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2. **Materials and Methods**
3. **Results and Discussion**
4. **Conclusion**
5. **References**

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2.1.1 Analytical Solutions of the Schrodinger equation

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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**.**
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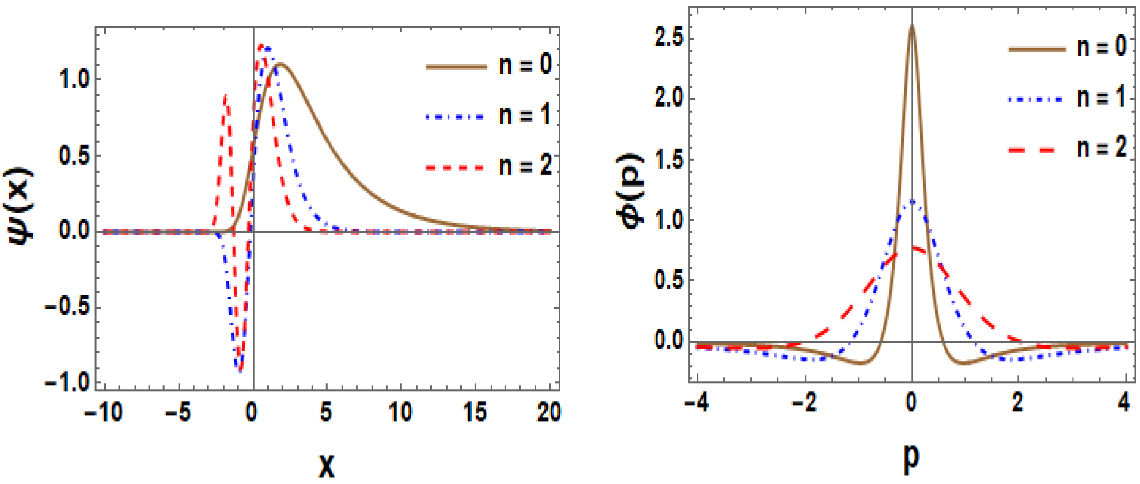

Figure 1: Wave function of the Position and Momentum spaces of shifted Morse Potential for ground, first and second excited states.

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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Estimation of Risk Dimension in Poultry Production in Akwa Ibom State, Nigeria.

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Abstract

The study was carried out to estimate risk dimension in poultry production in Akwa Ibom State, Nigeria. Multistage sampling technique was used to select 150 poultry farmers for the study. Data obtained were analyzed using descriptive, fuzzy logic model, ordered probit model and mann-whitney u-test. Most severe risk faced was: unavailability of credit facilities, high interest rate, high cost of feed, high cost of improved breeds. high cost of vaccines and shortage of feeds. Most popular risk management strategies adopted was: ensuring proper and timely vaccination, use of foot dips at the entrance, use of disease tolerant breed, fencing and netting, disinfecting the poultry house and attending extension workshops, Contribution of each dimension to the multidimensional risk management index: biosecurity (55.9%), medication (40.9%), mitigation (3.2%). The finding of this study revealed that the relative contribution of disease biosecurity to poultry risk management is high relative to medication and insurance. The study recommended that efforts should be made by providing more credit facilities, reducing interest rate and training of farmers on feed formulation.

Keywords: Risk Dimension; Poultry Production

Introduction

The poultry industry plays important roles in the development of Nigerian economy. It is a major source of eggs and meat which have a high nutritional value particularly in the supply of protein. Eggs are also important in the preparation of confectionary and vaccines. The (World Economic Forum, 2019) has estimated that by 2030, the demand for poultry products across the African continent will increase by 60% especially in Nigeria, its largest market. Recently, present consumption across the continent is almost 100million tones respectively for both poultry meat and egg products while in Nigeria, 192.69MT is consumed annually (Richie & Roser, 2020). The poultry industry serves as a source of food, income, employment and poverty alleviation. Poultry production is becoming the first priority to supply animal protein source foods and is an income generating activity. The poultry industry also provides employment opportunities for the populace, thereby serving as a source of income. The importance of the poultry industry in Nigeria has been demonstrated by the number of researches conducted. The risky nature of the enterprise is usually worsened by disease outbreak, attitude to risk and responses of poultry farmers to risk and agricultural insurance. Demand for livestock products, including poultry, is expanding in West Africa. This is due to the population growth and increased urbanization. Poultry is far the largest livestock group, consisting mainly of chickens, ducks and turkey. Poultry is the most commonly kept livestock. Production decisions are generally made under the environment of risk and uncertainties, yields, product prices, input prices and quantities are usually not known with certainty when investment decisions are being made. Risk is an innate characteristic of present-day poultry production. The poultry industry in Nigeria has suffered a great deal of losses which affects poultry farmers as well as consumers.

Risk and uncertainty are inescapable in all walks of life. In Agriculture, risk and uncertainty are ubiquitous and have numerous sources: the vagaries of weather, the unpredictable nature of biological processes, the pronounced seasonality of production and market cycles, the geographical separation of producers and end users of agricultural products, the unique and uncertain political economy of food and agriculture within and among Nations. In order to manage risk, it is important to identify the most crucial risk faced by farmers, understand the impacts and take possible steps that will reduce the impacts to prevent failure. In some parts of Akwa Ibom State and Rivers State, many of the existing poultry farms are folding up. This is due to the fact that some prospective investors are reluctant to invest in poultry farming due to the associated risks and uncertainties in poultry production. This could result in lower productivity and poor welfare of the poultry farmers. Thus, risk management effort is very important for sustainability of poultry farmers. Inability to manage risk will negatively affect the farmers' income, market stability and potential food security. (Abotsi, Dake & Agyepong, 2014) described risk management as involving the use of risk assessment techniques to determine the initial level of risk and, if it is excessive, to develop a strategy to ameliorate the risks until the overall level of risk is reduced to an acceptable level. Therefore, this research aims at ascertaining risk dimension, major risk faced risk management techniques adopted by poultry farmers; Thus, this study is set to analyse the risk dimension in poultry production in Akwa Ibom States, Nigeria.

Research Methodology

The study was carried out in Akwa Ibom State. Akwa Ibom State is located in the coastal southern part of the country, lying between latitudes 4°32′N and 5°33′N, and longitudes 7°25′E and 8°25′E. The state is located in the South-South geopolitical zone, and is bordered on the east by Cross River State, on the west by Rivers State and Abia State, and on the south by the Atlantic Ocean and the southernmost tip of Cross River State. Akwa Ibom is one of Nigeria's 36 states, with a population of over five million people in 2016. The population covered all poultry farmers in in Akwa Ibom States.

Respondents for this study were selected using multi-stage sampling techniques. Fifty (50) poultry farmers were selected from each of the three (3) LGAs; Oron, Uyo and Abak, giving a total of one hundred and fifty (150) respondents (poultry farmers). This constitutes the sample size for the study. Primary data were utilized in the study. The primary data were sourced through administration of structured questionnaires to suit the objectives of the study. The membership function of the level of biosecurity of poultry farm i is defined as:

$x_{ij} = 1$; farm i is of high level risk management. (1)

$0 \leq x_{ij} \leq 1$; if farm i reveals a partial degree of level of risk management.The determination of the individual membership function $F_P(x_i)$ depends on the type of variable. The variables that define indicators of biosecurity index are either dichotomous or categorical.

Following Costa (2002), the degree of membership to the fuzzy set P of the a_i^{th} chicken egg farm (i =1, 2… n) for the j^{th} attribute (j =1….m), is stated as follows:

$$F_p = (a_i)j = X_j(a_i) = x_{ij} \quad (2)$$

$X_j(a_i)$ is the m order of attributes that will result in a state of risk management if totally or partially owned by the a_i^{th} farm.

Ordinal or categorical discrete variables are those that present several modalities (more than two values). The lowest modality is denoted as $C_{inf,j}$ and the highest modality as $C_{sup,j}$, then, following (Cerioli & Zani, 1990; Costa ,2002; Dagum & Costa, 2004), the membership function of the a_i^{th} farm is expressed as:

$$F_p(a_i) = 1 \text{ if } 0 < C_{ij} \leq C_{inf,j}$$

$$F_P(a_i) = \frac{C_{sup,j} - C_{ij}}{C_{sup,j} - C_{inf,j}} \text{ if } C_{inf,j} < C_{ij} < C_{sup,j} \quad (3)$$

$F_p(a_i) = 0$ if $C_{ij} \geq C_{sup,j}$

The risk management index (MI) of the a_i^{th} poultry farm, $F_P(a_i)$ (i.e. the degree of membership of the a_i^{th}farm to the fuzzy set P) is defined as the weighted average of x_{ij} as equation 5 following (Akintunde &Adeoti, 2014):

$$F_p = \sum_{i=1}^{n}(a_i)n_i / \sum_{i=1}^{n} n_i \quad (4)$$

$F_p$is the Risk management index (MI) for the population of poultry egg farms studied, it will be expressed as equation 5:

$$F_p = \sum_{i=1}^{n} F_{P(a_i)n_i} / n \quad (5)$$

The degree of attainment of the selected risk management index (MI) will be expressed by equations 4 and 5. It will also be conceptualized as equation 6:

$$F_p = \sum_{j=1}^{m} x_{ij} w_j / \sum_{j=1}^{m} w_j \quad (6)$$

Where $w_j$is the weight given to the j^{th} attribute in equation 7 as:

$$w_j = logn \sum_{i=1}^{n} x_{ij} n_i \geq 0 \quad (7)$$

Result and Discussion

Socioeconomics Characteristics

Table 1 shows the age distribution among the poultry egg farmers in Akwa Ibom State The highest percentage (30.8%), fell within the age bracket of 36-55, while the lowest percentage (0.8%) fell within the age bracket, ≥25. The mean age was 48.8. This shows that relatively young and energetic people were more involved in poultry farming. According to (Shakirat et al, 2015), age is generally believed to be an important factor in farming activities. As noted by (Iheke, 2010) and (Iheke & Nwaru, 2014), the risk bearing abilities and innovativeness of a farmer, his mental capacity to cope with the daily challenges and demands of farm production activities and his ability to do manual work decrease with advancing age. Result showed that the highest percentage (36.9%) had HND/BSc. while the lowest percentage (1.5%) had no formal education. This level of education is expected to positively affect their attitude towards the adoption of scientific techniques to improve their level of disease management on the farm as also reported by (Bamiro *et al.*, 2013). This finding is in agreement with (Ada Okugbowa & Egbodion, 2017) who asserted that education has a positive and significant influence on farmer efficiency in production. Education has been described as being pivotal to unlocking the entrepreneurial abilities of farmers and enhancing their ability to understand and evaluate new production techniques (Obasi, 1991; Iheke, 2010; Nwaru et al., 2011). This observation also concurred with those of (Iheke & Igbelina, 2016). Similar study by (Obayelu et al., 2017) opined that the majority of the poultry farmers in Nigeria are literates. The highest percentage (78.5%) were married, the lowest percentage (3.0%) were separated. This indicates that the majority of the poultry egg farmers were married. Thus suggesting a major motivation for engagement in poultry farming to cater for their families. The result also implies that majority of the farm households are stable. According to (Nwaru, 2004), this stability should create conducive environments for good citizenship training, development of personal integrity and entrepreneurship, which are very important for efficient use of resources. Furthermore, the table showed that the highest percentage (57.7%) fell within an average monthly income bracket of ≥₦100,000., the lowest percentage (0.80%) fell within an average monthly income bracket of ₦400,001 - ₦500,000. with a mean of 13488.00. Respondents with the highest percentage (80%) were ≥1000 number of birds, the lowest percentage (6.9%) were above 2001 with a mean of 745.32. This result agrees with Omalayo (2018) who stated that majority of poultry farmers have less than

500 birds in their farms and this may be attributed to high cost required to operate in large scale. The highest percentage (63.8%) spent ≥₦20,000. and the lowest percentage (1.5%) spent within the bracket of ₦60,001 - ₦80,000. with a mean of 26243.33. The highest percentage (31.5%) spent within the bracket of ₦10,001 - ₦20,000. and the lowest percentage (5.4%) spent within the bracket of ₦40,001 - ₦50,000. with a mean of 26117.33. The highest percentage (76.9%) of the respondents spent ≥₦100,000. and the lowest percentage (5.4%) spent within the bracket of ₦500,001 - ₦1,000,000. with a mean of 144471.33.

Table 1: Distribution of the Respondents Based on Socioeconomics Characteristics

Variables	Frequency	Percentage	Mean	Std.Dev.
Age				
25	1	0.8		
25-35	13	10.0	48.8	9.83
36-45	40	30.8		
46-55	40	30.8		
56 and above	36	27.6		
Highest Level of Education				
No Formal Education	2	1.5		
Primary	8	6.2		
Secondary	27	20.8		
ND/NCE	39	30		
HND/BS.c	48	36.9		
Postgraduate	6	4.6		
Marital Status				
Single	17	13.1		
Married	102	78.5		
Separated	4	3.0		
Widowed	7	5.4		
Household Size				
1-3	39	30		
4-6	70	53.8	6	
7-9	18	13.9		
10 and above	3	2.30		
Average Monthly Income				
>100,000	75	57.7		
100,001-200,000	40	30.8	134880.00	107953.689
200,001-300,000	10	7.7		
300,001-400,000	2	1.5		
400,001-500,000	1	0.8		
Above 500,001	2	1.5		
Number of Birds				
Less than or equal to 1000	104	80	745.32	798.397
1001 -2000	17	13.1		
Above 2001	9	6.9		
Cost of Labour				
Less than or equal to 20,000	83	63.8	26243.33	38334.659

20,001 -40,000	27	20.8		
40,001 – 60,000	10	7.7		
60.001 -80,000	2	1.5		
Above 80,001	8	6.2		
Cost of Vaccination				
Less than 10000	36	27.7		
10,001 – 20,000	41	31.5	26117.33	23791.262
20,001 -30,000	22	16.9		
30,001 – 40,000	15	11.5		
40,001 – 50,000	7	5.4		
Above 50,001	9	7		
Cost of Feed				
Less than 100,000	100	76.9	144471.33	282862.476
100,001 -500,000	23	17.7		
500,001- 1000000	7	5.4		
Above 1000001	-	-		

Sources: Field Data Survey,2023

Major risks faced by the respondents and the severity of risk situations

The distribution of respondents according to severity of risk situations is shown in Table 1, The result on types of risk faced by farmers in this study area is summarized with respect to their mean values and order of importance. Using a three-point Likert Scale as presented in the table2. A weighted mean value of (1.93) was used as a bench mark to rank variables which describes the major severe risk faced by the respondents. A mean score of (1.93) and above indicate a major severe risk faced by the farmers while a mean score of less than (1.93) indicate less severe risk faced by the farmers. However, the most severe risked was ranked (1^{st} - 5^{th}) and the least severe risk was ranked (29^{th} - 25^{th}). For the most severe risk; unavailability of credit facilities was ranked 1^{st} (first) with a mean value of (2.21), high interest rate was ranked 2^{nd} (second) with a mean value of (2.20), high cost of feed was ranked 3^{rd} (third) with a mean value of (2.12), high cost of improved breeds and high cost of vaccines were ranked 4^{th} (fourth) with a mean value of (2.1) while shortage of feeds was ranked 5^{th} (fifth) with a mean value of (2.08). For the least severe risk; fluctuations in weather was ranked 24^{th} (twenty-fourth) with a mean value of (1.43), accident was ranked 23^{rd} (twenty-third) with a mean value of (1.68), low output was ranked 22^{nd} (twenty-second) with a mean value of (1.6), ill health of farmers/workers was ranked 21^{st} (twenty-first) with a mean value of (1.72) while technological failure was ranked 20^{th} (twentieth) with a mean value of (1.77).

