 6.7^b nmol/g in the dry season while *R. corymbosa* (controlled) recording the least activity of 23 ± 6.7^b nmol/g during the wet season.

The Superoxide diamutase activity was revealed to be expressively significant ($P < 0.05$) among species where *Rhynchospora corymbosa* under pollution recording the highest activity of 539 ± 32.8^a min/g and 595 ± 34.5^a min/g in dry and wet seasons respectively. *R.corymbosa* under pollution and *P.vaginatum* (controlled) and *Fimbristylis littoralis* under pollution recording the least activity of 307 ± 24.8^b min/g and 344 ± 26.3^b min/g in dry and wet seasons respectively.

The Peroxidase activity was expressively significant ($p < 0.05$) among species with *P.vaginatum* under pollution recording the highest activity of 4 ± 2.60 min/g and 6.11 ± 3.50 min/g in dry and wet seasons respectively. *R.corymbosa* and *F. littoralis* under pollution recording the least activity of 1.5 ± 0.8 min/g and 0.9 ± 0.5 min/g in dry and wet seasons respectively.

RESULTS

TABLE 2: TOTAL HYDROCARBON CONTENT IN SOIL AND PLANT ROOTS

PLANT SPECIES		DRY SEASON			WET SEASON		
		THC in soil (mg/kg)	THC accumulated in plant roots (mg/kg)	Bioaccumul ation Factor	THC in soil (mg/kg)	THC accumulated in plant roots (mg/kg)	Bioaccumul ation Factor
<i>Paspalum vaginatum</i>	Polluted	50727 ±318.2 ^a	1455.33 ± 53.95 ^a	0.03 ^{ab}	52952 ± 338.3a	1185.33 ± 48.69 ^a	0.022 ^{ab}
	Control	81 ± 9.4 ^b	0.60 ± 1.10 ^b	0.008 ^b	97 ± 8.2b	1.18±1.54 ^b	0.012 ^b
<i>Rhynchospora corymbosa</i>	Polluted	53076 ± 331.8 ^a	1342.67± 51.82 ^a	0.025 ^{ab}	53782 ± 349.9a	1134±47.62 ^a	0.021 ^{ab}
	Control	76±9.0 ^b	0.28±0.73 ^b	0.004 ^b	89±5.6b	1.05±1.45 ^b	0.012 ^b
<i>Fimbristylis littoralis</i>	Polluted	50858 ±320.8 ^a	1366.66±52.28 ^a	0.027 ^{ab}	48314±309.5a	1168±48.33 ^a	0.024 ^{ab}
	Control	66±8.1 ^b	0.58±1.07 ^b	0.09 ^b	92±6.7 ^b	1.13±1.50 ^b	0.007 ^b

TABLE 3: ENZYME ACTIVITY OF THE HALOPHYTE IN HYDROCARBON POLLUTED AND UNPOLLUTED SITES

SPECIES/ ENZYMES		DRY SEASON					WET SEASON				
		CAT u/g	PPO min/g	MDA nmol/g	SOD min/g	POD min/g	CAT u/g	PPO min/g	MDA nmol/g	SOD min/g	POD min/g
<i>Paspalum vaginatum</i>	Polluted	536±32.7 ^a	4.70±1.2 ^a	24±6.9 ^{ab}	334±22.9 ^b	4.00±2.6 ^a	581±34.1 ^a	1.30±0.9 ^a	33±8.1 ^a	375±27.4 ^b	6.11±3.5 ^a
	Control	350±26.5 ^b	0.70±0.3 ^b	23±6.8 ^b	307±24.8 ^b	2.40±1.2 ^{bc}	271±23.3 ^b	0.63±0.2 ^b	28±7.6 ^a	417±28.9 ^a	2.70±1.3 ^b
<i>Rhynchospora Corymbosa</i>	Polluted	345±26.3 ^b	2.80±1.4 ^a	26±7.3 ^{ab}	539±32.8 ^a	1.50±0.8 ^c	374±27.4 ^b	0.40±0.3 ^b	35±8.4 ^a	595±34.5 ^a	1.80±0.9 ^c
	Control	440±29.7 ^{ab}	0.70±0.2 ^b	26±7.3 ^{ab}	502±31.7 ^a	1.90±0.9 ^c	478±30.9 ^{ab}	0.80±0.4 ^{ab}	23±6.7 ^b	417±28.9 ^a	1.30±0.6 ^c
<i>Fimbristylis Littoralis</i>	Polluted	380±27.6 ^b	0.67±0.2 ^b	24±6.9 ^{ab}	384±27.7 ^b	2.00±1.0 ^{bc}	413±28.8 ^{ab}	0.90±0.5 ^{ab}	29±7.7 ^a	344±26.3 ^b	0.90±0.5 ^c
	Control	523±32.4 ^a	2.10±0.9 ^a	22±6.7 ^b	353±26.6 ^b	2.40±1.1 ^{bc}	517±32.1 ^a	0.40±0.2 ^b	28±7.6 ^a	440±29.7 ^a	1.60±0.8 ^c
MEAN		420	1.93	24.17	403.17	2.37	430	0.73	29.33	438.33	2.40
LSD(0.05)		84.31	0.99	3.31	59.03	1.09	82.72	0.82	3.84	59.93	1.79

The different superscripts within the columns represent the significant difference at (p < 0.05)

TABLE 4: PEARSON CORRELATION BETWEEN ENZYMES IN PLANTS AT DRY SEASON AND WET SEASONS

DRY SEASON						WET SEASON					
	PPO/min	POD/min	SOD/min	CAT U/g	MDA nmol/g		PPO/min	POD/min	SOD/min	CAT U/g	MDA nmol/g
PPO/MIN	1					PPO/min	1				
POD/min	0.68	1				POD/min	0.68	1			
SOD/min	-0.08	-0.67	1			SOD/min	-0.69	-0.21	1		
CAT U/g	0.56	0.71	-0.34	1		CAT U/g	0.49	0.43	-0.29	1	
MDA nmol/g	0.01	-0.40	0.87	-0.37	1	MDA nmol/g	0.04	0.45	0.46	0.01	1

Discussion:

Generally, the results (Table 2) reveal the enzyme concentrations that catalyze reactions to neutralize free radicals and reactive oxygen species as a result of the abiotic stresses the halophytes studied are exposed to. This revealed significant differences within and among the species in the different enzymatic activities and expressions in the hydrocarbon polluted and unpolluted sites. CAT, POD, MDA, SOD and PPO enzyme activities revealed different levels of representation within the species.

Furthermore, it could be deduced that the Catalase (CAT) and Superoxide Diamutase (SOD) had higher enzyme expressions in all the halophytes compared to other enzymes studied during the dry and wet season which collaborates the findings of Ermakov et al. (2019) which revealed that under stress conditions SOD reacts with superoxide leading to a dismutation reaction giving out peroxide while catalase splits hydrogen peroxide into water. Nonetheless, CAT and SOD revealed a negative correlation ($r = -0.34$) and ($r = -0.29$) at dry and wet season respectively revealing these enzymes act independent of each other. Furthermore, the increased activities of these enzymes SOD, CAT, PPO, and POD are significant in detoxifying ROS under abiotic stresses which include high salinity and hydrocarbon pollution collaborating with the findings of Almeselmani et al. (2006) and Sidiqi et al. (2017) that higher expression levels of enzymatic antioxidants induced by salt treatment suggests an efficient way to decrease saline toxicities. This is obtainable because the occurrence of abiotic stresses either individually or simultaneously triggers the overproduction of ROS in plant cells thereby increasing the enzymatic activities to ensure these plants grow optimally (Sachdev et al., 2021) and plants with efficient ROS scavenging systems are known to perform better under these stresses (Katano et al., 2018; Ahmad et al., 2020).

The lipid peroxidation product, MDA, indicates the degree of oxidative damage in the cell and hence a marker for the degree of the damage (Sharma et al., 2012; Das. & Roychoudhury, 2014; Sachdev et al., 2021). Under stress conditions, Reactive Oxygen Species is multiplied severally in plants leading to oxidative stress which leads to a decline in their productivity or death (Apel & Hirt, 2004, You & Chan, 2015). During the dry season, there was little or no variation between the halophytes exposed to only saline stress and those exposed to saline/hydrocarbon pollution stress. This implies that the oxidative damage within the cells of halophytes present in polluted and unpolluted sites were similar. However, during the wet season, there was an increase in the MDA

activity in halophytes present in polluted sites than the unpolluted revealing higher oxidative damage within their cells.

As such, a comparison of the halophytes studied at both seasons revealed an increase in the MDA activity and variations in the increase or decrease of corresponding antioxidant enzymes. During the dry season, the negative correlation between POD & MDA ($r = -0.39$), CAT & MDA ($r = -0.37$) and the positive correlation between SOD & MDA ($r = 0.87$), PPO & MDA ($r = 0.01$) as well as the weak correlation between PPO & MDA ($r = 0.04$), CAT & MDA ($r = 0.01$) and the positive correlation between SOD & MDA ($r = 0.46$), POD & MDA ($r = 0.45$) indicated variations in the increase of these antioxidant enzymes which did not prevent lipid peroxidation which is similar to the findings of Ayse and Sema (2013).

The results in Table 3 reveal that the plants under study have the potential to accumulate a high concentration of THC in their roots. However, the plants in the polluted site accumulated more THC during the dry season than the wet season which was the opposite for the plants in control. Nonetheless, the plants in the control recorded lower THC in soil thereby accumulating lower THC leading to a lower bioaccumulation factor. Consequently, an increase or decrease in bioaccumulation factor of THC in each respective plant did not receive a corresponding increase or decrease in expressions of all the enzymes which could be as a result of other factors propelling the production of certain enzymes in plants. This buttresses the findings of Bingol et al (2021) that variations in enzyme expressions be as a result of the co-factor necessary in its production as well as its place of production.

In conclusion, it could be deduced from the results that there are variations in the enzymatic expressions and response of *Paspalum vaginatum*, *Fimbristylis littoralis* and *Rhynchospora corymbosa* present in only saline stressed condition as well as in a combination of hydrocarbon and saline stress factors which is similar to the findings of Toranto et al. (2017) that stress enzymes expression differs from plant to plant. However, there were notable increases in the enzymatic expressions in these plants during the Wet season.

Conclusion:

This study investigated the enzyme expression of Catalase, Malondialdehyde, Polyphenoloxidase, Peroxidase and Superoxide diamutase in *Fimbristylis littoralis*, *Rhynchospora corymbosa* and *Paspalum vaginatum*. The results revealed variations in enzymatic expressions between the plant species present in the hydrocarbon impacted and unimpacted sites for the different enzymes studied. In summary, this study revealed that the impact of salinity stress on enzymatic expressions is similar to the impact of hydrocarbon impacted soils on them too.

Recommendations:

1. Co-factors of each plant stress enzymes should be studied in subsequent research to ascertain other factors propelling their expression and activity in plants.
2. Reactive Oxygen Species such as Superoxide, Hydrogen Peroxide should be analyzed alongside the stress enzymes in other to determine the efficacy of these enzymes in combating ROS.

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EVALUATION AND DESIGN OF WIND ENERGY GENERATION IN NIGERIA

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Abstract

Wind energy resources remain important sources of energy that can complement to a great extent power generation obtained from other energy resources in Nigeria such as hydropower, natural gas etc. This article is primarily on the evaluation and design of wind energy resources in Nigeria. To achieve this purpose the meteorological data of wind speed for six Nigerian cities was obtained from the Nigerian Meteorological Agency, NiMet. The cities investigated includes Port Harcourt, Owerri, Ibadan, Jos, Kaduna, Maiduguri. The findings from this research showed that the average wind power density ranged from 19.05 Wm⁻² in Owerri to 1,017.38 Wm⁻² in Jos at a height of 10m, 53.31Wm⁻² in Owerri to 1,814.39 Wm⁻² in Jos at a height of 30m and 103.76 Wm⁻² in Owerri to 2,637.66Wm⁻² in Jos at a height of 50m. The study showed that at a height of 10m ,Jos had the highest average wind speed of 4.21 m/s while Owerri has the lowest average wind speed of 1.21 m/s. The data obtained was processed and analyzed using the relevant statistical and computational methods like Weibull distribution model and other platforms. The wind potential of the six region/city was also classified according to strength at different heights to determine the region with the best wind potential. This article also includes the modelling of a location-specific wind turbine for use in the region with the best wind potential. The findings obtainable from this research will guide Nigerian government at all levels and private sector investors in making the right policies and decisions towards investments in wind energy resources.

1. Introduction

Nigeria's population is estimated at about 203,595,926 million and her population density hovers around 226 people/km² (586 people per square mile) of which 351,650 square miles (910, 770 square km) is the total land area. More than 40% of Nigeria's population have no access to electricity which is one of the reasons affecting the economic growth of the country. The demand of energy in Nigeria outweighs its availability or supply. Nigeria is endowed with abundant conventional (fossil fuel) energy resources, such as oil, gas, coal, etc. These sources have predominantly contributed over 90% of the country's income and also dominate the fuel sources for electrical energy production and other energy needs of the populace (Aliyu et al.,2015) . Although it has been generated for over a century, Nigeria is blessed with rich renewable energy

resources that can be used in producing electricity, the most viable ones being solar energy, small and large hydropower, wind and biomass (Aliyu.,2015). Wind is actively a reliable approach to sustainable development for developing and developed nation. Wind renewables have not been harnessed most appropriately in Nigeria considering its availability. These could be caused by a number of factors enumerated in this research. Nevertheless, an optimal exploitation of energy from wind sources for a region evaluation of the wind energy potential in that region, an in-depth knowledge of energy availability, as well as feasibility of wind energy systems in such areas for power generation. The purpose of this paper is to evaluate wind energy resources in Nigeria. It also reviews the potentials of wind energy resources in Nigeria, challenges and appropriate solutions over these challenges.

2. Materials and Methods

The seven year (2015-2021) Monthly wind speed data of six Nigerian cities was obtained from Nigerian Meteorological Agency (NiMet). Evaluation of the obtained wind speed data using the Weibull distribution model in order to ascertain the wind potentials of the studied locations was carried out. The weibull distribution model determines the wind power density of the investigated locations using their wind speed data over the seven year period. The wind power density is a measure of the wind potential of each of the investigated cities/locations. The outcome of the evaluation is summarized in Table 1. The mean yearly wind speed of the six cities for the seven year period is also determined and represented using Microsoft Excel in order to gain more insights

on the strength of wind resources in the investigated locations as shown in Figure 1. The wind potential of the investigated cities is analyzed to ascertain the cities with the best wind potentials. A location-specific wind turbine system suitable for use in the region with the best wind potential is modelled using Matlab simulink.

3. Results and Discussion

The following results was obtained after a thorough evaluation of the data obtained from the Nigerian Meterological Agency (NiMet) with respect to understanding the wind potentials of the six cities. The results provided a clear insight on the strength of the wind resources in the six locations selected from the six geopolitical zones of Nigeria.

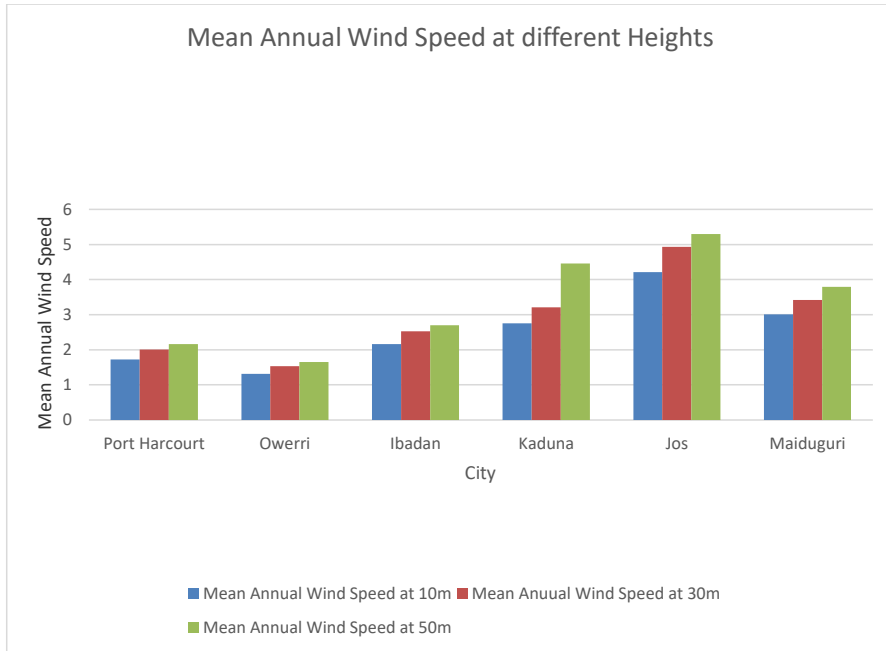


Figure 1: Mean Annual Wind Speed at a Height of 10m, 30m and 50m in Port Harcourt, Owerri, Ibadan, Kaduna, Jos and Maiduguri for the Period 2015-2021(Nigerian Meteorological Agency, NiMet)

Figure 1 clearly indicates that wind speed increases with height above sea level. It can also be observed that Jos has the highest wind speed during the investigated period while Owerri has the least wind speed.

Table 1: Annual Average Wind Power Density (AWPD) at Different Heights above Ground

Level

LOCATIO N	AWPD(Wm ⁻²) at 10m	CLAS S	AWPD(W m ⁻²) at 30m	CLAS S	AWPD(W m ⁻²) at 50m	CLASS	RESOURCE POTENTIAL at 50m
PORT HARCOUR T	42.44	1	108.24	1	173.93	1	Very Poor
OWERRI	19.05	1	53.31	1	103.76	1	Very Poor
IBADAN	90.32	1	216.74	2	327.55	3	Marginal
KADUNA	240.22	4	496.84	6	724.91	6	Excellent
JOS	1,017.38	7	1,814.39	7	2,637.66	7	Excellent
MAIDUGU RI	156.26	3	369.61	4	519.89	5	Very Good

Table 1 shows the average wind power density (AWPD) at different heights above ground level. The table indicates that the average wind power density ranged from 19.05 Wm⁻² to 1,017.38 Wm⁻² at a height of 10m, 53.31Wm⁻² to 1,814.39 Wm⁻² at a height of 30m and 103.76 Wm⁻² to 2,637.66Wm⁻² at a height of 50m. The table also indicated that the wind power density of a particular location increases with height. At the height of 50m, the wind potential of Kaduna and Jos is strong and can sustain large scale power generation. The wind potential of Maiduguri can support medium scale power generation while that of Ibadan can only support small scale power generation while the wind potential of Owerri and Port Harcourt are poor and may not be good

for harnessing wind energy unless energy is tapped from higher altitudes.

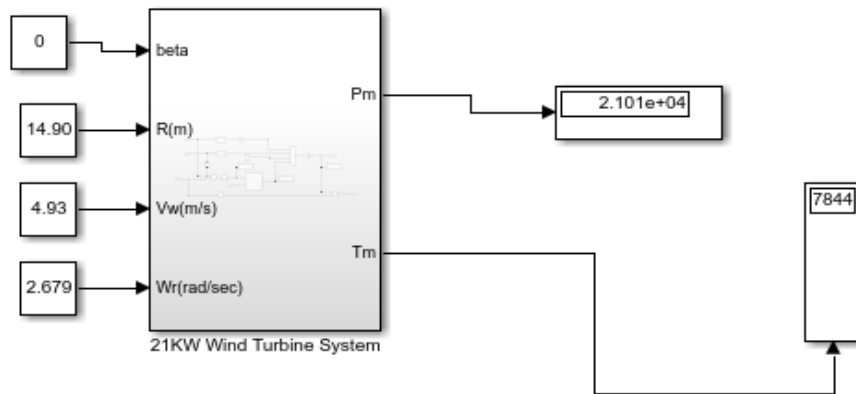
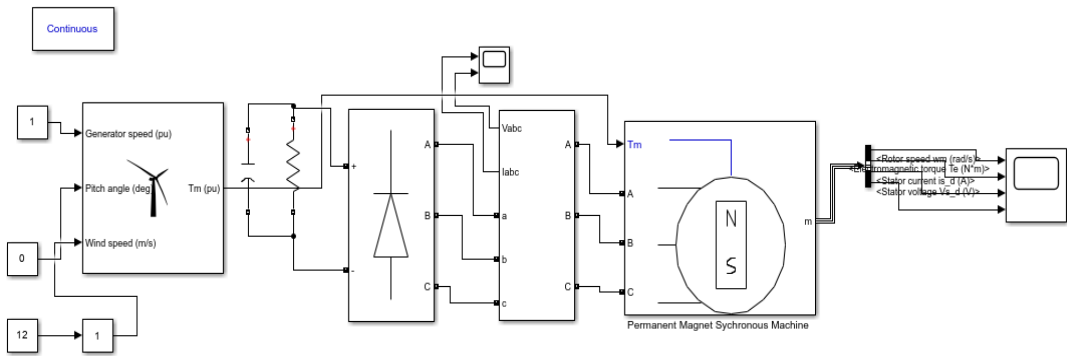


Figure 2: Wind power plant model

A location-specific wind turbine system suitable for use in Jos which is the region with the best wind potential is modelled using Matlab simulink. This is shown in Figure 2, Figure 3, Figure 4. The system in Figure 2 is a 21KW Turbine designed using Matlab. The output mechanical power, blade pitch angle, blade radius, wind speed, angular velocity and mechanical torque of the wind turbine is denoted as P_m , β , R_m , V_m , W_r , T_m . The values of the design parameters are indicated in Figure 2. The wind turbine was designed considering an average wind speed of 4.93 m/s at height of 30m above sea level obtainable in Jos for the period of years 2015 to 2021. The blade radius is 14.90 m/s as shown in Figure 2.

Figure 3: 21KW Wind Turbine System

Figure 3 is a modification of the initial wind turbine design of figure 2. This Simulink model now includes wind turbine and circuit elements to generate current. The circuit elements include permanent synchronous machine. This device operates as the generator that converts mechanical power of the wind to electricity. The circuit also includes the three phase V-I measurement that



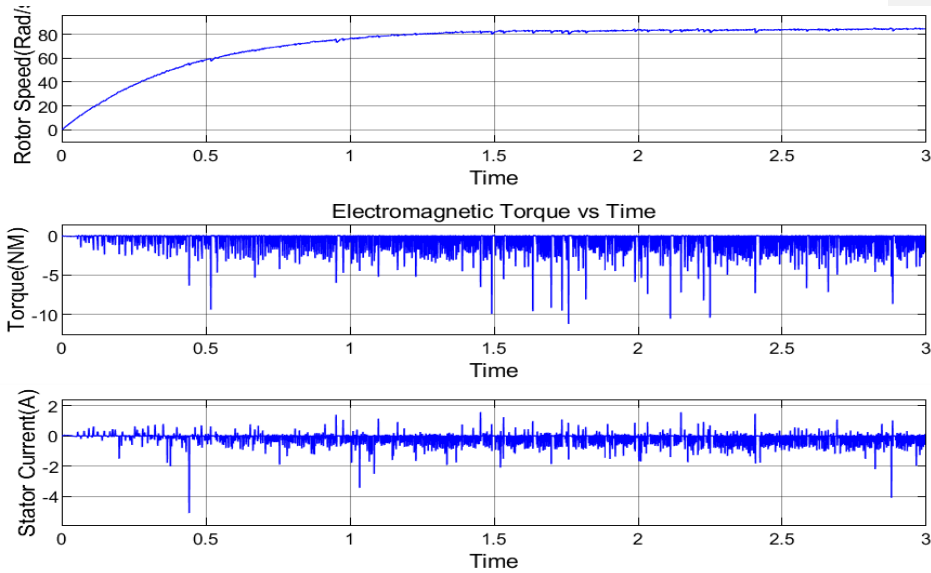


Figure 4: Wind Turbine Output Plots of Rotor Speed, Torque and Stator Current

Figure 4 is the output plot of stator current, rotor speed and electromagnetic Torque of the wind Turbine in Figure 3. The values of these variables depend on the power produced by the generator and value of the capacitance and resistor in wind turbine Simulink model.

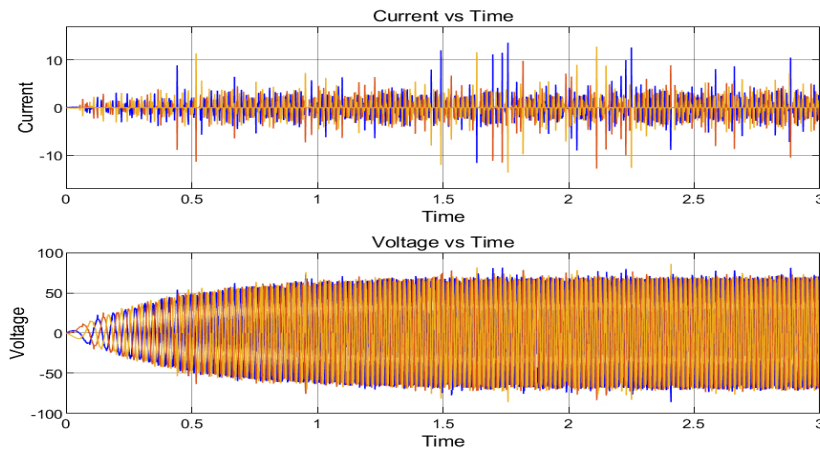


Figure 5: Wind Turbine Output Plots of Voltage and Current

Figure 5 is the output plot of voltage and current of the wind turbine design in Figure 3. The value of voltage and current depend on the power generated by the wind turbine.

Data obtained and analyzed for the six selected cities namely Port Harcourt, Owerri, Ibadan, Kaduna, Jos and Maiduguri. It was found that wind speed increases with height above sea level. This aligns with the study of (Okeniyi et al, 2015) that revealed that the wind speed as well as the wind potential of a region increases with height. The analysis of the data also made known that the northern cities have better wind potentials than the southern cities which is in line with the study conducted by (Okoye et al, 2020). This research also revealed that Jos has the highest wind strength while Owerri has the lowest wind strength amongst the six cities investigated on. The wind strength of Jos and Kaduna are strong and can support large scale electricity generation. The wind turbine model developed through Matlab showed the possibility of designing wind turbine systems that suits a given location by varying mainly the radius of the rotor blades as well as other design parameters.

4. Conclusion

Nigeria has wind potentials which can support both small and large scale electric power generation. Applying the (PNL) wind power classification at a height of 10M it was deduced that the wind power density of Jos has sufficient energy for large scale economic power generation. The wind power density of Kaduna is considered very good at a height of 50m and can support large scale electricity generation. The wind power potential of Maiduguri which is considered good at a height of 50m which is sufficient for medium power generation. The wind strength of Ibadan, Owerri and Port Harcourt is adequate for small scale electricity generation. Wind speed and wind power increases with elevation above sea level with respect to a given location. The findings of this research will create awareness and enlighten the public on the need in adopting renewable energy options which includes wind energy in tackling Nigerian electricity deficits. The study will also serve as an eye-opener to policy makers and private sector investors in wind energy on the potentials of different regions of the country. This research provides guidance to various organs and tiers of government in enacting laws that will deepen the growth of wind power as alternative energy sources in Nigeria.

The following suggestions are presented with respect to findings in this dissertation.

Given the vast amount of wind energy resources in Nigeria, the government and actors in the private sector should expand their investments in the production of wind electricity.

The Federal government should pass legislation that will encourage more investments in Nigeria's wind energy resources.

There should be better ways to incorporate solar and wind energy into structures, grids, and other types of electricity systems.

The large wind potential of Northern Nigerian states should be considered in constructing grid connected large scale wind power generation.

In Nigeria, additional research in the fields of wind energy should be promoted.

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RELIABILITY STUDIES OF OPOBO COMMUNITY DISTRIBUTION NETWORK IN RIVERS STATE

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Abstract

This research assessed the Reliability Studies of Opobo Community Distribution Network in Rivers State in the Opobo/Nkoro Local Government Area in Rivers South-East of Rivers State, Nigeria. Opobo Town has an area of 130.1km², population of about 214,700 people, population density of 1,310 per km² and it is about 80km (50mi) from Port Harcourt and has just lately been made accessible by land after being reached by boat and air. This study was evaluated using reliability based indices and the performance assessment observed a total of 407 outage hours within the distribution network based on the monthly outage data for the year 2022 as obtained from the Opobo Utility Board. New layout distribution route had 55.0 hours and 3.07 hours as the highest MTTF and MTTR respectively, DAPPA distribution routes recorded the lowest value of 0.8890 Availability, OPS distribution route had the greatest Unavailability value of 0.1022, New layout distribution route recorded the lowest Failure rate per year, Repair rate was same as MTTR, and the maximum and minimum outage frequency range were 0.0349 and 0.0172 for the OPS and New layout distribution routes respectively because the two distribution line routes have the biggest and lowest number of outages, respectively. The dependability indices graphs also shows their individual performance.

Keywords: MTTF, MTTR, Availability, Failure Rate and Frequency

1. Introduction

According to Towns to Villages report (2019), Opobo Town has an area of 130.1km², a population of about 214,700 people, a population density of 1,310 per

km², is about 80km (50mi) from Port Harcourt and has just lately been made accessible by land after being reached by boat and air. Opobo Town shares border with Akwa Ibom State, define as an island, has an approximate geographic coordinates of 04°34'N Latitude and 07°12'E Longitude. Opobo is situated around 7km (4.3 mi) from the Atlantic Ocean and two meters above sea level. Opobo has experience significant population growth and economic development in recent years. As a result of these growth, the Opobo distribution network must cope with higher loads and manage the increasing electricity demand effectively. Because of its age and a lack of regular maintenance, the Opobo distribution network's infrastructure is susceptible to aging and damage. Voltage fluctuations, unplanned outages, and other disruptions can have a big effect on customers and businesses in the Opobo Town. The significance of the study includes the evaluation of the network architecture in Opobo and the use of reliability indices as obtained from Opobo Utility Board, Rivers State, Nigeria for the performance of the distribution. However, ensuring optimal performance of the distribution system is critical for gathering the growing demand, minimizing losses, and enhancing overall system efficiency. One of

the ways of improving the system is by performing reliability Assessment of Distribution Network of Opobo Community in Rivers State. The most challenging issue in the operation and maintenance of the electric power distribution network is how to decrease the frequency of outages that consumers endure (Davis, 2012). The networks used to distribute electricity are very intricate and have many connections and parts. The infrastructure of power systems is made up of these parts to a degree of about 40% (Gonen, 2008).

2. Material and Methods

The primary data used in this research is obtained from the Opobo Utility Board of Rivers State and the distribution network is power from 2×2000KVA CAT Generator in the year 2022. The power is generated and the transmission line is step-up using a 2.5MVA transformer and it is distributed through 11kV distribution lines and delivered to consumers via Distribution Substations. Table 1 shows the summary from monthly to annual data collated for each Distribution Line Outage Data indicating the Power Outage Statistics for the Year 2022 in Opobo. Various reliability indices, such as the system average interruption frequency index, the system average interruption duration index,

the customer average interruption frequency index, the customer average interruption duration index, etc., can be used to assess the reliability of a power system. This research used Mean Time to Failure (MTTF), Mean

Time to Repair (MTTR), Availability (A), Unavailability (U), Failure Rate (λ), Repair Rate (r) and Outage Frequency (f) to calculate the dependability or reliability indices equations from (1) to(7).

MTTF = the time it takes for each component to fail

$$= \frac{\text{Actual Operational Duration (Hours)}}{\text{Total Number of Outages}} = \frac{\sum_{i=1}^n m_i}{n} \quad (1)$$

MTTR = the time to restore service or repair the faulty component

$$= \frac{\text{Total outage Duration (Hours)}}{\text{Total Number of Outages}} = \frac{\sum_{i=1}^n r_i}{n} \quad (2)$$

A = The degree to which the system, subsystem is in a specified operable state

$$= \frac{\text{Actual Operation Duration (Hours)}}{\text{Actual Operation Duration (Hours)} + \text{Total Outage Duration (Hours)}} = \frac{\sum_{i=1}^N T_{ui}}{\sum_{i=1}^N (T_{ui} + T_{di})} \quad (3)$$

U = The degree to which the system, subsystem is not in an operable state

$$= \frac{\text{Total Outage Duration (Hours)}}{\text{Total Outage Duration (Hours)} + \text{Actual Operation Duration (Hours)}} = \frac{\sum_{i=1}^N T_{di}}{\sum_{i=1}^N (T_{di} + T_{ui})} \quad (4)$$

$$\lambda = \frac{\text{Total Number of Outages}}{\text{Actual Operation Duration (Hours)}} = \frac{N}{\sum_{i=1}^N (T_{ui})} \quad (5)$$

r = The measure of the maintainability of repairable item(s)

$$= \frac{\text{Total Outage Duration (Hours)}}{\text{Total Number of Outages}} = \frac{\sum_{i=1}^n T_{di}}{N} = MTTR \quad (6)$$

f = The rate of occurrence within a specified period, its measured in hertz (Hz)

$$= \frac{\text{Total Number of Outages}}{\text{Actual Operation Duration (Hours)} + \text{Total Outage Duration (Hours)}} = \frac{N}{\sum_{i=1}^N (T_{ui} + T_{di})} \quad (7)$$

Table 1 results are listed based on annual data obtained from the Opobo Utility Board of Rivers State while table 2 results are calculated using equation (1) to (7) based on available data in table 1. The graph shown in figure 1 shows the “Total Number of Outages and Dependability Indices in Opobo Distribution System for the Year 2022”, which occurred along each route for the different electric power distribution lines. The graphs of the “dependability indices of

Opobo electrical power distribution system for the year 2022” were also provided in figure 2. The electric power transmission lines under study are assumed to be repairable components with a mean time to repair or to restore service. Most components in power systems are repairable or replaceable. If a component is repaired, it is assumed that it will perform its function as a new component with the same failure rate

Table 1: Opobo Electric Power Distribution Lines’ Outage Data for the Year 2022

S/N	Distribution Line Route	Voltage Level(kV)	Line Route Length(km)	Total Number of Outages	Desired Annual Operating Hours	Total Outage Duration (Hours)	Actual Operation Duration (Hours)
1	FUBARA II	11	0.05	53	2496	156	2340
2	NTUBO	11	0.55	56	2496	168	2328
3	DAPPA	11	1.05	86	2496	252	2244
4	OPS	11	1.35	87	2496	255	2247
5	PEMBE	11	1.7	82	2496	240	2256
6	NEW LAYOUT	11	2.8	43	2496	132	2364

Table 2: Electric Power Distribution Network Reliability Indices for Year the 2022

S/N	Distribution Line Route	MTTF	MTTR	Availability (A)	Unavailability (U)	Failure Rate (λ)	Repair Rate (r)	Outage Frequency (f)
1	FUBARA II	44.2	2.94	0.9375	0.0625	0.0226	2.94	0.0212
2	NTUBO	41.6	3.00	0.9327	0.0673	0.0241	3.00	0.0224
3	DAPPA	26.1	2.93	0.8990	0.1010	0.0383	2.93	0.0345
4	OPS	25.8	2.93	0.9002	0.1022	0.0387	2.93	0.0349
5	PEMBE	27.5	2.93	0.9038	0.0962	0.0363	2.93	0.0329
6	NEW LAYOUT	55.0	3.07	0.9471	0.0529	0.0182	3.07	0.0172

3. Results and Discussion

As illustrated in figure 1, for the year 2022, a graphical representation of power outages along several routes of electric power distribution is provided. According to the illustration there are 407 total outages; Opobo Primary School (OPS) distribution line route had 87 outages in 2022, which was the most. DAPPA and PEMBE, which each had 86 and 82 outages, were close behind. This is because there are larger load demands in the months of April and December 2022, which is why there are so many outages

during those times. During Opobo festive season, the outage rates significantly increased. This large number of outages is typically explained by the fact that there are more users connected to the lines used to transmit electrical current to consumers. Forty-three (43) power failures occurred along the New Layout distribution line route in 2022, which was the fewest. This may be due to the fact that the electrical current flows in a circular path and that there are less electrical demands on a roll than any other

distribution line routes. Also, figures 1 display the MTTF, MTTR and the Repair Rate of various electrical power transmission line routes for the year 2022. Figure 2 reveals that the New-layout transmission line route had the greatest MTTF value, which came in at 55.0hours, and the highest MTTR value, which came in at 3.07hours. A mean time to failure (MTTF) of 55.0 was exhibited by the new-layout transmission line route since it had the fewest number of outages of any distribution line route. While the routes for the New-layout and Ntubo electric power distribution lines had the highest repair times, 3.07hours and 3.00hours, respectively, while the routes for the Dappa, OPS, and Pembe distribution lines had the lowest repair times, 2.93hours. Figure 2, shows the graphs of Availability, Unavailability, Failure Rate and Outage Frequency. According to the said graph, all of the availability rates along the transmission line routes were much higher than normal, the Dappa distribution line route

had the lowest value of availabilities, which was reported at 0.8990, because the route of that distribution line specifically saw a lot of outages. The OPS electric power distribution line route got the highest value of unavailability among all the routes which had a value of 0.1022. The Dappa power distribution line route came in second with a value of 0.1010. The highest failure rate of 0.0387 failures per year was reported along the route of the OPS electric power distribution line. As can be seen in figure 2, the New-layout Distribution Line Route has the lowest annual failure rate of 0.0182, making it the best option. The OPS distribution line route had a maximum outage frequency rate of 0.0349 and a minimum outage frequency rate of 0.0172, whereas the New-layout distribution line route had neither. The reason for this is that the two distribution line routes have the biggest and lowest number of outages, respectively.

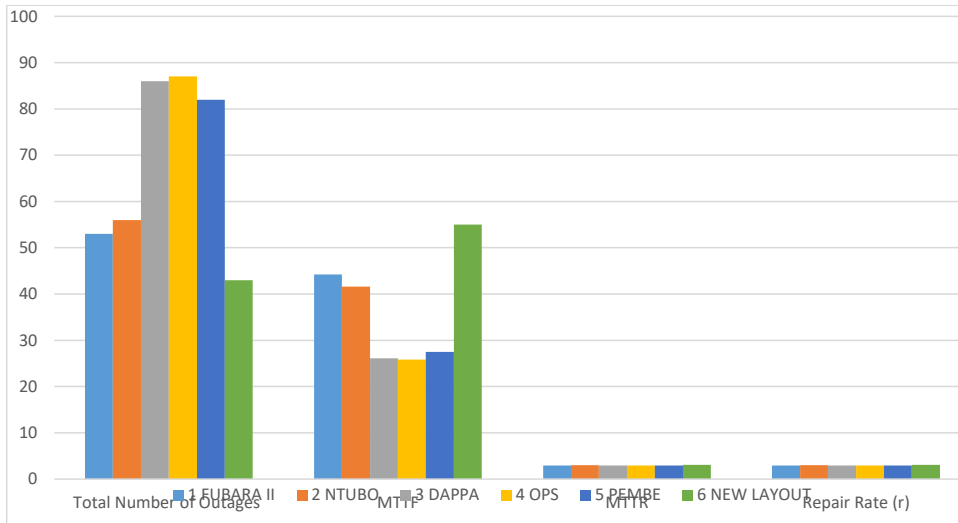


Figure 1: Total Number of Outages and Dependability Indices in Opobo Distribution System for the Year 2022

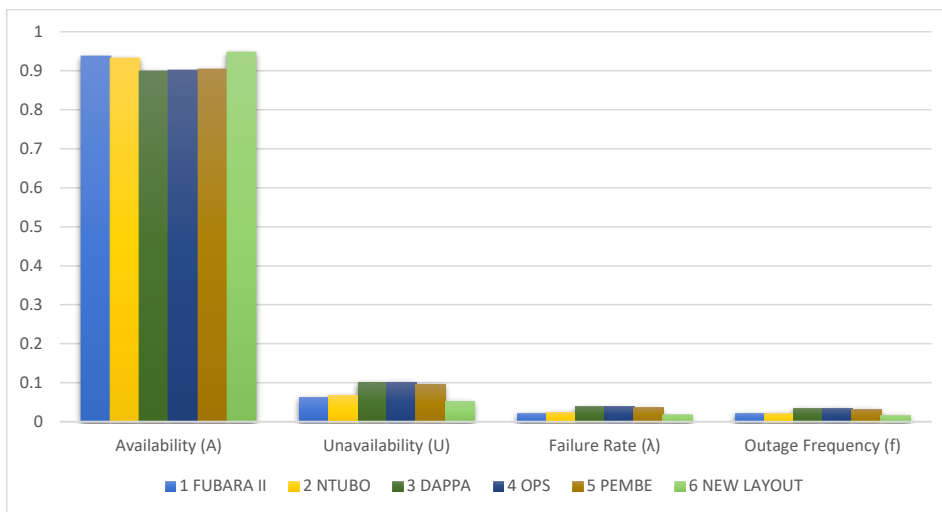


Figure 2: Dependability Indices of Opobo Electrical Power Distribution System for the Year 2022

4 Comparison of other Network Architectures

Based on this research, figure 3 compare the Opobo Network and other network architecture models side by side. In contrast to the Opobo model capacity, the other model of the aforementioned figure has a power of 100MVA, a voltage of 33kV, a frequency of 50Hz, surge and redundancy levels of 15%, and a power factor of 96% while the Opobo model has a power of 0.2MVA, a voltage of 11kV, a frequency of 50Hz, surge and redundancy levels of 5%, and a power factor of 86%. With periodic maintenance and optimization of the Opobo model, customers in Opobo Community in Rivers State may be certain of a consistent supply, particularly during the busiest times of year.