This is in agreement with (Akinbile, Akinpelu & Akwiwu, 2013), who stated that vaccination failure, scarcity of water and feeds are the three most important climate-related risks poultry farmers are faced with. The study of (Saddiq et al., 2016), identified outbreak of diseases as the highest source of risks in poultry businesses. The study of (Iheke & Igbelina, 2016) maintained that disease outbreak was among the most severe risk faced by poultry farmers. According to (Effiong et al., 2014; Salman et al., 2014), fluctuations of input and output prices were among the most popular risk sources faced by poultry farmers in Nigeria. Factor analysis shows that the three retained factors are production risk, financial risk and human risk. These risks if not well managed could adversely affect farmers' income which could lead to eventual closure of the farms. The results are in consonance with the submission of (Salman et al., 2014) who revealed that the poultry farmers in the country are faced mainly with production, financial and social risks.

Table 2: Distribution of respondents according to the major risk faced in the study areas.

Types of risk faced by farmers	Not Severe	Severe	Very Severe	Mean	Rank
Fluctuations in weather	76(58.5)	52(40.0)	2(1.5)	1.43	24th
Low output	48(36.9)	74(56.9)	8(6.2)	1.69	22nd
Technological failure	52(40.0)	56(43.1)	22(16.9)	1.77	20th
Poor parents stock	38(29.2)	63(48.5)	29(22.3)	1.93	14th
Low quality of feed	35(26.9)	63(48.5)	32(24.6)	1.98	11th
Theft	48(36.9)	55(42.3)	27(20.8)	1.84	18th
No brooding technical know-how for mass production of chicks	43(33.1)	59(45.4)	28(21.5)	1.88	15th
Inadequate information to upgrade production technique	39(30.0)	57(43.8)	34(26.2)	1.96	12th
Death of birds	31(23.8)	66(50.8)	33(25.4)	2.02	10th
Transportation problems	30(23.1)	64(49.2)	36(27.7)	2.05	7th
High cost of improved breeds	26(20.0)	65(50.0)	39(30.0)	2.10	4th
High cost of feed	30(23.1)	54(41.5)	46(35.4)	2.12	3rd
High cost of vaccines	25(19.2)	67(51.5)	38(29.2)	2.10	4th
Rotting of eggs at storage	56(43.1)	46(35.4)	28(21.5)	1.78	19th
Fluctuations in prices of output	30(23.1)	79(60.8)	21(16.2)	1.93	14th
Inadequate stock	37(28.5)	58(44.6)	35(26.9)	1.98	11th
High interest rate	22(16.9)	60(46.2)	48(36.9)	2.20	2nd
Unavailability of credit facilities	27(20.8)	49(37.7)	54(41.5)	2.21	1st
Unfavourable government policies	51(39.2)	46(35.4)	33(25.4)	1.86	17th
Erratic power supply	35(26.9)	67(51.5)	28(21.5)	1.95	13th
Shortage of feed	27(20.8)	66(50.8)	37(28.5)	2.08	5th
Shortage of water	30(23.1)	62(47.7)	38(29.2)	2.06	6th
Accumulation of dungs	34(26.2)	58(44.6)	38(29.2)	2.03	9th
Failed vaccines	35(26.9)	56(43.1)	39(30.0)	2.03	9t
Disease outbreak	37(28.5)	51(39.2)	42(32.3)	2.04	8th
Ill health of farmer/workers	58(44.6)	50(38.5)	22(16.9)	1.72	21st
Accident	58(44.6)	55(42.3)	17(13.1)	1.68	23nd
Poor personal management	42(32.3)	63(48.5)	25(19.2)	1.87	16th
Inefficiency of workers	43(33.1)	59(45.4)	28(21.5)	1.88	15th
Inadequate veterinary services	33(25.4)	69(53.1)	28(21.5)	1.96	12th

Source: Field survey, 2023. N = 130, n=30 weighted mean = 58.13/30= 1.93 no response, (x >1.93 = major risk faced, X< 1.93 = minor risk faced) Note: values in bracket represent percentage.

Risk Management Strategies Adopted by The Respondents in the Study areas

The distribution of respondents according to the most popular risk management strategies adopted by the respondents. is shown in Table 3. below The result is summarized with respect to their mean values and order of importance. Using a four-point Likert Scale as presented in table 3. A weighted mean value of (3.28) was used as a bench mark to rank variables which describes the most popular risk management strategies adopted by the respondents, A mean score of (3.28) and above indicates the most popular risk management strategies adopted by the respondents while a mean score of less than (3.28) indicates the least popular risk management strategies adopted by the respondents.

However, the most popular risk management strategies adopted was ranked (1st - 5th) and the least popular risk management strategies adopted was ranked (22nd - 18th). For the most popular risk management strategies adopted by the respondents; ensuring proper and timely vaccination was ranked 1st (first) with a mean value of (3.73), use of foot dips at the entrance and use of disease tolerant breed were ranked 2nd (second) with a mean value of (3.51), fencing and netting was ranked 3rd (third) with a mean value of (3.41), disinfecting the poultry house was ranked 4th (fourth) with a mean value of (3.42) while attending extension workshops was ranked 5th (fifth) with a mean value of (3.38). For the least popular risk management strategies adopted by the respondents; producing the feed myself was ranked 22nd (twenty- second) with a mean value of (2.91), provision of constant power was ranked 21st (twenty-first) with a mean value of (3.08), keeping extra cash at hand in case of emergency was ranked 20th (twentieth) with a mean value of (3.12), use of sawdust and buying input in advance was ranked 19th (nineteenth) with a mean value of (3.15) while taking a future market and control of rodent and pest were ranked 18th (eighteenth) with a mean value of (3.18).

The analysis revealed that ensuring proper and timely medication/vaccination, use of foot dips at the entrance, use of disease tolerant breed, fencing and netting, disinfecting the poultry house and attending extension workshops were the most popular risk management strategies adopted by the respondents. The least popular risk management strategies adopted by respondents were producing the feed, provision of constant power, keeping extra cash at hand in case of emergency, use of sawdust, taking future market and control of rodent and pest. This may not be unconnected with the high level of losses that farmers may experience in terms of mortality as a result of not giving the risks the attention required. Study by (Iheke&Igbelina, 2016) showed that poultry farmers rated the strategies very important.

Table 3: Distribution of Respondents According to Risk Management Strategies Adopted.

	Akwa Ibom State					
STATEMENT	**SD**	**D**	**A**	**SA**	**Mean**	**Rank**
Ensuring proper and timely vaccination	0	2(1.5)	31(23.8)	97(74.6)	3.73	1st
Use foot dips at the entrance	1(.8)	6(4.6)	49(37.7)	74(56.9)	3.51	2nd
Fencing and netting	2(1.5)	5(3.8)	53(40.8)	70(53.8)	3.47	3rd
Disinfecting the poultry house	4(3.1)	4(3.1)	55(42.3)	67(51.5)	3.42	4th
Diversifying into crop and other livestock activities	4(3.1)	22(16.9)	37(28.5)	67(51.5)	3.28	11th
Buying input in advance	6(4.6)	6(4.6)	80(61.5)	38(29.2)	3.15	19th
Appropriate nutrition in feed	4(3.1)	13(10.0)	53(40.8)	60(46.2)	3.30	9th
Producing the feed myself	14(10.8)	22(16.9)	56(43.1)	38(29.2)	2.91	22nd
Getting my feed from known source	6(4.6)	12(9.2)	53(40.8)	59(45.4)	3.27	12th
Getting water from safe and known source	4(3.1)	23(17.7)	34(26.2)	69(53.1)	3.29	10th
Keeping extra cash at hand in case of emergency	10(7.7)	13(10.0)	59(45.4)	48(36.9)	3.12	20th

Insuring my poultry birds	3(2.3)	19(14.6)	56(43.1)	52(40.0)	3.21	15th
Getting birds from safe and known source	5(3.8)	13(10.0)	56(43.1)	56(43.1)	3.25	13th
Use preventive medical treatment	5(3.8)	11(8.5)	55(42.3)	59(45.4)	3.29	10th
Quarantining of sick birds	6(4.6)	14(10.8)	42(32.3)	68(52.3)	3.32	8th
Off farm income	6(4.6)	15(11.5)	56(43.1)	53(40.8)	3.20	16th
No or controlled access to visitors	6(4.6)	12(9.2)	63(48.5)	49(37.7)	3.19	17th
Attending extension workshops	4(3.1)	14(10.8)	40(30.8)	72(55.4)	3.38	5th
Avoiding overcrowding of birds	3(2.3)	6(4.6)	62(47.7)	59(45.4)	3.36	7th
Separation of birds by age	1(.8)	17(13.1)	61(46.9)	51(39.2)	3.25	13th
Proper ventilation of poultry house	3(2.3)	10(7.7)	59(45.4)	58(44.6)	3.32	8th
Control of rodent and pest	4(3.1)	12(9.2)	70(53.8)	44(33.8)	3.18	18th
Use of sawdust	3(2.3)	21(16.2)	60(46.2)	46(35.4)	3.15	19th
Provision of constant power supply	9(6.9)	14(10.8)	65(50.0)	42(32.3)	3.08	21st
Taking future market	4(3.1)	17(13.1)	61(46.9)	48(36.9)	3.18	18th
Separation of birds by species	4(3.1)	13(10.0)	62(47.7)	51(39.2)	3.23	14th
Use of disease tolerant breed	2(1.5)	8(6.2)	42(32.3)	78(60.0)	3.51	2nd
Proper record keeping	2(1.5)	8(6.2)	60(46.2)	60(46.2)	3.37	6th
Proper collection of egg	2(1.5)	15(11.5)	58(44.6)	55(42.3)	3.28	11th
Proper storage of input and poultry products	5(3.8)	17(13.1)	54(41.5)	54(41.5)	3.21	15th

Source: Field survey, 2023. N = 130, n=30 weighted mean = 3.28 no response, (x >3.28 = major risk faced, X< 3.28= minor risk faced) Note: values in bracket represent percentage.

Multidimensional Risk Management Index:

Risk in agricultural enterprise come from different dimension. From the table below, each attribute contributes to the multidimensional risk management index. Each dimension for the study area was assessed, contribution of each dimension to the multidimensional risk management index shows that risk from biosecurity contributed about 55.9% to explained the overall degree of risk management practice in the study area as shown in Table 4, Medication strategies contributed 40.9% to explaining the overall degree of risk management practice while the contribution of mitigation was (3.2%). The finding of this study revealed that the relative contribution of disease biosecurity to poultry risk management is high relative to medication and insurance.

Table 4 Absolute and Relative contributions to Poultry Risk Management Index

Attributes	Absolute Contributions	Relative Contributions
Biosecurity		
Poultry farm's distance from public roads	0.4615	1.1220
Poultry farm's distance from the next poultry farm	0.4538	0.9024
Poultry farm's distance from a pond or lake	0.8154	0.5366
Poultry farm has a gate that restricts vehicle access	0.8077	1.1220
Poultry farm is surrounded by a fence	0.7769	0.3415
Disinfection of vehicles that come to the poultry farm	0.9538	0.7073
Rodent control plan	0.7538	0.4634
Keeping grass and weeds trimmed around the poultry house	0.7538	0.6829
Regular checking and repair of wire screening on the sides of the house	0.6462	0.0000
Control of other livestock within 50 metres of the poultry houses	0.8000	0.0000
Recent total cleanout of facility	0.6154	0.5366
Time interval of litter removal	0.5615	0.8537
Litter that is removed is stored in a covered shed	0.7769	0.5122
Composting litter in an approved and properly managed composting facility	0.8231	0.8780
Litter is not spread on fields adjacent to the poultry houses	0.8000	0.6341
The feed bin, boot, and auger are regularly cleaned and disinfected	0.7692	0.9024
Wearing street clothes or shoes in the poultry houses	0.9154	0.8780
Separate cap and pair of coveralls for each house	1.0000	0.6829
Separate pair of boots for each poultry house	0.7077	1.1220
Disinfectant dip pans at every poultry house entrance	0.6923	0.5366
The time interval of changing the disinfectant	0.6538	0.5854
All visitors who enter poultry houses must wear clean, sanitized caps, coveralls, and gloves.	0.5692	0.6585
The time taken to learn more about poultry diseases	0.7385	1.0000
Multiple age groups of birds on the farm	0.7308	0.7073
Specific employees caring for different age group	0.7077	0.5366
Total		**16.9024(55.9)**
Medication		
Birds are only vaccinated for agents known to have caused problems on the farm in the past	0.4538	0.3902
Vaccination of day-old chicks is done at the hatchery	0.8154	0.4146
Application of Immucox vaccine at 1-5 days	0.8077	0.7561
Application of Marek vaccine at 1 day old	0.7769	1.0000
Newcastle Disease Vaccine 1/0 at one-day-old chicks:	0.9538	0.9756
Vaccination of 1st Gumboro vaccine at 8-10 days old and 2nd vaccination a week after	0.7538	0.5854
Application of Newcastle Disease Vaccine Lasota at 2nd week and 5th week	0.7538	0.9024
Vaccination against Fowl Pox at 8 weeks	0.6462	1.1220
Application of Newcastle Disease Vaccine Komorov at 12th week	0.8000	1.1220
Routine Newcastle Disease Vaccine Lasota every month	0.6154	1.1220
Time interval of routine deworming	0.5615	0.5610
Time interval of routine application of antibiotics	0.7769	0.8780
Weeks at which delousing is done	0.8231	0.9268
Frequency of contact with a veterinary doctor	0.8000	0.6341

Regular examination of sick or dead birds	0.7692	0.9756
Total		**12.3659(40.9)**
Mitigation Use of livestock insurance	0.9154	0.9756
		0.9756(3.2)
Grand Score		**30.2439(100)**

Sources: Field Survey, 2023

Conclusion

From the result, it was observed that in poultry industry, the study area, relatively young and energetic people were more involved in poultry farming, and were mostly educated. It could be concluded that most farmers were faced by various sources of risk and young male individuals who are married owned poultry production enterprises. The most severe farming risk associated in poultry production in the area were unavailability of credit facilities, high interest rate, high cost of feed and high cost of improved breeds. Majority of the farmers employed ensuring proper and timely vaccination, use of foot dips at the entrance, use of disease tolerant breed, fencing and netting, disinfecting the poultry house and attending extension workshops as their major risk management strategies. The relative contribution of disease biosecurity to poultry risk management is high relative to medication and insurance. Therefore, efforts should be made by providing more credit facilities and reducing interest rate and training of farmers on feed formulation. In conclusion, more farmers should be encouraged to diversify into crops and other livestock related activities and purchase insurance as measures to help them manage risk in their poultry production enterprises

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Ecological Assessment of Soil Nutrient Properties of Two Ramsar Sites in Niger Delta, Nigeria

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Abstract

This study evaluates the soil nutrient concentration in two Ramsar sites, Oguta Lake and Upper Orashi Forest, located in the Niger Delta region of Nigeria. Soil samples were collected from two sampling points in each wetland at a depth of 0 – 15 cm and analyzed for total nitrogen, phosphorus, potassium, calcium, sodium, and magnesium. The results revealed significant variations in soil nutrient concentrations between the two sites. While total nitrogen concentrations did not differ significantly, Oguta Lake showed higher available phosphorus levels (21.17 mg/kg) compared to Upper Orashi Forest (8.88 mg/kg). Upper Orashi Forest had higher potassium concentrations (48.98 mg/kg) than Oguta Lake (13.21 mg/kg). Calcium concentrations were lower in Oguta Lake than in Upper Orashi Forest, showing a significant difference ($p < 0.05$). Similarly, magnesium concentrations were higher in Upper Orashi Forest (103.80 mg/kg) than in Oguta Lake (25.63 mg/kg). Sodium concentrations showed a significant difference ($p < 0.05$), with values of 13.21 mg/kg in Oguta Lake and 48.98 mg/kg in Upper Orashi Forest. The findings highlight the importance of managing soil nutrient dynamics in wetland ecosystems. Nitrogen limitations and inadequate phosphorus levels were identified. Effective soil management strategies are necessary to address these deficiencies and manage excessive nutrient levels, such as calcium and magnesium, for sustainable wetland ecosystems. The results provide valuable insights for targeted interventions and the development of specific nutrient management approaches tailored to the unique characteristics of Ramsar sites in the Niger Delta. Further research is needed to support optimal plant growth, enhance ecosystem functioning, and preserve the ecological integrity of these wetland areas.