5. Conclusion

Utilizing reliability indices, the reliability study of Distribution Network in Opobo Community in Rivers State was evaluated based on the monthly outage data for the year 2022 as obtained from the Opobo Utility Board; 407 was the total number of outages, as shown in Table 1. The OPS distribution line route experienced the greatest outages, with 87; following closely behind were DAPPA and PEMBE, with respective outages of 86 and 82. This explains why there are more outages in those months, especially during the Opobo festive season, as there are higher load demands between April and December 2022.

The New Layout distribution route had the highest MTTF and MTTR, which were 55.0 hours and 3.07 hours, respectively. The Dappa had the lowest availability, 0.8890, and the OPS distribution route had the best availability, 0.1022. The OPS and New Layout distribution routes had maximum and minimum outage frequency ranges of 0.0349 and 0.0172, respectively, due to the two distribution line routes having the biggest and smallest number of outages, respectively. The New Layout distribution route had the lowest Failure rate per year; the repair rate was the same as MTTR; and the maximum and minimum outage frequency ranges were 0.0349 and 0.0172, respectively. Taking into account the study in this research, I advise conducting additional research on the optimization of opobo distribution networks and power monitoring and control technologies. This will enhance data gathering, communication, safety, and reliability.

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**HYDROGEOPHYSICAL CHARACTERISATION OF GROUNDWATER IN OKRIKA,
RIVERS STATE, NIGERIA**

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ABSTRACT

Coastal aquifers are prone to the problem of seawater intrusion, which is a natural process that becomes more severe due to over-exploitation of groundwater, leading to water dearth. This study sought to delineate the aquifers in Okrika L.G.A in Rivers State, Nigeria, to address these issues. Ten Vertical Electrical Soundings (VES) were obtained in the Okrika coastal community using the ABEM Terrameter SAS 3000 and the Schlumberger configuration. The acquired data were analyzed and interpreted using the IPI2WIN software. The geoelectric sections displayed a total of three to four distinct layers, including topsoil, sand, and clay formations. The resistivity values throughout these layers varied from 14.9 Ω m to 1445 Ω m. The investigation discovered the presence of freshwater at depths ranging from 7.95m to 29.9m. Brackish and saline water were also identified within a depth range of 7.56m to 30.63m. This indicates that there is an overlap in the depth of aquifers containing both freshwater and saline water in Rivers State. Therefore, the determination of the depth of freshwater/saline aquifers should be customized to the specific characteristics of each location.

INTRODUCTION

Water is essential to human survival (Annan, 2005). Humans can use it for a variety of purposes, including household, agricultural, commercial, recreational, environmental, and other uses. The basic goal of the drinking water supply is to protect human health by providing adequate access to high-quality water. Traditionally, "drinking water" has been described as water that contains no dangerous bacteria or visible human-made or chemical pollutants (WHO, 2009). The principal source of drinkable water is groundwater, which can be acquired by boreholes. However, before drilling boreholes, the aquifer should be carefully determined by geophysics. Access to clean, uncontaminated drinking water is critical for both humans and other living creatures, even if it lacks caloric or organic nutritional value (Nitasha & Sanjiv, 2014). Potable water has become more widely available around the world in recent decades. However, around one billion people still do not have access to safe drinking water, and another 2.5 billion do not have adequate sanitation facilities. According to Kulshreshtha's (1998) estimates, over 60% of the global population will confront water scarcity by 2025. According to McKinsey (2009), water demand in some growing countries is expected to exceed supply by more than 50% by 2030. Water is important in the global economy because it acts as a solvent in numerous chemical preparations and is used in cooling towers, transportation, and manufacturing. According to Baroni et al. (2007), agricultural use accounts for over 70% of the world's freshwater resources. The quantity of water is becoming inadequate as the human population grows and there is a greater need for high-quality water for both home and economic purposes. Water quality is critical for both human health and the quantity and quality of grain harvests since it affects soils, crops, and the environment (Kimbrough and David, 1996; Ho & Hui, 2001). Water quality is determined by analysing the physical, chemical, and biological properties of water in reference to predetermined criteria. This examination determines if the water is safe to consume or poses any environmental problems. Various water-related activities, including as home use, farming, industry, mining, energy generation, and forestry, contribute to the degradation of water quality and quantity. This has a tremendous impact on the aquatic ecosystem and the supply of drinkable water for human consumption. Water quality and quantity are interrelated, yet they are

rarely measured concurrently. Hydrological monitoring stations capture characteristics including water level, discharge, and velocity to determine how much water is present.

LITERATURE REVIEW

Groundwater is of great significance because it is found everywhere beneath the Earth's surface. Groundwater is a frequently utilised water source for about 50% of the population in the United States, including almost all individuals who depend on home water delivery systems. The reason for this is the ample accessibility of potable groundwater and the inherent mechanisms that aid in the prevention of specific forms of pollution (Alley et al., 1999). Groundwater is an essential and indispensable source of potable water for a minimum of 50% of the global population. Approximately 2.5 billion individuals worldwide depend only on groundwater to fulfil their daily water needs. To accomplish the Sustainable Development Goals, notably Goal 6 which emphasizes clean water and sanitation, a greater number of individuals will rely on groundwater in the future (IGRAC, 2021). Hence, it is imperative to protect this invaluable asset.

The electrical resistivity method, which makes use of the Schlumberger array, has been the most extensively used geophysical approach that has been found to be beneficial for groundwater investigation (Imam & Hassan 2019). Its adoption has been credited to its affordability in comparison to alternative geophysical approaches (Anomohanran, 2013; Mohamaden & Ehab, 2017; Adagunodo et al., 2018). As well as its simplicity in the field (Sunmonu et al., 2012). The near-surface features and seawater intrusion in different coastal habitats throughout the world have been mapped and evaluated using the geoelectrical technique (Ebraheem et al., 1997; Batayneh, 2006; Bauer et al., 2006; Cimino et al., 2008; Adepelumi & Olorunfemi, 2000; Kalaivanan et al., 2019). The rate of groundwater withdrawal and recharge, the hydraulic gradient, and the geological makeup of the coastal environment have all been linked to the extent of saline water intrusion from that environment into the aquifers (Freeze & Cherry 1979). Since direct current (DC) resistivity surveys can quickly present an overall picture of saltwater intrusion based on the apparent resistivity contrast of the aquifers, the electrical resistivity method, was selected for this study.

The application of the electrical resistivity method is highly efficient in correctly determining the thickness of weathered or fractured zones. Although both the Wenner and Schlumberger electrode configuration approaches are frequently employed, the Schlumberger electrode configuration methodology is seen as more suitable for the field of study due to its ability to ensure superior

outcomes. The employed methodology demonstrates pragmatic, functional, and explanatory advantages when compared to alternative methods, such as the Wenner method of electrode arrangement (Zohdy et al., 1974).

Description and Geology of the Study Area

Rivers State is a constituent of the South-South geopolitical zone in Nigeria, which comprises six states. The region is bordered to the North by Imo, Abia, and Anambra States, to the East by Akwa Ibom State, to the South by the Atlantic Ocean, and to the West by Bayelsa and Delta States. Port Harcourt is the capital of the state. Rivers State encompasses diverse ecosystems including mangrove swamps, tropical rainforests, and several rivers. (Britannica, 2023)

The geographical coordinates of Rivers State are 4.8396° North latitude and 6.9112° East longitude. The total land area measures 11,077 square kilometres. The city's population was recorded as 5,198,716 in the 2006 census, and it is projected to reach 7,303,924 by 2016 according to ZODML (2023). Additionally, a population projection for 2022 estimates the population to be 7,476,800. The population density is currently 773.3 individuals per square kilometre, as reported by City Population (2022). The population of Rivers State constitutes 3.7% of Nigeria's overall population (ZODML, 2023).

The coastal community of Okrika, located in Rivers State, Nigeria, is situated within the sedimentary basin of the Niger Delta. The area possesses the sedimentary formations that are emblematic of the Niger Delta. An exhaustive account of the region's geology has been provided by Allen (1965), Reymont (1965), and Short and Stauble (1967). The region's terrain exhibits a northward inclination that extends to the Atlantic Ocean at its southernmost point. This gradual incline is a defining feature of the Niger Delta region. In the region, topographic heights seldom surpass 80 metres. Numerous rivers and tributaries drain the Okrika region, with the Bonny River being the most significant.

Lithostratigraphically, the rocks are divided into the oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the youngest Benin Formation (Miocene to Recent). Boreholes and wells extract water from the Benin Formation, which is composed of sediments found in the coastal plain. The thickness of the lacustrine and fluvial deposits in this formation varies but generally surpasses 1970 metres (Asseez, 1989). The Benin Formation is comprised of clayey intercalations, sands, silts, and gravel.

Various researchers have provided descriptions of the hydrogeology in the study area, including Etu-Efeotor (1981), Amadi et al. (1989), Edet (1993), Akpokodje et al. (1996), Edet & Okereke (2001), Udom et al. (2002), Oteri and Atolagbe (2003), Song et al. (2007), Adepelumi et al. (2008), and Nwankwoala and Udom (2011).

The Benin Formation serves as the region's water-bearing zone. It is composed primarily of swiftly alternating sequences of silty clay and sand that progressively gain prominence as one moves seawards; these deposits date back to the Quaternary and range in thickness from 40 to 150 metres (Etu-Efeotor and Akpokodje, 1990). In the Delta region, multi-aquifer systems have been predominantly detected through the analysis of strata records (Etu-Efeotor, 1981). In contrast to the remaining confined aquifers, the first is predominantly unconfined. The region's deep boreholes extract water from depths of at least 200 metres. Regarding water quality, Nwankwoala and Walter (2012) have observed that groundwater is generally potable and suitable for agricultural, industrial, and domestic use in the majority of Okrika. The region has a static water level that fluctuates between 0.5m and 7.9m. Direct precipitation constitutes the primary means of recharge in regions with annual precipitation ranging from 2000 to 2400 mm. To replenish the aquifers, the water permeates through the exceptionally permeable sediments of the Benin Formation. The research area is primarily characterised by groundwater occurring beneath water table conditions. The study area contains multi-aquifer systems, with the upper aquifers being predominantly unconfined (Edet, 1993; Udom, 2004; Etu-Efeotor, 1981; Offodile, 2002).

MATERIALS AND METHODS

The research investigation employed the electrical resistivity technique. The data utilised in this research were obtained through the application of the VES method and applying Schlumberger electrode design. A total of Ten VES positions were acquired. The maximal half-current electrode spacing ($AB/2$) was maintained between 80m and 100m, while the half-potential electrode spacing ($MN/2$) ranged from 6.25m to 8.75m. The subsoil's resistivity was quantified and documented utilising an ABEM SAS 3000 Terrameter instrument. Resistance R was determined for each electrode configuration for which an impression was taken, representing the volume of earth material contained within the electrode configuration's electrical space. To ascertain the apparent resistivity of the earth material, the resistance R was multiplied by the geometric factor K .

Coordinates of the Study Area

The study area – Okrika, is situated on an island south of Port Harcourt, making it a suburb of the much larger city (Britannica, 2009). The average elevation of Okrika is 452m. It lies on the north of the Bonny River and 35 miles (56 km) upstream from the Bight of Bonny. The town can be reached by vessels of a draft of 29 feet (9m) or less. The study area is accessible. There are tarred roads and a network of accessible link roads. Okrika can also be assessed by boats.

The coordinates of the sampling points of the study area are shown in Table 1. Map showing the sampling points of the Study Area in Okrika LGA of Rivers State is shown in Figure 1.

S/No	Sample Location	Sample Point	Coordinates
1	Okrika LGA	Ambemebiri Sandfilled	4°44'48.8"N 7°05'14.6"E
2	Okrika LGA	Christian Mission Compound Tomobiri, Kirike	4°44'42.9"N 7°05'16.4"E
3	Okrika LGA	Egwemebiri – Beside football Field, Kirike	4°44'43.2"N 7°05'10.6"E
4	Okrika LGA	Amayanabo Polo	4°44'49.3"N 7°05'09.6"E
5	Okrika LGA	Seaside Estate – Kangochuku (Oba/Adudumoru)	4°44'50.6"N 7°05'06.7"E
6	Okrika LGA	Kalio Polo	4°44'59.9"N 7°05'04.6"E
7	Okrika LGA	Church of Jesus Christ of Latter-Day Saints - Kalio Sandfilled	4°44'42.7"N 7°05'19.8"E
8	Okrika LGA	ATC Ring Road	4°44'26.5"N 7°04'39.1"E
9	Okrika LGA	Ogoloma Ring Road I	4°44'16.0"N 7°04'39.1"E
10	Okrika LGA	Ogoloma Ring Road II	4°44'08.6"N 7°04'42.7"E

Table 1: The Coordinates of The Sampling Points of the Study Area

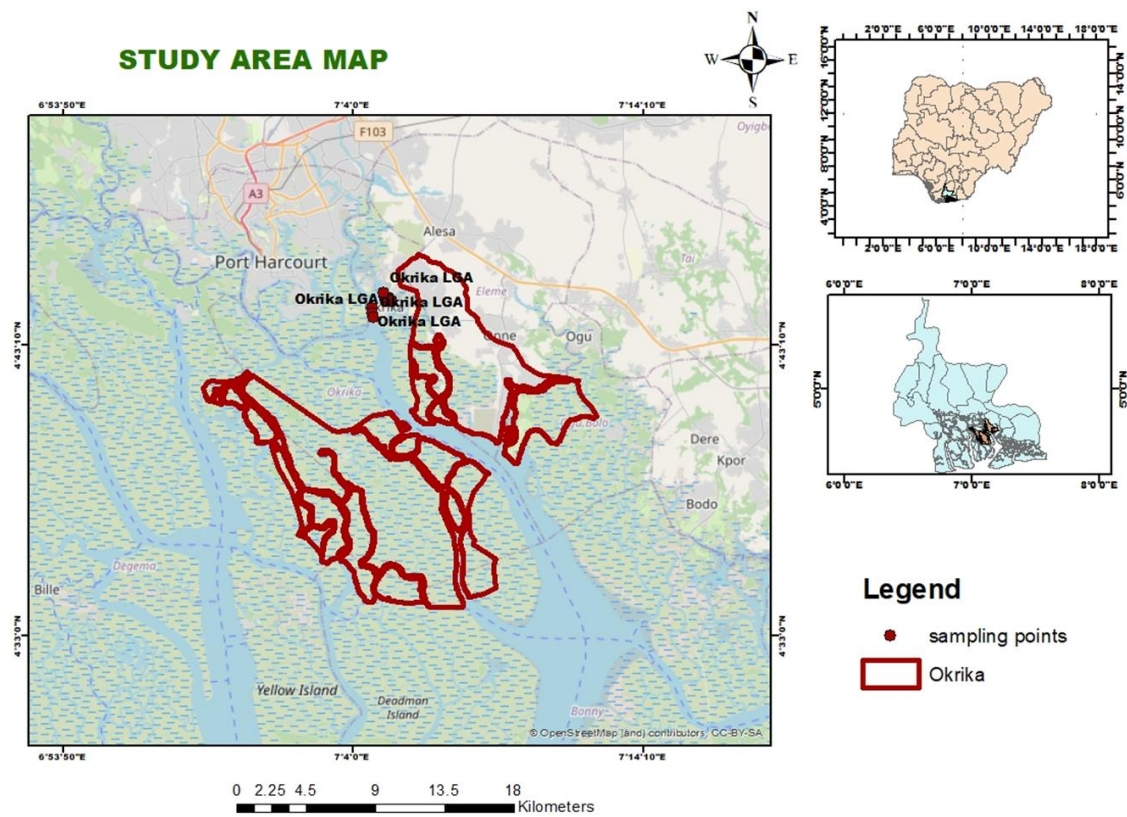
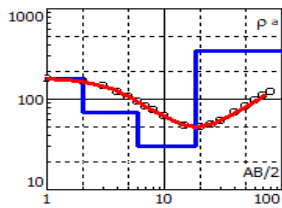


Figure 1: Map Showing the Sampling Points of the Study Area

RESULTS AND DISCUSSION

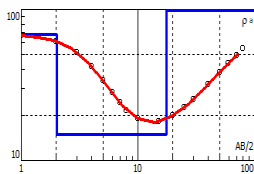
Presentation of Results

Following this, the apparent resistivity ρ_a (Ωm) values were generated for each VES station by applying this procedure to all the collected point data. The geoelectrical parameters were acquired using the sophisticated IPI2Win software to determine the true resistivity and depths of subsurface formations. In this study, it was determined that the Root Mean Square Error (RMS%) for the interpreted curves was less than 10% and exhibited QH, AK, HA and H-type curves with 3 to 4 interpretable geoelectric layers (Figure 2 to Figure 11)



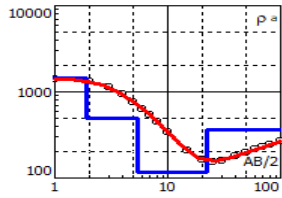
Resistivity (Ωm)	Thickness (m)	Depth (m)
169.00	2.00	2.00
70.90	6.03	8.03
30.20	18.20	26.23
341.00		

Figure 2: VES Curve for Ambemebiri Sandfilled



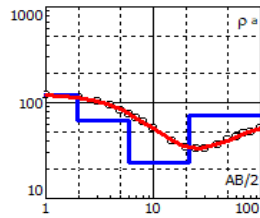
Resistivity (Ωm)	Thickness (m)	Depth (m)
68.50	2.03	2.03
14.90	17.60	19.63
176.00		

Figure 3: VES Curve for Tomobiri Kirike



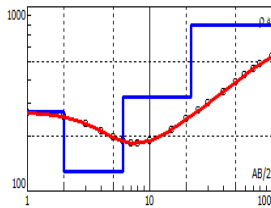
Resistivity (Ωm)	Thickness (m)	Depth (m)
1445.00	2.02	2.02
494.00	5.93	7.95
115.00	21.54	29.49
363.00		

Figure 4: VES Curve for Egwembiri Kirike



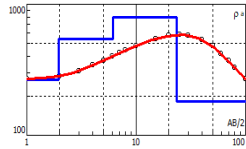
Resistivity (Ωm)	Thickness (m)	Depth (m)
120.00	1.96	1.96
65.10	5.93	7.89
23.60	21.50	29.39
73.60		

Figure 5: VES Curve for Amayanabo Polo



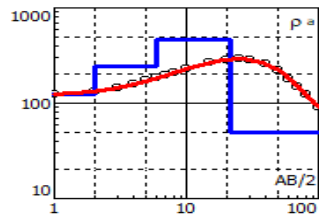
Resistivity (Ωm)	Thickness (m)	Depth (m)
270.00	1.99	1.99
128.00	6.03	8.02
324.00	21.88	29.9
794.00		

Figure 6: VES Curve for Seaside Estate



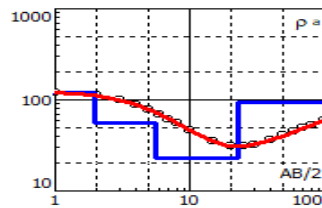
Resistivity (Ωm)	Thickness (m)	Depth (m)
265.00	2.02	2.02
543.00	5.93	7.95
796.00	21.54	29.49
181.00		

Figure 7: VES Curve for Kalio Polo



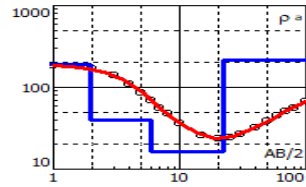
Resistivity (Ωm)	Thickness (m)	Depth (m)
124.00	2.02	2.02
243.60	5.93	7.95
464.20	21.54	29.49
49.36		

Figure 8: VES Curve for Kalio Sandfilled



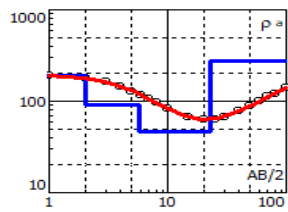
Resistivity (Ωm)	Thickness (m)	Depth (m)
121.00	1.98	1.98
55.80	5.58	7.56
22.90	22.90	30.46
94.00		

Figure 9: VES Curve for ATC Ring Road



Resistivity (Ωm)	Thickness (m)	Depth (m)
191.00	1.96	1.96
39.80	5.93	7.89
16.30	22.20	30.09
215.00		

Figure 10: VES Curve for Ogoloma Ring Road I



Resistivity (Ωm)	Thickness (m)	Depth (m)
191.00	1.98	1.98
91.20	5.75	7.73
46.40	22.90	30.63
275.00		

Figure 11: VES Curve for Ogoloma Ring Road II

The summary of the classification of the resistivity-sounding curves and the model frequency acquired at locations around the study area is presented in Table 2.

S/N	Curve Type	Resistivity Model	Model Frequency	% of Samples	VES Locations
1	Type QH	$(\rho_1 > \rho_2 > \rho_3 < \rho_4)$	6	60	Ambemebiri Sandfilled, Egwemebiri Kirike, Amayanabo Polo, ATC Ring Road, Ogoloma Ring Road I, Ogoloma Ring Road II.
2	Type AK	$(\rho_1 < \rho_2 < \rho_3 > \rho_4)$	2	20	Kalio Polo, Kalio Sandfilled.
4	Type HA	$(\rho_1 > \rho_2 < \rho_3 < \rho_4)$	1	10	Seaside Estate.
5	Type H	$(\rho_1 > \rho_2 < \rho_3)$	1	10	Tomobiri Kirike.
6	Total		10	100	

Table 2: Classification of the resistivity sounding curves for Okrika LGA

Discussion of Results

A total of 10 Vertical Electrical Sounding (VES) acquisitions were conducted. These stations include Ambemebiri Sandfilled, Tomobiri Kirike, Egwemebiri Kirike, Amayanabo Polo, Seaside Estate, Kalio Polo, Kalio Sandfilled, ATC Ring Road, Ogoloma Ring Road I, and Ogoloma Ring Road II. One station, Tomobiri Kirike, displayed three layers, whilst the other nine stations revealed four layers in the subsurface units that were explored. The qualitative examination of the results reveals that the QH curve type is the most prevalent form in the computer-modelled graphs, accounting for 60% of the data. The AK category is the second most common share, representing 20% of the data (Table 2).

The quantitative analysis of the geoelectric sections reveals that the resistivities of the top layers vary from $68.5\Omega\text{m}$ to $1445\Omega\text{m}$, while the thicknesses range from 1.96m to 2.03m. These layers primarily consist of dry/loose sands in most locations, with a few regions containing weathered organic topsoil. The resistivity of the second geo-electric layer ranges from $14.9\Omega\text{m}$ to $543\Omega\text{m}$, while its thickness ranges from 5.58m to 17.6m. The layer also exhibits varying degrees of saturation at an average depth of 9.06m. The model findings were analyzed in a precise manner to

determine the actual resistivity of the rock formations. The second layers' composition varies from clayey sand to fine sand, as indicated by the drill log data in the area. The study area inhabitants rely on this source for groundwater supply, which is used for manually dug wells and a few shallow boreholes. The resistivity of the second layer at some of the sounding sites was relatively low, typically less than $100\Omega\text{m}$, which is characteristic of QH and H curve types. However, stations 5 (Seaside Estate), 6 (Kalio Polo), and 7 (Kalio Sandfilled) had resistivities of $128\Omega\text{m}$, $543\Omega\text{m}$, and $243.6\Omega\text{m}$, respectively, falling into the HA and AK categories. The shallow and thin nature of this layer indicates that it is not confined, making it vulnerable to surface contaminants and pollution. Therefore, it is not a dependable source of groundwater and will not produce drinkable water for the local inhabitants. In the study area, the third and fourth layers are determined to be the aquiferous layers. The resistivity values of the 3rd layer range from $16.3\Omega\text{m}$ (Ogoloma Ring Road I) to $796\Omega\text{m}$ (Kalio Polo), with thicknesses varying from 18.2 m to 22.9 m. These values are found at an average depth of 30m below the ground surface.

The resistivity values of the 4th layer range from $49.36\Omega\text{m}$ (Kalio Sandfilled) to $794\Omega\text{m}$ (Seaside Estate). The presence of a fourth layer with an average resistivity value of $265\Omega\text{m}$ suggests the occurrence of freshwater. This layer begins at a probed depth greater than 30m and continues until the maximum half-current electrode spread (AB/2) of 100m is utilized.

These strata (3rd and 4th layers) primarily consist of medium to coarse sands, with the 4th layer including a higher proportion of coarser grains. In comparison, the fourth stratum is a more suitable area for extracting groundwater. The deeper the depth of the profile, the less susceptible it is to surface pollutants.

Furthermore, this layer exhibits increased porosity and permeability, mostly attributed to the presence of coarser sediments devoid of clay in the zone which also enhance groundwater transmission and yield (Okereke et al., 1998; Raju & Reddy, 1998).

CONCLUSIONS AND RECOMMENDATIONS

This work has shed light on several practical aspects. These findings provide insights into the hydrogeophysical properties of the groundwater found in the study area.

The results of the hydro-geophysical investigation of the study area using the electrical resistivity method (VES) technique have revealed the following:

- I. There were three to four geoelectric layers of subsurface structures in the study areas, composed mainly of sand and clay intercalations.
- II. The resistivity curve types observed in the study area included:
 - a. Type QH ($\rho_1 > \rho_2 > \rho_3 < \rho_4$) - constitutes 60% of the study area and consists of Ambemebiri Sandfilled, Egwemebiri Kirike, Amayanabo Polo, ATC Ring Road, Ogoloma Ring Road I, Ogoloma Ring Road II.
 - b. Type AK ($\rho_1 < \rho_2 < \rho_3 > \rho_4$) - which encompasses 20% of the research area and comprises Kalio Polo, and Kalio Sandfilled.
 - c. Type HA ($\rho_1 > \rho_2 < \rho_3 < \rho_4$), which encompasses Seaside Estate, accounts for 10% of the research area.
 - e. Type H ($\rho_1 > \rho_2 < \rho_3$), which accounts for 10% of the research area, includes Tomobiri Kirike.
- III. Within the study area, freshwater was observed at a depth of 7.95m below the surface, extending beyond the final investigated depth of 29.9m.
- IV. The study area had brackish and saline water within a depth range of 7.56m to 30.63m.
- V. As, demonstrated, the depth of freshwater and saline water aquifers within Okrika in Rivers State exhibits a degree of overlap.
- VI. Hence, the determination of the depth of freshwater/saline aquifers should be customized to each site.

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**EVALUATION OF PHYSICO-CHEMICAL AND MICROBIAL CONTENTS OF
GROUNDWATER IN OKRIKA, RIVERS STATE, NIGERIA**

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ABSTRACT

Groundwater is susceptible to overexploitation and pollution, causing water stress. Seawater intrusion makes coastal aquifer groundwater more vulnerable. Therefore, this study examined groundwater samples from Okrika coastal community aquifers in Rivers State, Nigeria. Standard field and laboratory methods were used to analyze physico-chemical and microbiological parameters in 10 groundwater samples from functional boreholes in the study region. The water was tested for drinking, household, and other uses. Mean values for the following parameters are shown: pH: 5.6; Temperature: 29.3°C; Turbidity: 2.1 NTU; Dissolved Oxygen: 6.6 mg/L; Biological and Chemical Oxygen Demands: 0.4 and 0.6 mg/L; Hardness: 21.2 mg/L; Residual chlorine: <0.01 mg/L; Electrical conductivity: 52.7 µS/cm; Salinity: 25.9 mg/L; Acidity: 0.4; Alkalinity: 6.6 mg/L; Total Suspended Solids: 0.5 mg/L; Total Dissolved Solids, 29mg/L; Nitrite, <0.001 mg/L; Chloride, 13.6 mg/L; Sulphate, 0.7 mg/L; Nitrate; 0.9 mg/L; Phosphate, 0.5 mg/L; Calcium, 0.3 mg/L; Sodium, 3.1mg/L; Iron, 0.1 mg/L; Magnesium, 0.9 mg/L; Zinc, 0.04 mg/L; Lead <0.001 mg/L; Total Coliform, 1574 MPN/100 mL; Faecal Coliform, 1510 MPN/100 mL. The parameters' values are within NSDWQ 2015 and WHO 2017 limits, except for Iron, which has a slightly high concentration, and Total and Faecal Coliform, which have high values in most of the study area. These data also suggest that the groundwater is soft, low in dissolved components, and slightly acidic. Few aquifers in the research area had salt-water incursion due to chloride levels. The water is appropriate for drinking and other domestic uses when compared to drinking water standards. The acidity of the water can be treated by base- exchange with dolomite, while iron by aeration and filtration methods. Total Coliform and Faecal Coliform treatment involve removing contamination sources, repairing systems, shock chlorinating and flushing impacted boreholes.

INTRODUCTION

Water is essential for maintaining hydration and, consequently, for sustaining life. For humans, it provides as a means for food preparation and cooking, maintaining cleanliness and hygiene, and fulfilling various other purposes. The main goal of the drinking water supply is to safeguard human health by guaranteeing access to enough high-quality water (WHO, 2009). The primary sources of potable water are surface water and groundwater, which can be obtained using boreholes. According to Diersing (2009), water quality refers to the characteristics of water in terms of its biological, chemical, and physical properties that determine its suitability for a specific purpose, based on safety considerations. Roy (2019) stated that regular monitoring of water sources is necessary to determine their suitability for certain purposes. This is important since poor water quality poses significant risks with potential economic and environmental consequences. Therefore, it is essential to thoroughly examine the quality of water before making any decision on its use, as stated by Kumar et al. (2014). Consuming water that fails to satisfy established criteria poses a risk of contracting diseases such as cholera, typhoid fever, hepatitis, gastrointestinal illnesses, as well as disorders affecting the nervous and reproductive systems (WHO, 2005; EPA, 2018).

Water has a crucial function in the global economy, acting as a solvent in many chemical preparations and being used in cooling towers, transportation, and manufacturing processes. Baroni et al. (2007) determined that almost 70% of the global freshwater resources are used for agricultural activities. As a result of the growing human population and the demand for clean water for both household and economic use, the availability of water is becoming insufficient. The water quality is essential for human health and the quantity and quality of grain crops. It affects the soils, crops, and the environment (Kimbrough & David, 1996; Ho & Hui, 2001). The evaluation of water quality involves the analysis of the physical, chemical, and biological attributes of water in reference to predetermined standards. This examination is performed to ascertain the potability of the water or to evaluate any potential environmental hazards it may present. Water is used for a variety of purposes, including domestic consumption, farming, industry, mining, energy generation, and forestry operations. However, many applications of water have negative effects on both its quality and quantity, leading to degradation. This has a substantial impact on the aquatic habitat and the accessibility of drinkable water for human consumption. The interdependence between water quality and quantity is often not assessed simultaneously. The

assessment of water quality is conducted through the analysis of water samples collected periodically by these monitoring stations. The results of water quality monitoring are essential for evaluating the spatial and temporal trends in surface water and groundwater (Nitasha & Sanjiv, 2014). Evaluations of water quality monitoring data at local, regional, and global scales offer valuable information about key features of aquatic environments and clarify the impacts, both positive and negative, of human actions.

LITERATURE REVIEW

Groundwater is a preferred source of drinkable water due to its abundant presence, accessibility, and consistently high quality in various locations. This has been the case for a significant portion of the past century. Additionally, it is highly reliable during periods of low rainfall and offers significant cost savings during construction (UNESCO, 2019). The relationship between groundwater and human well-being is a cause for concern, as it is directly influenced by the quality of recharged water, atmospheric precipitation, surface water, and subsurface geochemical processes. Ranjana (2010) clearly stated that the quality of groundwater is intricately linked to public health. Groundwater is highly regarded as one of the purest sources of water found in nature, and it is commonly used to supply the water needs of people living in rural and semi-rural areas (Tyagi et al., 2000). The appeal of groundwater for human activities, particularly in rural areas, is due to its reduced susceptibility to pollution and its lower treatment requirements before use (Oborie & Nwankwoala, 2012; Adetoyinbo et al., 2015). Groundwater is the preferred source of drinking water in the Niger Delta because to its lower susceptibility to pollution, according to its rare filtration process (Agbalagba et al., 2011). The over-exploitation of groundwater and deterioration of its quality has had a detrimental effect on the socio-economic framework of several regions worldwide, including the environmentally vulnerable Niger Delta regions of Nigeria (Udom et al., 2018).

The quality of potable water is mostly determined by its origin and the degree of contamination or pollution. Water contamination is responsible for almost 80% of tropical diseases, including cholera, typhoid, diarrhoea, and dysentery. Groundwater management presents a substantial challenge in numerous Nigerian towns because of industrial activities that result in oil spills and other perilous situations, predominantly caused by urbanisation, which is the primary factor contributing to groundwater contamination. The suitability of drinking water is assessed based on

its quality for human consumption. The composition of water, which is modified by geological processes and human activities, determines its quality. The evaluation of water quality is decided by a range of water characteristics, encompassing physical, chemical, and microbiological aspects. If these levels exceed the acceptable limits, it is a potential danger to human health (Akter, et al. 2016).

Geology of the Study Area

Okrika, a coastal community in Rivers State, Nigeria, is situated in the sedimentary basin of the Niger Delta. The region contains the sedimentary strata that are characteristic of the Niger Delta. Allen (1965), Reyment (1965), and Short and Stauble (1967) have offered a comprehensive description of the region's geology. The topography of the region slopes towards the north and reaches the Atlantic Ocean at its southernmost point. The gentle slope is a characteristic that distinguishes the Niger Delta region. In this area, the elevation rarely exceeds 80 metres. The Okrika region is characterised by a multitude of rivers and tributaries, among which the Bonny River stands out as the most prominent. From a lithostratigraphic perspective, the rocks can be classified into three distinct formations based on their age: the oldest is the Akata Formation from the Paleocene era, followed by the Agbada Formation from the Eocene era, and finally, the youngest is the Benin Formation from the Miocene to Recent era. Water is extracted from the Benin Formation, a sedimentary deposit located in the coastal plain, using boreholes and wells. The thickness of the lacustrine and river layers in this formation typically exceeds 1970 metres (Asseez, 1989). The Benin Formation consists of clayey intercalations, sands, silts, and gravel. The hydrogeology in the study area has been described by several researchers, including Etu-Efeotor (1981), Amadi et al. (1989), Edet (1993), Akpokodje et al. (1996), Edet & Okereke (2001), Udom et al. (2002), Oteri and Atolagbe (2003), Song et al. (2007), Adepelum et al. (2008), and Nwankwoala and Udom (2011). The Benin Formation functions as the aquifer in the area. The composition of this area consists mainly of rapidly alternating layers of silty clay and sand. These deposits, which date back to the Quaternary period, become more prominent as one travels towards the sea. They have a thickness ranging from 40 to 150 metres, as documented by Etu-Efeotor and Akpokodje in 1990. The identification of multi-aquifer systems in the Delta region has primarily been accomplished by analysing strata records (Etu-Efeotor, 1981). Unlike the other confined aquifers, the first aquifer

is mostly unconfined. The area's profound boreholes draw water from depths of no less than 200 metres. In their study, Nwankwoala and Walter (2012) found that the groundwater in Okrika is typically safe to drink and can be used for agricultural, industrial, and home purposes. The region exhibits a stable water level that varies between 0.5m and 7.9m. Precipitation is the main way that water is replenished in areas with annual rainfall between 2000 and 4500 mm (Adejuwon, 2012). To restore the aquifers, water infiltrates the highly permeable sediments of the Benin Formation. The research region is mainly distinguished by the presence of groundwater occurring below the water table. The research area consists of multi-aquifer systems, with the top aquifers being mostly unconfined (Edet, 1993; Udom, 2004; Etu-Efeotor, 1981; Offodile, 2002).

MATERIALS AND METHODS

Sampling Procedures/Laboratory Techniques

The water samples were analyzed for physico-chemical parameters using standard techniques. The parameters were determined using analytical procedures that followed the standards specified in the American Standard for Testing Materials - ASTM (1969) and the American Public Health Association - APHA (1992) Standards.

The heavy metals examined comprise Iron, Zinc, and Lead, as well as metals such as Calcium, Sodium, and Magnesium. The physicochemical parameters that were analysed include temperature, pH, total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), turbidity, hardness, salinity, acidity, alkalinity, sulphates, nitrates, nitrite, chloride, phosphates, residual chlorine, dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD). The microbiological parameters included the Total Coliform Count and the Faecal Coliform Count.

Sampling

The technique of collecting samples is crucial in the field of water studies. Groundwater samples were obtained from the vicinity of the wellhead of each of the sampled boreholes before undergoing any treatment or passing through tanks. A quantity of one (1) litre of water was gathered from every borehole. Before any sample collection took place, the wells were pumped for approximately three to five minutes. This was done to ensure the gathering of samples that accurately represent the whole. Three (3) 250ml polypropylene containers, marked and tightly corked, were used to collect the samples. A plastic container was selected to minimize

contaminants that could potentially modify the composition of the water. The initial container was designated for microbiological testing. To determine the cations, the second container was acidified by adding two (2) drops of pure Nitric acid (HNO₃).

The sample techniques and utilization of suitable sampling equipment, as prescribed in the Nigeria Standard for Water Quality (NSDWQ), World Health Organization (WHO), Federal Ministry of Environment (FMENV) recommendations, and other global guidelines, were strictly adhered to. The bottles and caps underwent a triple rinsing process using tap water prior to the collection of samples. The sampling bottles were meticulously filled to their maximum capacity and securely sealed to prevent any oxygen contamination, as such contamination could potentially induce reactions and compromise the accuracy of the data. All the samples were accurately tagged with the corresponding sampling parameter, sampling point, and date. The sampling bottles were securely sealed to prevent any spillage. A GARMIN Etrex 10, a portable Global Positioning System (GPS) unit, was utilized to capture coordinates and elevation readings. The following metrics were measured and recorded in-situ due to their volatile nature: Temperature, pH, Electrical Conductivity, and TDS. The field activities were primarily conducted during the wet season, specifically from May 2023 to June 2023. The samples were then transported to the laboratory in ice – packed coolers for analysis using standard methods as seen in Table 1. Analyses were promptly performed upon the arrival of the water samples at the laboratory. The quality assurance measures involved doing three analyses for each parameter in every sample and calculating the average of the results.

Parameters	Analytical Methods
Magnesium, Calcium, Iron, Zinc, Lead, Sodium	Direct Atomic Absorption
Salinity, Acidity, Alkalinity, Residual Chlorine, Biological Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen, Hardness, Chloride	Titration
TDS, TSS	Gravimetric
Total Coliform, Faecal Coliform	Most Probable Number (MPN)
Turbidity, Sulphate	Turbidimetric
Temperature, Electrical Conductivity, pH	Hanna Portable Pocket Combo-Meters

Nitrate, Nitrite	Automated Cadmium Reduction
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Table 1: Summary of Analytical Techniques used in the Laboratory

Coordinates of the Study Area

The study area – Okrika, is situated on an island south of Port Harcourt, making it a suburb of the much larger city (Britannica, 2009). The average elevation of Okrika is 452m. It lies on the north of the Bonny River and 35 miles (56 km) upstream from the Bight of Bonny. The town can be reached by vessels of a draft of 29 feet (9m) or less. The study area is accessible. There are tarred roads and a network of accessible link roads. Okrika can also be assessed by boats.

The coordinates of the sampling points of the study area are shown in Table 2. Map showing the sampling points of the Study Area in Okrika LGA of Rivers State is shown in Figure 1.

S/No	Sample Location	Sample Point	Coordinates
1	Okrika LGA	Ambemebiri Sandfilled	4°44'48.8"N 7°05'14.6"E
2	Okrika LGA	Christian Mission Compound Tomobiri, Kirike	4°44'42.9"N 7°05'16.4"E
3	Okrika LGA	Egwemebiri – Beside football Field, Kirike	4°44'43.2"N 7°05'10.6"E
4	Okrika LGA	Amayanabo Polo	4°44'49.3"N 7°05'09.6"E
5	Okrika LGA	Seaside Estate – Kangochuku (Oba/Adudumoru)	4°44'50.6"N 7°05'06.7"E
6	Okrika LGA	Kalio Polo	4°44'59.9"N 7°05'04.6"E
7	Okrika LGA	Church of Jesus Christ of Latter-Day Saints - Kalio Sandfilled	4°44'42.7"N 7°05'19.8"E
8	Okrika LGA	ATC Ring Road	4°44'26.5"N 7°04'39.1"E
9	Okrika LGA	Ogoloma Ring Road I	4°44'16.0"N 7°04'39.1"E

10	Okrika LGA	Ogoloma Ring Road II	4°44'08.6"N 7°04'42.7"E
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Table 2: The Coordinates of The Sampling Points of the Study Area

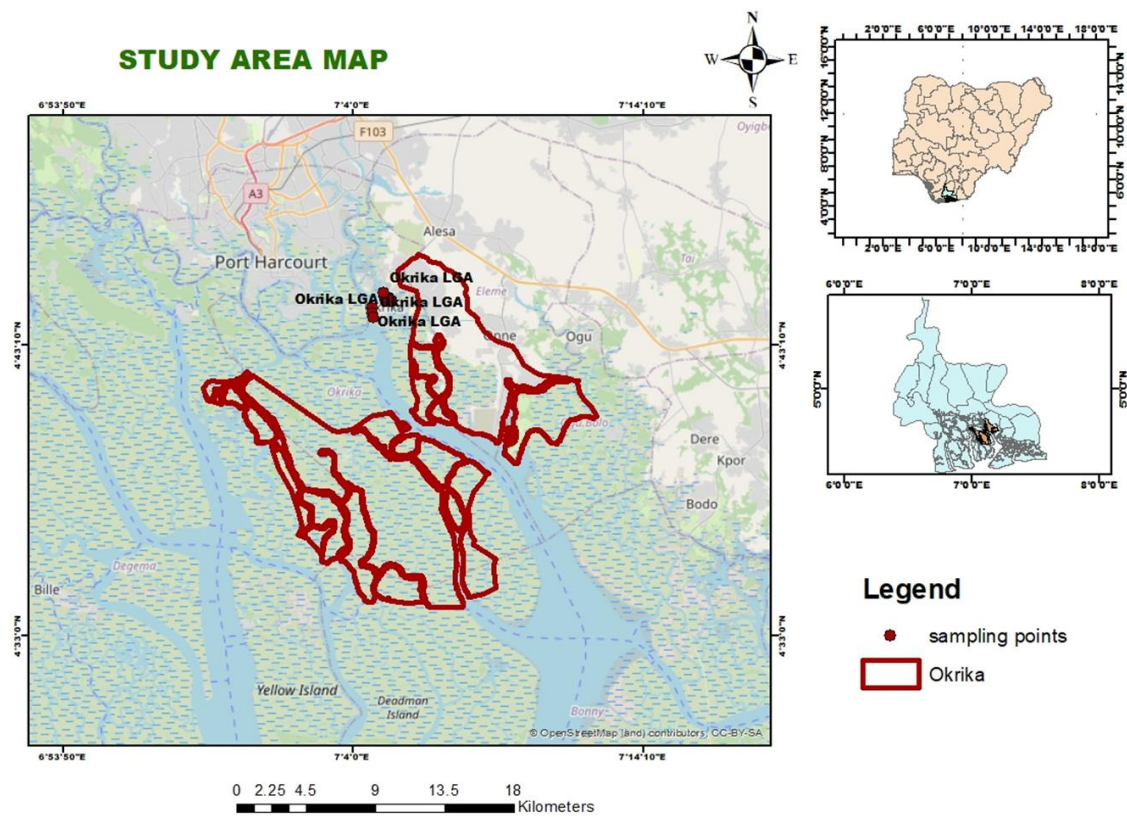


Figure 1: Map Showing the Sampling Points of the Study Area

RESULTS AND DISCUSSION

The results of all the analyzed physicochemical, heavy metals and microbiological parameters from the study area are presented hereunder in Table 3.

Study area groundwater temperatures range from 29.2°C to 29.5°C. NSDWQ (2015) and WHO (2017) do not suggest groundwater temperature. Groundwater pH in the study area ranges from 5.3 to 6, averaging 5.6. The Nigeria Standard for Drinking Water Quality (NSDWQ) and WHO recommend a pH range of 6.5 to 8.5 for drinking water. The water samples' pH is acidic and below the permissible range. Based on these criteria, these sites' water is unfit for drinking. The research area's water samples have dissolved oxygen (DO) levels ranging from 6 to 7.4 mg/L, with an average of 6.6 mg/L. Biochemical Oxygen Demand (BOD) water values in the research region range from 0.2 to 0.5 mg/L, averaging 0.4 mg/L. The NSDWQ and WHO have no groundwater Biochemical Oxygen Demand (BOD) criterion. Sensorex (2021) states that a low Biochemical Oxygen Demand (BOD) indicates a lack of organic components in the water, preserving water purity. The low Biochemical Oxygen Demand (BOD) means the water is safe for drinking and other household uses. The Chemical Oxygen Demand (COD) water values in the research region range from 0.3 to 0.8 mg/L, averaging 0.6 mg/L. The NSDWQ and WHO have not set groundwater COD thresholds. However, standard environmental contaminant discharge rules limit COD to 250 mg/L. COD should not exceed 294 mg/L, according to NAFDAC (1999). According to Chapman's categorization (1996) and NAFDAC (1999), a low COD implies that the water sample is appropriate for drinking, irrigation, and industrial use. The electrical conductivity ranges from 14 to 139 $\mu\text{S}/\text{cm}$. All samples meet the permissible range of 1000 $\mu\text{S}/\text{cm}$ and 900 $\mu\text{S}/\text{cm}$, as established by the NSDWQ (2015) and WHO (2017) recommendations. Water's electrical conductivity depends on ion concentration and movement. Electrical conductivity indicates dissolved ionizable compounds, according to research. All areas have low electrical conductivity, indicating low dissolved ions and enrichment of groundwater ionic activity. The research region's water samples have Total Dissolved Solids (TDS) values between 8 and 76 mg/L, with an average of 29 mg/L. The WHO and NSDWQ limit potable water TDS to 500 mg/L. Based on these criteria, the water is potable for drinking, household, and irrigation use. Groundwater must be categorized by Total Dissolved Solids (TDS), which is closely

related to Electrical Conductivity, to evaluate its suitability for any usage. Groundwater is classified for drinking and irrigation using Freeze and Cherry (1979) and Davis and De Wiest (1966) classifications. According to Davis and De Wiest (1966), this TDS level is safe for drinking, household, industrial, and irrigation. The research region's water samples have salinities from 7 to 70 mg/L, with an average of 25.9 mg/L. The readings meet the NSDWQ and WHO guidelines of 250–400 mg/L. This investigation's salinity measurements meet the threshold, indicating minor aquifer overexploitation. Based on salinity, these water sources are safe for drinking and irrigation. Research region water samples had Total Suspended Solids (TSS) values from 0 to 2 mg/L, with an average of 0.5 mg/L. The TSS values meet the NSDWQ and WHO 500 mg/L standard. TSS cannot pass through a two-micrometre sieve, unlike TDS. TSS stays suspended in solution indefinitely (Dezuane, 1997). All water samples had TSS levels between 0 and 2 mg/L, indicating the absence of suspended and colloidal contaminants such as damaged vegetation, sewage, and sediments. Concerning TSS, the water samples are suitable for drinking and other uses. Hardness in the 10 water samples ranges from 5 to 36 mg/L. The average hardness is 14mg/L. The values meet NSDWQ and WHO standards of 150 and 100 mg/L. None of the groundwater samples are hard, according to Sawyer and McCarthy (1967) and Todd (1980). The residual chlorine levels in this study were below 0.01 mg/L. This is because water samples were not treated. The groundwater samples in the research region contained iron values ranging from <0.001 mg/L to 0.8 mg/L, with an average of 0.1 mg/L. In 20% of water samples, the NSDWQ's 0.3 mg/L standard was exceeded. The main source of iron contamination is geological; therefore, this value still falls below the WHO's 1 mg/L standard for groundwater iron. According to Alabo et al. (1984), Benin Formation laterites are iron-rich and presumably discoloured by limonite and goethite. Leaching releases iron into groundwater from the elements specified (Ngha & Allen, 2006). Iron is discovered in drinking water due to steel and cast-iron pipe degradation during distribution, according to WHO (2006). Udom et al. (2015) found iron in most Niger Delta groundwater. The weathering of geologic igneous and metamorphic rocks causes most iron pollution. Benin Formation laterites are iron-rich and possibly discoloured by limonite, goethite, and hematite (Etu-Efeotor, 1981; Alabo et al., 1984). The use of coagulants and the erosion of steel and cast pipes in water distribution systems can also produce iron, according to WHO (2004). The groundwater samples in the studied location had zinc values ranging from <0.001 mg/L to 0.088 mg/L, with an average of 0.04 mg/L. These readings are below the NSDWQ and WHO drinking water limits of 3 mg/L and 1 mg/L,

respectively. This means that groundwater is uncontaminated from sources from steel mills, coal-fired power stations, or trash incineration. No water source tested positive for lead. The groundwater levels are below the NSDWQ and WHO 0.01 mg/L threshold. The 10 groundwater samples had CaCO₃-based acidity levels from 0.3 to 0.5 mg/L, averaging 0.4 mg/L. The NSDWQ and WHO have no groundwater acidity standard. All tested groundwater sources had alkalinity levels from 2 to 16 mg/L. The 10 groundwater sources averaged 6.6 mg/L alkalinity. The readings meet WHO standards of 100 mg/L. The NSDWQ has no groundwater alkalinity standard. Thus, these sites have alkalinity-safe drinking water. Lower chloride levels (4 mg/L) were seen in Seaside Estate and Kalio Sandfilled, while the highest was 42 mg/L at Amayanabo Polo. The average chloride content is 15.6 mg/L which is within the NSDWQ and WHO standard of 250 mg/L for drinking water. However, 10% of samples (Amayanabo Polo) have levels > 40 mg/L, indicating saltwater intrusion (Tremblay et al., 1973; Udom et al., 2002; Amadi, 2004; Nwankwoala, 2013). In 10% of the research area's aquifers, saltwater encroachment is evident. The research region's water samples had phosphate contents of 0.2 to 1.2 mg/L, averaging 0.5 mg/L. The NSDWQ (2015) and WHO (2017) have not set a groundwater phosphate concentration benchmark. However, the research region's phosphate concentrations are within the WHO's 5 mg/L and 12 mg/L drinking water guidelines (WHO, 2006; WHO, 2004). Groundwater samples in the research location show sodium values ranging from <0.001 mg/L to 9.9 mg/L, with an average of 3.1 mg/L. None of the water samples exceeded WHO and NSDWQ sodium limits of 75 mg/L and 200 mg/L, respectively. Given the sodium parameter, the research area's groundwater is potable. Todd (1980) said that groundwater often contains a sodium concentration of less than 100mg/l, which was confirmed in all the sampling points. Each water sample has sodium concentrations within drinkable water standards. When fresh water combines with saline water due to sea transgression, Rahman et al. (2015) observed that sodium concentration increases. All water samples in this investigation had nitrite values below 0.001 mg/L, suggesting no nitrite. These values are below the NSDWQ and WHO's 0.2 mg/L drinking water limit. The research region's water samples had nitrate amounts of 0.2 to 2.3 mg/L, averaging 0.9 mg/L. These levels are below the WHO and NSDWQ maximum allowed limits for drinkable water, 10 mg/L and 50 mg/L, respectively. The low nitrate levels in the area show that the groundwater is clean and acceptable for use in homes, agriculture, industry, and other applications. Nitrate in groundwater is caused by plant decomposition, human sewage, soakaways, industrial and domestic effluents,

livestock manure, erosion of natural deposits, farm fertilizer application, and combustion engine emissions. The research area's water samples have Sulphate readings from 0 to 2 mg/L, averaging 0.7 mg/L. As to the NSDWQ and WHO, all groundwater sulphate measurements are considerably below the maximum permitted values of 100 mg/L and 250 mg/L. Calcium values in water samples in the research location ranged from <0.001 mg/L to 0.3 mg/L, with an average of 0.03 mg/L. The NSDWQ (2015) and WHO (2017) have no groundwater calcium content standard. The mean calcium levels of 0.03mg/L are below the WHO (2006) calcium limit of 75 mg/L. The groundwater samples in the research region had magnesium contents ranging from 0 to 2.7 mg/L, averaging 0.9 mg/L. These levels are below the WHO and NSDWQ maximum permitted limits of 20 mg/L for drinkable water. Total coliform concentrations ranged from 0 MPN/100 mL to 2400 MPN/100 mL in all water sources. The average is 1574 MPN/100 mL. 80% of water tests exceed the Nigeria Standard for Drinking Water Quality (NSDWQ) Total coliform limit of 10 MPN / 100 mL. The WHO has not set a groundwater Total Coliform criterion. Total coliform contamination of groundwater sources can be caused by human and animal waste, inadequate borehole construction or drilling, storage tank contamination, manure preparation sites, and seepage from poorly constructed sewage disposal facilities. Pathogens from this site can enter borehole water without impermeable casings. These microbes can spread waterborne diseases such as dysentery, typhoid fever, cholera, and others in household water (Udoh, et al., 2021). Faecal coliform concentrations in water samples ranged from 0 to 2400 MPN/100 mL across all sources. The average MPN/100 mL value is 1510.0. 80% of water tests exceed the NSDWQ Faecal coliform limit of 0 MPN / 100 mL. The WHO has not set a groundwater Faecal Coliform criterion. Faecal coliforms are a better indicator of animal or human waste pollution than total coliforms. Although other diseases may be present, faecal contamination is the most dependable sign. Faecal coliform indicates bacterial pollution from humans and other warm-blooded creatures (Seiyaboh et al., 2020). High water faecal coliform levels can harm public health and the economy. The high faecal coliform bacteria content in water samples implies pollution. The NSDWQ requires drinking water to have a faecal coliform content of 0 MPN/100 mL. Thus, water must be treated to be safe for consumption.

LGA	S/N	Sampling Point	pH	Turbidity (NTU)	Chloride, Cl ⁻ (mg/L)	Temperature (oC)	Dissolved Oxygen, DO (mg/L)	Biochemical Oxygen Demand, BOD (mg/L)	Chemical Oxygen Demand, COD (mg/L)	Hardness (mg/L)	Residual Chlorine (mg/L)	Electrical Conductivity (µS/cm)	Salinity (mg/L)	Acidity CaCO ₃ (mg/L)	Alkalinity (mg/L)
OKRIKA LGA	1	Ambembiri Sandfilled	5.6	2	8	29.2	6.8	0.463	0.695	10	<0.01	29	14	0.5	5
	2	Tomobiri Kirike	5.8	2	34	29.5	6.5	0.257	0.386	25	<0.01	112	56	0.4	12
	3	Egwembiri Kirike	5.6	3	13	29.4	7.2	0.243	0.364	17	<0.01	44	22	0.4	8
	4	Amaynabo Polo	5.4	1	42	29.3	6.5	0.502	0.753	36	<0.01	139	70	0.5	16
	5	Seaside Estate	5.3	2	4	29.2	6.2	0.544	0.816	5	<0.01	14	7	0.5	2
	6	Kalio Polo	5.6	3	6	29.4	6.0	0.183	0.275	6	<0.01	22	10	0.4	3
	7	Kalio Sandfilled	6.0	3	4	29.2	7.4	0.451	0.676	5	<0.01	14	7	0.3	3
	8	ATC Ring Road	5.7	2	7	29.3	6.5	0.343	0.514	8	<0.01	23	11	0.4	4
	9	Ogoloma Ring Road I	5.3	3	5	29.3	6.3	0.373	0.560	6	<0.01	17	8	0.5	3
	10	Ogoloma Ring Road II	5.5	0	33	29.3	6.4	0.417	0.625	22	<0.01	113	54	0.5	10
	11	MEAN	5.6	2.1	15.6	29.3	6.6	0.4	0.6	14.0	<0.01	52.7	25.9	0.4	6.6
	12	MAX	6.0	3.0	42.0	29.5	7.4	0.5	0.8	36.0	<0.01	139.0	70.0	0.5	16.0
	13	MIN	5.3	0.0	4.0	29.2	6.0	0.2	0.3	5.0	<0.01	14.0	7.0	0.3	2.0
	14	RANGE	5.3-6	0-3	4-42	29.2-29.5	6-7.4	0.2-0.5	0.3-0.8	5-36	<0.01	14-139	7-70	0.3-0.5	2-16

Table 3: Physico-chemical and Heavy Metals Composition of Groundwater Samples in the Okrika LGA Sampling Points

LGA	S/N	Sampling Point	Nitrite, NO2 (mg/L)	Nitrate, NO3 (mg/L)	Sulphate, SO42 (mg/L)	Phosphate, PO43 (mg/L)	Total Suspended Solids, TSS (mg/L)	Total Dissolved Solids, TDS (mg/L)	Calcium, Ca (mg/L)	Sodium, Na (mg/L)	Iron, Fe (mg/L)	Magnesium, Mg (mg/L)	Zinc, Zn (mg/L)	Lead, Pb (mg/L)	Total Coliform (MPN/100mL)	Fecal Coliform (MPN/100mL)
OKRIKALA LGA	1	Ambembiri Sandfilled	<0.001	0.6	0	0.40	0	16	<0.001	0.492	0	0.133	0.043	<0.001	2,400	2,400
	2	TomobiriKinke	<0.001	1.8	2	1.02	0	62	<0.001	9.080	0	2.633	0.043	<0.001	2,400	2,400
	3	EgwembiriKinke	<0.001	0.8	1	0.45	0	24	<0.001	1.672	0	1.124	0.068	<0.001	2,400	2,400
	4	AmayanaboPolo	<0.001	2.3	2	1.15	0	76	<0.001	9.500	0.792	1.281	0.076	<0.001	0	0
	5	SeasideEstate	<0.001	0.2	0	0.18	0	8	0.344	0.080	0	0.334	0.010	<0.001	0	0
	6	KaloPolo	<0.001	0.4	0	0.30	0	12	<0.001	0.054	0.074	1.412	0.037	<0.001	2,400	2,400
	7	Kalo Sandfilled	<0.001	0.2	0	0.25	2	8	<0.001	0.058	0.315	0.347	0.088	<0.001	2,400	2,400
	8	ATCRingRoad	<0.001	0.4	0	0.32	2	13	<0.001	0	0	0.343	0.009	<0.001	2,400	2,400
	9	OgolomaRing RoadI	<0.001	0.2	0	0.21	1	9	<0.001	0.162	0	0.006	0.017	<0.001	240	240
	10	OgolomaRing RoadII	<0.001	1.9	2	1.03	0	62	<0.001	9.892	0	0.342	<0.001	<0.001	1,100	460
	11	MEAN	<0.001	0.9	0.7	0.5	0.5	29.0	0.3	3.1	0.1	0.9	0.04	<0.001	1574.0	1510.0
	12	MAX	<0.001	2.3	2.0	1.2	2.0	76.0	0.3	9.9	0.8	2.7	0.088	<0.001	2400.0	2400.0
	13	MIN	<0.001	0.2	0.0	0.2	0.0	8.0	<0.001	<0.001	<0.001	0.0	0.0	<0.001	0.0	0.0
	14	RANGE	<0.001	0.2-2.3	0-2	0.2-1.2	0-2	8-76	<0.001-0.3	<0.001-9.9	<0.001-0.8	0-2.7	<0.001-0.088	<0.001	0-2400	0-2400

Table 3: Physico-chemical and Heavy Metals Composition of Groundwater Samples in the Okrika LGA Sampling Points (Continued)

CONCLUSIONS AND RECOMMENDATIONS

The results of the physicochemical investigation of the study area have revealed the following:

- I. The analysis of the results of most of the physicochemical and heavy metals parameters of the groundwater are below the stipulated standards (NSDWQ and WHO), consequently, the water is found to be fresh and suitable for drinking, and domestic uses in view of these parameters.
- II. The results of the study show that pH values reveal slightly acidic groundwater in the study area. Consequently, the water should be treated to raise the value to the acceptable NSDWQ and WHO standard of 6.5 - 8.5. The base exchange method with dolomite is suitable for treating low pH. Another treatment method that can be used to treat low pH is Soda ash (sodium carbonate) and sodium hydroxide. This treatment technique raises the pH of water to near neutral when injected into a water system. Unlike neutralizing filters, which is another treatment method, they do not cause hardness problems in treated water. Acidic groundwater is aggressive, hence boreholes in the area should be constructed with polyvinyl chloride (PVC) pipes and other non-corrosive materials. This is imperative because if pH is treated at locations where it exceeds the acceptable limits, the water will be potable and suitable for drinking and other domestic purposes.
- III. Iron values are marginally high in some locations. The permissible limit of 0.3 mg/L as set by the NSDWQ was exceeded in some of the water samples. There are several methods for the removal of iron from drinking water such as ion exchange and water softening. The process of oxidation by aeration, supercritical fluid extraction, limestone treatment, chlorination, and ozonation followed by filtration is typically effective in eliminating iron from water.
- IV. The results of the study show that Total Coliform and Faecal Coliform values reveal considerably high values in 80% of the study area. Hence, at locations where Total Coliform and Faecal Coliform values are more than 10 MPN / 100 mL and 0 MPN / 100 mL respectively, as stipulated by NSDWQ as the permissible limit, it is essential to treat water acquired from these sources that exceeded the limit before consuming it. The best approach is to inspect the water system to find and eliminate any possible sources of contamination, once the source is identified, it can be resolved by making system repairs and having the borehole system disinfected by shock chlorination and flushing.

- V. The study also reveals saltwater intrusion in 10% of the locations as chloride concentrations in some boreholes are up to 40 mg/L. This agrees with Udom et al. (2002); Amadi (2004); Nwankwoala (2013) as an indication of saltwater intrusion using the specification of Tremblay et al. (1973). This is probably due to the closeness of these locations to the sea. Therefore, the seawater-freshwater interface should be delineated in the area.
- VI. The assessment of some contamination indicators, such as the concentrations levels of nitrate, phosphate, sulphate, lead, zinc, and nitrite indicates that the water chemistry has not been heavily contaminated by the land use in the area and is still mainly controlled by geogenic processes rather than anthropogenic activities.

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Data Analysis and Predictive Modelling in Nigeria Oil and Gas Industry: Components of Modelling for Safety Performance

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ABSTRACT

The oil and gas industry, a cornerstone of the global energy supply, faces multifaceted challenges that threaten its operational integrity, environmental sustainability, and socio-economic contributions, particularly in regions like Nigeria, where the sector's growth is pivotal to national development. This study embarked on a comprehensive Data Analysis and Predictive Modelling for Safety Performance to enhance operational growth within Nigeria's oil and gas operations. By embarking on growth incidents such as data collection and management, descriptive analytics, diagnostic analytics, prescriptive, machine learning and artificial intelligence, risk assessment and management, asset integrity and reliability, and environmental monitoring and compliance, the research aimed to shed light on the intricate web of hazards that jeopardize the sector's safety and efficiency. The investigation's intelligence discovered that remote engineering using hybrid first principal modelling could improve profitability and capital efficiency in the oil and gas sector by maximizing process analytics, monitoring performance, and reducing risks. Furthermore, the study emphasises the sector's effectiveness in combining machine learning models to improve reliability and maintenance strategies in the oil and gas industry through an ensemble predictive model for equipment failure analysis. This research aims to bolster technical and operational safety by proposing targeted mitigation strategies and addressing the socio-economic and environmental factors heightening the sector's susceptibility. The conclusion advocates for the ongoing refinement of safety measures, underscoring the importance of vigilance, evaluation, and adaptability in overcoming the complexities of the risk landscape in Nigeria's oil and gas sector.

Keywords: Oil, Gas, Data Analysis, Predictive Modelling, Safety Performance

INTRODUCTION

Data analysis and predictive modelling revolutionize oil and gas decision-making, operations, safety, and efficiency. Advanced analytics, machine learning, and AI are key to these developments. Oil and gas companies use massive amounts of data to improve decision-making, operations, and safety with Data Analysis and Predictive Modelling. Using statistical and machine learning models, these methods collect, process, and analyze data from various sources to predict future trends, behaviours, and events. Data helps oil and gas companies anticipate problems, mitigate risks, and seize opportunities to improve safety systems. Intelligent remote engineering using hybrid first principal modelling can improve profitability and capital efficiency in the oil and gas sector by maximizing process analytics, monitoring performance, and reducing risks (Hing et al., 2022). AI and data science have improved predictive maintenance by improving equipment failure predictions, optimizing scheduling, and reducing downtime and operational costs (Ohalet et al., 2023). According to Jia et al. (2022), IIoT-based predictive maintenance systems use machine learning and deep learning models to predict equipment lifespan, improving operational performance and safety. Data analytics can optimize drilling operations by addressing imbalance multi-class classification using ensemble methods and data resampling techniques (Tewari et al., 2021). Chen et al. (2023) demonstrated the effectiveness of combining machine learning models to improve reliability and maintenance strategies in the oil and gas industry through an ensemble predictive model for equipment failure analysis. Analyzing sustainable local content policy and human capacity development in Nigeria's oil and gas industry using simplified predictive models showed the importance of data analytics in policy assessment and development (Jacob et al., 2022).

According to Odili et al. (2024), AI can enhance recruitment efficiency and effectiveness by automating tasks and enabling data-driven decision-making, highlighting the impact of digital transformation on HR processes (Nwoye & Ugbebor, 2017). These examples illustrate the diverse applications and benefits of data analysis and predictive modelling, from enhancing operational efficiency and maintenance practices to supporting strategic decision-making and HR processes. Integrating digital technologies and analytics continues to drive innovation and transformation in this sector (Awolusi & Marks, 2016).

Integrating Data Analysis and Predictive Modelling into the oil and gas industry's strategic and operational practices represents a shift towards more agile, efficient, and predictive management. As technologies advance, the ability to analyze more complex datasets in real time will further enhance decision-making processes, driving the industry toward safer, more sustainable, and more profitable operations (Ovadia, 2014).

Modelling for Safety Performance in the oil and gas industry involves using various analytical and simulation techniques to understand, predict, and improve safety outcomes. This approach leverages data, statistical models, system simulations, and risk assessments to identify potential hazards, evaluate the effectiveness of safety measures, and guide decision-making toward reducing accidents and enhancing overall safety performance. By integrating these models into the safety management system, companies can proactively manage risks, tailor safety interventions, and continuously improve their safety culture (Sala-i-Martin & Subramanian, 2013).

Incorporating modelling into safety performance strategies represents a shift towards more sophisticated, data-driven safety management in the oil and gas sector. By utilizing the insights gained from various modelling techniques, companies can significantly improve safety outcomes, operational efficiency, and regulatory compliance, ultimately contributing to the industry's sustainability and social license to operate (Awolusi & Marks, 2016).

Safety is paramount in the oil and gas industry due to the nature of the operations and the potential for catastrophic accidents, both from a human and environmental perspective (Azadeh et al., 2015). Safety performance can be evaluated in several ways, including by examining incident rates, regulatory compliance, employee training, and the organization's overall safety culture. Notwithstanding the inherent risks of the work, the oil and gas industry must maintain a high standard of safety performance for the benefit of workers' health and safety as well as the industry's financial success (Nwoye & Ugbebor, 2017).

Modelling approaches are essential in safety management as they identify, analyze, and comprehend the risks and hazards inherent in oil and gas operations. These models serve as a tool to facilitate the decision-making process by providing clear and visual representations of potential issues. Additionally, they aid in effectively communicating these risks to the workforce, thus promoting safety awareness (Fazeres-Ferradosa et al., 2019).

Predictive modelling is an advanced technique that uses historical and current data to forecast future outcomes. It can be used in safety management to anticipate potential incidents by analyzing patterns and trends in existing safety data. Statistical algorithms and machine learning techniques create the predictive model, which forecasts the likelihood of specific outcomes. In oil and gas safety, predictive modelling can be instrumental in proactive hazard identification and safety planning (Kuhn & Johnson, 2013). Nigeria's oil and gas industry is a vital sector in the country's economy, making a substantial contribution to the nation's GDP. Nevertheless, this industry has been plagued by a diverse range of safety concerns, making safety performance an important area of focus (Islam, 2015). This study tends to examine the proposed model's feasibility in real-world scenarios within the sector.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was carried out in Nigeria's southern region, the Niger Delta. One of the largest in the world, this wetland is renowned for its rich biodiversity and is interconnected with the Niger River via an intricate network of creeks, rivers, and tributaries. The oil and gas industry is one of this region's most significant industrial sectors. Roughly 70,000 km³ (27,000 sq mi) or 7.5% of Nigeria's total land area is made up of the Niger Delta (Otoabasi, 2011). The region, home to over 30 million people, is between latitudes 4°16'48'' and 7°51'36'' and longitudes 4°16'12'' and 9°24'. Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers are among its nine states. The production and exploration of oil and gas, which significantly boosts Nigeria's economy and the world's oil supply, depend on the Niger Delta. Human activity and the environment coexist in a delicate balance within the infrastructure, pipelines, wells, and oil fields. The Niger Delta region's oil and gas businesses are the subject of this study. Because they are engaged in the exploration, extraction, transportation, and processing of hydrocarbon resources, these businesses are vital to the local economy. These companies engage in activities that significantly boost the local economy by creating jobs and supporting other services. This industry comprises skilled technicians, engineers, and administrative staff. The ecological sensitivity of the study area is crucial. This research focuses on the Niger Delta's complex ecosystem because it is essential to the region's overall health.

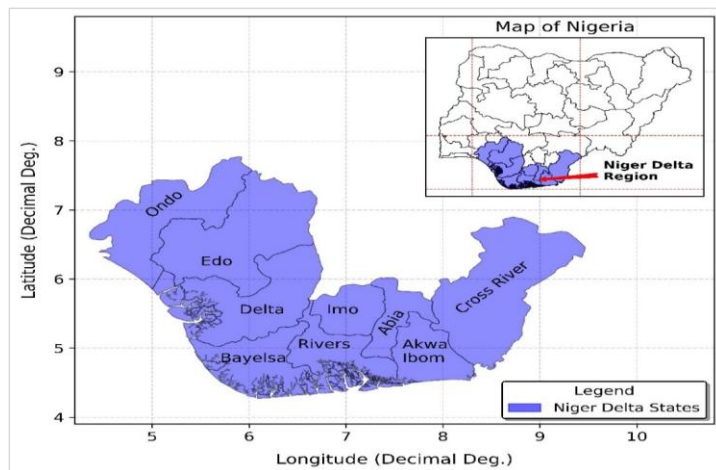


Figure 1: Map of the Study Area

2.2 Research Design

A quantitative research design approach was used in this study. Also, the research design was chosen to create a comprehensive data analysis on risk-based solutions for the oil and gas sector in Nigeria. To understand the risk environment of the industry, several thorough techniques were used, such as risk-based models, and questionnaires. For identifying hazards, a comprehensive hazard checklist was developed utilizing industry standards (ISO 17776) and professional expertise. After the hazards were identified, stakeholders, workers, and industry professionals in the Niger Delta's oil and gas sector were given a structured questionnaire. The purpose of the questionnaires was to collect professional opinions and ratings regarding the likelihood and gravity of various risks associated with the oil and gas sector. Data analysis was done after the data was collected. The mean, mode, standard deviation, minimum, and maximum values of the hazard ratings derived from the questionnaires were all computed as descriptive statistics. The quantitative analysis yielded significant insights into the perceived risk landscape of the industry. Additionally, quantitative information from checklists and questionnaires is used in qualitative risk assessment techniques. Using a qualitative approach, the risks connected to the identified hazards were thoroughly assessed. Each identified risk was evaluated for possible impact and likelihood of occurrence using expert opinions and industry-specific knowledge. A safer working

environment in Nigeria's oil and gas industry can be developed through the integration of quantitative and qualitative findings in targeted risk-based interventions.

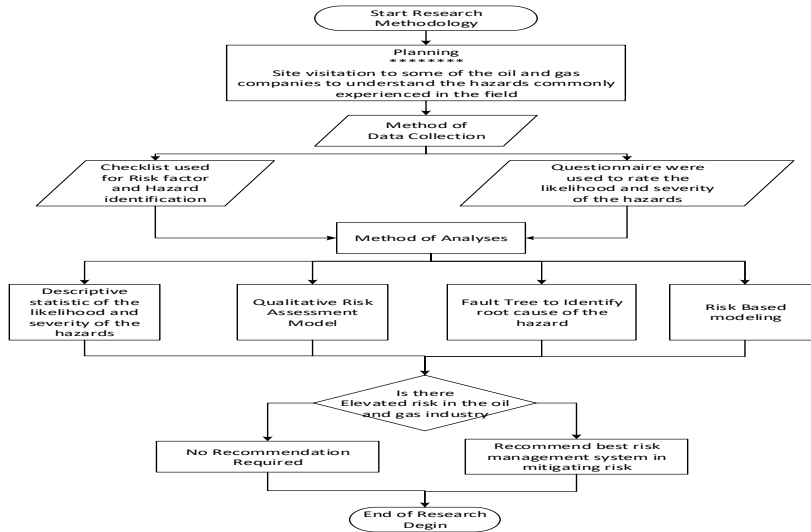


Figure 2: Research Design Flowchart

This study employed five notable oil and gas corporations operating in the Niger Delta region, where the companies have a direct impact on workers. American entities owned two companies, while European Union entities owned three. The research focuses predominantly on transnational oil corporations. The sampling locations' geographical coordinates are presented in Figure 1 and Table 1.

Table 1: Geographical coordinates of the sampling locations.

Oil and Gas Companies	Latitude (N)	Longitude (E)
NAOC (Agip)	4.808561	6.977848
TotalEnergies Nig. Ltd.	4.813701	7.028655
SPDC	5.537708	5.706377
Chevron	5.553242	5.730453
Baker Hughes	4.806761	7.029122

2.3 Sources of Data

Both primary and secondary data were used in the research project. Primary data were collected directly, as opposed to secondary data, which the researcher acquired indirectly. Copies of a structured questionnaire were given to a subset of Niger Delta oil and gas industry workers to gather primary data. These workers were selected from the workforces of the sampled companies and were instructed to assess their perceptions of hazards that were acknowledged using a Likert scale. The acquisition of secondary data involved conducting an extensive literature review on risk and risk assessment, risk management and controls, previous oil and gas industry incidents, safety management systems, and accident causation theories.

2.4 Study Population, Sampling Size, and Techniques

A research population is a sizable group of people or things that are the subject of a scientific study. Researchers typically use sampling techniques because it is costly and time-consuming to test every member of the population. In this case, the study focused on workers who are employed by specific oil and gas companies in the Niger Delta region of Nigeria. These workers include male and female drivers, cleaners, and security personnel between 18 and 60. The sample size for this study was meticulously chosen to guarantee robust statistical analysis and dependable results. The study utilizes diverse sampling techniques to guarantee that the sample precisely reflects the population. Oil and gas companies were selected using a non-probabilistic method, specifically convenience sampling. The selection of this method was based on pragmatic factors such as the ease of access to the facility and the willingness of the company to participate. Only companies that permitted the collection of employee names and email addresses within their premises were deemed eligible. This gave rise to the selection of five businesses within the local area. Purposive sampling was used to select individual survey respondents. Individuals with previous experience in risk assessment, specifically in the oil and gas industry, were deliberately selected for their expertise and applicability.

2.5 Sampling Size Calculation

Cochran's (1978) sample size formula for proportions was used to determine the appropriate and representative sample size. Equation (3.1) provides the formula for calculating sample size, considering an estimated population size of approximately 15,266 oil and gas employees in Nigeria, with a 95% confidence level and a 5% margin of error:

$$n_o n_o = \frac{Z^2 pq Z^2 pq}{e^2 e^2} \quad 3.1$$

Were,

$n_o n_o$ = sample size

e = margin of error = 5%

p = estimated proportion of an attribute that is present in the population,

q = 1-p

Z = abscissa of the normal curve that cuts off an area α at the tails ($1 - \alpha$ equals the desired confidence level, i.e., 95%) = 1.96

$$n_o n_o = \frac{1.96^2(0.63)(0.37)(1.96)^2(0.185)(1-0.185)}{0.05^2 (0.05)^2}$$

$n_o n_o$ = 350 copies of questionnaire.

A 10% allowance accounts for those who do not participate but drop out (non-response rate and incomplete responses). The study requires a minimum sample size of 392 individuals who meet the inclusion criteria (Lu & Tsai, 2010).

2.6 Risk-Based Model Development

To develop the data analysis on the risk-based model, a regression analysis was used to establish the relationship between the risk score, which served as the dependent variable, and the likelihood and severity of the hazards occurring, which served as the independent variables in the oil. The first risk-based model developed showed the relationship between the risk score and the likelihood of the hazard occurring. The second risk-based model developed showed the relationship between the risk score and the severity of the hazard occurring. The third risk-based model developed was a multiple linear

regression showing the relationship between the risk score, the dependent variable, and the severity and likelihood of hazards as the independent variables. After the risk assessment, the risk score, the likelihood of the hazard occurring, and the severity of the hazard occurring were obtained. Equations 3.2 and 3.3 show the model equation form for the linear regression, while Equation 3.3 shows the multiple linear regression from Edwards et al. (2013) and Uyanik and Guler (2013).

$$\text{Risk Score} = \beta_0 + \beta_1 * \text{Likelihood} \quad 3.2$$

$$\text{Risk Score} = \beta_0 + \beta_1 * \text{Severity} \quad 3.3$$

$$\text{Risk Score} = \beta_0 + \beta_1 * \text{Severity} + \beta_2 * \text{Likelihood} \quad 3.4$$

where β_0 is the intercept, β_1 and β_2 is the regression coefficient.

Various goodness of fit indicators was used to assess the model's goodness of fit. The goodness of fit indicators and what they measure are described below:

2.6.1 Coefficient of Determination (R^2): This is calculated to assess the proportion of the variance in the risk score that can be explained by the likelihood of hazards.

2.6.2 Adjusted R^2 : Calculated to provide a reliable indicator of model fit while considering the number of predictors.

2.6.3 Mean Square Error (MSE): Used to quantify the average deviation between the predicted and observed risk scores, indicating the model's accuracy.

2.6.4 Root Mean Square Error (RMSE): Derived from MSE, it represents the standard deviation of the residuals, reflecting the model's predictive performance.