Keywords: Ramsar, Nutrients, Ecosystem Management.

Introduction

The Niger Delta region in Nigeria is renowned for its diverse and ecologically valuable wetland ecosystems, which play a crucial role in maintaining ecological balance and supporting the livelihoods of local communities (Igu, 2016). Within this region, three wetlands, Apoi Creek, Oguta Lake, and Orashi Wetlands, were designated as Ramsar sites due to their unique features such as their soil and water properties (Nwankwoala, 2012) These wetlands serve as habitats for many plant and animal species, both aquatic and terrestrial, making them ecologically important for the socio-economic well-being of the local communities around them (Igu, 2016).

However, the huge oil and gas reserves of the Niger Delta have led to intensive industrial activities, raising concerns about the environmental impacts on the delicate ecosystem of its Ramsar sites. Oil spills, gas flaring, and other forms of pollution associated with oil exploration and extraction have been recognized as major threats to the ecological health of the Niger Delta wetlands (Ani *et al.*, 2015). These activities introduce pollutants into the soil and water, leading to ecosystem degradation, loss of biodiversity and destruction of ecosystem services (Ite & Ibok, 2013).

Soil macro elements are important for primary ecological process of production in wetland ecosystems. Nutrients are essential for plant growth and play a role in shaping species composition, population and dominance in aquatic ecosystems. Nitrogen, for instance, is a very important nutrient for plants in wetland ecosystems. It is a component of amino acids, proteins and chlorophyll, therefore its availability influences plant growth, productivity, and species composition (Bodelier et al., 2013). High nitrogen levels in wetlands promote the growth of species, leading to changes in vegetation structure and reduced biodiversity (Stevens et al., 2011). However, low nitrogen availability limit plant growth and nutrient cycling processes, affecting the overall functioning of wetland ecosystems (Vymazal, 2011).

Phosphorus is another important nutrient for wetland ecosystems. It plays necessary in cell division and DNA synthesis. Phosphorus availability influences plant growth, primary productivity, and nutrient-cycling processes in wetlands (Tang et al., 2020). Excessive phosphorus inputs from anthropogenic sources, such as agricultural runoff and wastewater discharge lead to eutrophication, algal blooms, oxygen depletion, and degradation of wetland habitats (Carpenter et al., 1998). Conversely, phosphorus deficiency limit plant growth and productivity which affect the overall ecological balance of wetland ecosystems (Tang et al., 2020). Potassium is essential for maintaining plant osmotic balance, enzyme activation, and photosynthesis. It is involved in various physiological and biochemical processes in plants (Sharma et al., 2013). Adequate potassium availability in wetland soils promotes plant growth, nutrient uptake, and stress tolerance (Pramanik et al., 2013). However, excessive potassium levels can disrupt nutrient balances and affect the availability of other essential elements, which could lead to ecological imbalances in wetland ecosystems (Khan et al., 2017). Other nutrients such as calcium, magnesium, iron and manganese also play critical roles in wetland ecosystems. These nutrients are involved in enzymatic reactions, chlorophyll synthesis and other metabolic processes.

To effectively manage and conserve biodiversity in these (Ramsar) sites, it is important to assess the soil nutrient status at the sites in order to gain insights into the health and productivity of the ecosystem, hence the thrust of this study. It is expected that results obtained from this study will provide basic knowledge of the nutrient status of these sites for monitoring.

Materials and Method

Site description

This study was carried out at two wetland sites in Niger Delta, Nigeria, namely: Oguta Lake in Imo State and Upper Orashi Forest in Rivers State. These wetlands are internationally recognized for their significance. Oguta Lake is located in Oguta Local Government Area. It is the largest natural lake in the state while the Upper Orashi Forest in Ahoada West Local Government Area in Rivers State is a freshwater swamp forest. Both areas experience ecosystem interference through different human activities through boat driving and transportation of humans and goods, bunkering of crude oil and its derivatives, forest destruction through farming activities, fishing, and unsustainable oil palm fruit harvest for oil palm oil production by the local people from its surrounding human communities.

The assessment was carried out using four sampling stations: two at Oguta Lake and two at Upper Orashi Forest. These stations were geographically located at Longitude 6º47’28.2ºE and Latitude 5º42’25.36ºN; Longitude 6º50’38.24^{0}E and Latitude 5º44’32.86^{0}N; Longitude 6º45´36.76^{0}E and Latitude 5º45’58.57^{0}E; Longitude 6º53´67.52^{0}E and Latitude 5º43’82.24^{0}E.

Soil Sample Collection and Analysis

Soil samples were collected using soil auger at soil depth of 0 - 15 cm. The samples were carefully placed in foil bags designed for sampling to maintain their integrity and prevent

contamination. Each of the foil sample bags was labeled with relevant information at the point of sample collection. Samples collected were taken to the Institute of Pollution Studies (IPS) laboratory, Rivers State University, Port Harcourt, Nigeria for determination of total nitrogen using Macrokjeldahl method as described by Bremmer and Mulvaney (1982). Phosphorus content was determined using the modified Bray No. 1 method according to Olsen et al. (1982). Potassium, calcium, sodium, and magnesium contents were analyzed using GBC XplorAA Atomic Absorption Spectrophotometer (made in Australia) after extraction with ammonium acetate as described by Zhang et al. (2012).
Results obtained were subjected to statistical evaluation of mean, Standard error mean (SEM) and t-test. The results were also compared with an international standard (FAO).

Results

Figure 1 shows that the total nitrogen contents of the two sites were low with no significant difference between them. It was also below the permissible limit.

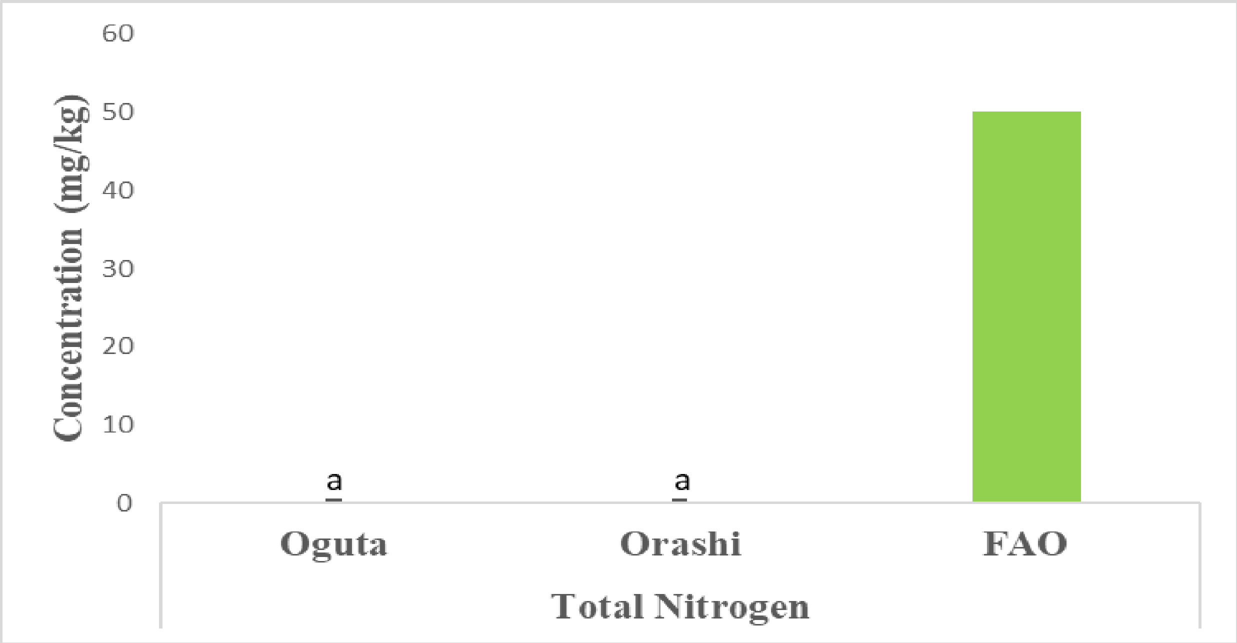

Figure 1: Values are means ± Standard Error Mean (SEM). Values with different superscripts are statistically different at ($P < 0.05$). Superscript (a,b) compares Orashi to Oguta across the row.

Available phosphorus of Oguta soil was significantly ($p=0.05$) higher than that of Orashi but the two stations were below the permissible limit by FAO (Figure 2).

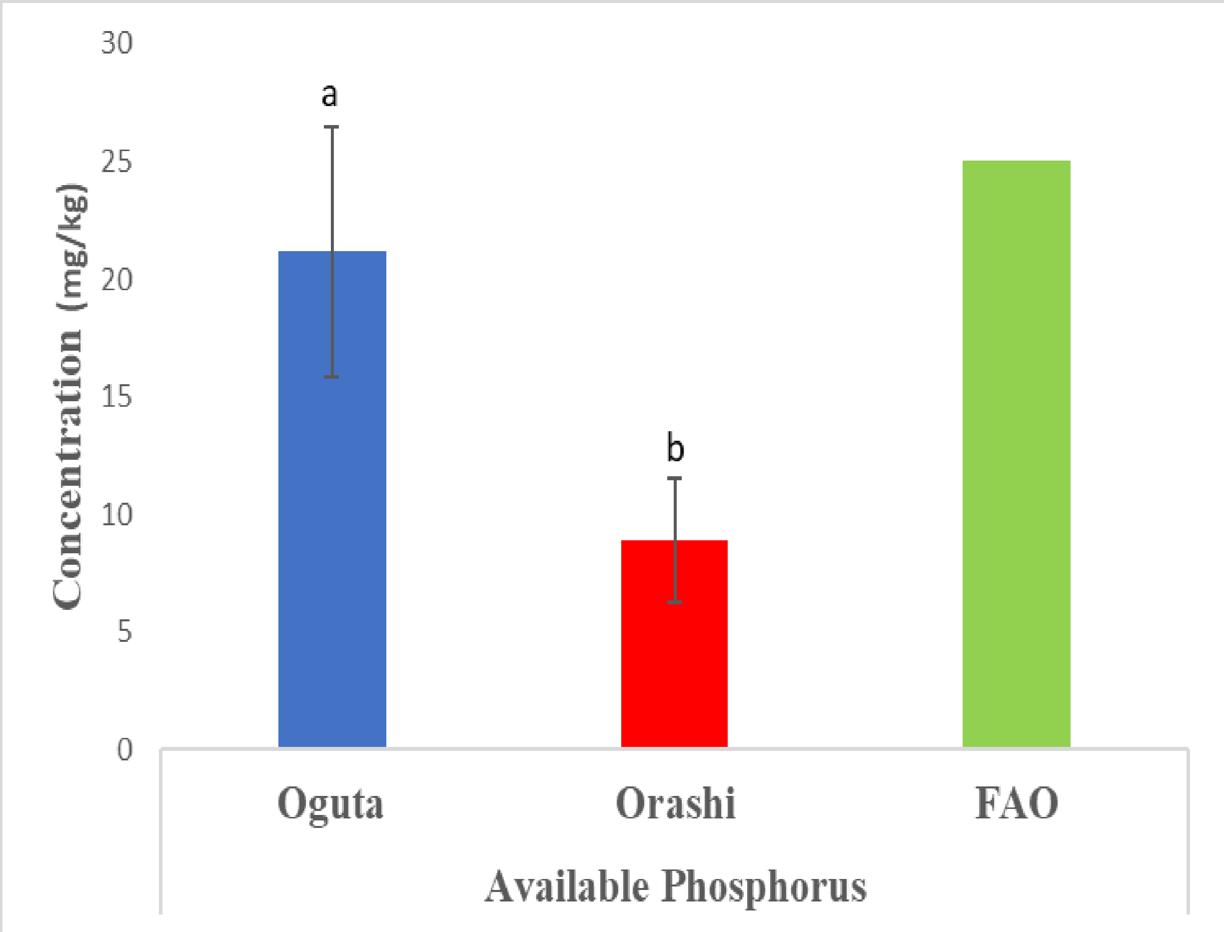

Figure 2: Values are means ± Standard Error Mean (SEM). Values with different superscripts are statistically different at ($P < 0.05$). Superscript (a,b) compares Orashi to Oguta across the row.

The potassium concentration at Orashi site was significantly higher than that of Oguta. The result also shows that the potaasium level at the Orashi wetland was above the permissible limit while that of Oguta was below the permissible limit by FAO (Figure 3).