2.6.5 Durbin-Watson Statistic (DW): This statistic is examined to detect any autocorrelation in the residuals, as a violation of the assumption of independence can affect model validity.

2.6.6 Analysis of Variance (ANOVA): This was conducted to evaluate the overall significance of the model, applying the F-statistic and p-value to assess the strength of the predictors. The risk-based model developed provides a quantitative approach to assessing and predicting the risk scores associated with different hazards in the oil and gas industry. It assists in identifying high-risk hazards and supports decision-making processes related to risk mitigation strategies, resource allocation, and safety enhancement.

3. RESULTS AND DISCUSSION

3.1 Data Analysis on Risk-Based Modelling

This section presents the modelling result. The model developed is related to the risk score obtained from the risk analysis, based on the likelihood and severity of the hazard occurring in the oil and gas industry.

3.2 Modelling the Risk Score against the Likelihood of Hazards

Table 1 presents the goodness of fit for the mode. The result from the goodness of fit showed good model fit as indicated by the coefficient of determination (R^2). The R^2 stands at 0.831, signifying that the model explains approximately 83.1% of the variance in the data. The adjusted R^2 , considering the number of predictors, is 0.826, indicating a robust fit. The mean square error (MSE) and root mean square error (RMSE) are 1.164 and 1.079, respectively, providing insights into the average deviation of observed values from predicted values. The Durbin-Watson statistic (DW) is 1.856, suggesting a lack of autocorrelation in the residuals.

Table 2 presents the variance analysis result which unveils the model's significant effect. The model F-statistic is 157.321, with an extremely low p-value (< 0.0001), indicating a strong influence of the

predictors. Table 3 provides details on the model parameters. The Likelihood coefficient is 4.536, with a standard error of 0.362, demonstrating a highly significant positive impact on the risk score ($p < 0.0001$). The result showed that as the likelihood of the hazard increases, there is a corresponding increase in the risk score and vice versa. Therefore, to reduce the risk of hazards in the oil and gas sector, the likelihood of the hazard occurring should be reduced to the barest minimum.

Table 1: Goodness of fit of the model

Observations	34.000
Sum of weights	34.000
DF	32.000
R ²	0.831
Adjusted R ²	0.826
MSE	1.164
RMSE	1.079
DW	1.856

Table 2: Analysis of Variance

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	183.169	183.169	157.321	< 0.0001
Error	32	37.258	1.164		
Corrected Total	33	220.427			

Computed against model $Y = \text{Mean}(Y)$

Table 3: Model parameters

Source	Value	Standard error	t	Pr > t	Lower bound (95%)	Upper bound (95%)
Intercept	-3.619	1.170	-3.093	0.004	-6.003	-1.236
Likelihood	4.536	0.362	12.543	< 0.0001	3.799	5.272

Risk score = $-3.619 + 4.536 * \text{likelihood}$

3.3 Modelling the Risk Score against the Severity of the Hazards

Table 4 outlines the goodness of fit for the model, presenting key metrics that evaluate its performance. The coefficient of determination (R²) is 0.676, indicating that the model explains approximately 67.6% of the variance in the data. The adjusted R², considering the number of predictors, is 0.666, suggesting a reasonably robust fit. The mean square error (MSE) and root mean square error (RMSE) are 2.229 and 1.493, respectively, offering insights into the average deviation of observed values from predicted values. The Durbin-Watson statistic (DW) is 1.956, suggesting a lack of autocorrelation in the residuals. Table 5 shows the analysis of variance which reveals a significant effect of the model. The model F-statistic is 66.881, with an extremely low p-value (< 0.0001), indicating a strong influence of the predictors. Table 6 provides details on the model parameters. The Severity coefficient is 5.574, with a standard error of 0.682, demonstrating a highly significant positive impact on the risk score ($p < 0.0001$). The result suggests that as the severity of the hazard increases, there is a corresponding increase in the risk score, highlighting the importance of addressing and mitigating severe hazards to reduce overall risk in the oil and gas sector.

Table 4: Goodness of fit of the model

Observations	34.000
Sum of weights	34.000
DF	32.000

R ²	0.676
Adjusted R ²	0.666
MSE	2.229
RMSE	1.493
DW	1.956

Table 5 Analysis of Variance

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	149.092	149.092	66.881	< 0.0001
Error	32	71.335	2.229		
Corrected Total	33	220.427			

Computed against model $Y = \text{Mean}(Y)$

Table 6: Model parameters

Source	Value	Standard error	t	Pr > t	Lower bound (95%)	Upper bound (95%)
Intercept	-7.934	2.314	-3.429	0.002	-12.647	-3.221
Severity	5.574	0.682	8.178	< 0.0001	4.186	6.962

*Risk score = -7.934 + 5.574 * severity*

3.4 Modelling the Risk Score against the Likelihood and Severity of the Hazards

Table 7 provides an overview of the goodness of fit for the model. The degrees of freedom (DF) are 31, and R² is exceptionally high at 0.994, indicating that the model explains approximately 99.4% of the variance in the data. The adjusted R² accounted for the number of predictors, which remained at 0.994, confirming an excellent fit. The mean square error (MSE) and root mean square error (RMSE) are 0.040 and 0.200, respectively, showcasing the minimal average deviation of observed values from predicted values. The Durbin-Watson statistic (DW) is 1.902, suggesting a lack of autocorrelation in the residuals. In Table 8, the analysis of variance demonstrated a highly significant effect of the model. The model F-statistic is 2733.635, with an extremely low p-value (< 0.0001), indicating a strong influence of the predictors. Table 9 presents the model parameters. The Likelihood coefficient is 3.296, with a standard error of 0.079, and the Severity coefficient is 3.218, with a standard error of 0.107. The model parameters for both likelihood and severity were positive, indicating that the hazard's likelihood and severity affect the risk score positively. An increase in the likelihood and severity of the hazards would lead to increased risk.

Table 7: Goodness of fit of the model

Observations	34.000
Sum of weights	34.000
DF	31.000
R ²	0.994
Adjusted R ²	0.994
MSE	0.040
RMSE	0.200
DW	1.902

Table 8: Analysis of Variance

Source	DF	Sum of squares	Mean squares	F	Pr > F
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Model	2	219.184	109.592	2733.635	< 0.0001
Error	31	1.243	0.040		
Corrected Total	33	220.427			

Computed against model $Y = \text{Mean}(Y)$

Table 9: Model parameters

Source	Value	Standard error	t	Pr > t	Lower bound (95%)	Upper bound (95%)
Intercept	-10.516	0.316	-33.239	< 0.0001	-11.162	-9.871
Likelihood	3.296	0.079	41.813	< 0.0001	3.135	3.457
Severity	3.218	0.107	29.972	< 0.0001	2.999	3.437

$$\text{Risk score} = -10.516 + 3.296 * \text{likelihood} + 3.218 * \text{severity}$$

3.5 Structural Failure, Gas Leak, Security Threat, Fire and Oil Spill Intervention

From the analysis, respondents agreed on the high likelihood of poor design or construction issues, emphasizing the urgency of addressing these concerns. The severity assessment indicated that poor design or construction could have catastrophic consequences, making it a top priority for mitigation efforts. Accidents impacting the platform were perceived as moderately likely but could cause severe damage. Interventions should focus on raising awareness about load limits, ensuring proper weight distribution, and mandating dynamic load assessments during platform design and operation. Edward et al. (2013), Swedler et al. (2015), Nordlof et al. (2015), and Zahoor et al. (2017) reported that poor safety culture may negate employee safety behaviour at work, and this can consequently lead to injuries and accident even to third parties. Respondents overwhelmingly identified valve failure as highly likely to occur, ranking it as the top hazard in terms of likelihood. This consensus underscores the urgency of addressing maintenance and inspection protocols related to valves. Seal failure, while slightly less likely, still poses a significant risk. Proactive seal maintenance, regular replacements, and careful material selection are imperative interventions to mitigate this risk effectively. Although perceived as unlikely, design flaws can have severe consequences if overlooked. Inadequate consideration of stress points, material compatibility issues, and the use of inappropriate materials were identified as root causes. Okoye and Okolie (2017) established that strengthening design evaluation processes, ensuring material compatibility, and adhering to industry standards are essential in preventing design-related gas leaks. Addressing material compatibility and implementing protective measures against corrosion, such as coatings and inhibitors, are vital interventions to mitigate the risk of metal deterioration. Studies from Ehiaguina and Moda (2020) reported that over 60% of participants acknowledged feeling pressured to put production first at the risk of their own lives and that of others. Respondents identified agitation by host communities as highly likely, indicating underlying socio-economic disparities and a lack of community engagement. Boughaba et al. (2014), historical grievances and unresolved conflicts further exacerbate community agitation, emphasizing the need for community development initiatives and conflict resolution programs. Militant and kidnapper activities are driven by socio-economic challenges and perceived injustices, highlighting the importance of addressing root causes such as unemployment and environmental degradation (Agumba et al., 2013, Avnet (2015), Hawash et al., (2020), Hussain et al. (2022). Implementing vocational training programs and educational initiatives and promoting sustainable development in local communities can mitigate the factors driving individuals towards militant activities. Pipeline vandalism can be reduced by bolstering law enforcement, implementing community-based environmental initiatives, and improving transparency in the oil and gas industry. Implementing stringent safety guidelines for storage facilities, routine inspections, and maintenance can mitigate the risks. Implementing strict safety protocols, including fire watch personnel and flame arrestors, and using advanced welding technologies can enhance the safety of hot work activities. For Corroded Pipelines, inadequate inspection and maintenance practices, exposure to corrosive environments, and aging infrastructure contribute to pipeline corrosion and potential oil spills. Gundus and Laitinen (2018), Xia et al. (2020), Morrow et al. (2014), and Naji et al. (2020). Studies emphasize the importance of implementing regular inspections by utilizing advanced technologies such as

intelligent pigging and cathodic protection systems. Incorporating corrosion-resistant materials during pipeline construction and ensuring prompt repairs for identified corrosion points can significantly mitigate the risks associated with corroded pipelines. Regular seal replacements based on predetermined intervals or condition-based assessments are essential (Ehiaguina & Moda, 2020). Additionally, installing leak detection systems can promptly identify seal failures, allowing for immediate corrective actions.

CONCLUSION

This study focuses on the Data Analysis and Predictive Modelling for safety performance in Nigeria's oil and gas industry. This methodology uses a flow diagram approach to effectively identify significant hazards, emphasizing the need for specific interventions to improve safety. Tackling these issues is critical for raising industry safety standards, protecting workers' well-being, and ensuring operational integrity. This study represents an important first step towards achieving a more secure and sustainable future in Nigeria's oil and gas sector.

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COMPETING INTERESTS

The authors declare that no conflicts of interest are associated with the course of this research.

AUTHOR CONTRIBUTIONS

Conceptualization, analysis and interpretation of the data: M.Z, J.N.U, U.B.N., and I.O.A; Drafting of the paper: M.Z., and U.B.N; Revisiting it critical for intellectual content: J.N.U and I.O.A; Final Approval of the version to be published: M.Z; U.B.N., J.N.U and I.O.A. All authors have read and agreed to be accountable for all aspects of the work.

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Polycyclic Aromatic Hydrocarbon concentrations in environmental media in Nigeria's Niger Delta region

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Abstract

Background: The oil and gas activities conducted in the Niger Delta region of Nigeria have been blamed for the release of pollutants including Polycyclic Aromatic Hydrocarbons (PAHs) into the environment. These pollutants are known for their calamitous environmental effects and inadvertent human health problems.

Aim: This study thus assessed the concentrations of PAHs in soil, food (garri & pumpkin leaves) and water in two selected communities in the Niger Delta region of Nigeria.

Material and methods: This descriptive, comparative study was conducted in Eleme, an oil-producing Local Government Area (LGA) in Rivers State and Aboh Mbaise, a non-oil-

producing LGA in Imo State. Soil, food (garri & pumpkin leaves) and water samples were collected using pre-existing environmental media collection guidelines and sent to the laboratory for extraction and quantification of PAHs using a Gas Chromatography Flame Ionization Detector (GC-FID). The data obtained was analyzed using the Statistical Package for Social Sciences (SPSS) software and statistical significance was set at 0.05.

Results: The mean concentration of PAHs in soil samples obtained from Eleme was 0.31 ± 0.26 (5.03) mg/kg and from Aboh Mbaise was 0.19 ± 0.18 (2.95) mg/kg. The mean concentration of PAHs in garri samples obtained from Eleme was 0.56 ± 0.45 (8.98) mg/kg and from Aboh Mbaise was 0.26 ± 0.18 (4.17) mg/kg. The mean concentration of PAHs in pumpkin leaf samples obtained from Eleme was 0.03 ± 0.02 (0.48) mg/kg and from Aboh Mbaise was 0.04 ± 0.02 (0.58) mg/kg. The mean concentration of PAHs in water samples obtained from Eleme was 0.02 ± 0.02 (0.39) mg/l and from Aboh Mbaise was 0.05 ± 0.04 (0.72) mg/l. Significant differences in the PAHs concentrations in water (p-value: of 0.035 and pumpkin leaves (p-value: 0.018) were also identified.

Conclusion: Concentrations of total PAHs in assessed environmental samples obtained from the two communities exceeded the acceptable limits for Σ PAHs for the respective media as stipulated by the United States Environmental Protection Agency and the Nigerian Petroleum Regulatory Authority. The Source of the PAHs in soil and pumpkin leaves was more petrogenic in Eleme and all others were more pyrolytic. There is a need for concerned environmental health stakeholders to focus on the elimination of pyrolytic sources of PAH pollution with the same vigor being used for eliminating the petrogenic sources.

Keywords: Crude oil exploration, Polycyclic Aromatic Hydrocarbons, Environmental pollution.

INTRODUCTION

In the African continent, one of the regions where crude oil is explored is the Niger Delta region of Nigeria which has seen years of oil and gas activities that have served as a huge source of revenue and foreign exchange to Nigeria (Odalonu & Eronmhonsele, 2015). The Niger Delta region of Nigeria has played host to more than 80% of these oil and gas activities (Odalonu & Eronmhonsele, 2015). The exploration and exploitation of crude oil in Nigeria has gone on for years and has largely contributed to the economy and development of the country, at the expense of depletion of the environment and occurrence of health problems (Adeniji et al., 2018; Obenade & Amangabara, 2014). This is a result of the formation and release of various hazardous organic products such as volatile organic compounds (VOCs), polycyclic aromatic

hydrocarbons (PAHs), and other inorganic pollutants during oil and gas exploitation activities (Yakubu, 2017).

Polycyclic aromatic hydrocarbons (PAHs) are a large subset of ubiquitous organic compounds that possess the capacity to be widely distributed in terrestrial and aquatic ecosystems (Boisa et al., 2019; Lawal, 2017). They are highly lipophilic and hydrophobic compounds that are environmentally persistent, hardly biodegradable, carcinogenic, mutagenic and environmentally toxic. The level of toxicity of these organic compounds is largely dependent on their molecular weight as the larger molecular weight PAHs (high MW PAHs) having four to seven aromatic rings are not acutely toxic but possess a greater capacity for carcinogenicity. Examples include fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(g,h,i)perylene, dibenz(a,h)anthracene and inden(1,2,3-c,d)pyrene. Conversely, the small molecular weight PAHs having two or three aromatic rings are more acutely toxic in and are more volatile, soluble and relatively environmentally mobile than the larger PAHs. Examples include naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene and anthracene (Nwaichi et al., 2017; Singh et al., 2016).

Whenever PAHs are released into the environment, they contaminate the water, soil and air of affected areas with the resultant degradation of the environment (Nriagu et al., 2016; Obenade & Amangabara, 2014; Ordinioha & Brisibe, 2013). A Netherland-based review which was conducted by Shell Global Solutions, reported that hydrocarbons released into the environment during illegal oil exploration activities, have the capacity to cause soil and water contamination (Brown et al., 2017). Contamination of vegetables and fruits can occur and is reported to be generally greater on plant surfaces than on the internal components of the plant. Foods of aquatic origin can also be exposed to contamination from PAHs present in water and sediments obtained from atmospheric pollution or oil spills (Srogi, 2007; Zelinkova & Wenzl, 2015).

They can also accumulate in animals, and humans indirectly through the food chain and can cause various health problems (Dum-Awara et al., 2023; Ogbuagu et al., 2011; Okuroemi et al., 2023; Olayinka et al., 2019). Bioaccumulation of PAHs has been reported in fish and invertebrates obtained from the Lagos Lagoon in Lagos, Nigeria. Typically, high molecular weight PAHs are known to bioaccumulate more than Low molecular weight PAHs, and can exert their harmful effects in the body (Rose et al., 2012). Thus, the extensive exposure to these compounds is an issue of great public health concern requiring a holistic approach to tackling it (Almeda et al., 2013; Brandt & Einhenkel-Arle, 2016; Ozoani et al., 2020). Health risks associated with PAHs are also dependent on the route of entry, intensity of exposure, age, duration of exposure, gender, individual susceptibility and immune system capabilities (Brandt & Einhenkel-Arle, 2016; Onanuga & Onanuga, 2014).

In Rivers State, especially in Ogoniland, PAHs have been identified to be 1000 times higher than permissible limits in air, water, and soil (Anyanwu et al., 2018; Onanuga & Onanuga, 2014; Yabrade & Tanee, 2016). Inhabitants of these communities are thus predisposed to high and chronic exposure to PAHs through ingestion, inhalation and adsorption portals (Ephraim-Emmanuel & Ordinioha, 2021; Kponee et al., 2015; Lawal, 2017). Though previous research has shown problems relating to concentrations of PAHs in environmental media, it is essential to constantly monitor its levels to ensure that it doesn't exceed safe limits for environmental safety, human habitation and consumption (Amangabara & Njoku, 2012; Ephraim-Emmanuel et al., 2022b; Kadafa, 2012; Odalonu, 2015; Odalonu & Eronmhonsele, 2015). To provide an up-to-date assessment of PAHs concentrations in environmental media within the Niger Delta region of Nigeria, it became necessary to conduct this study.

MATERIALS AND METHODS

This study adopted a descriptive, comparative design and was conducted in Eleme, an oil-producing Local Government Area (LGA) in Rivers State and Aboh Mbaise a non oil-producing LGA in Imo State; both within the Niger Delta region of Nigeria.

The formula for the sample size for comparing two means was used in calculating the sample size for environmental samples used for this study (Pandis, 2012). The mean and standard deviation ($2.12 \pm 3.53 \mu\text{g/l}$) of the attribute of interest (PAHs concentration in water) in a non-Niger Delta community was obtained from the study by Adekunle et al. (2020) at Ife North in Osun state (Adekunle et al., 2020). Also, the mean and standard deviation ($0.27 \pm 0.32 \mu\text{g/l}$) of the attribute of interest (PAH concentration in water) in a Niger Delta community was obtained from the study conducted by Aigberua (2020) in Bayelsa state (Aigberua, 2020). These were used to arrive at a total sample size of 44 used in this study.

Environmental assessment of the PAHs levels in surface soil, food (garri & pumpkin leaves) and water was done using the gas chromatography/flame ionization detector (GC/FID) method as described by Aigberua (Aigberua, 2020). Eleven samples of each of these four environmental media were obtained and involved in this assessment with 6 samples obtained from communities in Eleme, Rivers state and 5 samples from communities in Aboh Mbaise, Imo state. Topsoil samples were collected from the communities using a stainless soil auger and placed in pre-labeled bags for transport to the laboratory, pumpkin leaves samples were obtained from different farm locations while garri was obtained from local garri producers within communities in the study sites. Water samples were collected from different wells and taps in the communities as well, using previously cleaned one litre capacity glass bottles. These samples were immediately delivered to Endpoint Laboratories & Equipment Limited, Port Harcourt, Rivers State, Nigeria; for gas chromatographic analysis of the 16 priority PAHs. This was done using the Gas Chromatographic System - (HP Agilent 7890A Gas

Chromatography) equipped with a Flame Ionization Detector based on the USEPA method 8100 (United-States-Environmental-Protection-Agency, 1998).

Extraction and quantification of PAHs from soil and food samples

The extraction method described in the operating guide of the Agilent 7890A Gas Chromatograph was applied for the extraction of PAHs in the soil, garri and vegetable samples (Agilent Technologies, 2010). The vegetable samples were washed with distilled water and chopped into pieces while the soil and garri samples were properly ground using the laboratory grinder. Ten grammes of each well ground sample was transferred into a closed glass vial; whose mouth was wiped with a clean tissue paper and covered. For the samples in each batch, a matrix spike sample was selected and 1ml of the matrix spiking standard was added. One ml of appropriate surrogate spiking solution was also added to selected samples, quality control samples and blanks. Drying of the wet samples which did not have a free-flowing sandy texture was done using anhydrous sodium sulphate. Immediately Dichloromethane (DCM): Acetone mixture (1:1 v/v) was added to bring the total volume to 10ml considering the initial volumes of surrogate and matrix spiking solutions added. Extraction was then done by sonicating the samples and the solvent for 15 minutes. Also, filtration of the extract was carried out using a Whatman filter paper into a glass vial. The procedure was then repeated using 10ml of DCM: Acetone mixture (1:1) on the same extracted sample until the sample was exhaustively extracted. The extract was then concentrated to 2ml by passing it through a gentle stream of nitrogen gas, after which the extract was now ready for clean-up.

Extraction was done using the Extract Clean-up (3630C)-Silica Gel Technique. Firstly, the extract solvent was exchanged to cyclohexane by adding 4ml of cyclohexane following the concentration of the extract to 1-2mL. A slurry of 10g activated silica gel in DCM was placed into a chromatographic column; which was tapped to settle the silica gel and elute the

dichloromethane. One to two centimeters of anhydrous sodium sulphate was then added to the top of the silica gel and the column was pre-eluted with 40mL of pentane and the eluate discarded. Just before exposure of the sodium sulfate layer to the air, 2ml cyclohexane sample extract was transferred into the column using an additional 2ml cyclohexane to complete the transfer. Also, 25 ml of pentane was added and elution continued into a flask. This was then concentrated into 2ml volume by passing through a gentle stream of nitrogen gas collected into a vial bottle and capped as PAH extract.

With the use of a hypodermic syringe, exactly 1 μ L portion of the reconstituted extract was introduced into the injection port of the gas chromatograph-flame ionization detector (GC-FID). PAH components were eluted through the capillary column based on their boiling points (BP) and molecular weights (MW). Standard pre-set operating conditions of the GC-FID included an initial oven temperature of 65°C, final oven temperature of 320°C, injector temperature of 275°C, an inlet pressure of 14.8 psi as well as an inlet condition set to split. Others include setting the detector temperature at 310°C, nitrogen flow amount of 30 mL/ min, hydrogen flow amount of 35 mL/min, and an airflow rate of 250 mL/min (Aigberua & Seiyaboh, 2021; Ephraim-Emmanuel et al., 2022a).

Extraction and clean-up of PAHs from water samples

The liquid-liquid extraction technique was applied to extract PAHs in the surface water samples using the method described in the operating guide of the Agilent 7890A Gas Chromatograph and that applied in a previous study (Agilent Technologies, 2010; Ephraim-Emmanuel et al., 2022a). Firstly, the 250 mL water sample was homogenized before emptying the entire volume into a 500 mL separating funnel. Afterward, PAHs were extracted by a three-batch extraction process using 20 mL of dichloromethane (DCM)/n-hexane (1:3 v/v) mixed solvents at each time. The sample-solvent mixture in the separating funnel was vigorously agitated with

intermittent ejection of built-up pressure from the tap of the glass funnel. This was done to eliminate the risk of blowing up the glass material. Thereafter, the organic extract was dehydrated by filtering through anhydrous sodium sulfate. Organic contaminants in filtered extracts were cleaned by eluting through a 10 mm I.D (internal diameter) x 250 mm long chromatographic column packed with glass wool, a slurry of silica gel, and anhydrous sodium sulfate. The cleaned-up extract was reconstituted to about 1.0 mL, after being concentrated in a temperature-regulated water bath at 35 – 40°C. Finally, sample extracts were transferred into glass vials with rubber-crimped caps. Another 250 mL portion of the water sample was transferred into a separating funnel and spiked with a pre-deuterated PAHs mixture (naphthalened8, phenanthrene-d10, chrysene-d12 and perylene-d12) as internal standards, to establish the efficiency of the extraction protocol. The recovery rates ranged between 92% and 107%. Exactly 20 mL of dichloromethane (DCM)/n-hexane (1:3 v/v) mixed solvents were added to the sample mixture, thoroughly mixed and kept standing to allow for adequate phase separation before dehydration and filtration, followed by clean-up and elution through a chromatographic column. Afterward, the eluted extracts were concentrated to 1.0 mL volume and stored in air-tight rubber-crimp cap glass vials (Aigberua, 2020; Ephraim-Emmanuel et al., 2022a).

Quantification of PAHs from water samples

Exactly 1µL portion of the reconstituted extract was injected into the gas chromatograph-flame ionization detector (GC-FID) using a hypodermic syringe. Nitrogen served as the carrier gas while a combination of hydrogen and air was used to create an ionization environment at the detector head. The various fractions of the aromatic compounds were automatically detected at the FID (whose response is dependent on the composition of the eluted vapor) as they emerged from the column. Results were expressed in µg/L units. Standard pre-set operating conditions of the GC-FID were ensured (Aigberua, 2020; Ephraim-Emmanuel et al., 2022a).

The instrument conditions above are based on manufacturer recommendations and PAHs method suitability for repeatability of analytical data on the HP 6890 Plus GC-FID, version A.03.08. Quality assurance/quality control (QA/QC) parameters applied during GC-FID analysis included the spike concentration, concentration obtained, percentage recovery, limit of detection (LOD), and limit of quantification (LOQ) (Aigberua, 2020). The surface water (SW) matrix was used to calculate extraction recovery efficiency for different PAHs. The instrument limit of detection (LOD) and limit of quantification (LOQ) were also estimated and ranged between 0.001 – 0.04µg/mL and 0.004 – 0.10µg/mL respectively. The acceptable recovery range of the equipment was stipulated between 90 and 110% (Aigberua, 2020; Ephraim-Emmanuel et al., 2022a).

The Statistical Package for Social Sciences (SPSS) version 23 was used to perform both descriptive and inferential analyses. The student's t-test was used to compare the concentrations of PAHs in the soil, garri, vegetable and water samples obtained from the oil-producing and non-oil-producing study sites. All analyses were conducted at a 95% confidence level and a p-value ≤ 0.05 was considered as being statistically significant. Ethics approval for the research was obtained from the Research Ethics Committee of the University of Port Harcourt (Approval number: UPH/CEREMAD/REC/MM80/006). During the collection of samples from the environment, it was ensured that the appropriate techniques were applied and that no harm came to the environment in the course of doing so.

RESULTS

Polycyclic Aromatic Hydrocarbons (PAHs) concentrations in soil

Assessment of the concentrations of the 16-priority PAHs in soil obtained from the two study locations showed that the mean concentration of PAHs in the oil-producing area was 0.31 ± 0.26 mg/kg and total PAHs concentration (Σ PAHs) of 5.03 mg/kg. The mean concentration in soil

samples obtained from the non-oil-producing area was 0.19 ± 0.18 mg/kg with Σ PAHs of 2.95 mg/kg. Assessment of the concentrations of the 16-priority PAHs in the garri samples showed that the mean concentration from the oil-producing area was 0.56 ± 0.45 mg/kg and Σ PAHs of 8.98 mg/kg. The mean concentration in garri samples obtained from the non-oil-producing area was 0.26 ± 0.18 mg/kg with Σ PAHs of 4.17 mg/kg. Assessment of the concentrations of the 16-priority PAHs in pumpkin leaf samples showed that the mean concentration in samples obtained from the oil-producing area was 0.03 ± 0.02 mg/kg and Σ PAHs was 0.48 mg/kg. The mean concentration in samples obtained from the non-oil-producing area was 0.04 ± 0.02 mg/kg with Σ PAHs of 0.58 mg/kg. Assessment of the concentrations of the 16-priority PAHs in water samples showed that the mean concentration from the oil-producing area was 0.02 ± 0.02 mg/l and Σ PAHs was 0.39 mg/l. The mean concentration in samples obtained from the non-oil-producing area was 0.05 ± 0.04 mg/l with Σ PAHs of 0.72 mg/l. These are shown in Tables 1 to 4.

Table 1: Mean and total concentrations of PAHs in soil

PAHs (mg/kg)	Oil-producing community	Non-oil-producing community
Naphthalene	0.00	0.00
Acenaphthylene	0.03	0.01
Acenaphthene	0.00	0.00
Fluorene	0.12	0.12
Phenanthrene	0.43	0.13
Anthracene	0.37	0.23
Fluoranthene	0.24	0.15
Pyrene	0.38	0.18
Benzo(a)anthracene	0.24	0.11
Chrysene	0.69	0.45
Benzo(b)fluoranthene	0.35	0.23
Benzo(k)fluoranthene	0.93	0.66
Benzo(a)pyrene	0.59	0.39
Indeno(1,2,3-cd)pyrene	0.24	0.18
Dibenz(a,h) anthracene	0.15	0.06
Benzo(g,h,i)perylene	0.27	0.07
Total PAHs (Σ PAHs)	5.03	2.95
Mean \pm S.D	0.31 ± 0.26	0.19 ± 0.18

USEPA Maximum Contaminant Level for Σ PAHs: ≤ 0.2 mg/kg (Ofori et al., 2020).

Table 2: Mean and total concentrations of PAHs in garri

PAHs (mg/kg)	Oil-producing community	Non-oil-producing community
Naphthalene	0.00	0.00
Acenaphthylene	0.18	0.15
Acenaphthene	0.05	0.03
Fluorene	0.19	0.13
Phenanthrene	1.76	0.20
Anthracene	0.47	0.26
Fluoranthene	0.81	0.28
Pyrene	0.71	0.26
Benzo(a)anthracene	0.36	0.14
Chrysene	0.62	0.35
Benzo(b)fluoranthene	0.60	0.24
Benzo(k)fluoranthene	1.19	0.72
Benzo(a)pyrene	0.54	0.44
Indeno(1,2,3-cd)pyrene	0.77	0.34
Dibenz(a,h) anthracene	0.26	0.17
Benzo(g,h,i)perylene	0.46	0.44
Total PAHs (Σ PAHs)	8.98	4.17
Mean \pm S.D	0.56 \pm 0.45	0.26 \pm 0.18

USEPA Maximum Contaminant Level for Σ PAHs: ≤ 0.2 mg/kg (Rengarajan et al., 2015).

Table 3: Mean and total concentrations of PAHs in pumpkin leaves

PAHs (mg/kg)	Oil-producing community	Non-oil-producing community
Naphthalene	0.00	0.00
Acenaphthylene	0.01	0.02
Acenaphthene	0.00	0.01
Fluorene	0.01	0.01
Phenanthrene	0.02	0.03
Anthracene	0.02	0.05
Fluoranthene	0.02	0.04
Pyrene	0.05	0.05
Benzo(a)anthracene	0.02	0.03
Chrysene	0.06	0.07
Benzo(b)fluoranthene	0.05	0.06
Benzo(k)fluoranthene	0.07	0.08
Benzo(a)pyrene	0.03	0.04
Indeno(1,2,3-cd)pyrene	0.04	0.04
Dibenz(a,h) anthracene	0.04	0.04
Benzo(g,h,i)perylene	0.04	0.02
Total PAHs (Σ PAHs)	0.48	0.58
Mean \pm S.D	0.03 \pm 0.02	0.04 \pm 0.02

USEPA Maximum Contaminant Level for Σ PAHs: ≤ 0.2 mg/kg (Rengarajan et al., 2015).

Table 4: Mean and total concentrations of PAHs from water

PAHs (mg/l)	Oil-producing community	Non-oil-producing community
Naphthalene	0.00	0.00
Acenaphthylene	0.00	0.00
Acenaphthene	0.01	0.01
Fluorene	0.01	0.02
Phenanthrene	0.05	0.11
Anthracene	0.05	0.11
Fluoranthene	0.03	0.05
Pyrene	0.05	0.09
Benzo(a)anthracene	0.01	0.02
Chrysene	0.04	0.06
Benzo(b)fluoranthene	0.02	0.06
Benzo(k)fluoranthene	0.01	0.06
Benzo(a)pyrene	0.03	0.05
Indeno(1,2,3-cd)pyrene	0.03	0.05
Dibenz(a,h) anthracene	0.03	0.02
Benzo(g,h,i)perylene	0.01	0.02
Total PAHs (Σ PAHs)	0.39	0.72
Mean \pm S.D	0.02 \pm 0.02	0.05 \pm 0.04

USEPA Maximum Contaminant Level for Σ PAHs: **0.002** mg/l (Aigberua, 2020; World Health Organization, 2022).

Comparison of Polycyclic Aromatic Hydrocarbons (PAH) concentrations in oil-producing and non-oil-producing areas

Assessment of the PAHs concentrations in the environmental media from the oil-producing and non-oil-producing areas revealed statistically significant differences in the PAHs concentrations in water ($p=0.035$) and pumpkin leaves ($p=0.018$). This is shown in Table 5.

Source diagnostic ratios of the PAHs concentration in tested samples

Also, in soil samples obtained from the oil-producing area, source diagnostic ratios gave a Flt/(Flt+Pyr) ratio of 0.39; Ant/(Ant+Phe) ratio of 0.46, and a BaA/(BaA+Chr) ratio of 0.26. In samples obtained from the non-oil-producing area, Flt/(Flt+Pyr) ratio was found to be 0.36;

Ant/(Ant+Phe) ratio was 0.51 and BaA/(BaA+Chr) ratio was 0.59. Likewise, in the garri samples obtained from the oil-producing area, source diagnostic ratios gave a Flt/(Flt+Pyr) ratio of 0.53; Ant/(Ant+Phe) ratio of 0.21, and a BaA/(BaA+Chr) ratio of 0.37. In samples obtained from the non-oil-producing area, Flt/(Flt+Pyr) ratio was found to be 0.32; Ant/(Ant+Phe) ratio was 0.63 and BaA/(BaA+Chr) ratio was 0.39. Also, in pumpkin leaves samples obtained from the oil-producing area, source diagnostic ratios gave a Flt/(Flt+Pyr) ratio of 0.34; Ant/(Ant+Phe) ratio of 0.44, and a BaA/(BaA+Chr) ratio of 0.21. In samples obtained from the non-oil-producing area, Flt/(Flt+Pyr) ratio was found to be 0.31; Ant/(Ant+Phe) ratio was 0.79 and BaA/(BaA+Chr) ratio was 0.50. Finally, in water samples obtained from the oil-producing area, source diagnostic ratios gave a Flt/(Flt+Pyr) ratio of 0.80; Ant/(Ant+Phe) ratio of 0.39, and a BaA/(BaA+Chr) ratio of 0.63. In samples obtained from the non-oil-producing area, Flt/(Flt+Pyr) ratio was found to be 0.79; Ant/(Ant+Phe) ratio was 0.25 and BaA/(BaA+Chr) ratio was 0.35. These are shown in Table 6

Table 5: Levels of PAH in food (garri and vegetables), water and soil in the Niger Delta communities in oil and non-oil producing sites

Variables	Site		Student t-test (p-value)
	Oil-Producing (n=24)	Non-oil producing (n=20)	
	Mean ± SD	Mean ± SD	
Water (mg/l)			
Mean ± SD	0.02 ± 0.02	0.05 ± 0.04	2.207 (0.035) *
Pumpkin Leaves (mg/kg)			
Mean ± SD	0.48 ± 0.22	0.58 ± 0.24	2.512 (0.018) *
Garri (mg/kg)			
Mean ± SD	0.56 ± 0.45	0.26 ± 0.18	1.648 (0.110)
Soil (mg/kg)			
Mean ± SD	0.31 ± 0.26	0.19 ± 0.18	0.792 (0.434)

*Statistically significant ($p \leq 0.05$)

Table 6: Source identification of PAHs in environmental media

	Oil-producing	Non-oil-producing
PAHs (soil)	mg/kg	mg/kg
Flt/(Flt+Pyr) ratio	0.39	0.36
Ant/(Ant+Phe) ratio	0.46	0.51
BaA/(BaA+Chr) ratio	0.26	0.59
Source	More petrogenic	More pyrolytic
PAHs (garri)		
Flt/(Flt+Pyr) ratio	0.53	0.32
Ant/(Ant+Phe) ratio	0.21	0.63
BaA/(BaA+Chr) ratio	0.37	0.39
Source	More pyrolytic	More pyrolytic
PAHs (pumpkin leaves)		
Flt/(Flt+Pyr) ratio	0.34	0.31
Ant/(Ant+Phe) ratio	0.44	0.79
BaA/(BaA+Chr) ratio	0.21	0.50
Source	More petrogenic	More pyrolytic
PAHs (water)		
Flt/(Flt+Pyr) ratio	0.80	0.79
Ant/(Ant+Phe) ratio	0.39	0.25
BaA/(BaA+Chr) ratio	0.63	0.35
Source	More pyrolytic	More pyrolytic

Key: Flt/(Flt+Pyr) ratio > 0.5 shows more input of PAHs from pyrolytic sources

Ant/(Ant+Phe) ratio > 0.1 shows more input of PAHs from pyrolytic sources

BaA/(BaA+Chr) ratio > 0.35 shows more input of PAHs from pyrolytic sources

DISCUSSION

Polycyclic Aromatic Hydrocarbons (PAHs) were found to exist in the four environmental media assessed in this study from both the oil-producing and non-oil-producing areas. The total PAHs (\sum PAHs) concentration in all the media was found to exceed the guideline limits of PAHs for each tested medium as stipulated by environmental regulatory agencies (Aigberua, 2020; Honda & Suzuki, 2020; Oyediji et al., 2016; Patel et al., 2020).

In the soils, the total concentration of the 16-priority PAHs obtained from both the oil-producing and non-oil-producing areas exceeded the stipulated safe limits of PAHs in soil. (Rao

& Kumar, 2015) Applying source diagnostic ratios however revealed that the PAHs in the soil from the oil-producing area were more from petrogenic sources whereas the soil PAHs present in the non-oil-producing area were more from pyrolytic sources, for example bush burning, coal use and so on (Aigberua, 2020; Ephraim-Emmanuel et al., 2022a). The finding of petrogenic PAHs contamination in this study is similar to the findings of other authors who have reported elevated PAHs levels in soils from areas where oil exploratory activities are carried out (Aigberua, 2020; Chikere et al., 2020; Kuch & Bavumiragira, 2019; Nwaichi et al., 2014). Very high concentrations of PAHs have also been reported in crude oil-polluted soils obtained from an illegal oil exploratory site in Tombia in Rivers State (Chikere et al., 2020). Other studies are also in agreement with the finding of elevated PAHs levels of mostly pyrolytic sources of PAHs made in this study (Ephraim-Emmanuel et al., 2022a; Nieuwoudt et al., 2011). The use of biomass fuels for cooking has also been described as a potential source of PAHs release and subsequent contamination of the environment (Alexander et al., 2018). The implication of these findings of PAHs-polluted soils is the consequent adverse effect on soil biodiversity, fertility, and vitality and a resultant depletion of the soil and vegetation in affected areas (Douglas & Cornelius, 2018; Yabrade & Tanee, 2016). Furthermore, in areas where the major source of livelihood is agriculture; this pollution of the soil can result in the loss of livelihoods as well as a reduction of food production (Bede-Ojimadu & Orisakwe, 2020; Ephraim-Emmanuel et al., 2022b; The Strategic Partnership on Lobby & Advocacy Programme in Nigeria, 2020). These biomass fuels from wood, animal dung, and so on are used by a large proportion of populations in Africa despite the supplementation by fossil fuels and electricity in this modern era (Bede-Ojimadu & Orisakwe, 2020). They also remain a major source of energy for heating, cooking and other purposes in developing countries (Sola et al., 2017). It is crucial to provide alternatives to the use of these forms of energy in areas where they are known to be frequently used to avoid the risk of potential health effects that could arise

when foods obtained from PAHs contaminated soils are ingested and metabolized in the human body (Adeniji et al., 2019).

The concentration of Σ PAHs compounds in foods in this study was also identified to exceed the normal stipulated limits (Aigberua, 2020; Honda & Suzuki, 2020; Oyedeji et al., 2016; Patel et al., 2020) The PAHs in garri were however found to be predominantly from pyrolytic sources in both oil-producing and non-oil-producing areas. This finding is also in agreement with the findings of other authors whom have reported high levels of PAHs contamination in staple foods taken in Nigeria (Abiona et al., 2019; ATSDR, 2005; Ogbuagu & Ayoade, 2012). This kind of contamination from pyrolytic sources of PAHs in food has been described to be related to the use of biomass fuels for cooking, bush burning activities on farms which exposes surrounding vegetation (including unharvested pumpkin leaves) to PAHs contamination (Alexander et al., 2018; Okonkwo et al., 2018). Contamination of the waxy surface of vegetables and fruits can occur when low molecular mass PAHs attach and accumulate on them via surface adsorption (Zelinkova & Wenzl, 2015). Food processing methods have also been implicated as possible routes of exposure of food to PAHs contamination (Ingenbleek et al., 2019; Tiwo et al., 2019). An example, is the processing of cassava to produce garri, which is usually fried by local means that utilize wood or charcoal stoves (Bede-Ojimadu & Orisakwe, 2020; Owili et al., 2017). Smoking of food also has the propensity of causing the release of carcinogenic PAHs into the environment which have the potential to cause cancers in humans and animals (Orodu & Sunny, 2018).

The PAHs in pumpkin leaves assessed in the present study were however identified to be predominantly sourced from petrogenic sources in the oil-producing area but from pyrolytic sources in the non-oil-producing area. Food substances can thus also become polluted by PAHs from petrogenic sources as a result of crude oil exploratory activities as well as products of these activities. These PAHs compounds can be present in the air, soil, or water and have the

ability to affect the nutritional potential of such food products (Ipeaiyeda et al., 2015; Itodo et al., 2018).

The concentration of Σ PAHs compounds in water obtained from the oil-producing and non-oil-producing areas in this study was also found to exceed the required maximum contaminant level (MCL) of total PAHs to be found in water (Aigberua, 2020; United States Environmental Protection Agency, 2001). It was further revealed that the PAHs in the water samples were mostly from pyrolytic sources. This finding agrees with the findings of other authors who reported PAHs compounds from mostly pyrolytic sources, which were present in surface waters assessed in Imiringi, Bayelsa State, and in Shitou Koumen, China (Aigberua, 2020; Sun et al., 2015) The predominant contamination of pyrolytic-sourced PAHs in water bodies has been described to mainly occur among households in rural areas in developing countries. This is due to their exclusive reliance on burning wood for their cooking and heating needs (Bede-Ojimadu & Orisakwe, 2020). Other sources of pyrolytic-sourced PAHs compounds have also been reported to include waste incineration, dumping unsegregated waste along river banks, and biomass combustion among others (Aigberua, 2020; Lawal, 2017; Sun et al., 2015) The environmental and epidemiologic effects of pollution from pyrolytic sources can thus not be overlooked considering that they are also capable of evoking adverse consequences on environmental life and human health.

Conclusion

Polycyclic Aromatic Hydrocarbons (PAHs) were found to exist in the four environmental media assessed in this study from both the oil-producing and non-oil-producing areas. The total PAHs concentration in each of the assessed media was found to exceed the guideline limits stipulated by environmental regulatory agencies. The PAHs concentrations in water and pumpkin leaves from both areas also differed significantly.

Recommendations made for policymakers included that when conducting their oversight functions, there is the need for rigidly ensuring adherence to regulations promoting environmental health and safety during oil and gas exploration and exploitation in the Niger Delta. It was also recommended for policymakers to formulate policies that encourage the use of environmentally safe methods for transportation, cooking, energy and waste management. For real-life applications, the need for regular environmental monitoring by the concerned stakeholders in oil-producing regions was recommended. It was also advised that more effort be put into tackling the pyrolytic sources of PAHs pollution of the environment by environmental regulatory agencies alongside action to tackle the petrogenic sources of these compounds. There is a need for the government to provide an enabling environment that promotes the availability and accessibility of environmentally safe options for transportation e.g. electric vehicles, power supply e.g. solar energy, cooking as well as waste management.

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BREASTFEEDING PRACTICE EXPERIENCE OF NURSING MOTHERS IN OIL-BEARING COMMUNITIES IN THE NIGER DELTA REGION, NIGERIA: A DESKTOP REVIEW

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ABSTRACT

Background: The oil and gas activities conducted in the Niger Delta region of Nigeria have been blamed for the release of pollutants including Polycyclic Aromatic Hydrocarbons (PAHs) into the environment. These pollutants are known for their calamitous environmental effects and inadvertent human health problems.

Aim: To explore the breastfeeding experiences of mothers in the Niger Delta Region from 2010 to 2022 which include the active oil-exploitation period in the region.

Methods: PubMed, Scopus, and Google Scholar databases were searched, out of the 71 articles that meet the objectives of the study 9 were qualitative and 62 were quantitative, between 4 to 8 articles were reviewed per State.

Results: Out of the nine Niger Delta States six of them had EBF rates higher than the National rate, with Cross River at the top followed closely by Ondo, the Rivers then Akwa Ibom, then Abia, and the Edo. Delta State appears to be the last. Some cultural practices and socioeconomic activities were some reasons given to be responsible for the low EBF rates within the Niger Delta.

Conclusion: There is an overall positive attitude and a good awareness of breastfeeding, but three of the Niger Delta States had exclusive breastfeeding rates lower than the National average, however, the impact of oil exploration led to some sociocultural practices that may have affected the breastfeeding practice of mothers within the Niger Delta.

KEYWORDS

Breastfeeding experiences, oil-bearing communities, Niger-Delta.

INTRODUCTION

Breastfeeding is the act of a mother giving her child breastmilk either directly from the breast or by expressing the milk to the child as food. Breastfeeding has several advantages for both the mother and the baby. Human breastmilk contains antibodies, and therefore breastfeeding serves as the child's first vaccine, protecting him/her from diseases such as diarrhoea and pneumonia (Lee & Binns, 2020; Sankar et al., 2015). Other benefits of breastfeeding include protection from obesity later in life, increased intelligence quotient, reduced cost, and improved bonding between the mother and the child. Additionally, for the mother, breastfeeding protects against breast and ovarian malignancies, type 2 diabetes, hypertension, and myocardial infarction, as well as aiding in uterine involution and reducing vaginal bleeding after delivery (Bartick et al., 2017). Despite these benefits of breastfeeding, the pattern and duration of breastfeeding are influenced by breastfeeding experiences, which might be good or bad. Breastfeeding experiences are the mother's impressions or observations made while breastfeeding, which can affect her choice to breastfeed and how often she does so.

Located in the southern region of Nigeria, in the West African sub-region, are the oil-bearing communities of the Niger Delta (Ansa & Akinrotimi, 2018) but the oil-related revenue has had no discernible positive economic impact on them as social hardship, endemic conflict, environmental degradation, and extreme poverty are rampant (Babatunde, 2014). Means of livelihood among women in Nigeria's coastal communities of oil producing region include farming, homestead gardening, rearing of cattle and poultry, fishing, periwinkle, prawn, snail, and crab collecting, as well as engaging in varied types of handicrafts like making fishing nets, fish cages and goods from bamboo etc. Oil spillage from exploration and gas flaring going on

for decades, within their communities as well as the fast-growing population, has meant these traditional ways of earning a living no longer practicable or have experienced massive fall. The women are disproportionately affected by the oil spill and exploration as they are more exposed based on their occupation making them prone to worse health risk and outcomes. On the other hand, as a result of the prolonged problem of oil spillage and gas flaring, the women's means of livelihood suffer due to the destruction and contamination of crops and livestock putting them in lack. This pushes them into strenuous economic position as they have to provide food for their families. Lactating mothers may abandon their babies before the first six months of their life to go out in search of livelihood which is the routine, because when it comes to feeding the family, women shoulder that burden. This review, therefore, aims to investigate through existing literature, how the breastfeeding experiences of mothers in oil-bearing communities in the Niger Delta may be impacted by oil exploration.

BREASTFEEDING BENEFITS

During a child's early developmental stage, sustenance is achieved through food consumption, and breastfeeding serves as the fundamental source of proper nutrition and significantly influences the child's well-being (Akpan et al., 2015). Breastfeeding can occur in various forms: exclusive breastfeeding, which entails solely providing the infant with breastmilk for the initial six months of life; partial or mixed breastfeeding, where breastfeeding is combined with formula milk, predominant breastfeeding, whereby breastfeeding is supplemented with water and complementary feeding; breastfeeding with any other food including semi solid and solid after six months of life (Oyibo et al., 2011).

The World Health Organisation (WHO) recommends that mothers should initiate breastfeeding within one hour of delivery, breastfeed exclusively for the first six months of life, and continue breastfeeding till the child is aged twenty-four months or more with appropriate and adequate

complementary foods (Organization, 2017). The Nigerian Policy on Infant and Young Child Nutrition (2011) and the recent Maternal, Infant, and Young Child Nutrition (2022) have adopted these recommendations for all Nigerian infants and young children. Nigeria was a signatory to the Millennium Development Goals (2000-2015) and the ongoing Sustainable Development Goals (2016-2030) all of which included infant and young child feeding indices as indicators for measuring attainment of the goals: In the Global Nutrition Target for 2025, breastfeeding rates have been included as a means of assessing infant nutritional efforts and it's expected to increase to 50%. It is therefore important to explore the practices and experiences in the Niger Delta region to provide evidence for actions towards the attainment of the goals and improving the survival, growth, and development of children in the region (Organization, 2017).

OIL-BEARING COMMUNITIES OF THE NIGER DELTA REGION

The Niger Delta region is comprised of diverse ecological zones, including rainforests, mangroves, freshwater swamps, barrier islands, and estuaries. It stands as the largest wetland in Africa, encompassing a total area of approximately 70,000 square kilometres. The region comprises of nine States namely Abia, Akwa Ibom, Bayelsa, Cross Rivers, Delta, Edo, Imo, Ondo, and Rivers States (see Figure 1). The region accommodates numerous communities and oil facilities that engage in extensive offshore and onshore oil production operations and exhibit tendencies towards pollution caused by oil spills, thereby polluting farmlands and underground water, as well as gas flaring. It serves as the primary geographic location within the country for the conduct of crude oil exploration and production. The revenue of Nigeria is predominantly derived from crude oil, accounting for approximately 90% and constituting more than 90% of the total exports (Akpan & Akpabio, 2009; ThankGod et al., 2014).

The projected population exceeds 30 million individuals, with women of childbearing age constituting 22% of this population. The area exhibits a population density of 200 persons per

square kilometre and is home to 40 distinct ethnic groups, speaking over 250 languages and dialects (Izah, 2018). The occupation of the residents is mainly fishing, trading, farming, public service with some involved in oil-related activities.

The health effects resulting from oil and gas exploration impact various systems within the human body through the inhalation of toxic and volatile gases present in the air due to pollution, the consumption of contaminated food and water, and direct contact with these potentially carcinogenic substances. Numerous adverse effects have been documented, including complications in birth outcomes (Cushing et al., 2020; Epstein, 2017), cardiovascular and respiratory disorders such as asthma, bronchitis, and issues related to the eyes and skin (Nriagu et al., 2016).



Figure 1: Niger Delta states (Izah, 2018)

The residents of this region live and work in proximity to flares, contaminated soil, and water, without any protective measures. Moreover, oil spills and environmental contamination remain ongoing till date (ThankGod et al., 2014). Research has indicated that

certain toxic environmental pollutants, originating from both indoor and outdoor pollution sources, can be transmitted from mother to baby through breastfeeding. This transmission can occur via exposure through inhalation, absorption, and ingestion by the mother during both prenatal and postnatal periods. Studies have documented that exposure to Polycyclic Aromatic Hydrocarbon (PAH) during lactation can result in elevated levels of PAH in breastmilk (Lehmann et al., 2018; Pajewska-Szmyt et al., 2019; Panm, 2020). Despite the potential risks associated with environmental contaminants present in breastmilk, exclusive breastfeeding is still recommended as the optimal method of infant feeding during the first six months of life (van den Berg et al., 2017). It is therefore important to explore the breastfeeding experiences of mothers in the region during the first six months of life to identify the impact, if any, of these contaminants on breastfeeding through a desktop review of publications on the region.

AIM AND OBJECTIVES

This desktop review seeks to obtain information to explore the breastfeeding experiences of mothers in the Niger Delta Region from 2010 to 2022, which include the active oil-exploitation period in the region.

Specific Objectives

- To determine the breastfeeding rates of mothers in the different States in the region through literature review
- To identify factors (if any) that affect the breastfeeding practices in the region.

MATERIALS AND METHODS

An extensive literature search was conducted on Scopus, PubMed, and Google Scholar research databases. The search was done independently in each of the nine oil-producing States.

The following MeSH terms were used. “Exclusive breastfeeding” “breastfeeding practice” “breastfeeding experience” “perceptions of breastfeeding” “benefits of breastfeeding” “determinants of breastfeeding” “constraints to breastfeeding” and “hindrances to breastfeeding”. Articles retrieved through search from Scopus, PubMed, and Google Scholar and covered all studies from 2010 to date conducted within the Niger Delta region, Nigeria, and globally. Four to eight studies were found for each of the Niger Delta States (Fig 2).

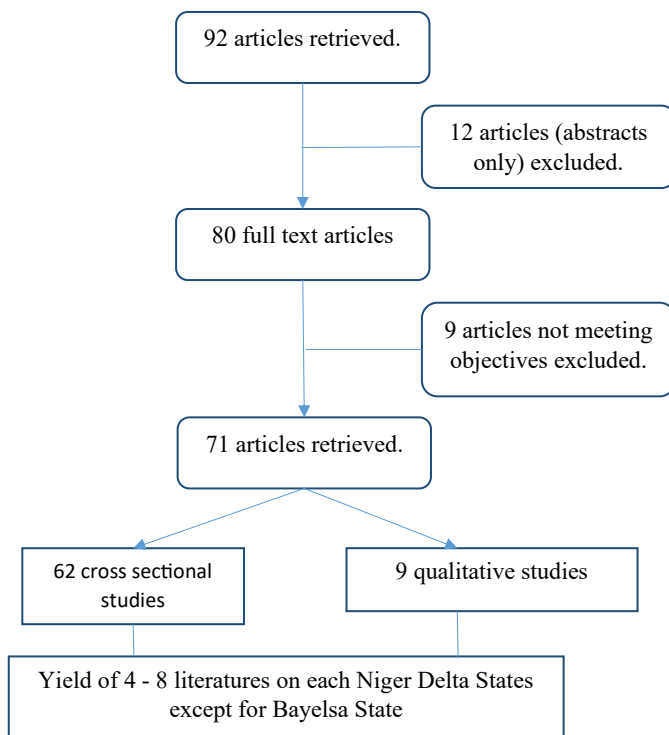


Figure 2: Result of literature search breastfeeding experiences in oil-bearing communities in the Niger Delta

Based on the heterogynous nature of the studies reviewed, the findings were put together on the indicators from the December 2022 breastfeeding scorecard of UNICEF to extract information observed as experiences on breastfeeding from nursing mothers in eight (8) thematic areas. They include: 1) Antenatal Care and Delivery in the health facilities, 2) Sources of information on breastfeeding, 3) Initiation of breastfeeding with one hour of birth, 4) Prevalence of Exclusive breastfeeding, 5) Complementary feeds after six month of age, 6) Standard Maternity leave of 14 weeks, 7) Safe workplace Support/ breastfeeding space, and 8) Family/ Community support.

DISCUSSION

This was based on five (5) thematic areas; prevalence of exclusive breastfeeding, sources of knowledge of breastfeeding, initiation and duration of exclusive breastfeeding, initiation of complementary breastfeeding and breastfeeding experiences

The experiences of breastfeeding mother within the oil-bearing communities are influenced by various factors, ranging from the level of knowledge, the attitude toward exclusive breastfeeding, socioeconomical, traditional, cultural, and health system-related factors. Breastfeeding was accepted as the norm in the region and country. The National rate for exclusive breastfeeding is 29% for children aged 0-6 months (National Population Commission - NPC & ICF, 2019). This review showed that more than half of the Niger Delta States (Ondo, Rivers, Akwa Ibom, Abia and Edo States) had rates higher than the National average. Cross Rivers State recorded the highest prevalence 67.8% (Ikobah et al., 2021) of exclusive breastfeeding in the Niger Delta followed closely by Ondo with a prevalence of 52.6% (Adebayo et al., 2021) next was Rivers State with 5.7% (Tobi et al., 2020) and Akwa Ibom State and Abia State at 42.4% and 42% respectively (Motilewa et al., 2019; Oguizu & Ogonnaya). Edo state had 36.6% (Agho et al., 2011). The lowest prevalence of 20.9% for

exclusive breastfeeding was recorded in Delta State (Dudu et al., 2016) which was followed closely by Imo State and Bayelsa State at 23.9% and 26.9% respectively (S. Ibe et al., 2017; Peterside et al., 2013) see figure 3.

The reasons for not sustaining the practice of breastfeeding included insufficient breastmilk production, the need to return to work, inadequate weight gain in the infant, concerns regarding the infant's dependence on breast milk alone, breast pain, maternal illness, the occurrence of subsequent pregnancies, dizziness during breastfeeding, infant refusal of breastmilk, fatigue associated with breastfeeding, societal pressure to wean the baby, lack of support from the husband, a perceived reduction in breast firmness, and feelings of embarrassment associated with public breastfeeding (Dudu et al., 2016).

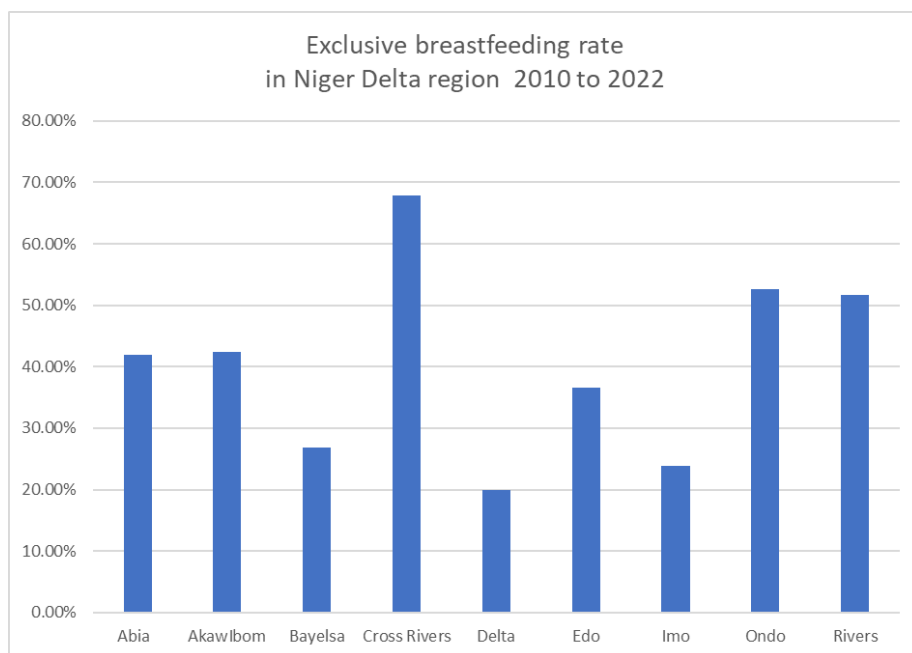


Fig 3: Exclusive Breastfeeding rates among mothers resident in the Niger Delta-Region

For all the states in the Niger Delta region, there existed a commendable level of awareness regarding exclusive breastfeeding. The primary source of information on this topic was the healthcare workers and the government health facilities, specifically the antenatal clinics. This information was found in various studies conducted by (Abasiattai et al., 2014; Adegboro, 2022; Akhimienho & Uwaibi, 2022; Bright Ogbondah, 2022; Ebirim et al., 2016; Ekeleme et al., 2021; Gabriel-Job & Azubogu, 2020; Ibe et al., 2017; Okari et al., 2020; Ukegbu & Ukegbu, 2010). The utilization of information communication technology played a significant role in disseminating knowledge regarding the significance of breastfeeding to nursing mothers, consequently leading to a positive change in behaviour (Eyo et al., 2022). In the case of Bayelsa State, the primary sources of knowledge on exclusive breastfeeding were healthcare workers and the mass media, as indicated by (Afolayan & George, 2010). Furthermore, many women including men (Ishikaku et al., 2022) possessed an accurate understanding of exclusive breastfeeding based on the definitions provided by the World Health Organization (WHO). Additionally, they firmly believed that exclusive breastfeeding was superior to infant formula and that its practice not only resulted in cost savings for the family but also contributed to child spacing (Ishikaku & Elenwa, 2022)

The initiation of breastfeeding within the first hour of life is of great importance for both the mother and the new-born. The colostrum contains a significant quantity of nutrients and antibodies that protect the infant from illnesses. The prompt initiation of breastfeeding also promotes a bond between the mother and her new-born, thereby facilitating the production of regular breastmilk. According to the Nigeria Demographic and Health Survey (NDHS) (National Population Commission - NPC & ICF, 2019) 42% of infants in Nigeria are breastfed within one hour of birth. Literature reviews have indicated that mothers in six out of the nine Niger Delta states (Abia, Bayelsa, Delta, Ondo, and Rivers) initiate breastfeeding within one hour of delivery. Various studies conducted by (Fatile, 2022b; Ikobah et al., 2021;

Neji et al., 2015; Oguizu & Ifendu, 2018; Okolo et al., 2015; West et al., 2020), have supported this finding. Again, it was observed that mothers who had more than four antenatal visits were more likely to initiate breastfeeding within one hour of delivery, as indicated by studies conducted by (Agho et al., 2011; Atimati & Adam, 2020; Atimati & Adam, 2019; West et al., 2020)

Literatures from Abia, Akwa Ibom, Cross Rivers, Edo, Ondo, and Rivers States showed that nursing mothers had a good attitude towards breastfeeding (Ebirim et al., 2016; Fatile, 2022a, 2022b; Gabriel-Job & Azubogu, 2020; Ibe et al., 2017; Motilewa et al., 2019; Neji et al., 2015; Oguizu & Ogbonnaya, 2021; Okari et al., 2020). Gabriel-Job (Gabriel-Job & Azubogu, 2020), in Rivers State observed that positive attitude towards exclusive breastfeeding was a result of the frequent antenatal visits, having to deliver in the hospital, maternal age, parity, marital status and her level of education, which agrees with the findings of NDHS (2018) and other literatures in Edo State (Augustine et al., 2015; Ebirim et al., 2016; Ibe & Obasi, 2017) and Akwa Ibom (Motilewa et al., 2019). Thus, women who had 4 or more antenatal clinic visits, had their deliveries supervised by skilled birth attendants, delivered in formal places of birth, married, and with higher levels of education were more likely to initiate early breastfeeding and keep their babies longer on the breast.

The main factors that hindered the continuation of breastfeeding were the limited length of maternity leave and the challenges faced in work environments. These challenges were particularly prevalent among women in oil-bearing communities, who had to work in either the formal or informal sector to support their families. As a result, many working mothers had to prematurely stop breastfeeding to attend to their work responsibilities or educational commitments (in the case of students). Consequently, they had to rely on crèche and daycare centres to care for their infants (Agbedeyi et al., 2015; Eke & Nte, 2019; Tobi et al., 2020). Therefore, the duration of breastfeeding was heavily influenced by the occupation of the

mother (Ibe et al., 2017). This finding is consistent with the National Demographic and Health Survey (2018), which revealed that women from the South-south geopolitical region (where 78% of the oil-bearing communities fall into) of the country breastfed their babies for shorter periods compared to women from other regions.

Farmers, traders, and business owners exhibited a higher prevalence of breastfeeding their infants in comparison to civil servants (Dudu et al., 2016). This phenomenon may stem from the advantageous accessibility that these individuals possess towards their babies throughout their work hours, unlike civil servants and company workers who must entrust their infants to crèches and day care centers to resume work (Adegboro, 2022; Eke & Nte, 2019). Nonetheless, these findings contradict studies conducted in Imo State, which revealed a diminished acceptance and practice of exclusive breastfeeding among rural populations when compared to urban nursing mothers who are in paid employment (Maduforo & Onuoha, 2011; Nwabuaku & Onyinye, 2020). This disparity arises from the belief held by rural communities that an infant cannot sustain themselves solely on breast milk for six months, leading to the introduction of water and water-based herbal remedies without perceiving them as obstacles to exclusive breastfeeding (Douglas et al., 2020).

Cultural factors also exerted an influence on the breastfeeding roles of the nursing mothers residing in the oil-bearing communities of the Niger Delta. The literature originating from Imo State has documented the Ibo tradition known as "Omugwu," in which the nursing mother's responsibilities are limited and she receives assistance, particularly from the traditional grandmother, during the initial stages of breastfeeding (Douglas et al., 2020; Ibe et al., 2017). These traditional grandmothers, who include both mothers and mothers-in-law, actively promote and provide breastfeeding support, thereby fostering positive breastfeeding experiences. However, due to the increasing prevalence of nuclear families, and the rising levels of female education and employment, these practices are experiencing a decline,

resulting in inadequate support for breastfeeding and a consequent decline in the practice of exclusive breastfeeding (Dudu et al., 2016).

The breastfeeding experiences of nursing mothers in the oil-bearing communities of the Niger Delta are influenced by various personal factors and health system factors, particularly those related to the mothers' medical records. Factors such as the mode of delivery (caesarean section), multiple births, and delayed lactation/letdown reflex contribute to poor breastfeeding experiences, leading to the introduction of infant formula and glucose water as pre-lacteal feeds. This has been observed in studies conducted by (Ejje et al., 2021) and (Onyearugha & Okoronkwo, 2019). Additionally, the perception that breastmilk alone is insufficient for the baby, as well as the need to return to school or work, have resulted in a shortened duration of breastfeeding and the subsequent introduction of formula milk and pap. These findings were reported by (Ejje et al., 2021) and (Okonkwo et al., 2022). Nursing mothers also face concerns such as feeling ashamed to breastfeed in public and the fear of a sagging breast, as reported by (Ella et al., 2016) and (Neji et al., 2015). Furthermore, ignorance and medical illnesses have been identified as reasons for not breastfeeding (Ahuizi, 2011).

Summary

Breastfeeding encountered significant variations among mothers resident in the oil-bearing communities of the Niger Delta. Most of the nursing mothers possessed a commendable level of knowledge, but their practical implementation of breastfeeding practices tended to be substandard (Dudu et al., 2016). The experiences of nursing mothers had a direct bearing on the timing of the initiation of breastfeeding, the specific type of breastfeeding employed, and the duration of exclusive breastfeeding. Some maternal experiences resulted in a delay, or even a complete absence, of breastfeeding initiation, whereas positive experiences had facilitated

early initiation and subsequently foster optimal growth and development through exclusive breastfeeding.

Conclusion

Breastfeeding plays a crucial role in facilitating the proper development and growth of newborns. Within the oil-bearing communities of the Niger Delta, both mothers and their infants are subjected to a double burden of the contaminated environment due to the activities of the oil industry and the challenging economic conditions. These conditions often force women to engage in various economic activities to provide for their families, thereby potentially influencing the initiation and sustainability of breastfeeding. The experiences of breastfeeding among nursing mothers within these oil-bearing communities in the Niger Delta exhibit significant variations, which may contribute to less than satisfactory rates of exclusive breastfeeding in a third of the states within the region, compared to the national average. Despite a generally high level of knowledge and positive attitudes towards exclusive breastfeeding, certain mothers encounter difficulties that hinder their ability to initiate or maintain breastfeeding. While most cultural practices in the area support positive breastfeeding experiences, the changing economic burden has hurt the breastfeeding experiences of mothers in the region.

Recommendations

- Raising awareness, economic empowerment, and environmental protection, while respecting local cultural practices.
- Recommending workplace policies that accommodate breastfeeding mothers, allowing for breaks and facilities to express milk.

- Adoption of maternity leave policies that support extended breastfeeding should be encouraged to enhance the positive experiences of mothers in breastfeeding their newborns.
- Nursing mothers should be enabled to balance work and breastfeeding by supporting economic empowerment programs for women in these oil-bearing communities of the Niger Delta.

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CONFLICTS OF INTEREST- Nil.

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Morphological and molecular characterisation of *Colocasia esculenta* (L.) Schott, *Xanthosoma mafaffa* (L.) Schott and *Caladium bicolor* (Aiton) Vent. (ARACEAE).

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ABSTRACT.

Morphological and molecular genetics investigations were carried out on the accessions of three genera (*Colocasia*, *Xanthosoma* and *Caladium*) to determine the level of their similarity. The color of the petiole to the midrib, the color of the petiole to the corm and cormel, the color of the leaf margin, and the color of the leaf base were all examined. Other leaf characteristics that were examined were leaf type, apex, shape, base, margin, and lamina. DNA was extracted, and gel electrophoresis and PCR were used to determine concentrations and purities. Using MEGA 7.0.26, the sequence nucleotide chromatogram extension was transformed into a

readable file. The Dendrogram was obtained using UPGMA. The results showed that the petiole attachment is peltate in *C. esculenta* and *Caladium bicolor*, whereas at the leaf margin in *X. maffafa*. *C. esculenta* has round basal lobes, but those of *X. maffafa* and *Caladium bicolor* are more elongated. The dark pinkish colour of the petiole to the corm distinguishes NXS 002 from other *Xanthosoma* studied. *Caladium bicolor* was distinguished from other genera by the colour of the leaf base, leaf blade and its variegated colour. The DNA extracted from the accessions were pure; the sequence alignment and Dendrogram result shows some level of similarity and dissimilarity among members across the three genera studied. However, there was a closer relationship between members of the same genera. It was also observed that (Ede Uhie) NXS 002 was different from other members of the *Xanthosoma* and should be considered as distinct sub specie

Introduction

Aroids of the subfamily Aroideae are among the ancestors of all Angiosperms. They comprise more than 1,500 species in 75 genera and is divided into 24 tribes belongs to the family Araceae (Nauheimer et al., 2012; Croat & Ortiz, 2020). With 9 subfamilies, 144 genera, and 3,645 species, the Araceae family is one of the most varied monocotyledonous families (Boyce & Croat, 2011). It is most diverse in the tropics, with the Pacific slopes of northern Andes housing most of the species (Croat, 1979; Mora *et al.*, 2006; Herrera *et al.*, 2008). The principal edible aroids are divided into two tribes, and five genera: Colocasiodeae (*Alocasia*, *Colocasia*, and *Xanthosoma*) and Lasioideae (which are *Amorphophallus* and *Cyrtosperma*). *Xanthosoma* and *Colocasia* are thus members of the five genera in the family Araceae which are significant economically (Gomez-Beloz & Rivero, 2006). The term "cocoyam" refers to two well-known and edible aroid genera, *Colocasia* (Schott) as well as *Xanthosoma* (Schott), which, respectively, are tuber plants that were brought to Africa from tropical America and Asia (Osawaru & Ogwu, 2015). Thus, the term "cocoyam" refers to a variety of edible aroids (Onwueme, 1978; Mwenye, 2009). Typically, cocoyams grow vegetatively from tuber fragments (Sama *et al.*, 2012).

On the other hand, *Caladium* is a member of the Neotropical tribe Caladieae, which is a part of the Aroideae subfamily. The colorful and diversely formed foliage of *Caladiums* is what attracts gardeners to these decorative aroids. They can be grown from seed; however, they exhibit significant variability in seedling populations and are extremely heterozygous (Hartman *et al.*, 1972). *Caladium* is a genus of 12 species, with *Caladium bicolor* serving as the main source of accessions (Mayo *et al.*, 1997).

Variability in the three genera of interest (*Colocasia*, *Xanthosoma* and *Caladium*), could lead to emergence of new species (speciation) as a result of long duration of the cultivation of this crop. Research on cocoyam is still in its early stages in Nigeria. According to a certain view, all *Xanthosoma* in Nigeria are actually members of the *X. maffafa* species, not the *X.*

sagittifolium species (Okeke, 2008), suggesting an error in the taxonomy of *Xanthosoma* species in Nigerian. This circumstance calls for rigorous research into these crops, particularly to generate further empirical information for the advancement of cocoyam and its difficult-to-improve wild relative (*Caladium*). As a result, there are no new or enhanced novel accessions. Current research on the taxonomic study of the cocoyam (*Colocasia* and *Xanthosoma*) is lacking. This implied that in-depth taxonomic analysis of this plant had not been done. As a result, a taxonomic study on these genera have become a necessity, hence this study.

Materials and methods

Source of Material and Study Area

The cocoyam accessions used in this study were generated using field material obtained from the National Root Crops Research Institute in Umudike, Umuahia. The plant materials consist of three accessions of *Xanthosoma*, "Ede Ocha" (NXS 001), "Ede Uhie" (NXS 002), and "Okorokoro" (NXS 003), as well as five accessions of *Colocasia*, "Coco India" (NCE 001), "Ede Ofe Green" (NCE 002), "Ede Ofe Purple" (NCE 003), " NCE stands for Nigeria *Colocasia* esculenta, while NXS refers for Nigeria *Xanthosoma* species. *Caladium bicolor* came from a natural source. In the University of Port Harcourt Botanic Garden, *Xanthosoma*, *Colocasia*, and *Caladium bicolor* corms and cormels were planted in plastic containers and given frequent watering.

Morphological Studies

The color of the petiole to the midrib, the color of the petiole to the corm and cormel, the color of the leaf margin, and the color of the leaf base were all examined. Other leaf characteristics that were examined were leaf type, apex, shape, base, margin, and lamina.

Molecular Studies

Table 1. List of Cocoyam Accessions and *Caladium bicolor* used in this study

SN	LAB	SCIENTIFIC	COMMON	ACCESSION
	ABBREVIATION	NAME	NAME	NUMBER

1	P23 RBCL 1	<i>Colocasia esculenta</i>	COCO INDIA	NCE 001
2	P24 RBCL 2	<i>Colocasia esculenta</i>	EDE OFE GREEN	NCE 002
3	P25 RBCL 3	<i>Colocasia esculenta</i>	EDE OFE PURPLE	NCE 003
4	P26 RBCL 4	<i>Colocasia esculenta</i>	UKPONG	NCE 005
5	P27 RBCL 5	<i>Colocasia esculenta</i>	AKIRI	NCE 010
6	P28 RBCL 6	<i>Xanthosoma maffafa</i>	EDE OCHA	NXS 001
7	P29 RBCL 7	<i>Xanthosoma maffafa</i>	EDE UHIE	NXS 002
8	P30 RBCL 8	<i>Xanthosoma maffafa</i>	OKOROKORO	NXS 003
9	P31 RBCL 9	<i>Caladium bicolor</i>		CB

Plant dna extraction protocol

C. esculenta, *X. maffafa*, and *C. bicolor*'s DNA was extracted using the Zymo Quick DNA Plant/Seed Miniprepkit. A final dilution of 0.5% (v/v), or 500 μ l per 100 mL, of beta-mecaptoethanol was added to the genomic Lysis buffer for best results. A 1.5 mL Eppendorf

tube containing BashingBead™ Buffer received 150 micrograms (150 mg) of a finely chopped plant sample. For one minute, the Eppendorf tube was centrifuged at 10,000 x g. A collecting tube containing 400 l of supernatant was transferred to the Zymo-Spin™ IIIIF Filter and centrifuged at 8,000 g for one minute. The Zymo-Spin™ IIIIF Filter was then put in the trash. The filtrate from Step 4's collecting tube was added to Genomic Lysis Buffer (1200 l), and it was thoroughly mixed. A collection tube containing 800 microliters (l) of the Step 4 combination was transferred to Zymo-Spin™ IIC and centrifuged at 10,000 g for one minute. After discarding the flow through from the Collection Tube, step 5 was repeated. The Zymo-Spin™ IIC Column was placed in a fresh collection tube with 200 l of DNA Pre-Wash Buffer and centrifuged at 10,000 x g for one minute. The Zymo-Spin™ IIC Column was filled with precisely 500 l g of DNA Wash Buffer before being centrifuged at 10,000 x g for one minute. A clean 1.5 ml micro centrifuge tube was used to transfer the Zymo-Spin™ IIC Column, and the column matrix was then directly infused with 60 l of DNA elution buffer. To elute the DNA, the substance was centrifuged at 10,000 x g for 30 seconds. 600 l of Prep Solution was introduced to a Zymo-Spin™ III-HRC Spin Filter, which was then centrifuged at 8,000 g for three minutes. After being transferred to a ready Zymo-Spin™ III-HRC Spin Filter in a clean 1.5 mL micro centrifuge tube, the eluted DNA was centrifuged at precisely 16,000g for 3 minutes. Now that the DNA had been filtered, it could be used in PCR and other applications. DNA Concentration and Purity Assessment Using a Nanodrop 2000c spectrophotometer (Thermo Fisher Scientific, USA), DNA concentration and purity were evaluated. Ultraviolet (UV) light absorbance at 260 nm to 280 nm is used as a proxy for purity. The sensor on the Nanodrop was cleaned with cotton wool and 70% ethanol while it was attached to a computer system. To reset the system, 1 l of the elution buffer—the solution used to re-suspend the DNA—was sprayed directly onto the Nanodrop sensor. DNA samples (1 l) were then sequentially put onto the sensor. Prior to loading a fresh sample, the sensor was typically

cleaned to prevent contamination. For each sample, a Nanodrop measurement was conducted twice.

Gel electrophoresis

1.5% agarose gel was used for the gel electrophoresis procedure. To make the clear solution, 0.75g of agarose powder was combined with 50ml of 1X Tris-Boris EDTA (TBE) buffer in a measuring flask and micro waved for 2 minutes. The conical flask's contents were mixed with 5L of EZ viewing dye (Blue Light), which was then put into the casting tray or gel holder. The comb was put inside the casting tray and let 20 to 30 minutes to firm at room temperature. The gel holder containing the gel was then put on the platform inside the gel tank, and TBE 1X was added to the gel tank until the gel was completely submerged. At this point, the gel electrophoresis unit was ready for use. DNA samples were independently inserted into the wells made by the comb on the gel after the molecular weight marker (1Kb DNA Ladder) was added into the first lane of the gel. One lot of 6X loading dye was combined with five individual DNA samples before being loaded into one gel lane. In addition, a control was loaded that had all of the PCR reaction mixture's ingredients without the template DNA. The system was left running at 100 volts for 40 minutes. The DNA fragments were observed at the conclusion of the experiment using a Gel Documentation Microdot from Cleaver Scientific Ltd. in the UK.

Polymerase chain reaction (pcr)

Onita® Quick-Load® 2X Master Mix (New England Bio laboratories, USA, Catalogue No. M0486) was used to amplify the target region in an Eppendorf Master cycler (Nexus Gradient 230, Germany) under the settings shown in Table 2.

Table 2: Polymerase chain reaction cocktail components

Component	Volume of a 12.5 μ l reaction
Template DNA	2 μ L
10 μ M Forward Primer	0.25 μ L (10nM)
10 μ M Reverse Primer	0.25 μ L (10nM)
One Taq Quick Load 2X Master Mix with Standard Buffer	6.25 μ L
Nuclease free water	3.75 μ L

The forward primer RBCL 1 - AACACCAGCTTTRAATCCAA and the reverse primer ATP - ACATCKARTACKGGACCAATAA made up the primer sets that were employed. The thermal cycling conditions were as follows: initial denaturation at 94°C for 5 min; then 35 cycles, each consisting of 30 s of denaturation at 94°C, 60 s of annealing at 50°C, and 90 s of extension at 72°C; and finally, a termination at 72°C for 10 mins. The PCR mixture was maintained at 4°C by the thermal cycler.