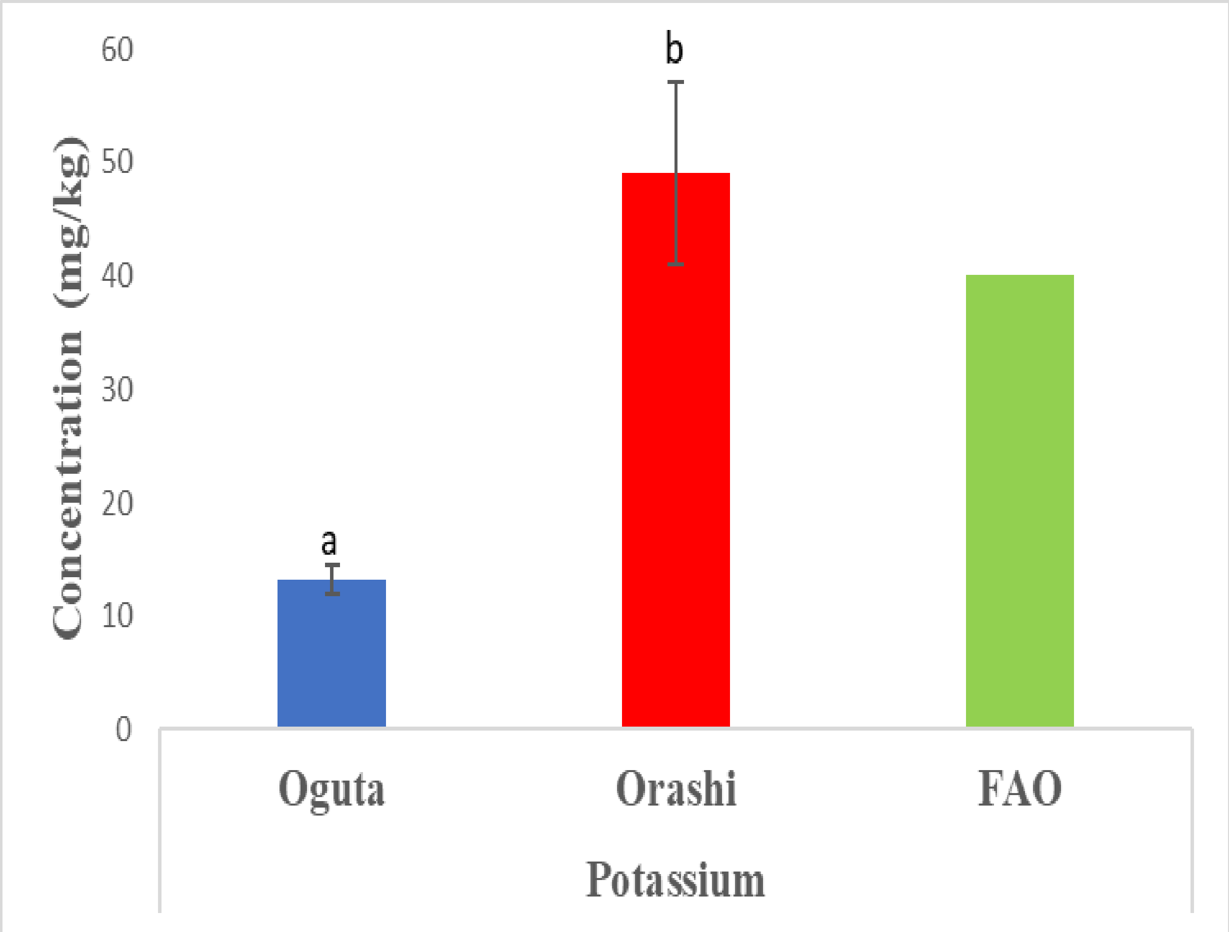

Figure 3: Values are means ± Standard Error Mean (SEM). Values with different superscripts are statistically different at ($P < 0.05$). Superscript (a,b) compares Orashi to Oguta across the row.

The soil reveals that the concentrations of calcium at the two sites were far above the permissible limit. Also, there was a significant difference between the two sites in which Orashi recorded a higher soil calcium content than Oguta (Figure 4).

Similar result was observed for Magnesium (Figure 5) and sodium (Figure 6) in which Orashi location recorded higher value than Oguta but were both below the permissible limit.

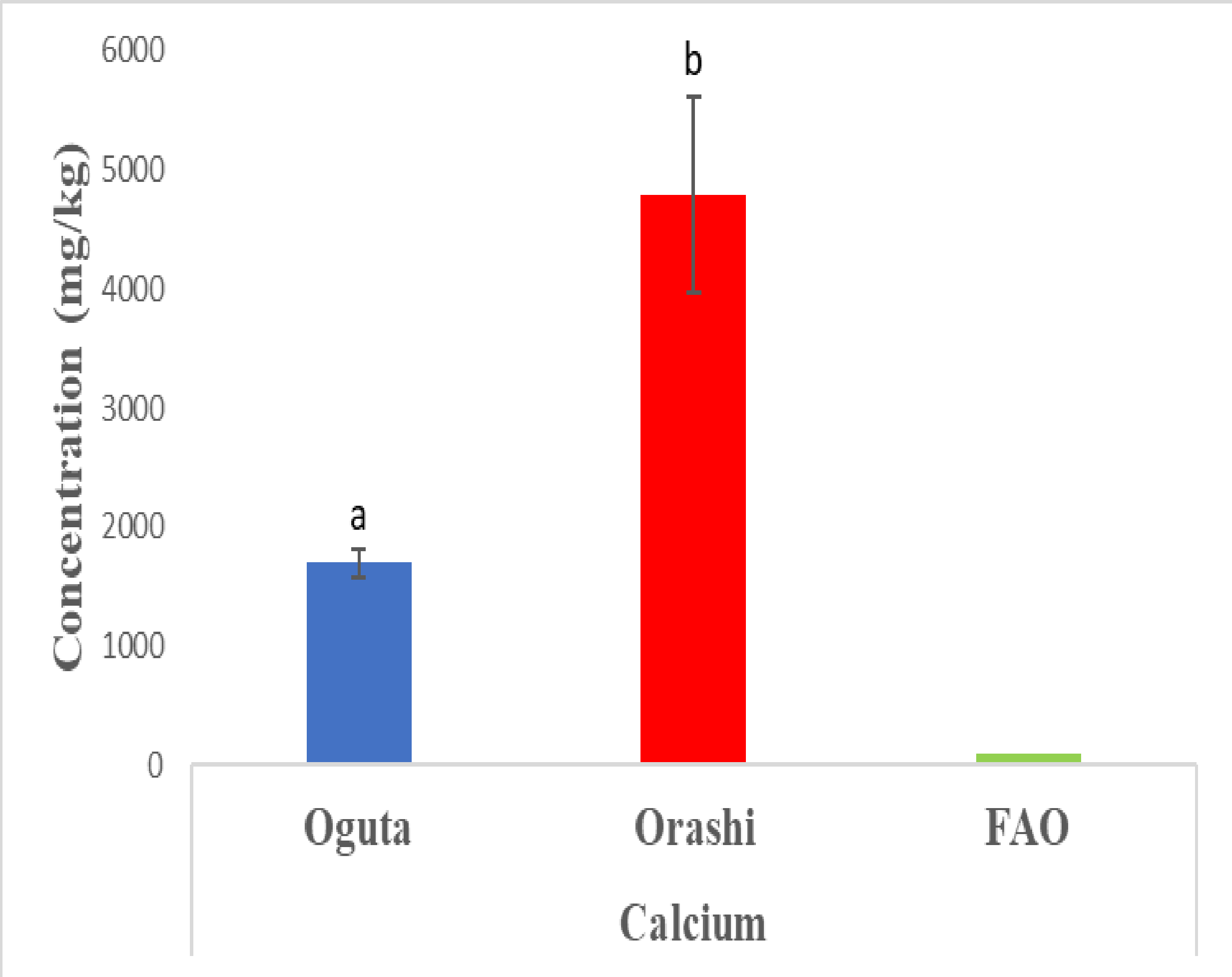

Figure 4: Values are means ± Standard Error Mean (SEM). Values with different superscripts are statistically different at ($P < 0.05$). Superscript (a,b) compares Orashi to Oguta across the row.

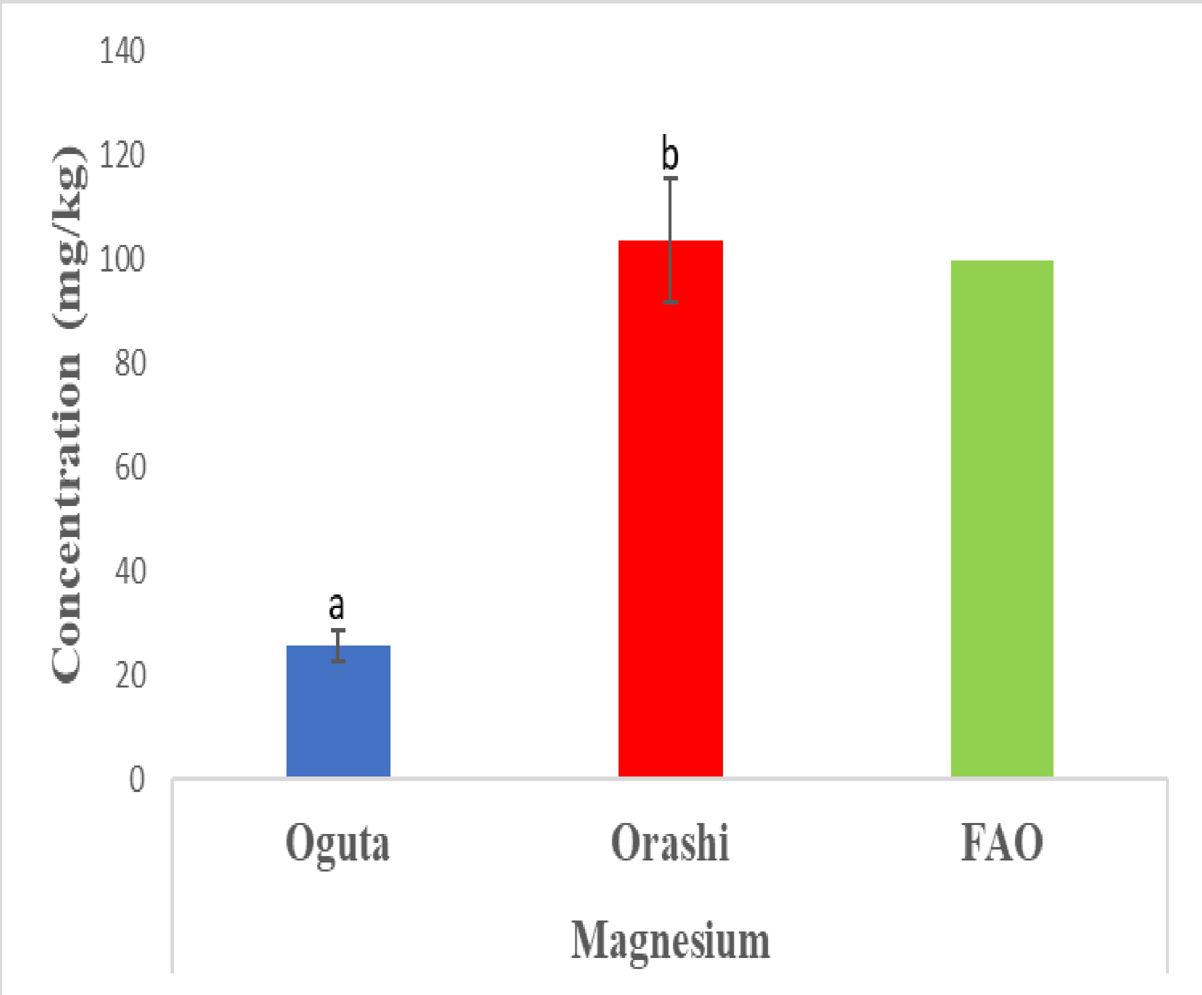

Figure 5: Values are means ± Standard Error Mean (SEM). Values with different superscripts are statistically different at ($P < 0.05$). Superscript (a,b) compares Orashi to Oguta across the row.

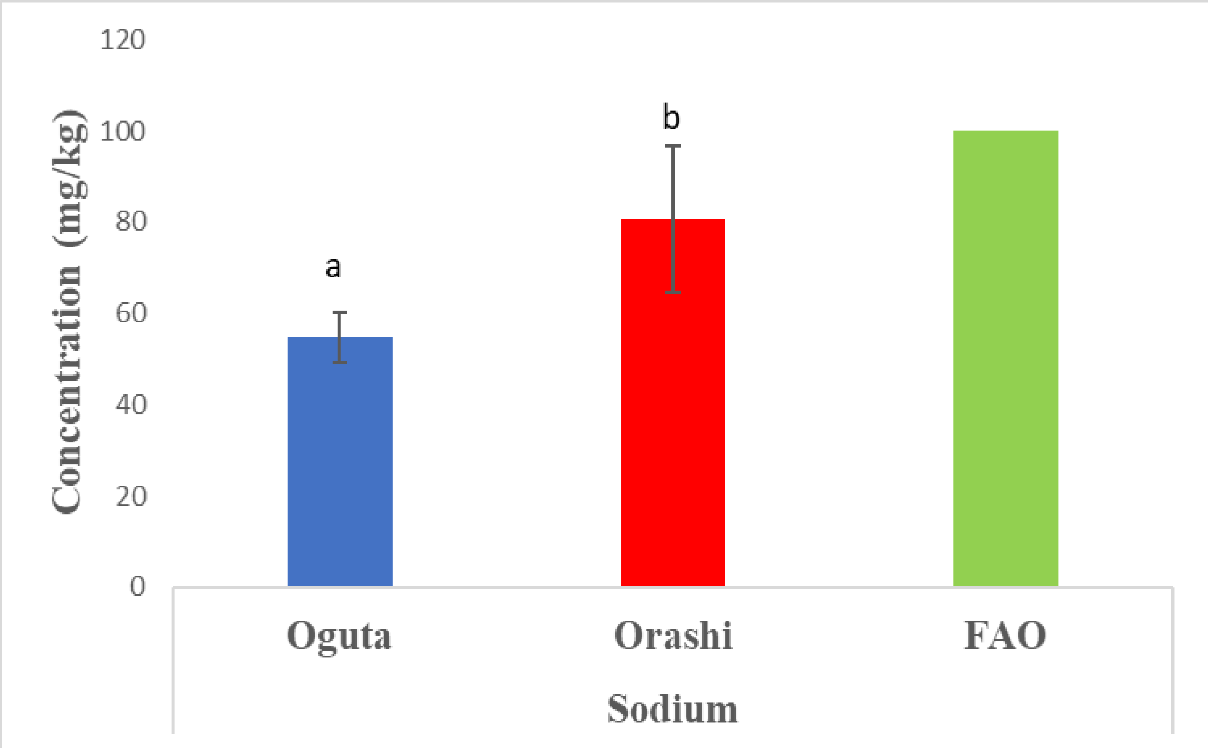

Figure 6: Values are means ± Standard Error Mean (SEM). Values with different superscripts are statistically different at ($P < 0.05$). Superscript (a,b) compares Orashi to Oguta across the row.

Discussion

Gambrell, (1994).) provide an explanation for the disparity in nutrient composition between wetland and upland soils, attributing it to their distinct hydrological and ecological characteristics. The concentration of nutrients within an ecosystem plays a crucial role in the growth and development of plants. Notably, the soil samples collected from the two Ramsar study sites exhibited significant variations in all the analyzed parameters, except nitrogen. This research reveals that nitrogen concentration was particularly low compared to other soil nutrients under investigation. In support of this finding, Du et al. (2020) reported that nitrogen is a highly limited nutrient for plant growth and productivity in soils. This limitation arises due to the high demand for nitrogen by crops and the potential for losses through leaching, runoff, and volatilization. Available phosphorus in the two study sites was found to be lower than the recommended value of 25 - 50 mg/kg, as suggested by Pe et al. (2009) for healthy soil. Sharma et al. (2013) conducted a study showing that available phosphorus has a positive effect on crop yield and quality. Having sufficient phosphorus levels in the soil is associated with benefits such as better root development, stronger seedling growth, improved flowering and fruiting, and higher crop yields. Conversely, inadequate phosphorus availability can result in stunted plant growth, decreased crop productivity, and inefficient nutrient utilization, which were some of the observations made at the study site.

Sufficient potassium levels in the soil facilitate the process of photosynthesis, leading to higher crop yields and enhanced crop quality. Moreover, potassium has a beneficial impact on the utilization of other crucial nutrients like nitrogen and phosphorus, as it aids in their absorption and movement within plants. Additionally, it plays a crucial role in fortifying the structure of cell walls (Mahmud et al., 2021). In the case of Oguta soil, the potassium concentration was found to be lower than the minimum recommended limit of 40 – 80 mg/kg. However, the Orashi value exceeded the acceptable range.

Soil calcium concentrations of Oguta and Orashi exceeded the recommended limit of 100 mg/kg for agricultural practices (FAO, 2014a). The high level of calcium recorded at these study sites are likely the result of human-induced deposition of terrestrial materials into the soil. The presence of a high concentration of calcium in the soil can have various detrimental effects on both plant growth and soil health, as noted by Gupta et al. (2018). Excessive calcium levels can induce soil alkalinity, leading to a rise in pH levels beyond the optimal range for most plants, as reported by Hinsinger et al. (2018). This increased pH can hinder nutrient availability by reducing the solubility of vital elements such as iron, manganese, and phosphorus, as highlighted by Kumar et al. (2019). Consequently, plants may encounter deficiencies in these nutrients, resulting in stunted growth and diminished yields.

Magnesium values at Oguta were within the limit of 100mg/kg recommended by FAO standards, while the concentration in Orashi exceeded the acceptable limit. Magnesium plays a crucial role in maintaining the health and functioning of wetland soil. In a study conducted by Ren et al. (2022), it was discovered that magnesium contributes to the formation of stable soil aggregates, which helps prevent soil erosion and preserve wetland integrity. Additionally, Miransari, (2011) emphasized the significance of magnesium in enhancing nutrient availability and promoting plant growth in wetland soils based on their research findings. However, it has been shown that high concentrations of magnesium in the soil can result in reduced seed germination, stunted plant growth, and decreased nutrient uptake in certain plant species (Singha and Singh, 2019). As compared to Ca^{2+}, Na^{+} concentration at Oguta and Orashi was within the acceptable limit of 100mg/kg. Leaching, adsorption, and plant uptake processes can result in a low concentration of sodium in wetland soils.

Conclusion

The variations in soil nutrient concentrations between the two Ramsar sites highlight the importance of understanding and managing soil nutrients in wetland ecosystems. Addressing nutrient limitations, such as nitrogen and phosphorus deficiencies, and managing excessive levels of calcium and magnesium are essential for sustaining healthy wetland soils and supporting optimal plant growth and productivity. Further studies and targeted interventions are required to develop appropriate soil management strategies for these unique ecosystems, considering the specific nutrient dynamics and ecological characteristics of Ramsar sites in the Niger Delta.

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Trace metal concentrations and public health in Ishiagu area of the Lower Benue Trough, Nigeria.

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ABSTRACT

Trace metal concentrations and their effects on public health in Ishiagu area of the Lower Benue Trough Nigeria were studied. Thirty eight (38) samples obtained from various communities comprising rocks (10), soils (10), water (8), vegetables-cucumber (5) and scavenger chicken (5) were analysed using XRF spectrometer to determine the presence and concentrations of the trace metals (Pb, Cr, Ni, Zn, Co, Cu, Cd, As, V, Sb, B, Mo and Se) in the various samples. Results showed low to high concentrations of Pb, Zn, Cd, V, Co, Ni, Se, Cu and As. The concentration ranges for different trace metals across the sampled media (rocks, soils, surface water, edible vegetables and chicken offal) are Pb (-0.003 to 210ppm); Zn (0.067 to 3140 ppm); Cd (0.002 to 320ppm); V (-0.056 to 820ppm); Co (0.021 to 30ppm); Ni (0.039 to 180ppm); Se (0.00 to 320ppm); Cu (0.021 to 460ppm); Sb (0.00 to 140ppm) and As (0.00 to 60ppm). Contamination Factor (CF) index used for evaluation showed that Pb, Zn, Cd, V, Co, Ni, Se, Cu and As are the major pollutants of the study area. The results showed Ishiagu is excessively polluted with As in water, Cd in soils, Pb, Cd, V, and Sb in vegetables and in chicken offal Zn, Se, Cu, Cd, Pb. There are health implications of inhaling and ingesting Ni, Se, As, Cd, As, Sb, Zn, Pb, and V in excessive quantities. The residents of Ishiagu are prone to kidney and cardiovascular diseases, fatigue, chills, decaying teeth, abdominal pain, rapid heart rate, miscarriage, and premature birth. The high concentrations of essential and toxic trace metals As, Pb, Cu, Cd, Sb in the source rocks or other materials portend great danger to public health in the area. These pollution types which can lead to adverse effects on the health of the people in the study area require medical intervention and control to protect the inhabitants.

Key words: Trace metals, Public health. Lower Benue

INTRODUCTION

Trace metals are chemical elements with very low concentration expressed in parts per million. Some biometals are trace metals and are found in small but measurable amounts in animal and plant cells and tissues, due to their relevance in making up their nutrition and physiology (Bender *et al.*, 2009). The study area (Ishiagu) is characterized by igneous intrusions comprising mainly minor intrusions. These igneous rocks and other environmental materials (soils from weathered rocks, and plants) contain small amounts of several trace metals.

Ingestion of trace metals and exposure to excessive quantities can be toxic to the environment and public health (Ogbonna *et al.*, 2015). Trace metal toxicity in the environment does not only depend on its level but also, where it is found in the environment (water, plant, air, soil), the source (mining activity or natural rock weathering), how acidic the environment is (acidic areas have more problems with trace metals), and if the metal exists independently or constitute a part of larger chemical compounds (Gamberg *et al.*, 2005). Excess trace metals present in the soil result in reduced soil microbial population thereby reducing the rate of biodegradation of organic matter, and reduces soil fertility of the area (Singh *et al.*, 2012).

Vegetables are an essential part of the human diet with well-known nourishment to keep in place normal physiological functions of the body (Ogwulumba *et al.,* 2010). It has been widely known that trace metals taken up by plants are the major source of accumulation in food and the main path through which it gets into human body by the consumption of the vegetables (Nganje *et al*, 2013). According to Zafar *et al*., (2016) Pd, Cd, As, Fe, Zn are concentrated in the offal of animals. Trace metal deficiencies play a role in the reduction of antioxidant potentials in organisms, high rate of aging, developmental retardation in children and increase in pregnancy abnormalities.

The dissolution of metals from bedrock is continuous and the acidity level of water determines the solubility of many metals. Chemically weathered fine-grained organic and metal-rich sediments with pH=7 results in dissolution of minerals, leading to the release of metals from its surface into water. Scavenger animals feed from their environment and accumulate high concentrations of trace metals in their offal. The concentration of metals in the environment resulted from the parent materials that formed soil.

GEOLOGIC SETTING

The study area Ishiagu in the Lower Benue Trough (Fig. 1) which lies within the Asu River Group is underlain by the Abakaliki Formation and the Ezeaku Formation (Ezepue, 1984). The Ezeaku Sandstone Formation dated Turonian unconformably overlies the Abakaliki Formation (McConnel, 1949). Field expressions show that the pyroclastics erupted parallel to the axial plane of the Abakiliki anticlinorium in the NE-SW direction and are spatially associated with shales of the Asu River Group and Nkporo Shale (Ukaegbu, 2008). Ishiagu lies on latitude 5º 56’ 33” N, and longitude 7º 34’0”E (Ogbonna *et al.,* 2015), and topographically, Ishiagu has an undulating terrain (Mc Connel, 1949). The igneous rocks in the study area mostly occur as dykes and sills of dolerite within the Abakaliki Formation (Chukwu, 1981). The magmas that form igneous intrusive are from partial melting of existing rocks in either the Earth’s crust or mantle.

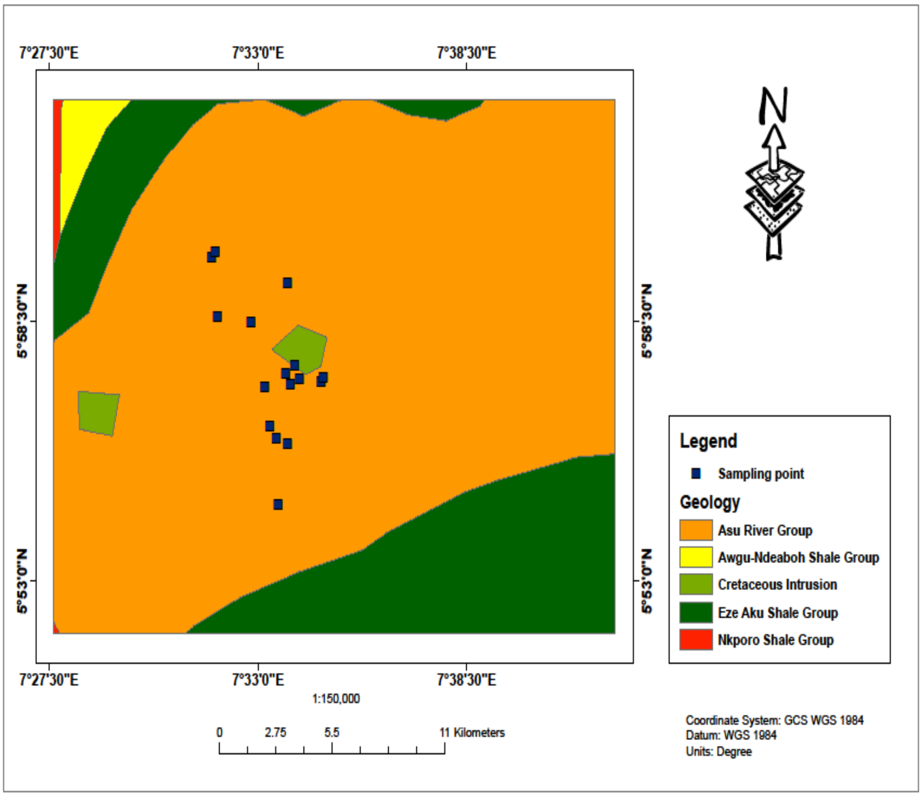

Figure 1: Geologic map of study area

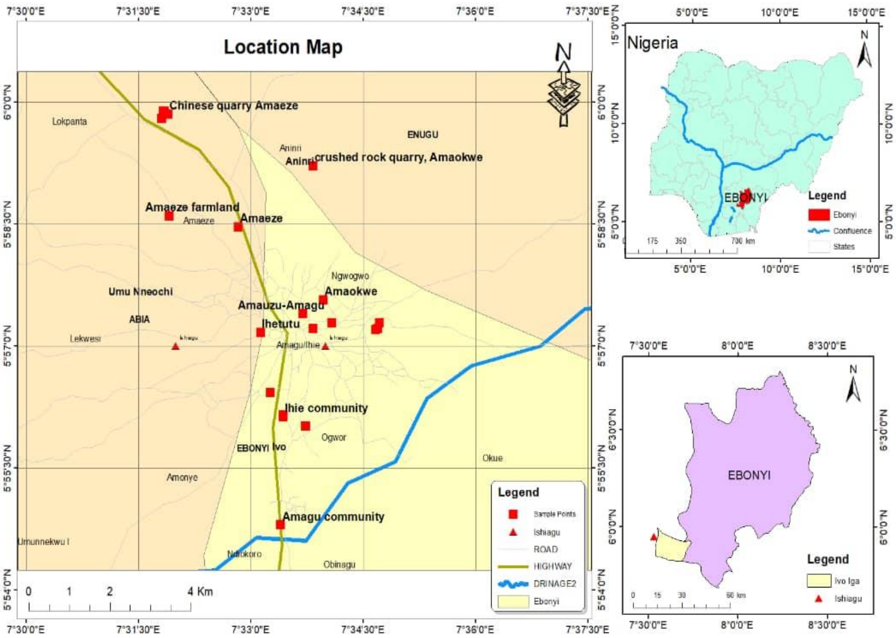

Figure 2: Location map of study area showing sample point.

Ishiagu is of the Asu River group with two mappable formations of shale, sandstones, and the Asu River Shales that were intruded by igneous rocks (Fig. 2). According to Ezepue (1984), there are mappable features running from northwest to southwest in the area which run transversely to the fold axis and described as a set of fractures running and may have been caused by the same tectonic activity that folded the rocks. The Asu River shales are enriched in trace metals, which are components of existing rocks. Some of these trace metals may have been absorbed from the ancient depositional environment (Obiora and Umeji, 1995).

METHOD OF STUDY

All rock samples were collected from different sites and prepared using Concrete Compression Testing (CCT) machine 2000KN. Soil samples were collected at a shallow depth of 0.15m and bagged. After pulverization of the rock and soil samples, they were passed through the sieve shakers of different diameters. The dust retained from the least diameter of 0.09mm mesh size was packaged at 20g weight for the geochemical analysis. The vegetable samples (cucumber) were properly washed with distilled water and oven dried to make it flaky for easy pounding with the porcelain mortar and pestle. Each vegetable sample powder was packaged at 2g weight. The local scavenger chicken offal (liver, kidney, intestines) and bones are the parts needed for the geochemical analysis (Hashemi, 2018). The powdered form obtained from the crushing with porcelain mortar and pestle was well packaged at 2grams weight per sample for the analysis. Water samples were collected from mining sites and ponds within Ishiagu town in one litre bottle each and stored at room temperature. The bottles were properly rinsed with the sample water before filling up. One litre quantity of water is recommended for the analysis of trace metals. The samples (rocks, soils, vegetable and chicken offal) evaluation were carried out at the Bayero University Kano laboratory, using XRF spectrometer, while the water samples were analysed using the Agilient MP Expert.

RESULTS

Ten rock samples, ten soil samples, eight water samples, five edible vegetable samples, and five chicken (offal and bones) samples, were evaluated to determine the trace metals that exceeded the permissible limits, thereby making them toxic. Table 1.1 to 1.5 are the results of Pb, Cr, Ni, Zn, Co, Cu, Cd, As, V, Sb, Ba, Mo and Se for analyzed rocks, soils, water, vegetables and chicken offal samples.

The magmas that form igneous intrusive are from partial melting of existing rocks either in earth’s crust or mantle.

Plate 1: Igneous intrusion at Chinese quarry Amaeze, Ishiagu.