PCR products were purified using an enzymatic method (Exocarp) as follows:

1. Exocarp master mix was prepared by adding the following to a 0.6ml micro-centrifuge tube:
 - a. 50 μ l of 20U/ μ l Exonuclease I (Catalogue No. NEB M0293L)
 - b. 200 μ l of 1U/ μ l of Shrimp Alkaline Phosphatase (Catalogue No. NEB M0371)
2. The reaction mixture was prepared by mixing the following and incubating the resulting mix at 37°C for 15mins and at 80°C for 15mins.
 - a. Amplified PCR Product- 10 μ l
 - b. Exocarp Mix (step 1)- 2.5 μ l

Sequencing and Sequence Analysis

The process of figuring out a fragment of DNA's nucleotide base sequence—As, Ts, Cs, and Gs—is known as DNA sequencing. The Gene Amplic PCR system 9700 was utilized for this process, and ribulose-1,5-6 biphosphate caboxylase (rbcL) was used as the marker

According to the manufacturer's instructions, the fragments were sequenced using the

Imagen, Brilliant Dye™ Terminator Cycle Sequencing Kit V3.1, BRD3-100/1000:

[https://www.nimagen.com/products/Sequencing/Capillary-Electrophoresis/BrilliantDye-](https://www.nimagen.com/products/Sequencing/Capillary-Electrophoresis/BrilliantDye-Terminator-Cycle-Sequencing-Kit/)

[Terminator-Cycle-Sequencing-Kit/](https://www.nimagen.com/products/Sequencing/Capillary-Electrophoresis/BrilliantDye-Terminator-Cycle-Sequencing-Kit/).The ZR-96 DNA Sequencing Clean-up Kit (Catalogue

No. D4053) was then used to clean the labeled products:

<http://www.zymoresearch.com/downloads/dl/file/id/52/d4052i.pdf>

POP7 was used to inject the cleaned products utilizing a 50cm array into the Applied Bio

Systems ABI 3500XL Genetic

Analyzer.<https://www.thermofisher.com/order/catalog/product/4406016> and sequence

information gathered.

Data analysis

Chroma light was used for base calling and to show the sequences produced by the sequencer.

Before using the NCBI (National Centre for Biotechnology Information) database to run a

Basic Local Alignment Search Tool (BLAST) search, Bio alter was used to alter the sequence.

ClustyalW was used to align comparable downloaded sequences.

Using MEGA 7.0.26, the sequence nucleotide chromatogram (abi fie) extension was

transformed into a readable file. A matrix was created by compiling and aligning the nucleotide

sequences. Using the Unweighted Pair Group approach with Arithmetic Mean (UPGMA)

hierarchical clustering approach (Sneath and Sokal, 1973), the evolutionary history of all nine

accessions was deduced in order to create a phylogenetic tree. The evolutionary distances are

expressed in base substitutions per site and were calculated using the Maximum Composite Likelihood technique. Included were the codon locations 1st+2nd+3rd+No1Noncoding. Every position with missing data and gaps was removed. The final dataset contained 558 locations in total.

Phylogenetic tree

Nei and Saitou (1987) state that the Neighbor-Joining technique was used to infer the evolutionary history. It shows the perfect tree. Next to the branches in the bootstrap test (500 repetitions), the proportion of duplicate trees in which similar taxa were placed together is displayed (Felsenstein, 1985). The phylogenetic tree is demonstrated to scale with branch lengths measured in the same evolutionary distances. The evolutionary distances, which are given as base substitutions per site, were calculated using the Jukes-Cantor technique (Jukes and Cantor, 1969). There were five distinct nucleotide sequences in this study. For every set of sequences, all ambiguous sites were eliminated (pairwise deletion option). The final dataset contained 668 sites in total. MEGA11 was used for evolutionary study (Tamura et al., 2021). The genetic comparison was done using the NCBI website.

Result and discussion

Morphology

Below is a table showing morphological characteristics of the nine accessions studied across the three genera.

Table 3: Morphological Characteristics Of The Nine Accessions Studied Across The Three

Scientific name	Local name	Accessions	Leaf type	Petiole attachment	Colour of lamina	Leaf shape	Leaf margin	Leaf apex	COLOR of leaf base	Colour of petiole to the corm	Colour of the leaf margin
<i>C. esculenta</i>	Coco India	NCE 001	Simple	Peltate	Dark green	cordate	Entire	Apiculate	Purple	Greenish purple	Green
<i>C. esculenta</i>	Ede Ofè Green	NCE 002	Simple	Peltate	Light green	Cordate	Entire	Apiculate	Light green	Green	Green
<i>C. esculenta</i>	Ede Ofè Purple	NCE 003	Simple	Peltate	Dark green	Cordate	Entire	Apiculate	Light green	Purple	Green
<i>C. esculenta</i>	Ukpong	NCE 005	Simple	Peltate	Light green	Cordate	Entire	Apiculate	Light green	Light green	Green
<i>C. esculenta</i>	Akiri	NCE 010	Simple	Peltate	Dark green	Cordate	Entire	Apiculate	Light green	Light green	Green
<i>Xanthosoma maffafa</i>	Ede Ocha	NXS 001	simple	Leaf margin	Light green	Sagittate	Entire	cuspidate	Light green	Light green	Green
<i>Xanthosoma maffafa</i>	Ede Uhie	NXS 002	Simple	Leaf margin	Dark green	sagittate	Entire	cuspidate	Light green	Dark pink	Greenish purple
<i>Xanthosoma maffafa</i>	Okorokoro	NXS 003	Simple	Leaf margin	Dark green	Sagittate	Entire	Cuspidate	Light green	Light green	Green
<i>Caladium bicolor</i>		CB	simple	Peltate	Variegated	sagittate	Entire	cuspidate	Light pink	purple	Green

Morphological observations showed that leaves of all the accessions were simple (Table 3). Leaf shapes of the *C. esculenta* were all cordate while that of the *Xanthosoma* and *Caladium bicolor* were sagittate. The petiole attachment was peltate in *C. esculenta* and *Caladium bicolor*, whereas at the leaf margin in *X. maffafa*. *C. esculenta* had round basal lobes, but those of *X. maffafa* and *Caladium bicolor* were more elongated (Plate 3). The leaf margins of all the accessions were entire. The leaf apices of all the *C. esculenta* were apiculate and that of the *X. maffafa* were all cuspidate while that of *Caladium bicolor* was cuspidate (Table 3.).

Between the genera *Colocasia* and *Xanthosoma*, there was no distinction in the color of the lamina (Plates 4.1–4.16). The variegated shades of *Caladium bicolor*'s lamina set it apart from other genera under study (Plates 4.17–4.18). The presence of a purple color at the leaf base (the location where the petiole attaches to the leaf) distinguishes Coco India (NCE 001) from other *Colocasia* species (Plates 4.1–4.2). *Caladium bicolor* was distinguished from other genera by the color of the leaf base, which serves as the point where the petiole attaches to the leaf (Plates 4.17–4.18). NCE 002, NCE 003, NCE 005, NCE 010, NXS 001, NXS 002 and NXS 003 possessed light green color at the leaf base (Plate 4. 3 to 4.16). There was variation in the color of petiole attached to the corm across the various genus and accessions studied respectively (Plate 4. 1 to 4.18).

The only notable difference encountered among the cocoyam was the greenish color of the leaf margin in NXS 002 (*X. maffafa*) (Plate 4.12).



Plate 1. a: Adaxial leaf surface of Coco India (*C. esculenta*, NCE 001)

b: Abaxial leaf surface of Coco India (*C. esculenta*, NCE 001)

c: Adaxial Leaf Surface of Ede Ofe Green (*C. esculenta*, NCE 002)

d: Abaxial Leaf Surface of Ede Ofe Green (*C. esculenta*, NCE 002)

e: Adaxial Leaf Surface of Ede Ofe Purple (*C. esculenta*, NCE 003)

f: Abaxial Leaf Surface of Ede Ofe Purple (*C. esculenta*, NCE 003)



Plate 2.

g: Adaxial Leaf Surface of Ukpong (*C. esculenta*, NCE 005)

h: Abaxial Leaf Surface of Ukpong (*C. esculenta*, NCE 005)

i: Adaxial Leaf Surface of Akiri (*C. esculenta*, NCE 010)

j. Abaxial Leaf Surface of Akiri (*C. esculenta*, NCE 010)

k. Adaxial Leaf Surface of Ede Ocha (*X. maffafa*, NXS 001)

l. Abaxial Leaf Surface of Ede Ocha (*X. maffafa*, NXS 001)

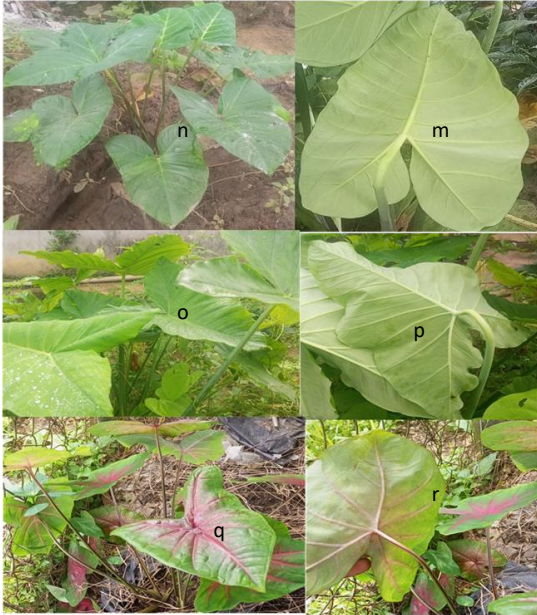


Plate 3. m. Adaxial Leaf Surface of Ede Uhie (*X. maffafa*, NXS 002)

n: Abaxial Leaf Surface of Ede Uhie (*X. maffafa*, NXS 002)

o: Adaxial Leaf Surface of Okorokoro (*X. maffafa*, NXS 003)

p. Abaxial Leaf Surface of Okorokoro (*X. maffafa*, NXS 003)

q. Adaxial leaf surface of *Caladium bicolor*

r. Abaxial leaf surface of *Caladium bicolor*

Molecular result

The result of the genomic DNA quantification using the Nanodrop spectrophotometer and agarose gel electrophoresis revealed that the DNAs extracted from the plants are pure, with the purity index ranging between 1.70 and 1.94 and concentration between 8.55 and 281.5 ng/fly (Table 4.8). The

rbcl primer was efficient in amplifying the ribulose biphosphate carboxylase (*rbcl*) gene of interest.

Table 4: Genomic DNA quantification result using NanoDrop spectrophotometer

Scientific name	Local name	Accessions	Lab name	DNA Conc. (ng/μl)	Absorbance (nm)		
					260	280	260/280
<i>C. esculenta</i>	COCO INDIA	NCE 001	RCBBR_P2 3	281.55	5.631	3.042	1.85
<i>C. esculenta</i>	EDE OFE GREEN	NCE 002	RCBBR_P2 4	140.4	2.809	1.537	1.83
<i>C. esculenta</i>	EDE OFE PURPLE	NCE 003	RCBBR_P2 5	178.0	3.561	1.965	1.81
<i>C. esculenta</i>	UKPONG	NCE 005	RCBBR_P2 6	36.2	0.723	0.398	1.82
<i>C. esculenta</i>	AKIRI	NCE 010	RCBBR_P2 7	59.85	1.187	0.65	1.83
<i>X. maffafa</i>	EDE OCHA	NXS 001	RCBBR_P2 8	26.6	0.532	0.275	1.94
<i>X. maffafa</i>	EDE UHIE	NXS 002	RCBBR_P2 9	8.55	0.172	0.107	1.70
<i>X. maffafa</i>	OKOROKORO	NXS 003	RCBBR_P3 0	64.27	1.286	0.711	1.80
<i>Caladium bicolor</i>		CB	RCBBR_P3 1	49.6	1.985	1.094	1.82

The table shows the summary of the genomic DNA result using NanoDrop spectrophotometer. the results of DNA isolation obtained DNA concentration values in the range of 8.55-281.5 with an

average concentration value of 93.89. The purity value of isolated DNA was in the range of 1.70-1.94 with an average purity value of 1.82(Table 4).

KEYS

P23 NCE 001(COCO INDIA), P24 NCE 002 (EDE OFE GREEN), P25 NCE 003(EDE OFE PURPLE), P26NCE 005 (UKPONG), P27 NCE 010(AKIRI), P28 NXS 001(EDE OCHA), P29 NXS 002(EDE UHEI), P30 NXS 003 (OKOROKORO) P31 CB

NCE Nigeria *Colocasia*, NXS Nigeria *Xanthosoma*, CB *Caladium bicolor*

KEYS

P23 NCE 001(COCO INDIA), P24 NCE 002 (EDE OFE GREEN), P26 NCE 003(EDE OFE PURPLE), P26 NCE 005(UKPONG), P27 NCE 010(AKIRI), P28 NXS 001(EDE OCHA), P29 NXS 002(EDE UHEI), P30 NXS 003 (OKOROKORO) P31 CB

NCE Nigeria *Colocasia*, NXS Nigeria *Xanthosoma*, CB *Caladium bicolor*

Dna sequencing

The result of the sequencing of the nine accessions is shown in Figure 1. From the result it was observed that the colors of the bases of the nucleotides were presented in four colors red: thymine (T), blue: cytosine (C), purple: guanine (G), green: adenine (A). These different colors allowed for easy reading of the sequences (Figure 1).

Observations from the sequence alignment showed that 1 RBCL, 3 RBCL AND 5 RBCL had similar nucleotides in their sequences, 4 RBCL and 2 RBCL also had similar nucleotides in their sequences (Figure 1).

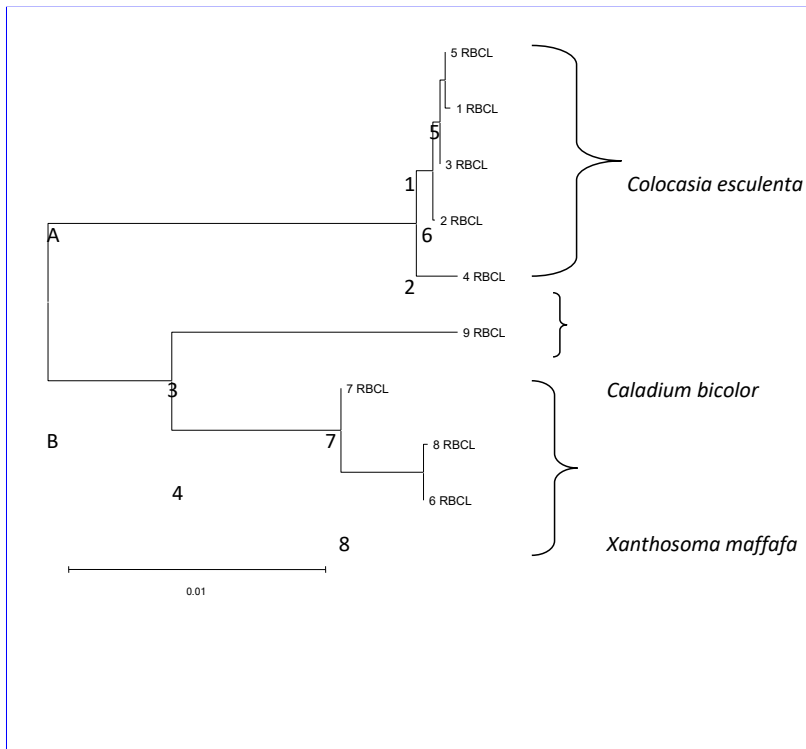


FIGURE 2. Dendrogram obtained from rbcl analysis using UPGMA

KEYS.

NCE Nigeria *Colocasia*, NXS Nigeria *Xanthosoma*, CB *Caladium bicolor*

1 RBCL (NCE 001, COCO INDIA *Colocasia esculenta*), 2 RBCL (NCE 002 EDE OFE GREEN, *Colocasia esculenta*), 3 RBCL (NCE 003 EDE OFE PURP *Colocasia esculenta* LE,), 4 RBCL (NCE 005 UKPONG, *Colocasia esculenta*), 5 RBCL (NCE 010 AKIRI, *Colocasia esculenta*),

6 RBCL (NXS 001 EDE OCHA, *Xanthosoma maffafa*), 7 RBCL (NXS 002, EDE UHEI, *Xanthosoma maffafa*), 8 RBCL (NXS 003 OKOROKORO, *Xanthosoma maffafa*) AND 9 RBCL *Caladium bicolor* (FIGURE 2).

The Dendrogram revealed two major clusters A and B. Cluster [A] was further divided to form 2 sub clusters [1] and [2]. Cluster 1 diverted to form TWO additional clusters 5 and 6. Cluster 5 gave rise to accessions 5 RBCL, 1 RBCL and 3 RBCL of which accessions 5 RBCL and 1 RBCL were grouped as the most similar. Accessions 5 RBCL and 1 RBCL were also seen to be similar to Accession 3 RBCL. Furthermore cluster 6 gave rise to accession 2 RBCL which also shared some level of similarity with accessions 5 RBCL and 1 RBCL(Figure 2).

Major diversion took place in cluster 2 to form accession 4 RBCL which was the most distant accession in the genus *Colocasia* (Figure 2).

Similarly, cluster B divided into two clusters 3 and 4. Cluster 3 formed 9 RBCL which gave rise to the genus *Caladium* (Figure 2).

While cluster 4 diverted into two clusters to form cluster 7 and 8. Cluster 8 formed two accessions which were very similar to each other. Cluster 7 formed accession 7 RBCL which shared some level of similarity and dissimilarity with cluster 8, and it appeared as the most distant in the genus *Xanthosoma*

Discussions

The petiole attachment was peltate in *Colocasia esculenta* and *Caladium bicolor*, but close to the leaf margin in *Xanthosoma maffafa*. This is consistent with the results of Ezeabara et al. (2015), who found that *Xanthosoma* petiole attachment is located at the leaf's margin. The basal lobes of *Caladium bicolor* and *Xanthosoma* species were longer and more or less rounded than those of *C. esculenta*, which had rounded basal lobes. According to Manner (2011) the location at which the petiole is joined to the leaf as well as the nature of the basal lobes makes *Colocasia* easily distinguishable from *Xanthosoma*. Therefore, in these studies, *Colocasia* and *Xanthosoma* can be distinguished from one another by these characteristics. The variegated shades of *Caladium bicolor*'s lamina differentiated from other genera studied. The only notable difference encountered in the color of the leaf margin was in NXS 002 (*X. maffafa*) which had a greenish purple color. Leaf character has reportedly been described as a crucial tool in taxonomists' hands for the categorization and separation of taxa (Iloh et al., 2011).

According to the DNA isolation data, DNA concentrations ranged from 8.55 to 281.5, with an average concentration of 93.89. Isolated DNA had a purity rating that ranged from 1.70 to 1.94, with an average purity value of 1.82. Complete information as shown in Table 4.8. According to

Kriby 1990 and Sambrook 1989 reports, the average DNA concentrations and purity values of all the species and accessions tested fall within the range of a good DNA concentration and purity; If the concentration of isolated DNA is greater than 20 (ng/l), and the purity is read using a Nano photometer at wavelength A260/A280, it is considered to have a good value of DNA concentration and purity. Eppendorf (2016) offered a contrasting perspective, stating that the ideal value of DNA purity measured by a Nano photometer and read at wavelengths A260/A280 was in the region of 1.8-1.9, while the optimal value of RNA was in the range of 1.9-2.0. As shown in the table, residuals may be to blame for the value decline that can be seen in P29 (NXS 002) Ede Uhie. According to Matlock (2015), the reason for the poor quality of the extracted DNA purity may be due to the presence of phenol or other compounds left over after the extraction process. In order to prevent the DNA isolation process from failing, it is crucial to pay attention to each stage of the job that must be completed in accordance with the correct technique when performing the DNA extraction or isolation process (Sophian et al., 2021; Sophian, 2021).

The range of genetic diversity values, in general, shows how homogeneous or heterogeneous the various genotypes of the plant species are (Goswami & Ranade, 1999). From this study, the result of the phylogenetic tree showed close relationship between members of the same genera, moving from up to bottom of the tree it is noticeable that 5 RBCL (NCE 010 AKIRI, *Colocasia esculenta*) and 1 RBCL (NCE 001, COCO INDIA *Colocasia esculenta*) are considered one cluster and are the most similar. 3 RBCL (NCE 003 EDE OFE PURPLE *Colocasia esculenta*) is closer to 5 RBCL and 1 RBCL. 4 RBCL (NCE 005 UKPONG, *Colocasia esculenta*) shows to be the most distant accession among the genus *Colocasia*.

In the genus *Xanthosoma*, 6 RBCL (NXS 001 EDE OCHA, *Xanthosoma maffafa*) is very close to 8 RBCL (NXS 003 OKOROKORO, *Xanthosoma maffafa*). The phylogenetic tree also revealed

that 7 RBCL (NXS 002, EDE UHEI, *Xanthosoma maffafa*) is different from other members of the genus *Xanthosoma*. This discovery and the other findings in this work imply that NXS 002 should be regarded as a distinct subspecies. There was variation among the xanthosoma genotypes examined, according to Solomon et al. (2014), and this would also lead to genetic improvement for desired traits.

The genus *Caladium* (9 RBCL *Caladium bicolor*) diverted to form a distinct cluster.

Generally moving from the bottom to the top, all the genera appear to be the same, but going further some noticeable diversion took place. These diversions brought about some similarity and dissimilarity.

Conclusion and recommendations

This study has provided vital information on the morphological and molecular characteristics of the taxa studied. Based on the results recorded, it is noticeable that there is a level of similarity between the three genera. It is also important to state that there is a very close relationship between members of the genus *Colocasia*. However, NXS 002 (EDE UHIE) showed obvious differences from other members of the genus *Xanthosoma* and should be considered as a distinct subspecies.

Recommendations

The under listed are recommended from this research

1. Detailed Cytological study should be carried out on all the species to obtain more precise and empirical data.
2. Microstructural studies of the species should be undertaken

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BENCHMARKING OF OIL AND GAS WELL INTERVENTION COSTS

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Abstract

This study aims to benchmark the costs associated with oil and gas well intervention projects across various regions, emphasizing through-tubing interventions. Utilizing a comprehensive cost benchmarking methodology, the research evaluates critical cost components such as personnel, equipment, fluids, and rig services, along with regional factors influencing project expenses. Data was gathered from multiple oil-producing countries, including Nigeria, Norway, and the United States, and analysed using advanced tools like Microsoft Power BI for comparative insights. The findings reveal significant variations in man-hour rates, with Norway having the highest rates and Nigeria the lowest. Global costs for rigless well intervention services, such as saturation logging and tubing punching, also display substantial regional disparities influenced by factors like security, regulatory frameworks, and logistical challenges. Effective cost management practices, including standardized metrics and robust analytics, were identified as crucial for optimizing project efficiency. The study concludes that cost benchmarking is essential for improving operational competitiveness and financial performance. Recommendations include the adoption of advanced data analytics tools, fostering global data sharing for reliable comparisons, and implementing standardized metrics to guide decision-making. These steps aim to enhance cost efficiency, ensure sustainable practices, and improve the profitability of well intervention projects.

Introduction

Project costs are crucial in determining the success and profitability of oil and gas industry operations. Evaluating project costs to ensure that they are justifiable, competitive, and compatible with industry standards and best practices is an essential step towards the success of the project. Cost benchmarking is the process of measuring and comparing the project costs with those of similar projects or organizations in the industry or sector (Ortiz-Volcan *et al.*, 2018). This process is useful for assessing cost competitiveness and efficiency, as well as identifying areas of improvement and potential savings. It can also help you learn from the best performers, adopt best practices, set realistic and achievable cost targets and budgets, and monitor and evaluate cost performance and progress. The objectives of this paper were to benchmark cost of well intervention projects across oil and gas producing countries in different regions. It will also investigate the cost of through-tubing well intervention projects (Frank *et al.*, 2016).

Munkerud and Inderberg (2007) defined well intervention “as any operation performed on an oil or gas well at or towards the end of its productive life that modifies the well's condition or geometry, offers well diagnostics, or regulates the well's output.” This means that well interventions are performed to restore a shut-in well to production, optimize production from flowing wells, or for data acquisition. Well intervention is a technique for extending the life of wells to meet the increasing global oil and gas demand (Setiawan *et al.*, 2016). Of course, drilling new wells all the time is a capital-intensive project. Hence, there is a need to restore existing wells to production and optimize production from flowing wells. Well intervention accounts for over five per cent of global oil and gas production annually.

Well intervention is broadly classified as restoration and optimisation. Restoration activities involve bringing wells back to production like the condition (rate and pressure) at which they were shut in. Examples of restoration intervention include nitrogen lift, Surface Controlled Sub-Surface Safety Valves (SCSSSV) repair, de-waxing, and sand cleanout. On the other hand, optimisation intervention leads to an increase in good productivity. Examples include stimulation, perforation extension, solvent squeeze, gas-lift startup. Optimization candidate wells are aimed at increasing oil and gas production rate. Restoration candidates are mainly shut-in wells while optimization candidates may be wells still on production but diagnosed with performance challenges like skin effect and liquid loading.

Oil and gas well intervention projects involve various activities aimed at enhancing or restoring the productivity of existing wells. These projects can include well maintenance, workover operations, and interventions to improve or restore production. The costs related to well intervention tasks may fluctuate based on various factors, such as the type of intervention, well intricacy, geographical location, and specific objectives of the project. The cost associated with a well intervention project is determined by several important components.

These components include:

Well Analysis and Planning: Before initiating a well intervention project, a comprehensive analysis of the well's condition and performance is conducted. This analysis includes review of well logs, production data, and reservoir evaluation. The planning stage involves designing the intervention strategy, selecting the appropriate tools and techniques, and determining the required resources. The cost of well analysis and planning includes manpower, data analysis, and engineering expertise.

Equipment and Tools: Well intervention projects require specialized equipment and tools tailored to the specific intervention objectives. These can include wireline tools, coiled tubing units,

snubbing units, hydraulic workover units, well control equipment, and various diagnostic instruments. The costs associated with equipment rental, purchase, maintenance, and transportation contribute to the overall project expenses.

Personnel and Labour: Well intervention projects require skilled personnel to operate the equipment and perform the necessary tasks. The personnel involved may include engineers, technicians, rig operators, wellsite supervisors, and safety personnel. The costs associated with labour include wages, benefits, training, and accommodation, which can vary depending on the project's duration and location.

Fluids and Chemicals: Well interventions often require the use of fluids and chemicals for various purposes such as well cleaning, wellbore stability, corrosion inhibition, scale prevention, and stimulation. The cost of these fluids and chemicals depends on the volume required, the type of treatment, and the prices in the market.

Rig Services: Depending on the nature of the intervention, well intervention projects may require the use of drilling rigs or well intervention units. The cost of rig services includes mobilization and demobilization, rig rental rates, personnel on the rig, and associated equipment.

Safety and Environmental Considerations: Well intervention projects must adhere to strict safety and environmental regulations. Costs associated with safety measures, personal protective equipment (PPE), safety audits, and environmental monitoring contribute to the overall project expenses.

Miscellaneous Costs: There may be additional costs related to logistics, transportation, permits, regulatory compliance, community, security, and administrative overhead. These costs can vary depending on the project location and the specific requirements of the intervention.

Well intervention costs vary depending on the project's complexity and scope. Factors like the well type and age, location, and necessary equipment and personnel impact the overall cost. Evaluating each project's requirements is important to determine an accurate estimate. The costs can range from thousands to millions of dollars, depending on factors such as the type of intervention, the number of wells involved, the depth and condition of the well, and the overall project duration. Effective project management, careful planning, and cost control are crucial for optimizing well intervention project costs. Estimating well intervention cost has many uncertainties, which could result in cost overruns during the project execution. Inadequate understanding of the activities involved in the project under estimation will have an adverse effect in the cost estimate (Boschee, 2012).

The cost of rigless well intervention projects may differ based on factors such as the type of intervention, well depth, well complexity, location, and the extent of work required. According to Khurana (2003), there are essential cost factors to consider for rigless well intervention projects, comprising:

Mobilization and Demobilization Costs: Mobilization costs include expenses related to moving equipment, personnel, and materials to the wellsite. This includes transportation, logistics, and setup costs. Demobilization costs involve the removal of equipment and personnel from the wellsite after the project is completed. Well intervention projects require specialized equipment and tools such as wireline units, coiled tubing units, snubbing units, hydraulic workover units, and well control systems. The costs associated with renting, leasing, or purchasing this equipment can significantly impact project costs. Various fluids and chemicals are used during well interventions, including drilling fluids, completion fluids, wellbore cleaning chemicals, and corrosion inhibitors. The cost of procuring and using these fluids and chemicals should be considered.

Downhole Tools and Consumables: Downhole tools, such as packers, plugs, and valves, are often used during well intervention activities. The cost of these tools, as well as any consumables that are expended during the intervention, need to be factored into the project budget.

Permits and Regulatory Compliance: The acquisition of permits and adherence to regulatory requirements are essential components of well intervention projects. Costs associated with permit applications, environmental assessments, safety audits, and other compliance-related activities should be considered during well intervention cost estimation.

Contingency and Unexpected Costs: Well intervention projects can encounter unexpected challenges, such as equipment failures, wellbore complications, community blockade or changes in scope. It is important to allocate a contingency budget to address unforeseen circumstances and mitigate risks.

Personnel: Skilled personnel, including engineers, technicians, operators, and supervisors, are required to execute well intervention projects. Labour costs, including wages, benefits, and accommodations, contribute to the overall project expenses.

Cost Benchmarking

Cost benchmarking is essential as the costs per barrel of crude oil production differ from one country to another. This procedure tries to enhance cost management and operational efficiency by helping companies identify areas where they may be overspending, inefficient, or performing below expectations. It is important to understand that cost benchmarking involves more than simply expense reduction; it also entails finding room for expansion and development. There is a possibility of implementing best practices and initiatives that improve operational performance and financial results by comparing costs from oil and gas companies globally (Goncharuk, 2008).

When it comes to cost benchmarking, one of the challenges is finding reliable and relevant sources of data and information. Sources such as industry reports and publications, professional associations and networks, consultants and experts, peer organizations or competitors, and even historical or current cost data can provide accurate and meaningful comparisons. These sources can offer cost databases, surveys, or benchmarks for their members or subscribers, as well as the ability to share cost data or experiences with you to compare the performance over time or across different projects (Ikpe *et al.*, 2015)

Cost benchmarking is an effective tool for improving cost management and performance but requires careful planning, execution, and evaluation. Defining clear objectives and scope aligned with the business strategy is important to get the most out of cost benchmarking. Choosing reliable sources and benchmarks

that are valid, accurate, and comparable is also essential. Utilizing appropriate methods and tools for conducting the analysis and applying consistent criteria and standards improves the accuracy of the result. Interpret the analysis results with caution and context, avoiding biased conclusions or assumptions. Involving the project team, stakeholders, and sponsors in the process helps to promote collaboration and learning (Lenkova, 2015).

Key Steps in Cost Benchmarking

Metrics and KPIs Identification: Begin by identifying the metrics and key performance indicators (KPIs) pertinent to the sector and business operations. These could be indicators like labour costs, material costs, overhead costs, manufacturing efficiency, and others (Tripathi *et al.*, 2018)

Choose Peers or Benchmarks: Pick organizations or benchmarking peers that are comparable in size, sector, and activities. These might be direct rivals, businesses of a comparable size operating in various industries, or standards set by the industry.

Collect Information: Compile thorough information on expenses and operational effectiveness in the prioritised areas. Ensure that data collection is accurate and reliable.

Performance comparison: Evaluate the company's performance indicators against those of the chosen benchmark organizations. Find out where the expenses are greater, and the performance is less strong.

Analyse Disparities: Examine the variations in expenses and output and recognise the causes of these variations. The practices, tactics, and technology employed by the benchmark organisations may require more investigation.

Decide on the best practices that the benchmark organisations adopt, as these help them perform better or at lower costs. These could involve things like implementing new technology, managing personnel, and improving processes.

Create Action Plans: Based on the learnings from the benchmarking process, create action plans to enhance cost management and operational efficiency. This might entail implementing new procedures, making technological investments, rearranging personnel, or pursuing other tactics. Implement the action plans. It is important to monitor the outcomes closely to ensure that the modifications are producing the intended results (Shields *et al.*, 2017).

Track Progress: Monitor the advancement of the improvements you've made and the organisation's performance in comparison to the benchmarks.

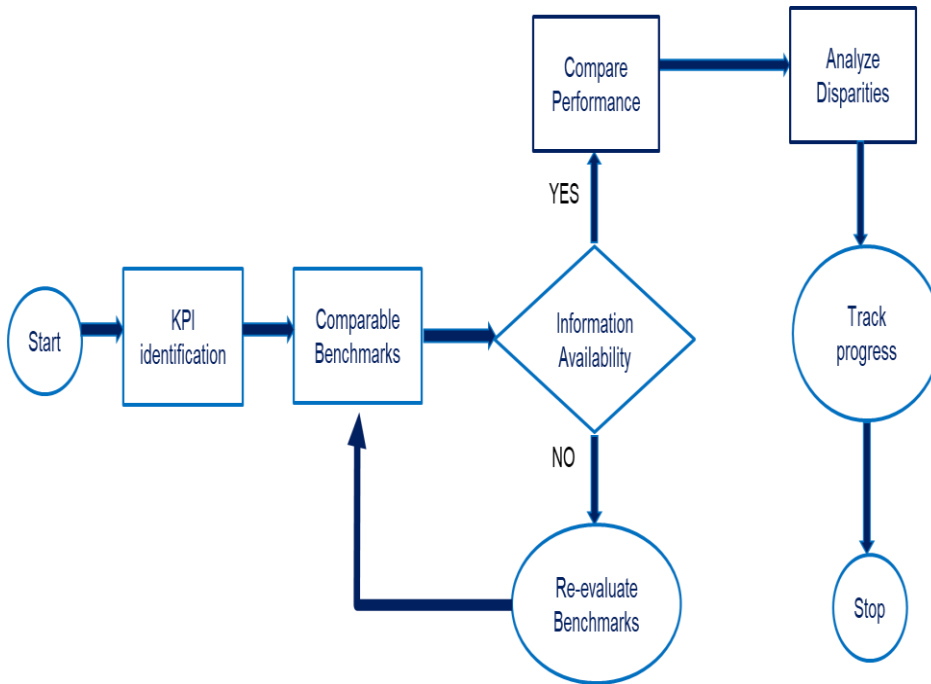


Figure 1: Key Steps in Cost Benchmarking

Cost benchmarking is a continual process, so iterate and improve. To ensure that the industry maintains its competitiveness and continues to increase its cost-effectiveness, there should be a periodic review of the benchmarking process (Mittas, 2022).

The results of the cost benchmarking analysis can provide valuable insights and recommendations for improving cost management and performance. Communicating and sharing the results with the project team, stakeholders, and sponsors is vital to receive feedback and suggestions. Additionally, there is a need to develop and implement action plans to address any gaps, issues, or opportunities identified by the analysis. This could include reducing waste, optimizing resources, improving quality, enhancing efficiency, or innovating solutions. More importantly, monitor and track the impact of the action plans and strategies, measuring the changes and improvements in the cost performance and competitiveness. Furthermore, periodically review and update the cost benchmarking analysis, repeating the process as needed to ensure continuous learning and improvement (Frank *et al.*, 2016).

Microsoft Power Business Intelligence for Cost Benchmarking Analysis

Microsoft's Power BI is a solution for corporate analytics that enables users to share and visualize data findings. It is a component of the Microsoft Power Platform, which also consists of Microsoft Flow and Power Apps (formerly known as Power Automate). The Microsoft Power BI application aids in data

gathering, analysis, and visualization. It is a cloud-based platform that is accessible to companies of all sizes (Shields *et al.*, 2017)

For processing, analyzing, and visualizing data from diverse sources, Power BI offers several capabilities. Databases, spreadsheets, cloud services, and online APIs are all examples of data sources that can be connected to Power BI. With this attribute, users may then combine data from several sources onto a single platform. Data transformation capabilities are available in Power BI for cleaning, transforming, and manipulating data. Users may utilize a user-friendly interface or the sophisticated Power Query language to merge tables, filter data, generate calculated columns, and more. Regarding data modeling, users may form hierarchies and establish linkages between various tables to develop a logical data model. This paradigm provides the basis for building interactive visualisations (Mittas, 2022).

Charts, graphs, tables, maps, and custom graphics are just a few of the interactive data visualization choices that Power BI provides. Users may add visual components by dragging and dropping them onto the canvas to build reports and dashboards. Custom computations, aggregations, and measurements may be made using Power BI's DAX (Data Analysis Expressions) formula language. Users may use it to do intricate computations and analysis of their data. Regarding reports and dashboards, Power BI enables users to build interactive reports and dashboards that let users' audience members explore and engage with the data. These reports can be distributed among team members or securely uploaded to the cloud for public consumption. For data sharing, Power BI offers several methods for disseminating reports and dashboards, including emailing reports, sharing links, and embedding them in websites (Frank *et al.*, 2015)

Power BI supports periodic or on-demand data refresh, ensuring that reports and dashboards always show the most recent data. The Power BI service is a cloud-based platform that enables users to publish reports and dashboards, share them with others, collaborate on them, and view them from any location using web browsers or mobile apps. The Windows software used to produce reports and visualisations is called Power BI Desktop. Users may create intricate reports and upload them to the Power BI service using the extensive writing experience it offers. When using Power BI Mobile, users can view their reports and dashboards on the move using Power BI's mobile applications. The free Power BI Desktop edition, Power BI Pro, and Power BI Premium are among the several editions of Power BI. The Power BI Pro and Premium editions offer more sophisticated functionality, more data storage, and improved collaboration tools. Businesses and organizations generally utilise Power BI extensively to turn raw data into insightful understandings, allowing data-driven decision-making and improved comprehension of company performance (Ikpe *et al.*, 2015)

An explanation of how to approach a cost benchmarking study using Power BI is provided below:

Firstly, make visual representations that directly contrast the expenses of the organization with benchmarking data—for instance, comparing your prices to benchmark costs for several cost categories using side-by-side bar charts. It is important to compare historical cost patterns to benchmark trends using line plots. A benchmark is also achievable by comparing individual cost components to benchmarks using scatter plots. Key Performance Index cards displaying significant data points like cost variance percentages help to improve the visualization of the historical plots.

The second approach is drilling down and specifics. The Drill-through capabilities should allow users to explore the data in more detail and allow them to click on data points to discover the underlying information that influences cost disparities.

Finally, develop a dashboard. It is important to create a dashboard with the visualizations put together and rationally arrange the graphics to create a clear flow of ideas. This will help to contextualise and explain findings and provide text boxes or commentary.

Gathering and Preparing Data: Collect pertinent data from many sources, such as the internal and external benchmarking data. Use Power Query to import the data into Power BI, which enables connection to different data sources and modify the data as necessary. To guarantee consistency and correctness, the data should be cleaned and transformed.

Modeling data: In Power BI, define associations between tables to create a data model. Tables for pricing information, benchmarking information, time frames, and pertinent qualities may be included.

Create calculated columns and measures using DAX to compute metrics like cost per unit, cost ratios, etc., that are crucial for your benchmarking research.

Visualisation: Create visualisations that allow you to compare your organisation's expenditures to benchmark data. Examples of common visualizations are tables, bar charts, line charts, and scatter plots.

Slicers can provide interactive filtering by criteria such as time, product, location, or other pertinent properties.

Results and Discussion

Result of the Analysis on Cost Benchmarking

The hourly rate of well intervention project team across different regions is presented in Figure 2. The data shows the minimum, maximum and average of the rates for the project team members including Nigeria, Canada, United Arab Emirates, Houston, Malaysia, Brazil, Norway, United Kingdom, and Mexico. From the regions analysed so far, Nigeria has the lowest man-hour rate while Norway has the highest man-hour rate. On average, the global man-hour rate of well intervention project team personnel is USD 220 per hour.