	Rck 1 Amaeze quarry 1 (ppm)	Rck 2 Amaeze quarry 2 (ppm)	Rck 3 Amaeze quarry3(ppm)	Rck 4 Amaeze farm 1 (ppm)	Rck 5 Amaeze farm 2 (ppm)	Rck 6 Amaokwe 1 (ppm)	Rck 7Amaokwe 2 (ppm)	Rck 8 Ama okwe 3 (ppm)	Rck 9 Amagu (ppm)	Rck 10 Ihie (ppm)	Min	Max	Mean	WHO (mg/kg)
Nickel	100	100	0	200	200	0	200	100	0	100	100	200	110	105
Zinc	400	300	300	300	300	400	300	400	300	400	300	400	340	111.4
Copper	100	100	100	200	200	100	200	100	100	100	100	200	130	35.7
Cobalt	0	0	0	0	0	0	300	0	0	0	0	300	30	53.3
Lead	0	0	0	0	0	0	100	0	0	0	0	100	10	-
Cadmium	100	0	100	100	100	100	100	100	100	100	0	100	90	-
Arsenic	100	0	0	0	0	0	100	0	0		0	100	20	2
Vana	0	0	0	0	0	0	0	0			0	100	10	

Trace Metals	Soil 1 Amaeze quarry 1	Soil 2 Amaeze quarry 2	Soil 3 Amaeze quarry 3	Soil 4 Amaeze farm 1	Soil 5 Amaeze farm 2	Soil 6 Amaokwe 1	Soil 7 Amaokwe 2	Soil 8 Amaokwe 3	Soil 9 Amagu	Soil 10 Ihie	Min	Max	Mean	DPR 1991 (mg/kg)
									0	100				-
dium														
Selinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05
Chromium	0	0	100	0	300	0	0	0	0	0	100	300	40	-
Molybdenum	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5
Antimony	0	0	0	0	0	NIL	0	0	0	0	0	0	0	-
Barium	0	0	0	0	0	0	0	0	200	200	0	200	40	500

Table 1.1: Rock samples XRF analysis results

Nickel	200	200	200	0	100	100	300	100	100	100	100	300	140	35
Zinc	300	300	300	100	200	400	400	900	200	200	100	900	330	50
Copper	100	100	100	100	100	100	200	0	100	NIL	100	200	90	36
Cobalt	0	0	0	100	0	0	0	0	100	0	0	100	20	10.5
Lead	0	0	100	0	100	0	0	1700	100	100	100	1700	210	85
Cadmium	100	100	100	100	100	100	100	100	100	100	100	100	100	0.8
Arsenic	0	100	0	0	0	0	0	0	0	0	0	100	10	0.15
Vanadium	0	300	0	0	0	0	300	0	0	0	0	300	60	0.5
Selinium	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Chromium	0	0	200	0	300	0	0	0	100	0	100	300	60	100
Molybdenum	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Antimony	100	0	0	0	0	0	0	100	100	100	0	100	40	-
Bariu	300	300	100	0	0	0	1000	0	0	0	100	1000	170	-

m														

Table 1.2: Soil samples XRF analysis results

Trace Metals	WS1 Amaeze quarry 1	WS2 Amaeze quarry 2	WS3 Amaeze pond	WS4 Amagu	WS5 Amaokwe 1	WS6 Amaokwe 2	WS7 Amaokwe 3	WS8 Ihie	Min	Max	Mean	WHO 2020 (mg/l)
Nickel	0.14	0	0.01	0.02	0.02	0.08	0.02	0.02	0	0.14	0.039	0.07
Zinc	0.426	0.016	0.022	0.01	0.02	0.018	0.007	0.015	0.01	0.426	0.067	5.0
Copper	0.11	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.11	0.021	2.0
Cobalt	0.12	0.01	0	0.01	0.01	0.01	0.01	0	0.01	0.12	0.021	0.08
Lead	-0.01	0	0	0	0	-0.01	0	0	0	-0.01	-0.003	0.01
Cadmium	0.003	0.003	0.001	0.004	0.001	0.002	0.003	0	0.001	0.004	0.002	0.003
Arsenic	0.57	0.46	0.67	0.51	0.46	0.48	0.45	0.43	0.43	0.67	0.504	0.01
Vanadium	-1.16	0.2	0.16	0.08	0.07	0.1	0.05	0.05	-1.16	0.2	-	

											0.056	0.10
Selinium	0.19	-0.02	0.21	0.06	0.04	0.08	-0.1	-0.03	-0.03	0.21	0.054	0.02
Chromium	0.01	0.002	0	0.002	0.002	0.032	0.009	0.008	0.01	0.032	0.008	0.05
Molybdenum	0	0.01	0.04	0	0	0	0	0	0.01	0.04	0.006	**-**
Antimony	2.36	0.99	-0.25	1.25	1.09	2.08	1.29	1.24	-0.25	2.36	1.256	0.006
Barium	0.35	0.05	0.47	0.1	0.08	0.13	0.02	0.02	0.02	0.47	0.153	**-**

Trace Metals	**VEG1 Ihie**	**VEG2 Amaeke 1**	**VEG3 Amaeke 2**	**VEG4 Amaeke 3**	**VEG5 Amaeke 4**	**Min**	**Max**	**Mean**	**IPL 2012 (mg/kg)**

Table 1.3: Results of physiochemical analysis on water samples

Trace Metals	CH 1 Amokwe	CH 2 Amuzu-Amagu	CH 3 Iheteutu I	CH 4 Ihetutu II	CH 5 Amaeze	Min	Max	Mean	WHO 2020 (mg/kg)
Nickel	0	0	0	300	100	100	300	80	10
Zinc	1100	900	1000	1100	1000	900	1100	1020	99.4
Copper	300	300	400	500	400	300	500	380	73.3
Cobalt	0	0	0	0	100	0	100	20	0.01
Lead	100	100	100	200	100	100	200	120	0.3
Cadmium	300	200	200	300	200	200	300	240	0.02
Arsenic	0	0	0	0	0	0	0	0	0.5
Vanadium	1500	1000	400	1200	0	400	1500	820	0.03
Selinium	200	100	100	200	100	100	200	140	0.02
Chromium	0	0	0	0	0	0	0	0	1.3
Molybdenum	100	0	0	100	100	0	100	60	-
Antimony	100	0	0	0	100	0	100	40	-
Barium	0	0	0	0	0	0	0	0	-

Table 1.4: Vegetable samples XRF analysis results

Nickel	0	0	100	500	300	100	500	180	0.25
Zinc	1900	1500	2900	3800	5600	1500	5600	3140	5.0
Copper	0	200	500	900	700	200	900	460	0.2
Cobalt	0	0	0	100	0	0	100	20	-
Lead	0	100	200	200	0	100	200	100	0.05
Cadmium	500	100	0	500	500	100	500	320	0.01
Arsenic	0	0	0	300	0	0	300	60	0.2
Vanadium	0	0	0	800	0	0	800	160	0.1
Selinium	100	200	300	500	500	100	500	320	0.05
Chromium	0	0	NIL	NIL	0	0	0	0	-
Molybdenum	0	0	NIL	NIL	0	0	0	0	0.03
Antimony	0	100	0	600	0	100	600	140	-
Barium	0	0	0	4900	0	0	4900	980	-

Table 1.5: Chicken samples XRF analysis results

Table 1.6: Contamination Factor interval / Pollution index by Lacatusu (2000).

Class index	**Contamination / Pollution value**	**Quality Contamination / Pollution**
1	<0.1	Very slight contamination
2	0.10-0.25	Slight Contamination
3	0.26-0.5	Moderate Contamination
4	0.51-0.75	Severe Contamination
5	0.76-1.00	Very Severe Contamination

6	1.10-2.0	Slight Pollution
7	2.1-4.0	Moderate Pollution
8	4.1-9.0	Severe Pollution
9	9 .1-16.0	Very Severe Pollution
10	>16	Excessive Pollution

DISCUSSION

Table 1.7: Showing report of all trace metal mean concentrations from samples analysis, with local and international permissible limits.

The range of trace metals reported across all samples from Ishiagu are: Pb (-0.003 to 210ppm); Zn (0.067 to 3140 ppm); Cd (0.002 to 320ppm); V (-0.056 to 820ppm); Co (0.021 to 30ppm); Ni (0.039 to 180ppm); Se (0.00 to 320ppm); Cu (0.021 to 460ppm); Sb (0.00 to

TRACE METALS	Rock Mean values	Soil Mean values	Water Mean values	Veges. Mean values	Chicken Mean values	WHO (2020) for igneous rocks	DPR (1991) for soils	WHO (2020) for water	IPL (2012) for veges.	WHO (2020) for chicken
Nickel	110	140	0.039	80	180	105	35	0.07	10	0.25
Zinc	340	330	0.067	1020	3140	111.4	50	5.0	99.4	5.0
Copper	130	90	0.021	380	460	35.7	36	2.0	73.3	0.2
Cobalt	30	20	0.021	20	20	53.3	10.5	0.08	0.01	-
Lead	10	210	-0.003	120	100	-	85	0.01	0.3	0.05
Cadmium	90	100	0.002	240	320	-	0.8	0.003	0.02	0.01
Arsenic	20	10	0.504	0	60	2	0.15	0.01	0.5	0.2
Vanadium	10	60	-0.056	820	160	-	0.5	0.10	0.03	0.1
Selinium	0	0	0.054	140	320	0.05	-	0.02	0.02	0.05
Chromium	40	60	0.008	0	0	-	100	0.05	1.3	-
Molybdenum	0	0	0.006	60	0	1.5	-	-	-	0.03
Antimony	0	40	1.256	40	140	-	-	0.006	-	-
Barium	40	170	0.153	0	980	500	-	-	-	-

140ppm), and As (0.00 to 60ppm). The font colours in red represent mean values of trace metals that exceeded the permissible limit, while the font in blue colour shows mean values that are below or fall within the permissible limit. It is observed that Ni, As, Zn and Cu in rock samples are the trace metals with mean values exceeding the permissible limits of the WHO (2020) standard values. This indicates the rock samples are excessively polluted with Ni, As, Zn and Cu and when these metals are released into the environment, are capable of causing harm to humans.

Contamination Factor (CF) equation

In deriving the contamination factor (CF) of Lacatusu (2000) for the samples, WHO (2020) and DPR (1991), and IPL (2012) values were used as background concentrations.

Table 1.8 shows the Contamination Factor (CF) calculated for trace metals in rock samples using the WHO (2020) control limit while Table 1.9 shows the Contamination / Pollution index for rock samples. The contamination / pollution quality from the Contamination Factor interval / Pollution index shows the quality of pollution or contamination index for each trace metal reported in the rock samples 1 – rock sample 10 (R1 – R10).

Arsenic in Amaeze quarry 1 and Amaokwe 2 recorded excessive pollution, Zn in all ten rock samples recorded moderate pollution, Cu in Amaeze farm 1, Amaeze farm 2 and Amaokwe 2 recorded severe pollution while other samples location recorded moderate pollution. The effect of As toxicity in humans muscle weakness, skin cancer, sensory-predominant peripheral neuropathy (Rahman *et al.,* 2001); zinc toxicity symptoms include low immunity, loss of appetite, nausea, vomiting, stomach cramps (Ajah *et al.*, 2022); Cu toxicity results in diarrhea, nose and throat irritation, liver and kidney damage in humans (WHO, 1996).

Table 1.8: The contamination factors (CF) of trace metals in rock samples using WHO (2020) guidelines in ppm as control.

Sample ID	Ni (CF)	Zn (CF)	Ba (CF)	Cu (CF)	Co (CF)	As (CF)
R1	0.95	3.6	0.00	2.8	0.00	50
R2	0.95	2.7	0.00	2.8	0.00	0
R3	0	2.7	0.00	2.8	0.00	0
R4	1.9	2.7	0.00	5.6	0.00	0
R5	1.9	2.7	0.00	5.6	0.00	0
R6	0	3.6	0.00	2.8	0.00	0
R7	1.9	2.7	0.00	5.6	5.6	50
R8	0.95	3.6	0.00	2.8	0.00	0
R9	0	2.7	0.4	2.8	0.00	0
R10	0.95	3.6	0.4	2.8	0.00	0

Sample ID	Ni	Zn	Ba	Cu	Co	As

R1	V. Se. C	M.P	V.S.C	M. P	V.S.C	E.P
R2	V. Se. C	M.P	V.S.C	M. P	V.S.C	V.S.C
R3	V. S. C	M.P	V.S.C	M. P	V.S.C	V.S.C
R4	S. P	M.P	V.S.C	Se. P	V.S.C	V.S.C
R5	S. P	M.P	V.S.C	Se. P	V.S.C	V.S.C
R6	V.S.C	M.P	V.S.C	M. P	V.S.C	V.S.C
R7	S. P	M.P	V.S.C	Se. P	Se. P	E.P
R8	V. Se. P	M.P	V.S.C	M. P	V.S.C	V.S.C
R9	V. S. C	M.P	M.C	M. P	V.S.C	V.S.C
R10	V. Se. C	M.P	M.C	M. P	V.S.C	V.S.C

Table 1.9: The significance of contamination interval from the trace metals in rock samples after Lacatusu, (2000).

R1 – R10 = Rock sample 1 – Rock sample 10

V.S.C: Very Slight Contamination, S.C: Slight Contamination, M.P: Moderate Pollution, E.P: Excessive Pollution, V. Se. C: Very Severe Contamination, S.P: Slight Pollution, V. Se. P: Very Severe Pollution, M.C: Moderate Contamination, Se. C: Severe Contamination, Se. P: Severe Pollution

The mean values of the concentrations of As, Cu, Ni, Cr, Pb, V, Zn, Co in soil samples are above the DPR (1991) permissible standard in soils. The Zn average concentration of 330ppm by far exceeded the DPR (1991) standard of 50ppm for zinc in soils. This indicates that the residents of the area will suffer from the toxicity of zinc which results to such health issues as nausea, vomiting, epigastric pain, lethargy, fatigue as well as anaemia, dizziness, osteoponia, and retarded growth in children (Bennet *et al.*, 1997). Ni concentration in soil samples have mean value (140ppm), and exceed the DPR (1991) threshold of (35mg/kg). It shows the soil have Ni poisoning and pose health risk like intense pulmonary and gastrointestinal toxicity, kidney and cardiovascular diseases (Kalu and Ogbonna, 2021) to the residents as they consume food crops grown in the area.

Cu concentration in soil samples exceeded the DPR (1991) standard. Comparing the average concentration of (90ppm) of Cu in soil samples with DPR (1991) standard of (36ppm), copper concentration in soils within the study area exceeds the permissible limit. This indicates the copper poisoning in the study area. Excess copper can result to diarrhea, hemolytic anemia, cramps, kidney disease, liver damage and vomiting (Brito *et al.,* 2005). Co average concentration in soil (20ppm) when compared with DPR (1991) allowable standard of (10.5mg/kg) for cobalt availability in soils shows excessive pollution. Co effects are on the heart muscles, (heart enlargement without proper pumping of blood), and causes cardiomyopathy, increased red blood cells (polycythemia) which in the long term can cause cognitive heart failure. Pb concentration in soils has a mean value of (210ppm). The DPR (1991) standard for Pb in soils (85ppm), was exceeded by Amaeze quarry 3, Amaeze farm 2, Amaokwe 3, Amagu and Ihie. The health of residents living within the above mentioned locations are bound to suffer the effects of Pb toxicity especially at Amaokwe 3 (1700ppm). According to Goyer 1993, toxicity of lead in children (probably radiogenic lead) within those areas with high occurrence can result in unhealthy brains and nervous system development, while in adults, kidney damage, high blood pressure, miscarriage, premature births and stillbirths in pregnant women. Cd in soils with an average concentration of 100ppm when compared with DPR (1991) standard of Cd in soils (0.8ppm) shows that the values exceeded the permissible limit, indicating possible Cd poisoning in the soils within the area. Exposure to excess quantity of Cd in humans will result in damage to kidneys, lungs and bones, increased risk of lung cancer (EFSA, 2009).

V concentration was reported only in two samples each with (300ppm) concentration. V has a mean value of (60ppm), and a control value of (0.5mg/kg) for soil. This is dangerous! Amaeze quarry 2 and Amaokwe 2 are at a high risk of excess V in their environment. Excess V in the body causes upper respiratory tract irritation with symptoms of rhinitis, wheezing, nasal hemorrhage, and conjunctivitis (Venkataraman and Sudha, 2005). Cr concentration mean values for samples are; rocks (40ppm), soil (60ppm), water (0.008ppm). Amaeze quarry 2 (200ppm), Amaeze farm 2 (300ppm) have concentration values above DPR (1991) standard of (100ppm) for Cr in soils. This exceeded the threshold and poses a potential health risk such as ulcer, anemia, and lung cancer on the inhabitants of the two areas. Cd contamination factor for all ten soil samples, showed excessive pollution. Pb gave the contamination factor of slight contamination (S. C) to excessive pollution (E.P). Cr gave slight contamination in most samples and slight pollution to moderate pollution in few others. Zn showed moderate pollution (M.P) in few samples and moderate to severe pollution in most samples. The contamination factor (CF) for Cu recorded moderate pollution for few soil samples and slight to severe pollution in others. Thus, from the results of the Contamination Factor, trace metals such as As, Pb, Zn, V, Co, Ni, Cu, Cd, are the major pollutants of soil in Ishiagu.

Table 1.10: The contamination factors (CF) of trace metals in ten soil samples with DPR (1991) guidelines in ppm.

Sample ID	**Ni (CF)**	**Pb (CF)**	**Cd (CF)**	**Zn (CF)**	**Cu (CF)**	**As V (CF) (CF)**	**Cr (CF)**
S1	5.71	0	192	2.14	2.78	0 0	0
S2	5.71	0	192	2.14	2.78	666.7 120	0
S3	5.71	1.18	192	2.14	2.78	0	2

						0	
S4	0	0	192	0.71	2.78	0 0	0
S5	2.86	1.18	192	1.43	2.78	0 0	3
S6	2.86	0	192	2.86	2.78	0 0	0
S7	8.57	0	192	2.86	5.56	0 120	0
S8	2.86	20	192	6.43	0	0 0	0
S9	2.86	1.18	192	1.43	2.78	0 0	1
S10	2.86	1.18	192	1.43	-	0 0	0

Table 1.11: The significance of contamination interval from the trace metals in soil samples after Lacatusu, (2000).

Samples	**Ni**	**Pb**	**Cd**	**Zn**	**Cu**	**As**	**Cr**	**V**
S1	Se.P	S.C	E.P	M.P	M.P	V.S.C	V.S.C	V.S.C
S2	Se.P	S.C	E.P	M.P	M.P	E.P	V.S.C	E.P
S3	Se.P	S.P	E.P	M.P	M.P	V.S.C	S.P	V.S.C
S4	S.C	S.C	E.P	S.P	M.P	V.S.C	V.S.C	V.S.C
S5	M.P	S.P	E.P	M.P	M.P	V.S.C	M.P	V.S.C
S6	M.P	S.C	E.P	S.P	M.P	V.S.C	V.S.C	V.S.C
S7	V.Se. P	S.C	E.P	S.P	Se. P	V.S.C	V.S.C	E.P

S8	M.P	E.P	E.P	E. P	S.C	V.S.C	V.S.C	V.S.C
S9	M.P	S.P	E.P	M.P	M.P	V.S.C	V.Se.C	V.S.C
S10	M.P	S.P	E.P	M.P	-	V.S.C	V.S.C	V.S.C

S1 – S10 = Soil sample 1 – Soil sample 10

As in water samples ranges from (0.43 - 0.67ppm); it recorded its highest concentration in Amaeze pond (0.67ppm) and a mean concentration value was (0.504ppm). The WHO (2020) permissible limit of As in water (0.01mg/l) was exceeded by the mean concentration value, which is dangerous to the inhabitants. Sb recorded concentrations ranging from (-0.25 - 2.36ppm), with a mean value of (1.256ppm). The WHO (2020) benchmark for Sb in water is (0.006mg/l) which was exceeded by Sb mean concentration value. This portends danger to the residents of Ishiagu. Se in water samples had the highest concentration reported in Ameze pond at 0.21mg/l. The mean value of Se (0.054mg/l) is above the WHO (2020) permissible limit (0.02mg/l) in humans thereby making surface water in the area very severely polluted with Se. Co concentration mean value of 0.021mg/l was below the WHO (2020) standard of (0.08mg/l) for water. The water samples are considered safe and free from the effects of Co toxicity. V in water samples has a mean value of (-0.56mg/l) in comparison with the WHO (2020) limit of (0.10mg/l). The negative mean value of V (-0.056), shows the level of unavailability of the trace metal V. It shows the water samples are free of V poisoning or pollution. Cd mean value (0.002mg/l) is less than WHO (2020) limit for Cd in water (0.003mg/l), making the surface water free from Cd toxicity effects and fit for use in the area.

Surface water quality within the area is not so suitable for consumption by the locals, animals as well as organisms, and plants due to the level of contamination recorded for some metals in the analysis. Comparing the mean concentrations of trace metals in water samples with the guidelines on water quality given by WHO (2020), Pb (-0.003mg/l), Co (0.021mg/l), Cu (0.021mg/l), Zn, (0.067mg/l), Ni (0.039mg/l), V (-0.056mg/l), Cr (0.008mg/l), Cd (0.002mg/l) have mean values below the WHO (2020) guidelines for these trace metals. Only Sb (1.256mg/l), Se (0.02mg/l) and As (0.504mg/l) have mean values above the permissible limit. This is a sign of danger to the health of the residents in Ishiagu. Sb recorded excessive pollution in all eight samples/locations, and As recorded very severe pollution in the samples from contamination factor evaluation in Table 1.13.

Table 1.12: The evaluation of contamination factors (CF) of trace metals in eight water samples.

Water Samples	Sb (CF)	Cu (CF)	Cd (CF)	Se (CF)	Ni (CF)	As (CF)

W1	393	0.16	1	9.5	7	11.4
W2	165	0.00	1	-1	0.00	9.2
W3	-42	0.05	0.3	10.5	0.5	13.4
W4	208	0.05	1.3	3.0	1	10.2
W5	182	0.05	0.3	2.0	1	9.2
W6	47	0.05	0.7	4.0	4	9.6
W7	207	0.05	1	-5	1	9
W8	206	0.00	0.00	-1.5	1	8.6

Table 1.13: The significance of contamination factors evaluated in the eight water samples.

Water Samples	Sb	Cu	Cd	Se	Ni	As
W1	E.P	S.C	V.Se. C	V.Se.P	S.P	V. Se. P
W2	E.P	V.S.C	V.Se.C	V.S.C	V.S.C	V. Se. P
W3	E.P	S.C	M.C	V.Se.P	M.C	V. Se. P
W4	E.P	S.C	S.P	M.P	V. Se. C	V. Se. P
W5	E.P	S.C	M.C	S.P	V. Se. C	V. Se. P
W6	E.P	S.C	Se. C	M.P	M.P	V. Se. P
W7	E.P	S.C	V.Se.C	V.S.C	V. Se. C	V. Se. P
W8	E.P	V.S.C	V.S.C	V.S.C	V. Se. C	Se. P

W1 – W8 = Water sample 1 – Water sample 8

Zn mean value of 1020mg/kg compared to the control standard of IPL (2012) (99.4mg/kg) is quite extremely high and is a potent Zn poisoning in vegetable source on the residents especially as it promotes low immunity making the people prone to frequent infections, loss of appetite, headaches, stomach cramps, lowering of copper below its right proportion to deficient state that results in unhealthy bones (Ajah *et al.*, 2022). Cd in all vegetable samples showed concentration above the IPL (2012) control standard, with a mean value (240mg/kg) which is much higher than the control value (0.02mg/kg). Symptoms of Cd toxicity are abdominal pain, chronic symptoms of kidney disease resulting in glucosuria (glucose in urine) and proteinuria (protein in urine), lung damage (Nordberg, 1999). Pb in vegetables recorded a mean value of (120mg/kg). When this is compared to the IPL (2012) control standard of (0.3mg/kg), there is high potential for Pb poisoning in the area. The effects of radiogenic Pb in humans include low intelligence quotient in children, high blood pressure in adults, and infertility in men (Mason *et al.*, 2014).

V mean value (820ppm) in vegetable samples within the area is extremely high compared to standard of IPL (2012) permissible limit of (0.03mg/kg), with concentrations ranging from 0.00ppm to 1500ppm. Vanadium toxicity effects are stomach discomfort, nausea, gas, high blood pressure, eye infection, nasal hemorrhage (Crans *et al.*, 2019).

Co in vegetables have a mean value of (20mg/kg) and when compared with IPL (2012) standard of (0.01mg/kg) for vegetables, there is a potentially high Co poisoning in the area. Excessive intake of Co in humans can result to hyperthyroidism, cardiomyopathy, and cough (Czarnek *et al.*, 2015). Ni was recorded in only two of the five vegetable samples. The mean value obtained for (Ni) (100mg/kg) analyzed in vegetable samples from the study area, is higher than acceptable limit of IPL (2012) standard of 80mg/kg. From Ahmed and Ashraf 2012, when exposed to higher percentage concentration of Ni, one can suffer diseases like cancer of the respiratory tract, lungs fibrosis, kidney and cardiovascular disease, contact dermatitis, headaches, gastro intestinal manifestations. Cu was recorded in all five vegetable samples, with mean value of (380mg/kg). IPL (2012) permissible limit of (73.3mg/kg) for copper in vegetables was greatly exceeded. This is an indication of copper pollution in vegetables.

The mean values of Ni, Zn, Cu, Co, Pb, Cd, V, and Se in all five vegetable samples exceeded the permissible limit of IPL (2012). This indicates a high possibility of toxicity in human bodies within Ishiagu. Cr and As mean values were below the IPL (2012) permissible standard. In Table 1.15, Cu recorded severe pollution in all locations; Zn in all five locations recorded very severe pollution; Ni in Ihie, Amaeke 1 and Amaeke 2 recorded slight contamination, excessive pollution in sample Amaeke 3, and very severe pollution in Amaeke 4; Cd recorded excessive pollution in all five samples. In conclusion, Ihie, Amaeke 1, Amaeke 2, Amaeke 3 and Amaeke 4 of Ishiagu area are excessively polluted with Pb, Cd, V and Se. The inhabitants are at a risk of suffering from kidney and cardiovascular diseases, rapid heart rate, miscarriage, chills.

Table 1.14: The evaluation of contamination factors (CF) of trace metals in five vegetable samples.

Samples ID	Cu (CF)	Zn (CF)	Ni (CF)	Pb (CF)	Cd (CF)	V (CF)	Se (CF)
VI	4.1	11	0	333	15,000	50,000	10,000
V2	4.1	9.1	0	333	10,000	33,300	5,000
V3	5.5	10.1	0	333	10,000	13,300	5,000

V4	6.8	11	30	666	15,000	40,000	10,000
V5	5.5	10.1	10	333	10,000	0	5,000

Table 1.15: The significance of contamination factors evaluated from trace metals in five vegetable samples.

Samples ID	Cu	Zn	Ni	Pb	Cd	V	Se
V1	Se. P	V. Se. P	V.S.C	E.P	E.P	E.P	E.P
V2	Se. P	V. Se. P	V.S.C	E.P	E.P	E.P	E.P
V3	Se. P	V. Se. P	V.S.C	E.P	E.P	E.P	E.P
V4	Se. P	V. Se. P	E.P	E.P	E.P	E.P	E.P
V5	Se. P	V. Se. P	V. Se. P	E.P	E.P	V.S.C	E.P

V1 – V5 = Vegetable sample 1 – Vegetable sample 5

Pb recorded 100ppm mean value in chicken samples of which 50ppm in diet can cause reproductive defects in some predators, and dietary levels as low as 0.10ppm are associated with learning deficits in some vertebrates (Eisler, 1988). The WHO (2020) threshold of (0.05mg/kg) was exceeded by the samples from Amuzu-Amagu- (100mg/kg), Ihetutu I-(200mg/kg) and Ihetutu II- (200mg/kg), while two samples values were below detectable limit 0.00ppm. Ni average of 180mg/kg in all 3 female chicken samples obtained from Ihetutu 1, Ihetutu II & Amaeze were above the permissible standard (0.25mg/kg) by WHO (2020). Ni was absent in male chicken offal. The migration of nickel into foodstuffs should be as low as reasonably achievable and not more than 0.1mg/kg, Council of Europe, (2001). V in chicken offal has mean concentration of (160mg/kg) which exceeded the WHO (2020) limit of (0.1mg/kg). There is vanadium poisoning in chicken offal. Zn concentration mean value for chicken offal of (3140mg/kg) is far above the WHO (2020) permissible limit of (5.0mg/kg). This shows acute toxicity of zinc in the area.

Cu, Co, Cd, As, Se also exceeded the WHO (2020) control standard values. The excessive availability of these trace metals in chicken offal is probably as a result of the environment being polluted from weathering process of rocks to soil which the scavenger chickens feed from. It was noted that only Zn, Cd, and Se occurred as trace metals of interest in male chicken sample one. The concentrations of Zn, Ni, Cd, V, Cu, As, Se, and Pb form the primary concern of trace metals presence in chicken offal samples, because of their toxicity effects on human health. From the Contamination Factor in Table 1.16, all trace metals present in the chicken samples, Zn, Se, Cu, Pb, Cd, and Ni showed excessive pollution in scavenger chicken offal within the entire Ishiagu area, with zinc having the highest concentration mean value. As showed very slight contamination in chicken offal at Amaokwe, Amuzu-Amagu, Ihetutu 1 and Amaeze, except in Ihetutu II that showed excessive pollution.

Table 1.16: The evaluation of contamination factors (CF) of trace metals in five chicken samples.

Samples ID	Zn (CF)	Cu (CF)	Pb (CF)	Cd (CF)	Ni (CF)	As (CF)	Se (CF)
C1M	380	0	0	50,000	0	0	2000
C2M	300	1000	2000	10,000	0	0	4000
C3M	580	2500	4000	0	400	0	6000
C4M	760	4500	4000	50,000	2000	1500	10000
C5M	1120	3500	0	50,000	1200	0	10000

Table 1.17: The significance of contamination factors as evaluated from the trace metals in the five chicken samples.