Figure 3 shows the global cost of rigless well intervention projects. The data is based on cost provided by an international service provider in the oil and gas industry and the cost is the same across the globe where they provide those services. The most expensive service is saturation logging while tubing punching is the least expensive service. The cost will differ from region to region due to factors like security, location, and local content regulations in each region.

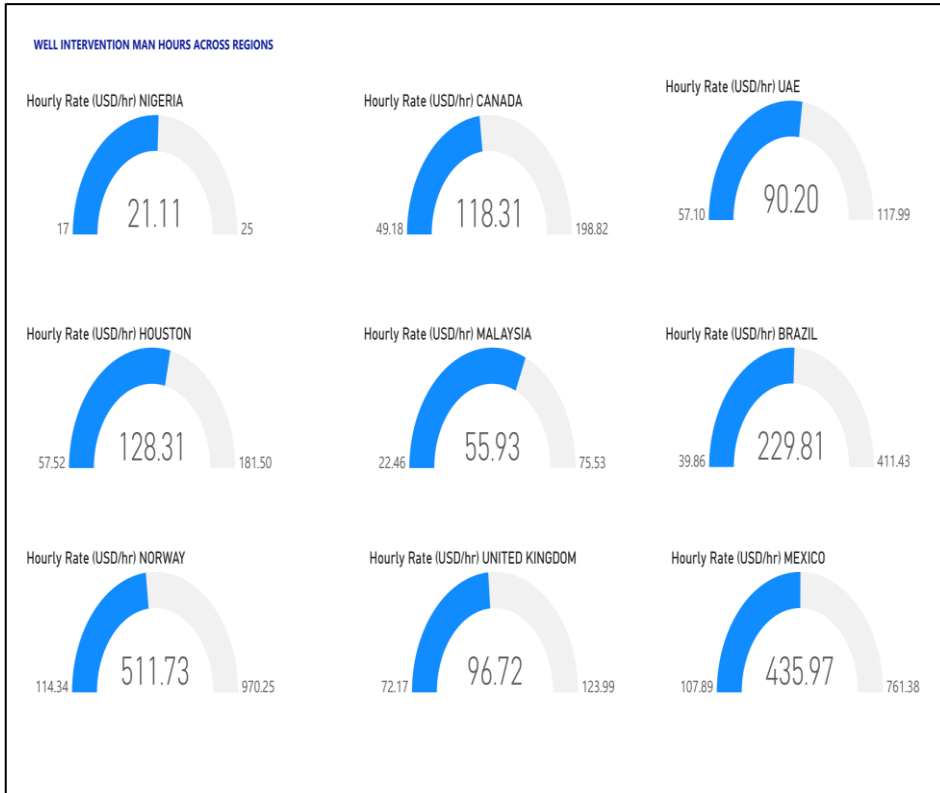


Figure 2: Hourly rate of well intervention project team across different regions.

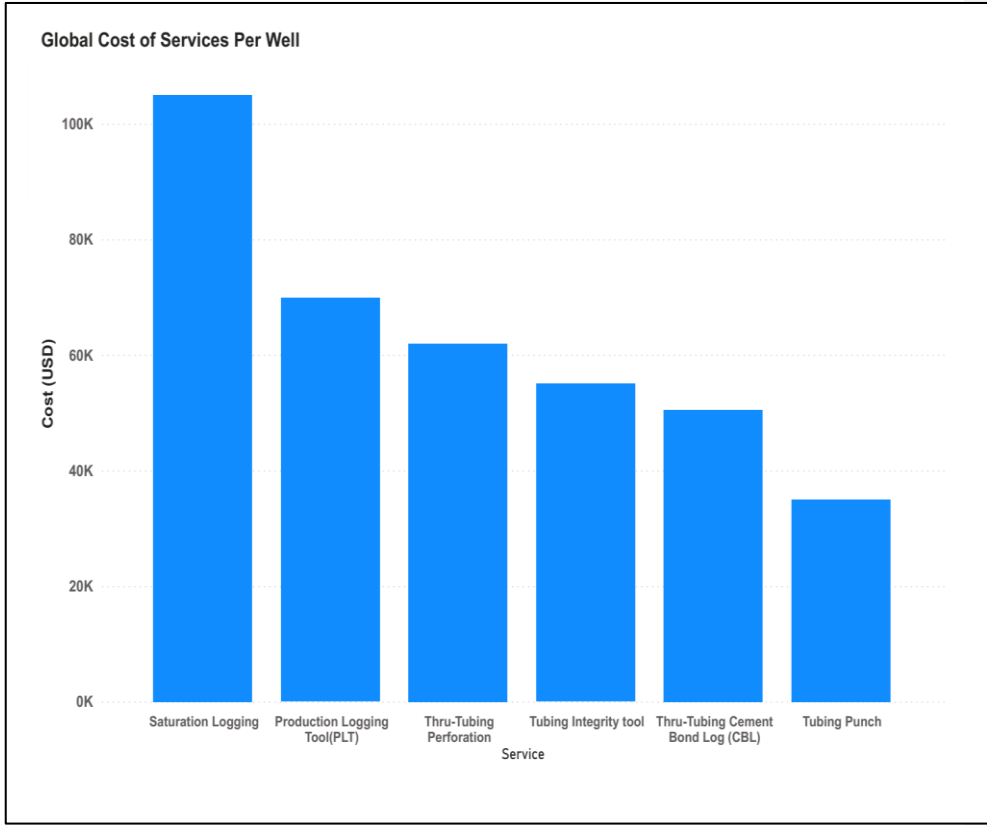


Figure 3: Shows the global cost of rigless well intervention projects.

The hourly rate of well intervention project team across different regions (Nigeria, Canada, United Arab Emirates, Houston, Malaysia, Brazil, Norway, United Kingdom, and Mexico) shows that Nigeria has the lowest man-hour rate while Norway has the highest man-hour rate. On average, the global man-hour rate of well intervention project team personnel is USD 220 per hour.

The most expensive through-tubing well intervention service is saturation logging while tubing punching is the least expensive service. The cost differs from region to region due to factors like security, location, and local content regulations in each region.

Conclusion

Well intervention projects costs were analyzed for oil and gas producing countries including Nigeria, Canada, USA, Malaysia, Brazil, Norway, United Kingdom and Mexico. The man-hour rate for the project team differs from region to region. The cost of through-tubing well intervention project ranges from 30,000 to 100,000 USD. Also, the saturation logging projects were the most expensive while tubing punch projects were the least expensive well intervention project costs.

Recommendations

The paper highlights the critical role of cost benchmarking in optimizing well intervention expenses and improving project efficiency across various regions and methodologies. To further strengthen these practices, the following actions are recommended:

1. Adopt Standardized Metrics and KPIs such as cost-per-barrel, man-hour rates, and equipment utilization efficiency, to ensure comparability across projects and regions.
2. Leverage Advanced Data Analytics tools like Microsoft Power BI to collect, analyse, and visualize cost data effectively. This enables interactive dashboards and real-time insights into disparities in costs and performance across regions, identifying actionable trends.
3. Foster Global Data Sharing within the oil and gas industry to access and share global cost benchmarking data. This will enhance the reliability of comparisons and uncover innovative best practices.

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The Impact of Electricity Prices, Energy Consumption from Renewable Energy Sources on Unemployment in Nigeria.

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ABSTRACT

Nigeria faces significant challenges related to youth unemployment, which has far-reaching socio-economic consequences. Renewable energy offers a promising potential to tackle youth unemployment by job creation in manufacturing, installation, and sales of renewable energy solutions. This study examines the impact of renewable energy consumption and electricity tariffs on unemployment rate of Nigeria. The study considers the casual relationship and vector decomposition between various renewable energy sources (solar, hydro and biomass), electricity price and unemployment rate using an unrestricted vector error correction model (VECM). In addition, other robust econometric techniques were applied to the time series of unemployment rate, electricity price and energy consumption from renewable energy sources from 1980 to 2021. The findings indicate that electricity prices and energy consumption from renewable energy sources do not significantly impact unemployment rate in Nigeria in the long-run. In the short-run, a 1% increase in the difference in the log value of the first lag of hydro electricity consumption leads to a 29% decrease in the unemployment rate in Nigeria, while a 1% increase in the difference in the log value of the first lag of electricity prices causes a 21% decrease in the unemployment rate in Nigeria. The coefficient of the Error Correction Model (ECM) is negative (-0.05) and statistically significant implying that short-run change from the long-run equilibrium is corrected by 5% annually. A unidirectional causality from solar electricity consumption to unemployment rate in the long run was observed, with solar, hydro, biomass and electricity price explaining 54%, 2% 2% & 7% respectively of fluctuations in the unemployment rate in the long-run. The study recommends policies that can effectively reduce the unemployment rate through the development of renewable energy projects.

Keywords: Renewable Energy, Electricity Price, Unemployment, Econometric, Energy Consumption

1. INTRODUCTION

Nigeria is confronted with significant issues regarding youth unemployment, which has profound socio-economic implications. With a population estimated at 180 million, Nigeria ranks as the seventh most populous nation globally. Despite being the eighth largest producer of oil, Nigeria faces severe challenges such as high poverty rates and unemployment, with a low ranking of 158th on the Human Development Index (HDI). Of particular concern is the high unemployment rate among Nigerian youth, leading to feelings of frustration, dependency, and susceptibility to criminal activities. Income inequality is widespread, concentrating wealth in the hands of a minority (ActionAid Nigeria, 2009).

Youth are pivotal to any society, often considered its greatest asset. In Nigeria, individuals aged 18 to 35 make up 60% of the population (NBS, 2012). Alarming, youth unemployment rates in Nigeria have reached up to 50%, with reports suggesting even higher figures due to underreporting (Doreo Partner, 2015; NBS, 2017). Factors contributing to this crisis include rapid population growth, inadequate job skills, mismatches between available jobs and skills, governance issues, unreliable power supply, agricultural neglect, and insufficient sustainable measures (Musari, 2009; Agufo, 2013; Nigerian Finder, 2015).

Renewable energy presents a promising avenue to combat youth unemployment in Nigeria. By expanding renewable energy sources like photovoltaic cells, wind power, and biofuels, the country could potentially create more than a million direct and indirect jobs within two years. This expansion not only addresses unemployment but also enhances productivity and promotes environmental sustainability by reducing carbon emissions.

2. LITERATURE REVIEW

The global shift towards renewable energy, particularly solar power, not only addresses environmental concerns but also presents opportunities for job creation. Numerous studies have highlighted the surge in job opportunities within the solar installation and maintenance sector. Reports from the International Renewable Energy Agency (IRENA) emphasize the direct employment generated by the installation and ongoing maintenance of solar photovoltaic (PV) systems (IRENA, 2019). Solar power adoption has spurred the growth of manufacturing and supply chain industries. Research by Sovacool and Dworkin (2015) demonstrates the positive correlation between increased solar capacity and job creation in the manufacturing of solar panels, inverters, and other components.

Solar power has provided fertile ground for the emergence of small and medium-sized enterprises (SMEs) in the renewable energy sector. Studies by Rai and Sigrin (2013) and Oseni et al. (2017) emphasize the role of entrepreneurship in solar-related businesses, contributing to local economic development and job opportunities. Advancements in solar technology require significant research and development efforts. The work of Bogachkov et al. (2020) highlights the employment opportunities arising from research and innovation in solar power, including positions in academia, laboratories, and private research institutions. Solar power initiatives aimed at rural electrification and community-based projects contribute to job creation at the grassroots level. Case studies in rural Nigeria (Azapagic et al., 2018) showcase how decentralized solar solutions create employment in local communities, supporting the operation and maintenance of solar microgrids.

Government policies play a pivotal role in shaping the job landscape in the solar industry. Research by Mencin et al. (2016) and REN21 (2021) underscores the importance of supportive policies, such as feed-in tariffs and incentives, in fostering a conducive environment for job creation in the solar sector. While the solar industry presents substantial job opportunities, there are challenges, including the need for skill development and addressing gender disparities. The work of Sovacool and Hirsch (2018) explores strategies to ensure inclusive job growth in the solar sector. Klinsky et al (2012) in their publication “Comparing public rationales for Justice in two successful cases of solar energy implementation in Canada” analyzed the socio-economic impacts of solar energy implementation, emphasizing job creation, and explored the public justifications for supporting solar projects in Canada.

Schaeffer et al (2015). evaluated the economic and environmental impacts of increasing solar PV capacity in developing countries using case studies of Brazil and Cote d'Ivoire. The study provides empirical evidence on the economic and employment impacts of solar photovoltaic (PV) capacity expansion in developing countries, using case studies from Brazil and Cote d'Ivoire. Rai and Hobbs (2010) performed a quantitative analysis of the potential for deployment of solar home systems

empirically assessing the potential for job creation, this study analyzes the deployment of solar home systems in the developing world, emphasizing the decentralized nature of solar power and its impact on local employment. Brown, E., & Riddell (2018) assessed the local economic development and social benefits of solar projects in the United States using a case study on the Desert Sunlight Solar Farm. Focusing on the United States, this study empirically evaluates the local economic and social benefits, including job creation, associated with a large-scale solar farm.

Mai and Sandor (2018) evaluated the impact of state policy on job creation in the solar industry using evidence from the Solar Energy Industries Association's state solar jobs census. This empirical study investigates the influence of state policies on job creation within the solar industry, utilizing data from the Solar Energy Industries Association's State Solar Jobs Census. Pueyo and Diaz-Chao (2019) explores the role of women in the renewable energy sector, providing empirical insights into job creation and gender dynamics in the context of the European clean energy initiatives. The National Solar Jobs Census 2017, conducted by Hernandez and Hoffacker (2017) on behalf of The Solar Foundation, provides a comprehensive and detailed analysis of solar-related employment in the United States. The study stands out for its empirical approach, employing a thorough survey methodology to capture the dynamics of the solar job market. The authors conducted a nationwide survey that targeted a diverse range of solar establishments, including manufacturers, installers, and project developers. By collecting data directly from employers, the study provides a real-world perspective on the state of the solar job market in 2017. The study encompasses various segments of the solar industry, offering a holistic view of employment trends. This inclusivity allows for a nuanced understanding of job creation across different sectors, from manufacturing to installation and project development. The report presents detailed findings on the number of solar-related jobs, demographic characteristics of the workforce, and employment trends over time. The granularity of the data allows policymakers, industry stakeholders, and researchers to make informed decisions and assess the impact of solar energy on the U.S. labor market.

Feldman et al.'s (2016) study published in *The Electricity Journal* aims to investigate the impact of solar photovoltaic (PV) system size and ownership structure on the overall value of solar energy. The research addresses a critical aspect of solar energy integration by exploring how factors such as project scale and ownership influence the economic viability and benefits of solar installations. The study reveals that the size of solar PV projects significantly influences their economic value. Larger solar installations exhibit economies of scale, resulting in a lower levelized cost of electricity (LCOE) and increased economic benefits. Feldman et al. highlighted the importance of ownership structures in determining the economic value of solar energy. Specifically, the research underscores that third-party ownership models, such as power purchase agreements (PPAs) and leases, contribute to the widespread adoption of solar energy by reducing upfront costs for

consumers. The study utilizes financial metrics, including the levelized cost of electricity (LCOE) and net present value (NPV), to assess the economic performance of solar projects. This approach provides a comprehensive understanding of the economic viability of solar energy across different project sizes and ownership structures. The study benefits from a robust dataset comprising a diverse range of solar projects, enabling a comprehensive analysis of the impact of solar PV size and ownership on economic value. The combination of econometric modeling and financial analysis enhances the reliability and depth of the findings, allowing for a nuanced exploration of the economic dynamics within the solar energy sector. However, the study's focus on U.S.-based solar projects may limit the generalizability of findings to other regions with distinct market dynamics, policy environments, and solar potential.

Turrentine and Siderius (2018) Using input-output modeling investigated the economic contributions and job creation potential of the solar industry in the United States. The research specifically analyzes the manufacturing sector, providing insights into the employment effects of solar manufacturing activities. Lai, Lee, and Sigrin (2019) contribute to the literature by conducting a regional analysis to explore the impact of rooftop solar photovoltaic (PV) systems on employment. The study addresses an important aspect of the solar industry, examining not only the environmental benefits but also the socio-economic implications of decentralized solar installation. The authors utilize a regional analysis approach, providing a nuanced understanding of how rooftop solar PV systems influence employment in specific geographic areas. The research focuses on uncovering the relationship between solar adoption and job creation, shedding light on the local economic dynamics associated with distributed solar energy.

Rai and Chandrasekhar (2019) delve into the evolving landscape of solar energy deployment with a specific focus on community solar power initiatives. The study explores the potential of community solar projects to not only contribute to sustainable energy solutions but also address issues of equity in solar access. As the demand for renewable energy increases globally, understanding the dynamics of community solar becomes crucial for achieving a more inclusive and diversified energy transition. The primary objective of the study is to assess community solar power as a pathway for equitable solar deployment. The authors aim to uncover the social, economic, and environmental implications of community-based solar projects, shedding light on their potential to bridge gaps in solar access and benefits. The research employs a qualitative approach, utilizing case studies and interviews to capture the multifaceted dimensions of community solar power. This methodology allows the authors to delve into the real-world dynamics of various community solar initiatives, providing a rich and context-specific understanding of their impact on local communities. By combining interviews and case studies, the study captures both quantitative and qualitative data, offering a comprehensive exploration of community solar deployment. The study finds that community solar power projects have the

potential to provide more equitable access to solar energy, particularly in regions where individual solar installations may face financial or logistical barriers. Rai and Chandrasekhar (2019) reveal that community solar initiatives contribute to local economic development by generating jobs and fostering entrepreneurship. This finding underscores the potential for community solar projects to become catalysts for sustainable development. The study uncovers the social dynamics involved in community solar initiatives, emphasizing the importance of community engagement, collaboration, and ownership. It highlights how these factors influence the success and sustainability of such projects. Rai and Chandrasekhar (2019) acknowledge the existence of challenges, such as regulatory complexities and community dynamics, that can impact the effectiveness of community solar projects. Understanding and addressing these challenges are crucial for ensuring the success of equitable solar deployment.

This research examines the influence of renewable energy consumption and electricity price using econometric analysis and proposes informed policy directions based on findings that would reduce the unemployment rate in Nigeria.

3. METHODOLOGY

This research employs an ex-post facto research design to study the impact of renewable energy consumption on the economy of Nigeria between 1980 to 2021. An empirical econometric approach is adopted in analyzing data on the research variables. The data collection procedure is non-probabilistic. Based on the perceived causal relationship between the identified variables of the research problem of interest, a multiple regression model is specified to forge a link between the sets of variables.

The model of interest is presented in equation 1.

$$GDP = f(\text{Solar, Hydro, Biomass, Electricity Price, } \epsilon) \quad (1)$$

To simplify the estimate process, equation 1 is converted into a log-log form as follows:

$$\log(UNEMP_t) = \alpha_1 + \beta_{SOL} \log(SOLAR_t) + \beta_{HYDRO} \log(HYDRO_t) + \beta_{BIO} \log(BIO_t) + \beta_{PRICE} \log(EPRICE_t) + \varepsilon_{1t} \quad (2)$$

Where:

$UNEMP_t$ = Unemployment rate at lag t

α = Coefficient of the intercept

$SOLAR_t$ = Solar energy consumption at lag t

β_{SOL} = Coefficient of solar energy consumption

$HYDRO_t$ = Hydro electricity consumption at lag t

β_{HYDRO} = Coefficient of hydro electricity consumption

BIO_t = Bioenergy consumption at lag t

β_{BIO} = Coefficient of bio energy consumption

$EPRICE_t$ = Electricity price at lag t

β_{PRICE} = Coefficient of electricity price

ε_t = error term

3.1 The ARDL Estimation Technique

To ensure the data met the basic requirements for Ordinary Least Squares estimation, the study first assessed the stochastic properties of the series. The Augmented Dickey-Fuller (ADF) test was employed for testing the series' integration order, among various available techniques. The presence of both stationary (I(0)) and non-stationary (I(1)) variables prompted the adoption of the Autoregressive Distributed Lag (ARDL) model as the preferred econometric approach. This model can establish simultaneous short- and long-term relationships given an adequate sample size. It evaluates cointegration across variables using the Ordinary Least Squares (OLS) method. The specific ARDL equation for the variables under study is as follows:

$$\Delta \log (UNEMP_t) = \alpha_1 + \sum_{i=1}^p \delta_i \Delta \log (UNEMP_{t-i}) + \sum_{n=1}^{q_1} \beta_{SOLn} \log (SOL_{t-n}) + \sum_{n=1}^{q_2} \beta_{HYDRON} \log (HYDRO_{t-n}) + \sum_{n=1}^{q_3} \beta_{BION} \log (BIO_{t-n}) + \sum_{n=1}^{q_4} \beta_{PRICEn} \log (EPRICE_{t-n}) + \varepsilon_{1t} \quad (3)$$

$$\Delta \log (GDP_t) = a_{01} + b_{11} \log (GDP_{t-1}) + b_{21} \log (SOL_{t-n}) + b_{31} \log (HYDRO_{t-n}) + b_{41} \log (BIO_{t-n}) + b_{51} \log (EP_{t-n}) + \sum_{i=1}^p \delta_i \Delta \log (GDP_{t-i}) + \sum_{n=1}^{q_1} \beta_{SOLARn} \Delta \log (SOL_{t-n}) + \sum_{n=1}^{q_2} \beta_{HYDRON} \Delta \log (HYDRO_{t-n}) + \sum_{n=1}^{q_3} \beta_{BION} \Delta \log (BIO_{t-n}) + \sum_{n=1}^{q_4} \beta_{PRICEn} \Delta \log (EPRICE_{t-n}) + \varepsilon_{1t} \quad (4)$$

The lag length for the ARDL model was determined using the Schwartz Information Criterion (SIC), which showed the smallest value compared to the Akaike Information Criterion (AIC) and Hannan-Quinn Criterion. A lag length of two (2) was selected for both the independent variables and the dependent variable. The study then examined the long-run and short-run dynamics using the Bounds Test and the Error Correction Model respectively (equation 4). To investigate the impact of shocks in unemployment on electricity consumption from renewable sources (such as solar, hydro, and biomass), Granger causality tests and the Vector Error Correction Model (VECM) were employed.

4. RESULT

Following the standard procedures for variables with time series properties, we consider the individual and group statistical features of the series starting with the descriptive statistics. The mean statistic shows that average electricity consumption is relatively higher for hydroelectricity sources compared to other renewable electricity sources. More so, the statistical summary shows that the yearly average unemployment rate is at 4.6 percent within the period of analysis. The statistical analysis of the data series shows the mean, standard deviation, skewness, kurtosis, and Jarque-Bera. We use the linear form of the datasets to compare the moments of the distribution of the data series. Electricity consumed from biomass sources are positively skewed and platykurtic. The unemployment rate, electricity consumed from solar sources and electricity prices are positively skewed and leptokurtic while electricity consumed from hydroelectricity sources is negatively skewed and platykurtic.

Table 1: Data Descriptive Analysis (Source: Authors)

	Unemployment Rate [%]	Electricity Consumption from Solar [billion kWh]	Electricity Consumption from Hydro [billion kWh]	Electricity Consumption from Biomass [billion kWh]	Electricity Price [#/kWh]
Mean	4.6	0.0	5.5	0.0	11.4
Std. Dev.	1.1	0.0	1.8	0.0	14.5
Maximum	7.4	0.0	8.4	0.0	45.6
Minimum	3.7	0.0	1.9	0.0	0.8
Skewness	1.3	1.6	-0.3	0.2	1.4
Kurtosis	3.3	4.0	2.3	1.5	3.4
Jarque-Bera	11.2***	18.9***	1.4	4.5	13.0***
Observations	42	42	42	42	42
	Positive Skewness and Leptokurtic	Positive Skewness and Leptokurtic	Negative Skewness and Platykurtic	Positive Skewness and Platykurtic	Positive Skewness and Leptokurtic

In order to visually inspect any possible co-movement between unemployment rate, and electricity consumption from renewable electricity sources and electricity price, we plot the unemployment rate, against each of the selected electricity consumption indexes and electricity prices.

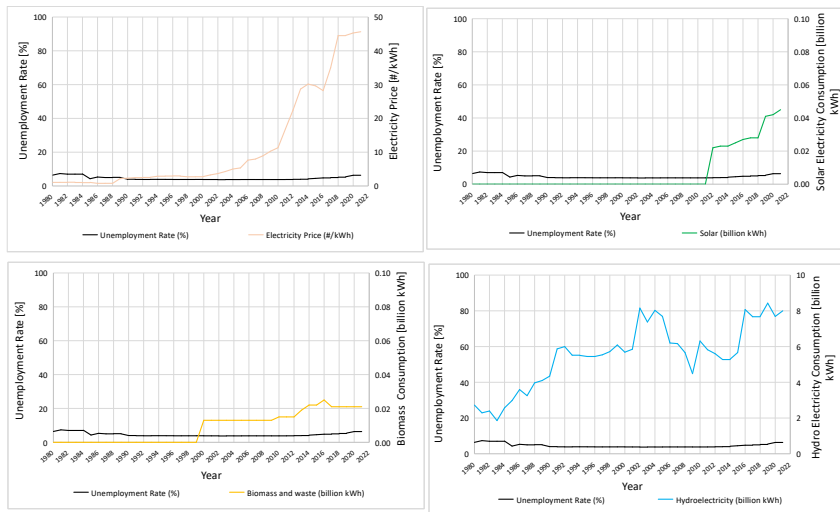


FIGURE 1: PLOT OF UNEMPLOYMENT RATE WITH ELECTRICITY PRICE, SOLAR, HYDRO AND BIOMASS ELECTRICITY CONSUMPTION (SOURCE: AUTHORS)

As conventional for time series with large T, we subject the relevant variables to a unit root test. We find that the various electricity consumption indexes are integrated of order zero [I(1)]. The unit root test results affirm the appropriateness of our choice of ARDL model as the preferred estimation framework in the context of this study.

4.1. Unit Root Test

Table 2 shows the report of stationarity analysis carried out on the level I(0) and the first difference I(1) state representing none, constant and constant plus trend specification respectively. We observe from the level of significance, the rejection of the null hypothesis for the stationary model for the variables after taking the first difference.

Table 2: Augmented Dickey Fuller (ADF) Unit Root Analysis (Source: Authors)

Unit Root Test	Level	First Difference
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Variable	Variable	Constant & Trend			Constant & Trend			I(n)
		Constant	t & Trend	None	Constant	Constant & Trend	None	
Log of Unemployment Rate	LUNEMP	-0.8768	-1.0771	1.8135	-8.2038***	-9.8670***	-8.3012***	I(1)
Log of Electricity Consumption (Solar)	LSOL_EC	-0.2753	-1.8676	1.2461	-6.3847***	-6.4662***	6.2224***	I(1)
Log of Electricity Consumption (Hydro)	LHYDRO_EC	-1.5899	-2.1237	0.7274	-7.7392***	-7.7555***	7.4603***	I(1)
Log of Electricity Consumption (Biomass)	LBIO_EC	-0.9855	-1.9971	1.4158	-6.3377***	-6.2545***	6.2444***	I(1)
Log of Electricity Price	LEPRICE	0.3056	-2.3985	2.4474	-5.7772***	-5.7907***	4.8848***	I(1)

***, **, * Indicates the significant levels at 1%, 5%, and 10% respectively.

All variables were observed to be stationary at I(1) with a 1% level of significance at constant, constant & trend and no constant and no trend (none) specification indicating the presence of unit root, hence further test has to be performed to check for cointegration for each equation

4.2. Long Run Analysis and Bound Cointegration Test.

After affirming the presence of unit root, the next step is to test for co-integration to determine presence of short run or long run equilibrium. Table 4.2 reports co-integration results of among

variables using equation 4 for an Unrestricted constant and no trend specification model. The result from the Bounds test shows that there is co-integration among the investigated variable, renewable electricity consumption sources, electricity price and unemployment rate in Nigeria as the F-statistics (is greater than I(0) and I(1) bounds at 5% and 10% significance level. The exhibition of a long-run relationship among variables suggests that there are shocks even in the short-run which may affect movement in the individual series which converges with time in the long-run. Therefore, a long-run and short-run model should be specified.

The Error coefficient in the levels equation in Table 3 presents the long run form of the impact of renewable electricity consumption sources, electricity price and unemployment rate in Nigeria. The results of the error coefficient show that the investigated variables have no significant impact on the unemployment rate in Nigeria in the long run.

4.3. Short Run Analysis

Table 4 present the short run OLS regression after estimating the error correction model from the long run residuals. These estimated values also show that it is only the first period lag value of the unemployment rate that is significant in causing changes in the current level of unemployment. This implies that a 1% increase in this value would likely lead to a 0.74% decrease in the current value of the unemployment rate.

The short run model also shows that there is a negative and significant impact of the difference in the log value of the first lag of hydro electricity consumption and electricity prices on unemployment rate in Nigeria at 1%, 5% and 10% significant levels. Implying that a 1% increase in the difference in the log value of the first lag of hydro electricity consumption leads to a 29% decrease in the unemployment rate in Nigeria, while a 1% increase in the difference in the log value of the first lag of electricity prices causes a 21% decrease in the unemployment rate in Nigeria.

The coefficient of the Error Correction Term (-0.05) is negative with an absolute coefficient which is less than 1 and is also statistically significant at 1%, 5% and 10%. This implies that the effect of a surprise change in the unemployment rate is not temporary. Moreover, this result shows that the short-run change from the long-run equilibrium is corrected by 5% each year. This speed of adjustment is relatively slow. Therefore, it requires effective policy attention to drive the unemployment rate to long-run equilibrium.

Table 3: Long Run and Bounds Co-integration Test: Impact of Renewable Energy Consumption and Electricity Price on Unemployment Rate (Source: Authors)

Levels Equation		Case 1: No Constant and No Trend		
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LSOLAR	0.153397	0.212228	0.722792	0.476
LHYDRO	2.09704	2.468221	0.849616	0.403
LBIO	-0.037096	0.057908	-0.640599	0.5272
LEPRICE	0.218802	0.620993	0.352342	0.7273

$$EC = LUNEMP - (0.1534*LSOLAR + 2.0970*LHYDRO - 0.0371*LBIO + 0.2188*LEPRICE)$$

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
Asymptotic: n=1000				
F-statistic	5.186071	10%	1.9	3.01
k	4	5.00%	2.26	3.48
		3%	2.62	3.9
		1%	3.07	4.44
Actual Sample Size	39	Finite Sample: n=40		

Table 4: Short Run Analysis: Impact of Renewable Energy Consumption and Electricity Price on Unemployment Rate (Source: Authors)

ECM Regression		Case 3: Unrestricted Constant and No Trend	
Variable	Coefficient	Std. Error	t-Statistic
D(LUNEMP(-1))	-0.73673***	0.152064	-4.844861
D(LUNEMP(-2))	-0.204776	0.138243	-1.48128
D(LHYDRO)	-0.105243	0.078994	-1.332297
D(LHYDRO(-1))	-0.288356***	0.084953	-3.39432
D(LEPRICE)	0.03776	0.060225	0.62698
D(LEPRICE(-1))	-0.208808***	0.059484	-3.510311
D(LEPRICE(-2))	-0.082983	0.064359	-1.289383
CointEq(-1)*	-0.049329	0.009041	-5.456362
R-squared	0.602873	Mean dependent var	-0.00329
Adjusted R-squared	0.513199	S.D. dependent var	0.101633
S.E. of regression	0.07091	Akaike info criterion	-2.274118
Sum squared resid	0.155877	Schwarz criterion	-1.932875
Log likelihood	52.34531	Hannan-Quinn criter.	-2.151683
Durbin-Watson stat	2.112602		

Table 5: Diagnostic Test: Impact of Renewable Energy Consumption and Electricity Price on Unemployment Rate (Source: Authors)

Test	Test Type	F-Stat
Linearity	Ramsey RESET	2.063663
Heteroskedasticity	ARCH[2]	0.014964
Serial Correlation	Breusch-Godfrey	2.588668
Normality	Jarque-Bera	218.5849***

***, **, * Indicates the significant levels at 1%, 5%, and 10% respectively.

The diagnostics test in Table 5 shows that the model Output from the Ramsey reset test reports the test regression, the F-statistic for testing the hypothesis that the coefficients on the powers of fitted values from the regression are jointly zero, that is, the model is correctly specified. The null cannot be rejected since the p-value is more than 10%. Similarly, the model is also homoskedastic and has no serial correlation as the F-statistics of the ARCH[2] and Breusch-Godfrey LM are not significant therefore the null hypothesis cannot be rejected. Normality test from the Jarque -Bera test shows the data are not normally distributed.

The CUSUM test for stability is meant to determine the appropriateness and the stability of the model. Put differently, the CUSUM test is used to show whether the model is stable and is suitable for making long run decisions. Figure 2 shows that the plot of CUSUM for the model under consideration is within the five percent critical bound. This by implication suggests that the parameters of the model do not suffer from any structural instability over the period of study. That is, all the coefficients in the error correction model are stable. The CUSUM of Squares trend as shown in Figure 2 also suggests the model is stable within the 5% critical bound. Model forecast performance (Figure 3) shows a good trend with the historic data set for the unemployment rate.

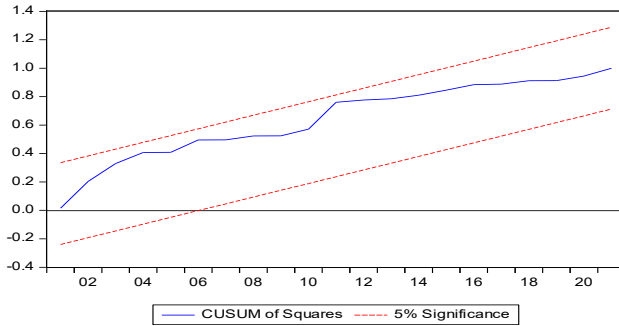
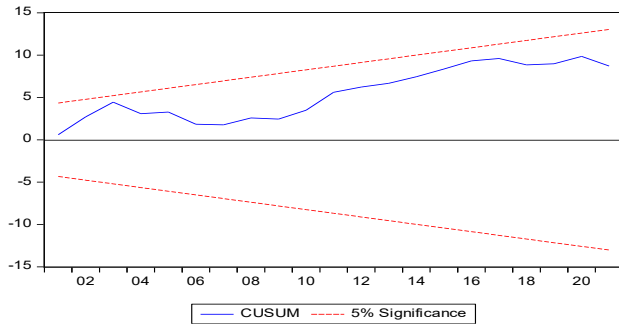


FIGURE 2: CUSUM TEST AND CUSUM OF SQUARES TEST FOR UNEMPLOYMENT RATE (SOURCE: AUTHORS)

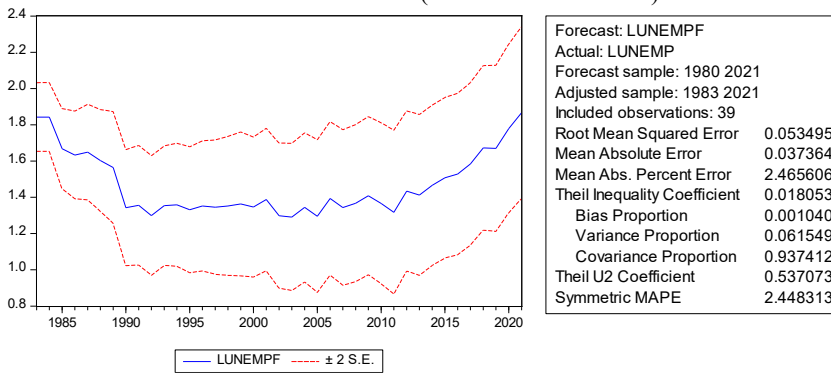


FIGURE 3: MODEL FORECAST PERFORMANCE FOR UNEMPLOYMENT RATE (SOURCE: AUTHORS)

4.4. Granger Causality Analysis

Table 6 displays the results of the Granger causality results. The results when the unemployment rate is the dependent variable show that solar electricity consumption causes unemployment at 5% and 10% significance level. The long-run results suggested a unidirectional causality flowing from solar electricity consumption to economic growth measured by the unemployment rate.

Table 6: Granger Causality Analysis: Impact of Renewable Energy Consumption and Electricity Price on Unemployment Rate (Source: Authors)

Null Hypothesis (H0):	Obs	F-Statistic	Prob.	Decision	Causality
LSOLAR does not Granger Cause LUNEMP	41	4.34122	0.044	Reject	Unidirectional
LUNEMP does not Granger Cause LSOLAR		0.6165	0.4372	Accept	
LHYDRO does not Granger Cause LUNEMP	41	0.46655	0.4987	Accept	
LUNEMP does not Granger Cause LHYDRO		0.88425	0.353	Accept	
LBIO does not Granger Cause LUNEMP	41	1.32671	0.2566	Accept	
LUNEMP does not Granger Cause LBIO		1.11426	0.2978	Accept	
LEPRICE does not Granger Cause LUNEMP	41	2.59949	0.1152	Accept	
LUNEMP does not Granger Cause LEPRICE		0.40985	0.5259	Accept	

LHYDRO does not Granger Cause LSOLAR	41	0.37703	0.5429	Accept	
LSOLAR does not Granger Cause LHYDRO		1.01554	0.32	Accept	
LBIO does not Granger Cause LSOLAR	41	3.46137	0.0706	Reject	Unidirectional
LSOLAR does not Granger Cause LBIO		0.00315	0.9556	Accept	
LEPRICE does not Granger Cause LSOLAR	41	7.67155	0.0086	Reject	Unidirectional
LSOLAR does not Granger Cause LEPRICE		0.21753	0.6436	Accept	
LBIO does not Granger Cause LHYDRO	41	0.61789	0.4367	Accept	
LHYDRO does not Granger Cause LBIO		2.03855	0.1615	Accept	
LEPRICE does not Granger Cause LHYDRO	41	1.06728	0.3081	Accept	
LHYDRO does not Granger Cause LEPRICE		2.26312	0.1408	Accept	
LEPRICE does not Granger Cause LBIO	41	0.5059	0.4813	Accept	
LBIO does not Granger Cause LEPRICE		3.98185	0.0532	Reject	Unidirectional

4.5.

Variance

Decomposition

Variance decomposition explains the proportion of the forecast error variance that impacts its own shocks and the other variables in the unrestricted Vector Error Correction Model (VECM). Figure 4 presents the graph representations of the variance decomposition renewable electricity consumption sources, electricity prices and the unemployment rate in Nigeria.

From the variance decomposition in the short-run (year 3), solar, hydro, biomass, electricity prices and unemployment rate, account for 9%, 6%, 0.04%, 13% and 72% respectively for fluctuation in the unemployment rate (own shock). In the long-run (year 10), shocks to solar, hydro, biomass, electricity price and unemployment rate, account for 54%, 2%, 2%, 7% and 36% respectively for fluctuation in unemployment rate (own shock).

In the short-run (year 3), solar, hydro, biomass, electricity prices and unemployment rate, account for 82%, 0.3%, 2%, 5% and 11% respectively for fluctuation in solar electricity consumption (own shock). In the long-run (year 10), shocks to solar, hydro, biomass, electricity price and unemployment rate, account for 76.5%, 0.5%, 2%, 6% and 15% respectively for fluctuation in solar electricity consumption (own shock).

In the short-run (year 3), solar, hydro, biomass, electricity prices and unemployment rate, account for 0.04%, 78%, 0.1%, 0.4% and 21% respectively for fluctuation in hydro electricity consumption (own shock). In the long-run (year 10), shocks to solar, hydro, biomass, electricity price and unemployment rate, account for 0.7%, 76%, 0.2%, 0.2% and 23% respectively for fluctuation in hydro electricity consumption (own shock).

In the short-run (year 3), solar, hydro, biomass, electricity prices and unemployment rate, account for 0.1%, 1%, 98%, 0.2% and 0.01% respectively for fluctuation in biomass consumption (own shock). In the long-run (year 10), shocks to solar, hydro, biomass, electricity price and the unemployment rate, account for 0.5%, 1%, 98%, 0.4% and 0.01% respectively for fluctuation in biomass consumption (own shock).

In the short-run (year 3), solar, hydro, biomass, electricity prices and the unemployment rate, account for 4%, 1%, 0.2%, 91% and 3% respectively for fluctuation in electricity price (own shock). In the long-run (year 10), shocks to solar, hydro, biomass, electricity price and the unemployment rate, account for 8%, 1%, 0.2%, 87% and 3% respectively for fluctuation in electricity price (own shock)

These results from variance decomposition shows that electricity price, solar, hydro and biomass electricity consumption are strongly endogenous to itself. while unemployment rate exhibits weak

endogenous influence itself as solar electricity consumption exhibits strongly endogenous influence on unemployment rate.

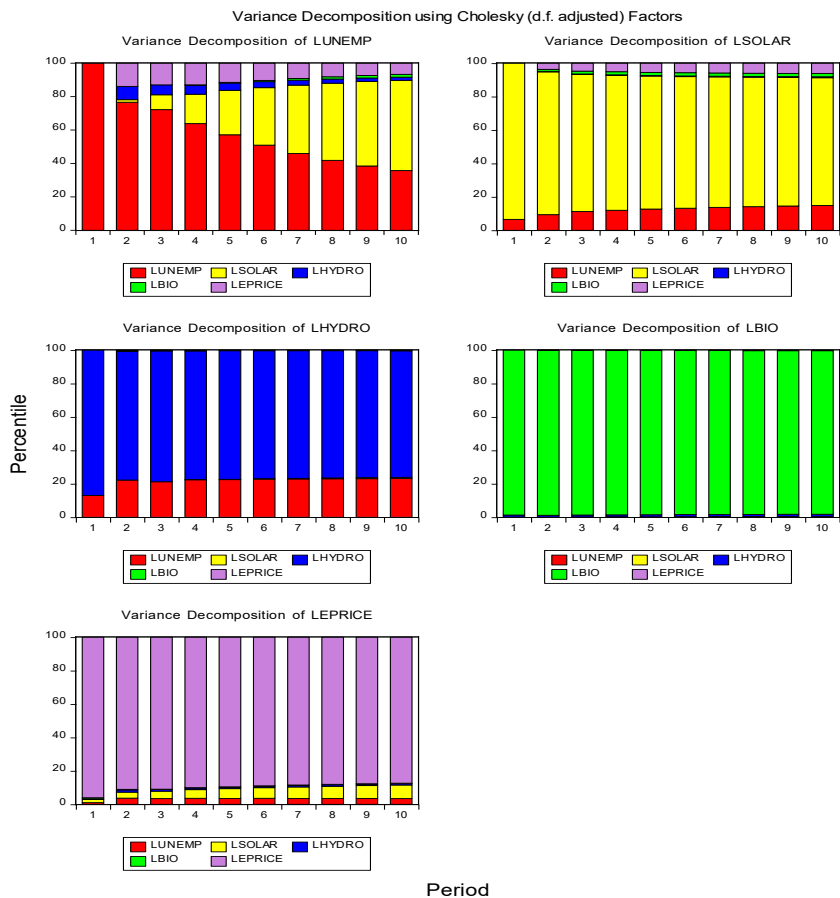


FIGURE 4: VARIANCE DECOMPOSITION OF UNEMPLOYMENT RATE, ELECTRICITY CONSUMPTION FROM RENEWABLE SOURCES AND ELECTRICITY PRICE (SOURCE: AUTHORS)

5. DISCUSSION

The impact of electricity consumption on the economy of Nigeria was evaluated. The main determinants of Nigeria's economy within the study period were; the unemployment rate as a function of electricity price and renewable energy sources such as solar electricity consumption,

hydropower electricity consumption and biomass consumption. The unit root test performed using the Augmented Dickey Fuller (ADF) test on the level $I(0)$ and the first difference $I(1)$ state indicated the observe from the level of significance, the rejection of the null hypothesis for the stationary model for all the variables after taking the first difference. The Bounds Cointegration test also shows that there is co integration between the various variables therefore long run and short run model relationship between the dependent variables (Unemployment rate) and the independent variables (electricity price and renewable energy sources such as solar electricity consumption, hydro power electricity consumption and bio mass consumption) were estimated..

The long run analysis for the impact on electricity consumption and price on the unemployment rate showed no significant impact on the economic growth of Nigeria measured by the Unemployment Rate. However, the difference lags of hydro electricity consumption and electricity prices showed significant and negative impacts implying that increasing these values reduces the unemployment rate in the short run. The coefficient of the Error Correction Term (ECT) in the short run is negative with an absolute coefficient which is less than 1 and is also statistically significant at 1%, 5% and 10%. The implication is that the effect of a surprise change in unemployment is not temporary. Moreover, this result shows that the short-run change from the long-run equilibrium is corrected by approximately 5% each year. The diagnostic test from the probability values of the F-statistics shows that the model is linear, homoskedastic and has no serial correlation. The stability diagnostics using CUSUM and CUSUMSQ indicate that the models are suitable for forecasting.

Granger causality test results suggest long-run unidirectional causality from solar electricity consumption to the unemployment rate. This one-way causality indicates solar electricity consumption is a driver for Nigeria’s economic development.



FIGURE 5: SHORT RUN AND LONG RUN VARIANCE DECOMPOSITION OF UNEMPLOYMENT RATE, ELECTRICITY CONSUMPTION FROM RENEWABLE SOURCES AND ELECTRICITY PRICE (SOURCE: AUTHORS).

Variance decomposition analysis (Figure 5) indicates that the unemployment rate displays weak endogenous influence, shocks to the unemployment rate in the long run can be explained by solar electricity consumption by about 55%.

Table 7: Summary of Long and Short Run Impact Compared to an Ideal Growing Economy (Source: Authors)

Long Run Impact	Long Run	Short Run
Variable	Unemployment Rate	Unemployment Rate
Growing Economy	Decrease	Decrease
LSOL_EC	Not significant*	Decrease
LHYDRO_EC	Not significant	Not signification
LBIO_EC	Not significant	Decrease
LEPRICE	Not significant	Decrease

* Unidirectional causality from independent variable to dependent variable

** Unidirectional causality from dependent variable to independent variable

6. Conclusion

The econometric model study explains the effects of electricity prices and electricity consumption from renewable energy sources on unemployment rate in Nigeria through the investigation of electricity consumption from renewable energy sources, and macroeconomic relationship using an unrestricted vector error correction model (VECM) during the period (1980 - 2021).

A growing economy above all others is characterized by a decreasing unemployment rate. The study findings indicate policies to foster hydro electricity consumption would decrease the unemployment rate by creating jobs. Long-run unidirectional causality from solar electricity consumption to the unemployment rate. This one-way causality indicates solar electricity consumption is a driver for Nigeria's economic development through the unemployment reduction as also deduced by the variance decomposition of the unemployment rate with solar electricity consumption explaining up to 54% of the fluctuations of the unemployment rate. Government policies to promote hydro power and solar energy installations could improve electricity generation and the direct benefits from consumption while fostering economic growth through job creation.

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Petrophysical Evaluation of Well Logs for Reservoir Characterisation in VIA Field, Niger Delta BASIN

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Abstract

Evaluating petrophysical properties in a petroleum field is a crucial part of exploration and development of reservoirs, especially when determining their producibility. This study characterizes a reservoir within the VIA field, Niger Delta Basin, by estimating key petrophysical properties (porosity, volume of shale and water saturation) using well log data and empirical equations. The analysis reveals an intercalation of shale, sandy shale and sand in the field, with five potential hydrocarbon intervals identified. Reservoir 4, the interval of interest, exhibits promising petrophysical properties: porosity (17-23%), volume of shale (14-25%), and water saturation (15-43%). These values fall within the range typically observed for good quality reservoirs in the Niger Delta Basin. This suggests significant hydrocarbon potential within VIA field. The approach employed in this study highlights the effectiveness of well log data analysis as a cost-effective alternative to core analysis for reservoir characterization. The estimated petrophysical properties provide valuable insights for further exploration and development activities in the VIA field.

Key words: Petrophysical Evaluation, Reservoir Characterisation, Niger Delta Basin

Introduction

The Niger Delta Basin, a prolific hydrocarbon province in West Africa, harbors numerous oil and gas fields with significant economic importance. Accurate characterization of reservoirs within these fields is crucial for successful exploration, development, and production. This characterization relies heavily on the evaluation of petrophysical properties. Petrophysical properties like porosity, volume of shale (Vsh), and water saturation (Sw) are critical for determining a reservoir's potential hydrocarbon volume and flow characteristics. Traditionally,

these properties are obtained through core analysis, a method that involves extracting and analysing rock samples from the wellbore. However, core analysis can be expensive and time-consuming.

Advancements have led to the development of reliable and cost-effective techniques for estimating petrophysical properties from well log data. This approach utilizes the responses of various logging tools, such as Gamma Ray, Neutron Porosity, Bulk Density and resistivity logs, to infer the rock's characteristics. While empirical equations offer a convenient and cost-effective way to estimate petrophysical properties, their accuracy can be a point of contention. These equations are often derived from specific geological settings and may not translate perfectly to other formations. However, they remain a good pointer in reservoir evaluation studies.

Numerous studies in the Niger Delta carried out petrophysical evaluation to estimate petrophysical properties. For instance, Adizua et al. (2013) highlighted the importance of petrophysical evaluation in their study of the NEMA field, Niger Delta. They demonstrated how well log data analysis can reveal crucial parameters like net-to-gross thickness, porosity, permeability, and fluid saturation, all essential for hydrocarbon prospectivity assessment. Similarly, research by Ugiomoh et al. (2014) showcased the application of wireline logs for petrophysical evaluation in an onshore field within the Niger Delta Basin. They emphasized the role of logs like gamma ray and resistivity in analysing reservoir properties and identifying hydrocarbon zones.

By employing empirical equations and well log data, this current study aims to estimate key petrophysical properties (porosity, volume of shale and water saturation) and assess the reservoir's potential for hydrocarbon production. By analysing the estimated petrophysical properties and identifying potential hydrocarbon intervals, this work lays the groundwork for further exploration and development activities in VIA field.

The area of study is located in Niger Delta Basin's Central Swamp, Nigeria (Figure 1). The basin resides within a larger tectonic structure, Benue Trough, bordering the south-western portion of the basin. On the opposite side, the basin is bounded by Cameroon Volcanic Line and transform passive continental margin (Ejedawe, 1981). Notably, the basin is rich in hydrocarbons and characterized by clastic sedimentary deposits formed from separate depobelts that eventually merged to create the current Niger Delta sedimentary basin (Reijers et al., 1997).

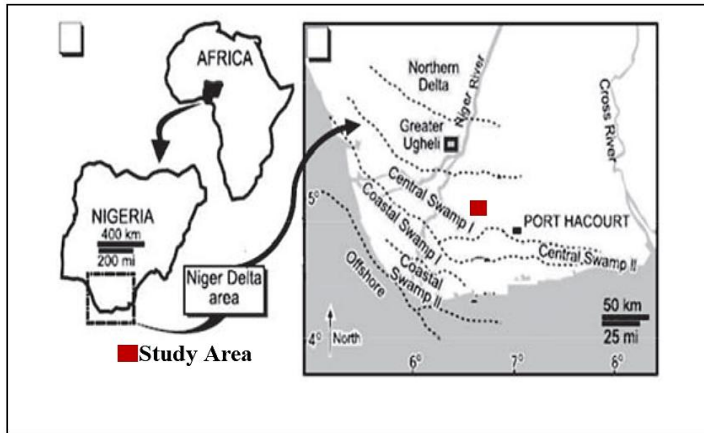


Figure 1: Location map of the study area (adapted from Doust and Omatsola (1990))

Materials and Methods

Materials

The data available for the study consist of a suite of six deviated wells (VIA1, VIA2, VIA3, VIA4, VIA5 and VIA6) comprising of different well log data and associated well data such as well headers and well deviation. Also all wells had the basic well log data essential for petrophysical analysis: Gamma Ray (GR), Neutron Porosity (NPHI), Bulk Density (RHOB) and Resistivity (ILD). TECHLOG 2015 software was used for the analysis of the available data.

Methods

Well Log QA/QC

The first step of the methodology was data quality assurance and control check (data QA/QC). The uniformity of the Coordinate Reference System (CSR) as well as the depth measuring unit and the well header information of all the wells, were confirmed. A quality check was done on the displayed well logs, for any missen data or anomalies that could hinder the analysis. Missen data of Neutron Porosity and Bulk Density were observed at some depth portions of wells VIA1 and VIA3, as well as corresponding GR log of well VIA3 alone.

Well Log Quick-Look Interpretation (QLI) and pre-computations

The well logs were correlated to discriminate probable hydrocarbon reservoirs present in the field. After the wells had been correlated (using GR log signatures), the probable reservoirs delineated and the fluid content and contact determined; pre-computations were performed to obtain some input logs. These logs included fluid density log, fluid log, and apparent water resistivity; all necessary for computation of petrophysical properties of wells. The fluid density log was useful while estimating porosity. It was developed assuming the following values of densities for each fluid possibly present in the reservoirs:

$$\rho_w = 1 \text{ g/cc}$$

$$\rho_{oil} = 0.745 \text{ g/cc}$$

$$\rho_{gas} = 0.605 \text{ g/cc}$$

Where ρ_w : water densi, ρ_{oil} : oil dens and ρ_{gas} : gas dens.

Codes were assigned to each fluid type to compute the fluid density log: 1 for water, 2 for oil and 3 for gas. A conditional statement as stated in Equation 1 was used for the purpose;

$$\text{Fluid Density} = \text{iff}(\text{Fluids} == 1, 1, \text{iff}(\text{Fluids} == 2, 0.745, \text{iff}(\text{Fluids} == -9999, 1, 1))) \quad (1)$$

That is, if fluid code is 1, then fluid density is 1g/cc; if fluid code is 2, then fluid density is 0.745g/cc and if fluid code is 3, then density of fluid is 0.605 g/cc; otherwise fluid density of 1g/cc is used. With this a fluid density log as well as fluid type log, were computed for each delineated reservoir zone.

The apparent water resistivity representing the formation's resistivity when entirely saturated with water was computed using Equation 2 (Asquith & Gibson, 1982):

$$R_{wa} = \frac{\phi^m R_t}{a} \quad (2)$$

Where,

R_{wa} : Formation water resistivity at 100% water saturation

a : Factor tortuosity

ϕ : Total porosity

m : Factor cementation

R_t : True formation resistivity

In soft rocks (sandstones); a=1 and m=2.

This was useful for the estimation of water saturation in a formation.

Estimation of Petrophysical Properties

The well logs were used to estimate petrophysical properties in reservoirs of interest, namely Volume of Shale, Porosity and Water Saturation. Three methods were used to estimate volume of shale of reservoirs of interest: GR linear method, Larionov (Gamma-Ray non-linear) method and the Neutron-Density method. The research of Kamayou et al. (2021) gives more details on these methods and the results obtained.

Porosity was then estimated. The density log method assumed to provide the best estimate of porosity values, was used following Equation 3 (Bassiouni, 1994).

$$\phi_T = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (3)$$

Where,

ρ_{ma} : Matrix RHOB – Density log reading at 100% clean sand

ρ_b : Log reading density

ρ_f : Density Fluid

Fluid density log determined from Equation 1 was used.

The equation of Archie known to best represent the study area, was used following Equation 4 (Archie, 1942).

$$S_w^n = \frac{a}{\phi^m} \frac{R_w}{R_t} \quad (4)$$

Where,

a: Tortuosity factor

ϕ: Total porosity

m: Cementation factor

Sw: Water Saturation

n: Saturation factor

R_w: Water resistivity formation

R_t: True resistivity formation

In soft rocks (sandstones); a=1, m=2 and n=2.

Results Presentation

The signatures of GR, Resistivity, NPHI and RHOB cross logs were utilised to correlate potential reservoir sands across the wells. Five (5) potential petroleum reservoirs were identified and their corresponding fluid logs were computed (Figure 2). From the GR log, intercalations of sands (yellow) and shales (brown) are observed across the entire wells' depth. Within the reservoir intervals, intercalations of clean sand and thin layers of unclean sand (probable sandy shale) and shale, were observed. Low values of GR (0-50 API), mid values of GR (50-75 API) and high values of GR (75-150 API), were observed in pure sand, sandy shale and shale respectively.

Hydrocarbon sands were discriminated from brine sands in the various reservoirs using the resistivity logs. Hydrocarbon sands showed high readings of Resistivity (40-1000 Ohm.m), while brine sands and shale zones showed low values of Resistivity (0-40 Ohm.m). NPHI and RHOB cross logs were employed to better discriminate gas and oil infills in hydrocarbon sands. Only the shallowest reservoir (Reservoir Sand 1) contained gas (green colour on fluid log) in wells VIA1, 2 and 3. Other hydrocarbon reservoir sands were saturated with oil only (red colour on fluid log). Varying thickness and reservoirs' tops and bases were observed from the reservoirs correlated across the wells. This may be an evidence of tectonic (faulting) and stratigraphic activities in the field of interest. From this quick look analysis, Reservoir Sand 5 (Res. 5) visually had the largest thickness in all well. However, Res. 5 was not continuous across all the wells, as the well log values are missing in well VIA 4 for Res. 5 interval. Reservoir Sand 4 (Res. 4) was the second thickest reservoir and was continuous across all wells. On this basis, the emphasis in this study was on Res. 4.

Vsh, porosity and Sw were calculated from logs using empirical models. Table 1 is a summary of the average values of all calculated petrophysical properties at Reservoir 4 interval, including the thickness and probable Oil-Water-Contact (OWC). Volume of shale values in all wells varied from 12 to 24%, Porosity from 17 to 23%; while Water Saturation values varied from 15% to 43% and reservoir thickness from 91 to 148m. From the Vsh results, it can be deduced that the Res. 4 intervals in wells VIA2 and VIA6 are the "dirtiest" due to their high content of shale. On the other hand, the Res. 4 intervals in wells VIA4, 5 and 1 can be said to be the "cleanest" due to their relatively low shale content. The highest values of porosity are found in well VIA5 and the lowest values of Sw in well VIA2 respectively. Overall, properties average values are pointers of good reservoir quality: low Vsh, high porosity, low Sw and high thickness.

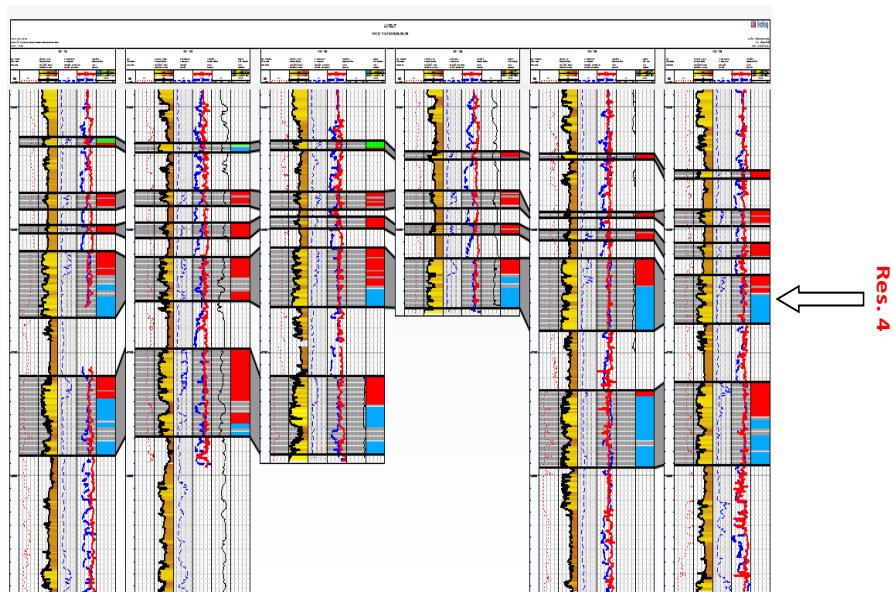


Figure 2: Correlation of logs through wells

Table 0.1: Res. 4 Estimated Properties Summary

Wells	Top (m)	Base (m)	Thickness (m)	OWC (m)	Vsh (%)	Φ (%)	Sw (%)
VIA1	3544	3680	136	3593	14	21	36
VIA2	3555	3646	91	-	24	20	15
VIA3	3535	3659	124	3614	16	21	43
VIA4	3557	3659	102	3590	12	17	28
VIA5	3557	3705	148	3613	13	23	25
VIA6	3591	3691	100	3629	21	21	29
Average			117	3007	17	20.5	29

Discussion

The quick-look well log analysis successfully identified five potential reservoir zones, reflecting a complex depositional environment and burial history with intercalations of clean sand, mixed shale, and pure shale. This complexity is characteristic of the Niger Delta Basin, where fluvial-deltaic processes often result in highly heterogeneous reservoirs (Stampe et al., 2010). The differentiation between hydrocarbon-bearing sands (high resistivity) and brine-filled sands (low resistivity) within each reservoir further underscores this complexity. Notably, the presence of free gas was restricted to the shallowest reservoir (Reservoir Sand 1) in wells VIA1, 2, and 3. The absence of gas in deeper reservoirs aligns with observations from Afolayan et al. (2013), who documented gas caps primarily limited to the shallower sections of the Agbada Formation in the Niger Delta, potentially due to buoyancy segregation within the reservoir system.

The observed variations in reservoirs' thickness and depth across wells, evident from the log correlation, suggest potential influences from faulting and/or stratigraphic events. This is in line with the work of Adegbite et al. (2012), who documented the impact of growth faults on reservoir thickness variations within the Niger Delta depobelts. While Reservoir Sand 5 appeared visually to be the thickest, Reservoir Sand 4 (Res. 4) was chosen for further analysis due to its apparent continuity across all the studied wells. This highlights the importance of not solely relying on thickness but also considering factors like lateral continuity for reservoir evaluation and development planning, as emphasized by Essien (2018) in their study of reservoir characterization in Niger Delta.

The available well logs were used for estimations of Vsh, porosity, and Sw through empirical equations. Observed variations in Vsh, porosity, and Sw across wells (12-24% for Vsh, 17-23% for poro, 15-43% for Sw, 91-148m for thickness) highlight reservoir heterogeneity within the studied interval. The average reservoir properties of 17%, 20.5%, 29%, 117 m for Vsh, poro., Sw and thickness respectively, indicate good reservoir quality, consistent with expectations for the Niger Delta (Adagunodo et al., 2022; Osinowo et al., 2018; Saadu & Nwankwo, 2018; Stampe et al., 2010). Based on these results, wells VIA4, 5, and 1, respectively, appear to be the "cleanest" with the highest quality, while wells VIA 2 and 6 exhibit lower quality.

Conclusion

This study effectively characterized a reservoir in VIA field Niger Delta Basin, by estimating petrophysical properties (porosity, Vsh and Sw) from empirical equations. The petrophysical evaluation of the wells, suggested an intercalation of shale and sand within the field and also the presence of five possible hydrocarbon intervals. From the interval of interest (Reservoir 4), petrophysical properties were computed. These values varied from 17 to 23%, 14 to 25% and 15 to 43%, for porosity, volume of shale and water saturation respectively. This suggests a good quality of the reservoir in accordance with the values generally observed in the Niger Delta.

Recommendations

Based on the results of this study the following recommendations are made:

1. Core analysis could be done for a more quantitative fluid identification and also as a means to validate the results of this study.
2. A Rock Physics Cross Plot Analysis could be performed to further characterize the reservoir in terms of lithology and fluid content discrimination.

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Energy Dispatch Strategies for Hybrid Energy Systems, A Review

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Abstract

Hybrid energy systems (HES) integrate renewable and conventional energy sources to meet growing energy demands sustainably and reliably. They offer economic benefits by optimizing resource use and reducing fossil fuel dependence, environmental advantages by incorporating emissions-free renewables, and social gains by providing reliable energy to remote areas. However, HES faces challenges like the intermittency of renewables, integration complexity, high initial costs, maintenance needs, and regulatory barriers. Effective dispatch strategies, technological advancements, and supportive policies are essential to address these issues. This review analyzes various dispatch strategies, highlighting the need for advanced optimization and real-time data integration to enhance the performance and sustainability of HES.

1. Introduction

Hybrid energy systems (HES) have emerged as a promising solution to meet the growing global demand for reliable and sustainable energy. These systems integrate various energy sources, both renewable and conventional, to ensure a continuous and stable power supply while minimizing environmental impacts.

The key benefits of HES span economic, environmental, and social dimensions. Economically, HES can be cost-effective by optimizing resource use and reducing reliance on volatile fossil fuel prices. Environmentally, HES contributes to sustainability by incorporating renewable sources that generate electricity without greenhouse gas emissions, mitigating the environmental impact of traditional power generation. Socially, HES plays a crucial role in providing reliable energy access to remote and isolated communities, enabling essential services and fostering economic growth.

Despite their advantages, operating HES efficiently presents several challenges. The intermittency of renewable energy sources, such as solar and wind power, can cause mismatches between energy supply and demand, potentially leading to shortages or surpluses. Effective energy storage solutions and advanced control strategies are essential to mitigate these fluctuations and maintain a stable energy supply.

Integrating and coordinating multiple energy sources within an HES is another challenge. Each energy source has unique operational characteristics, and seamlessly integrating these components while optimizing their collective performance requires sophisticated energy management strategies and control

algorithms. Poor coordination can result in inefficiencies, increased wear and tear, and suboptimal system performance.

Economic viability is a significant concern for HES. Although the costs of renewable energy technologies are decreasing, the initial capital investment for HES can be substantial. Accurately estimating and evaluating lifetime costs, including maintenance and replacement expenses, is crucial for ensuring economic viability.

Maintenance and reliability issues also pose challenges. The integration of multiple energy sources and complex control systems increases the potential for component failures and system downtime. Robust maintenance strategies and the availability of skilled personnel and spare parts are critical to minimizing system disruptions and maximizing operational uptime.

Regulatory and policy frameworks can influence the adoption and operation of HES. Inconsistent or outdated policies regarding grid interconnection, energy pricing, and incentives for renewable energy can create barriers to deploying these systems. Addressing these regulatory challenges through proactive policymaking and stakeholder engagement is vital for fostering HES's widespread adoption.

To address these operational challenges, technological advancements, effective system design, robust control strategies, and supportive policies are crucial. Advanced energy dispatch strategies are essential for optimizing power generation by balancing cost, reliability, and sustainability. These strategies manage renewable energy sources' variability by prioritizing dispatchable sources, integrating energy storage, and utilizing demand-side management to ensure stable grid operations.

HES are intricate assemblies of renewable energy sources, conventional generators, and energy storage technologies designed to provide reliable and sustainable power. They utilize renewable sources like solar photovoltaic (PV) panels and wind turbines to generate clean electricity, while incorporating conventional power generators like diesel and natural gas generators to counteract the variability of renewable sources.

Energy storage systems (ESS) are crucial for balancing supply and demand within HES. Batteries, particularly lithium-ion, are commonly used due to their high energy density and efficiency, storing excess energy for use during low renewable output. Other ESS include pumped hydro storage and flywheels, providing both short-term and large-scale energy storage solutions.

Power electronics manage the flow of electricity within HES, ensuring compatibility between various power sources and storage systems, converting DC electricity to AC for grid use, and maintaining voltage and frequency stability. Control and management systems optimize HES performance by monitoring real-time data, predicting energy demand, and managing power source dispatch and storage, using advanced algorithms and incorporating artificial intelligence and machine learning.

Hybrid energy systems integrate renewable energy sources, conventional generators, energy storage solutions, and sophisticated control mechanisms to provide reliable, efficient, and sustainable power. By addressing the operational challenges through technological advancements, effective system design, robust control strategies, and supportive policies, HES can unlock its full potential as a reliable, sustainable, and cost-effective solution for meeting global energy demands.

This review analyzes energy dispatch strategies for hybrid systems, integrating renewables with conventional power and storage. It categorizes strategies and parameters for evaluating economic and environmental impacts, assesses technical performance, and explores future research trends.

2. Review of Energy Dispatch Strategies

Energy dispatch strategies for hybrid energy systems are essential for optimizing the use of various energy sources like solar, wind, and conventional generators. These strategies ensure reliable, cost-effective power generation while minimizing environmental impact.

One key approach is predictive and real-time optimization, which uses forecasts of solar irradiance, wind speed, and electricity demand to plan power generation. Machine learning algorithms analyze historical data to predict future energy needs. Real-time monitoring allows for adjustments based on forecast deviations, ensuring efficient renewable energy use while maintaining grid stability.

Another strategy is rule-based dispatch, where pre-defined rules prioritize dispatch decisions based on factors such as fuel costs, carbon emission targets, and renewable availability. This approach typically prioritizes solar and wind during peak production periods, reducing reliance on conventional generators, which step in when renewable output is insufficient. This simpler method is effective for smaller systems but may need adjustments for larger, more complex setups.

Advanced strategies incorporate load-following and cycle-charging techniques. Load-following adjusts energy output based on operating costs and availability, prioritizing renewables first. Cycle-charging stores excess renewable energy in batteries during low-demand periods and dispatches it during high demand, ensuring a consistent energy supply.

The choice of dispatch strategy depends on system composition, demand patterns, local considerations. Combining predictive optimization and rule-based dispatch can leverage long-term planning benefits with real-time management efficiency. Effective dispatch strategies optimize energy use, enhance sustainability, and improve the resilience of hybrid energy systems.

Energy dispatch strategies for hybrid energy systems are essential for optimizing the use of diverse energy sources like solar, wind, and conventional generators. Each strategy has unique characteristics, advantages, and challenges, making them suitable for various applications based on system size, complexity, and operational goals.

The Load Following (LF) strategy dynamically adjusts the output from different energy sources to match the current demand. This approach aims to maximize the use of renewable energy, thereby reducing fuel costs and enhancing grid stability. However, it requires sophisticated forecasting and real-time data management, which can make implementation complex and demanding (Aziz et al., 2019; Gupta et al., 2011; Toopshekan et al., 2020; Uwineza et al., 2022).

The Cycle Charging (CC) strategy focuses on storing excess renewable energy in batteries during periods of low demand and releasing it during high demand or when renewable sources are insufficient. This ensures a consistent and reliable energy supply, optimizing the use of storage systems. However, the strategy is heavily dependent on the capacity and efficiency of battery storage, which can involve significant initial costs (Aziz et al., 2019; Nayak et al., 2018; Upadhyay & Sharma, 2015).

State of Charge (SOC) based strategies manage energy storage systems by closely monitoring and controlling the batteries' state of charge. This method helps extend battery life, improve energy storage management, and balance supply and demand effectively. However, it requires precise SOC monitoring and may be less effective without a robust storage infrastructure by (Ajewole et al., 2022; Chatzigeorgiou et al., 2024; A. Kumar et al., 2019; R. P. Kumar & Karthikeyan, 2024; Xinxin et al., 2023)

Forecast-based strategies utilize predictions of energy production and demand to plan energy dispatch. These strategies enhance efficiency, reduce reliance on conventional energy sources, and support proactive management. However, their effectiveness is heavily reliant on the accuracy of forecasts, necessitating advanced data analytics and prediction tools (Akinyele et al., 2020; Ding et al., 2023; Wang et al., 2024).

Rule-based strategies use predefined rules to determine energy dispatch decisions based on factors such as fuel costs and renewable availability. This approach is straightforward to implement and effective for smaller systems, reducing dependency on conventional energy sources. Nevertheless, it lacks flexibility and may require frequent adjustments for larger or more complex systems (Jafari & Malekjamshidi, 2020; Restrepo et al., 2021; Yuan et al., 2022).

Optimization-based strategies employ mathematical optimization techniques to determine the most cost-effective and efficient way to dispatch energy. These strategies can significantly reduce operational costs

and maximize renewable energy use, making them adaptable to various scenarios. However, they are computationally intensive and require specialized software and expertise, making them more suitable for large-scale and complex hybrid systems (Dey et al., 2021).

Table 1 – Advantages, Disadvantages and Applications for the Energy Dispatch Strategies

Strategy	Description	Advantages	Disadvantages	Suitable Applications
Load Following (LF) Strategy	Dynamically adjusts the output from various energy sources to match current demand.	Maximizes renewable usage, reduces fuel costs, improves grid stability	Requires advanced forecasting and real-time data, complex to implement	Systems with fluctuating demand
Cycle Charging (CC) Strategy	Stores surplus renewable energy in batteries during low demand and releases it during high demand or when renewables are insufficient.	Ensures consistent energy supply, optimizes storage system utilization	Heavily dependent on battery capacity and efficiency, high initial cost	Systems with substantial renewable generation and storage capabilities
State of Charge (SOC) Based Strategies	Monitors and controls battery state of charge to manage energy storage systems for optimal performance.	Prolongs battery life, enhances energy storage management, balances supply and demand	Requires precise SOC monitoring, less effective without robust storage infrastructure	Systems with significant battery storage
Forecast-Based Strategies	Uses predictions of energy production and demand to plan energy dispatch.	Increases efficiency, reduces reliance on conventional sources, enables proactive management	Dependent on accuracy of forecasts, needs advanced data analytics and prediction tools	Systems with high renewable penetration and variability
Rule-Based Strategies	Employs predefined rules to determine energy dispatch based on factors	Simple to implement, effective for smaller systems, lowers reliance on	Lacks flexibility, may need frequent updates for larger or more complex systems	Smaller or simpler hybrid systems

	like fuel costs and renewable availability.	conventional sources		
Optimization-Based Strategies	Uses mathematical optimization to determine the most cost-effective and efficient energy dispatch.	Reduces operational costs, maximizes renewable usage, adaptable to various scenarios	Computationally demanding, requires specialized software and expertise	Large and complex hybrid systems

In summary, each energy dispatch strategy offers specific benefits and challenges. The choice of strategy depends on the particular needs and characteristics of the hybrid energy system, including its size, the variability of demand, the proportion of renewable energy, and economic considerations.

3. Methodology

3.1 Selection Criteria for Appropriate Dispatch Strategy

Selecting an optimal energy dispatch strategy for a hybrid energy system requires a careful evaluation of various economic, technical, and environmental criteria to ensure efficiency, reliability, and sustainability.

Economic criteria are crucial in evaluating the financial viability of the system. Assessing the Cost of Energy (TCOE) helps identify strategies with lower costs, encompassing capital expenditures, operational and maintenance costs, and fuel expenses (Adetoro et al., 2022). Additionally, evaluating the Return on Investment (ROI) and Net Present Value (NPV) ensures the financial viability and long-term profitability of the system. Effective market participation also enhances revenue through fluctuating electricity prices.

Technical criteria are essential in ensuring the reliability and efficiency of the system. System reliability is measured by metrics like Loss of Load Probability (LOLP), while energy efficiency reflects the effective conversion of inputs into usable power. Ramp rate management, capacity utilization, and response time are also critical in evaluating the system's performance (Benjamin et al., 2019).

Environmental criteria are vital in ensuring the sustainability of the system. Minimizing the carbon footprint by reducing greenhouse gas emissions is crucial. Integrating renewable energy sources like solar and wind power maximizes the proportion of energy from clean sources. Additionally, minimizing air pollutant emissions and water consumption ensures improved environmental sustainability (Oladigbolu et al., 2021).

The selection process should also consider energy resource availability, load demand patterns, energy storage capacity, system flexibility, and regulatory compliance. By balancing these economic, technical, and environmental criteria, an appropriate energy dispatch strategy can be selected for the hybrid energy

system. This strategy should optimize performance, minimize costs and emissions, and ensure long-term sustainability and reliability.

4. Result and Discussions

4.1 Comparative Analysis and Discussion

A comparison of the different energy dispatch strategies for hybrid energy systems was carried out using the metrics of system reliability, cost optimization, carbon footprint, and storage integration:

System Reliability:

1. Forecast-based and Optimization-based strategies - High reliability, as they can proactively manage supply and demand and optimize dispatch to maintain consistent power.
2. Load Following (LF) strategy - High reliability, as it responds quickly to changes in demand to maintain power supply.
3. SOC-Based strategy - High reliability, as it maintains a target state of charge to ensure a reliable power supply.
4. Cycle Charging strategy - Moderate reliability, as it can maintain a target SOC but has limited flexibility.
5. Rule-based strategy - Moderate reliability, as it follows predefined rules that may not adapt well to changing conditions.

Cost Optimization:

1. Optimization-Based strategy – High-cost optimization, using advanced algorithms to minimize overall system costs.
2. Forecast-Based strategy - High-cost optimization, using forecasts to optimize dispatch and storage to reduce costs.
3. Cycle Charging, SOC-Based, and Rule-Based strategies - Moderate cost optimization, with limited overall system optimization.
4. Load Following (LF) strategy - Moderate cost optimization, as it responds to demand but may not optimize long-term costs.

Carbon Footprint:

1. Forecast-Based and Optimization-Based strategies - Low carbon footprint, as they can optimize the integration of renewable energy sources and minimize the use of fossil fuel generators.

2. Cycle Charging and SOC-Based strategies - Moderate carbon footprint, as they can manage storage to reduce reliance on fossil fuels, but have limited optimization.

3. Load Following (LF) and Rule-Based strategies - Moderate to high carbon footprint, as they have limited optimization of renewable energy integration and fossil fuel usage.

Storage Integration:

1. Optimization-based strategy - High storage integration, as it can optimize the use of energy storage to balance supply and demand.

2. Cycle Charging and SOC-based strategies - High storage integration, as they are designed to manage storage systems.

3. Forecast-based strategy - Moderate to high storage integration, as it can optimize storage use based on forecasts.

4. Load Following (LF) and Rule-Based strategies - Moderate storage integration, as they have limited optimization of storage systems.

Ranking:

1. Optimization-based strategy - Highest overall performance across all metrics.

2. Forecast-based strategy - Strong performance in cost optimization, reliability, and carbon footprint.

3. SOC-based and Cycle Charging strategies - Moderate to high performance in reliability and storage integration.

4. Load Following (LF) strategy - Moderate performance in reliability and cost optimization.

5. Rule-based strategy - Moderate performance in reliability and limited optimization across other metrics.

The Optimization-Based and Forecast-Based strategies generally outperform the other approaches, as they can more effectively manage the hybrid energy system to optimize performance, minimize costs, and reduce environmental impact. The SOC-Based and Cycle Charging strategies also perform well in terms of reliability and storage integration, while the Load Following and Rule-Based strategies have more limited optimization capabilities.

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4.3 Emerging Trends and Future Directions

Emerging trends in energy dispatch strategies for hybrid energy systems (HES) include using advanced optimization algorithms like machine learning and AI to enhance efficiency and adaptability. There is a shift towards strategies that dynamically respond to real-time data on energy demand and renewable generation. Smart grids and IoT technologies enable precise, automated energy management, integrating distributed energy resources (DERs) like rooftop solar. Blockchain technology is poised to revolutionize energy markets with real-time peer-to-peer trading. Emphasis on sustainability and reducing carbon footprints drives innovations in renewable integration and dispatch optimization. Energy storage systems, such as batteries and hydrogen, are crucial for grid stability and resilience, ensuring efficient and sustainable energy systems.

5. Conclusions

Hybrid energy systems (HES) are a promising solution for reliable and sustainable energy, integrating renewable and conventional sources. Despite their benefits, they face challenges like renewable intermittency, integration complexity, economic viability, maintenance, and regulatory issues. Addressing these requires technological advancements, effective design, robust control strategies, and supportive policies. Advanced energy dispatch strategies, including predictive optimization and machine learning, are essential for efficient power generation, balancing cost, reliability, and sustainability. As the energy landscape evolves, HES, supported by innovative technologies and proactive policies, is poised to become a key component in meeting global energy demands while minimizing environmental impacts.

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