Samples	Zn	Cu	Pb	Cd	Ni	As	Se
CM1	E.P	V.S.C	V.S.C	E.P	V.S.C	V.S.C	E.P
CM2	E.P	E.P	E.P	E.P	V.S.C	V.S.C	E,P
CF3	E.P	E.P	E.P	V.S.C	E.P	V.S.C	E.P
CF4	E.P	E.P	E,P	E.P	E.P	E.P	E.P
CF5	E.P	E.P	V.S.C	E.P	E.P	V.S.C	E.P

C1 – C5 = Chicken sample 1 – Chicken sample 5, CM = Chicken Male, CF = Chicken Female

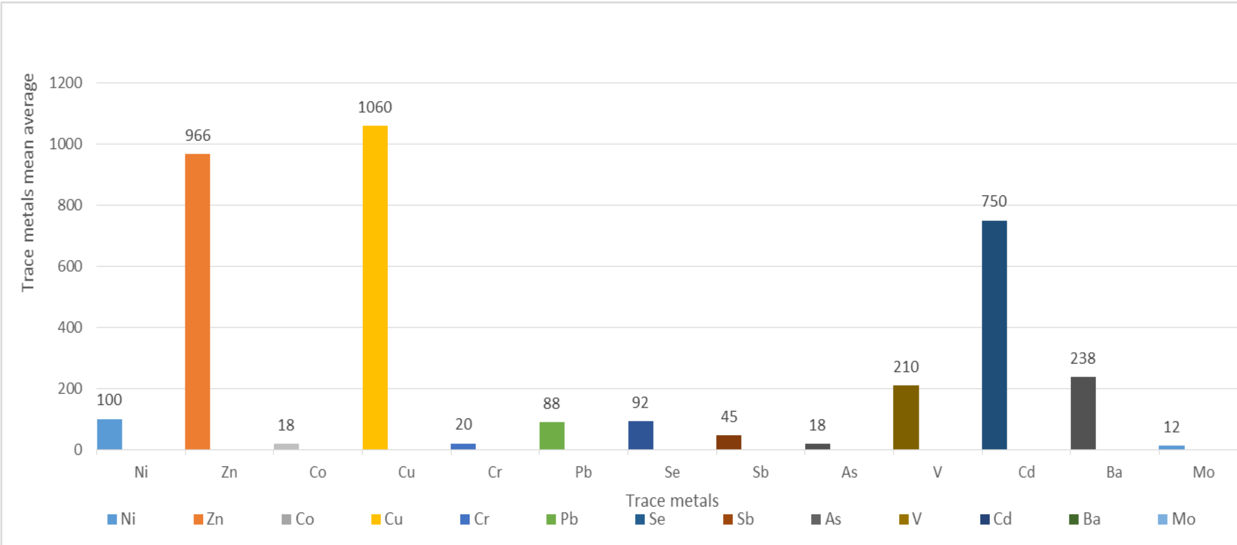

Figure 1: A bar chart showing trace metals mean concentrations for all evaluated samples.

Conclusion

The intrusions of igneous rocks in Ishiagu in the Lower Benue Trough of Nigeria caused excessive pollution of Pb, Co, Zn, Ni, Cu, V and Cd in soil samples, Pb, Co, Zn, Ni, Se, V, Cu and Cd in vegetable samples, Pb, Zn, Ni, Se, V, Cu, As and Cd in chicken offal samples, and moderate contamination of Sb and As in the surface water samples. The pollution types which can lead to adverse effects on the health of the people require urgent medical intervention and control to protect the inhabitants.

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Assessing Policies in promoting Autogas adoption in Nigeria: A comparative Analysis using the triple helix Model

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Abstract

This paper explores the significance of Autogas as a viable alternative to traditional automotive fuels in Nigeria. The study focuses on policy thrust for understanding the adoption of Autogas in Nigeria. An empirical literature review methodology was employed to gather insights from existing studies, reports, and relevant literature. The research examines Autogas adoption strategies of Iran, Egypt, Italy and India, and proffered strategies to jumpstart its adoption in Nigeria using the triple helix model. The findings highlight the significance of collaborative approach in Autogas adoption in Nigeria which includes targeted Autogas refuelling infrastructural development, provision of subsidies for gas fuelled vehicles, academic courses for capacity building which will provide valuable lessons for policymakers and industry stakeholders. The research also proposes a tax on vehicles using PMS through the window of road worthiness and offers recommendations for promoting Autogas adoption in Nigeria.

Introduction:

To transform chemical energy into kinetic energy through thermal energy conversion, the internal combustion engine has traditionally relied on fossil fuels, notably gasoline and gasoil made from petroleum. However, these fuels are now much more expensive in Nigeria due to the recent elimination of subsidies. As a result, there is a greater demand for sustainable transportation options. The goal of sustainable transportation is to address the economic, social, and environmental effects of energy supply, both now and in the future. According to Guillén-Royo et al. (2023), it includes elements like energy availability, efficiency, and cost, as well as the kinds of vehicles used, and the energy sources used. Exploring alternate choices, like the adoption of autogas, becomes crucial to achieving sustainable transportation goals in light of the rising costs of conventional fuels in Nigeria.

Concerns about the sustainability of the environment, the security of the energy supply, and the economic feasibility of conventional vehicle fuels have significantly fueled the global conversation about alternative fuels (Zhao et al., 2020). In the Nigerian environment, where subsidies for conventional fuels have recently been eliminated, the adoption of Autogas stands out as a particularly pertinent area of study. This paper aims to offer a thorough study of the studies and research already conducted on the adoption of Autogas, including an examination of its advantages, disadvantages, regulatory frameworks, and comparisons with other nations (Ackah & Tetteh, 2016). This review, which examines the available literature, looks at the potential of Autogas as a workable alternative fuel option in Nigeria, providing insightful information that will help decision-making processes and ease the transition to a more environmentally friendly and economically transportation system that is devoid of frequent pipeline incidents that has gravely polluted the environment (Emeke & Chioma, 2022).

Autogas adoption policy framework is key to creating the enabling environment for the Autogas market to thrive, hence the need to integrate all stakeholders. The triple helix model is a framework that highlights the interactions and collaborations among three key actors in a system: government, industry, and academia. It emphasizes the dynamic relationship and mutual influence between these entities in driving innovation and socio-economic development.

In the triple helix model, the government plays a crucial role in setting policies, providing funding, and creating an enabling environment for innovation. Industry brings practical expertise, resources, and market perspectives, while academia contributes scientific research, knowledge generation, and human capital development. The model recognizes that the boundaries between these actors are not fixed and encourages cross-pollination of ideas and expertise (Etzkowitz & Leydesdorff,1995).

This study aim's to compare the autogas adoption strategies and experiences of Iran, Egypt, and India to gain insights and identify best policy pathways for Nigeria's Autogas adoption using the triple helix model.

Benefits of Autogas as an Alternative Fuel

Liquefied petroleum gas (LPG), often known as Autogas, is a combination of combustible hydrocarbon gases. It can be made by refining fossil fuels like natural gas or petroleum. About 3% of the world's energy is consumed in this way. It is frequently referred to as Autogas when used as fuel in internal combustion engines. It mostly comprises of diverse combinations of propane, butane, propylene, and butylene (Ognianov, 2018). LPG has numerous advantageous qualities, such as technological, economic, and environmental advantages, even if it can suffocate by displacing oxygen and explode when conditions are right. With minimal soot production and low Sulphur emissions, LPG burns comparatively cleanly. In comparison to gasoline and gasoil, it produces fewer smoke pollutants and uses less fuel (Sethiya, 2014).

Technically, alternative fuels like Autogas have many advantages over traditional fuels. Engines initially made to run on conventional fuels can be converted for a reasonable price to run on Autogas. The kits ensure quick and simple gasification of liquid LPG at the proper air-fuel ratio. The kit also includes a closed-loop feedback mechanism that continuously checks and adjusts the air-fuel ratio and needed oxygen content of the exhaust, respectively, to ensure the engine is operating at its most efficient level (Ghadikolaei et al., 2021).

Because the air/fuel mixture in LPG vehicles is gaseous, as opposed to liquid fuel-run engines, the combustion chambers are free of cold-starting competitors. In contrast to petrol engines, which produce significant emission levels when running cold, it has normal emission levels and produces less when running hot or cold. LPG's gaseous state prevents it from removing engine oil from cylinder walls (Nevad & Nevad, 2013). When the engine is cold, it does not also thin the oil. As a result of optimal combustion efficiency in combustion chambers brought about by an effective air/fuel mix, LPG-run engines have little carbon build-up as compared to gasoil and gasoline-run engines. In contrast, LPG engines have a longer lifespan and require less upkeep (Ognianov, 2018).

Despite having a shorter driving range, LPG has similar power delivery, acceleration, and cruising speed characteristics as petrol. The former's nondestructive knocking qualities, however, make up for this constraint. LPG engines are a superior alternative to gasoline and gasoil because of their greater and better tuning capabilities, higher octane rating (105), and higher engine power output and fuel efficiency (Ackah & Tetteh, 2016). So, compared to using petrol, using LPG could often result in cost savings of between 5% and 30%. LPG dispensing equipment is built at a cost that is comparable to that of petrol dispensing systems. Within a short amount of time, that is, between four and eight months, conversion expenditures can be recouped through fuel savings (Ognianov, 2018).

Existing Policies and Infrastructure in Nigeria that support Autogas Adoption

The infrastructure and laws in place in Nigeria are very important in encouraging the use of Autogas as a viable substitute for conventional vehicle fuels. With these programmes, the nation's use of Autogas is to be encouraged. he National Gas Policy (NGP), established in 2008, is a significant initiative aimed at promoting the utilization of Autogas. Autogas plays a pivotal role in Nigeria's energy composition, and the NGP encompasses regulations designed to incentivize its adoption. These policies include the creation of a national infrastructure for Autogas refueling, which entails the construction of refueling stations across the nation to guarantee easy access by motorists to autogas. The NGP also places a focus on offering incentives to drivers who switch their cars over to autogas, creating a supportive atmosphere for adoption (Emodi et al., 2017).

The National Automotive Policy (NAP), which was unveiled in 2013, is another key initiative The NAP outlines steps to encourage its use and acknowledges the potential of Autogas as a major fuel in the automobile industry. According to a notable NAP policy (Emodi et al., 2017), it is mandated that all newly manufactured vehicles must be bi-fuel, capable of running on both petrol and Autogas. In addition to encouraging the use of Autogas, this policy gives consumers a variety of fuel options. Additionally, the NAP has provisions for subsidies to encourage the conversion of current vehicles to Autogas, increasing the accessibility and affordability of the transition for vehicle owners (Emodi et al., 2017).

Another significant project that encourages the uptake of Autogas in Nigeria is the government-led National LPG Expansion Programme (NLEP), which was introduced in 2017. The National Liquefied Petroleum Gas (NLEP) Programme promotes the use of Liquefied Petroleum Gas (LPG) in several industries, notably transportation. New LPG refueling stations are being built as part of this programme to meet the rising demand for Autogas. According to Emodi et al. (2017), these filling stations are essential in providing the infrastructure required for drivers to easily access and use Autogas.

Nigeria has been spending money on infrastructure improvements in addition to regulations to facilitate the broad use of Autogas. With a projected 2,000 stations operating by 2020 (Emodi et al., 2017), the nation has seen a considerable increase in the number of LPG refueling stations. This figure is anticipated to increase during the ensuing years, significantly boosting the accessibility and availability of Autogas. Additionally, the existence of LPG pipelines provides a consistent supply of the fuel to refueling facilities, adding to its total availability. Storage facilities all around the nation are essential for preserving a sufficient supply of LPG for Autogas refueling stations, guaranteeing that drivers always have access to Autogas as a fuel choice (Emeke et al., 2023).

A favorable environment for the use of Autogas in Nigeria is produced by the fusion of supportive policies and the growth of infrastructure. Together, these programs encourage the use of Autogas as a practical substitute for conventional vehicle fuels. Autogas has a number of advantages over conventional fuels, including lower emissions, cost savings, and energy efficiency (Ognianov, 2018).. Execution of these far-reaching policies will provide the opportunity to enlarge the gas demand envelop which will then stimulate the utilization of different gas fuel sources to power the transport sector. (Emeke et al.,2023).

Nigeria can pick up valuable lessons from nations who have significantly migrated from the traditional fuel type for transportation to the use of gas fuels. For example, Iran implemented series of comprehensive autogas policies, including fuel conversion programs, financial incentives, and the establishment of refueling infrastructure, contributing to the significant growth of autogas adoption in the country (Sarabi, 2011). While Egypt introduced progressive Autogas policies, such as tax incentives and the conversion of public transportation fleets to Autogas, leading to reduced emissions and enhanced energy security." (Akin-Tepede, 2010). India implemented an ambitious Autogas policies, including the promotion of LPG as an automotive fuel, conversion subsidies, and the development of a robust refueling infrastructure, fostering the widespread adoption of Autogas in the country." (Swain & Mishra, 2020). Italy on the other hand, established a supportive Autogas policies, encompassing tax incentives, grants for vehicle conversions, and the expansion of Autogas refueling infrastructure, contributing to Italy's leadership in Autogas adoption." (Ionel Simion, 2018)

Materials and Methods

This paper focuses on key areas that are crucial for understanding the benefits of adopting Autogas ants its policies. The methodology employed is an empirical literature review, which involves an extensive analysis of existing studies, reports, and relevant literature in order to gather insights and draw meaningful conclusions. The following areas will be examined:

- Existing policies and infrastructure in Nigeria that support the adoption of Autogas.
- The Autogas adoption strategies of Iran, Egypt, Italy and India.

The data collected from the literature review will be analysed using a variety of methods, including content analysis, thematic analysis, and statistical analysis. The analysis will focus on identifying the key initiatives and policies that will influence the adoption of Autogas in Nigeria.

Result/Discussion

Comparing Autogas Adoption Strategies of Iran, Egypt, and India

Autogas adoption strategies vary across different countries, including Iran, Egypt, and India. Examining these strategies can provide valuable insights for Autogas adoption in Nigeria. Let's compare the Autogas adoption strategies of these countries and highlight key lessons that can be applied to Nigeria:

A. **Iran:** Iran has been a global leader in Autogas adoption, with a substantial portion of its vehicle fleet running on Autogas. The country's Autogas adoption strategy includes the following elements:

1. Government Subsidies: Iran offers significant subsidies on Autogas to make it an attractive and cost-effective option for vehicle owners. For example, the Iranian government has implemented a Fuel Card System, which provides financial assistance to vehicle owners by subsidizing the cost of Autogas, making it more affordable compared to traditional fuels (Sarabi, 2011).

2. Infrastructure Development: Iran has established a robust Autogas refueling infrastructure, with a wide network of refueling stations across the country. The availability of refueling stations is crucial to ensure convenient access to Autogas for motorists. Iran's infrastructure development efforts include the construction of dedicated Autogas refueling stations and the retrofitting of existing gasoline stations to accommodate Autogas dispensing facilities (Sarabi, 2011).

3. Conversion Programs: The government of Iran has implemented conversion programs to encourage vehicle owners to convert their vehicles to run on Autogas. These programs provide financial assistance and support for the conversion process. For instance, the Iranian government has introduced a subsidy program that covers a significant portion of the conversion costs, making it financially viable for vehicle owners to switch to Autogas (Sarabi, 2011).

Insights for Nigeria: Nigeria can draw lessons from Iran's Autogas adoption strategy by considering the implementation of government subsidies and incentives to encourage vehicle owners to switch to Autogas. Additionally, investing in the development of a widespread Autogas refueling infrastructure, such as constructing dedicated Autogas refueling stations and retrofitting existing stations, would be crucial to ensure easy accessibility for motorists.

B. **Egypt**: Egypt has made significant progress in promoting the use of Autogas as an alternative fuel. Some key elements of Egypt's Autogas adoption strategy include:

- Market Liberalization: Egypt has implemented policies to liberalize the Autogas market, allowing private sector participation and investment in Autogas infrastructure. For example, the government has introduced regulations that facilitate private investment in Autogas refueling stations, leading to an increase in the number of stations across the country (Akin-Tepede, 2010).

- Conversion Programs: The government has launched conversion programs to incentivize vehicle owners to convert their vehicles to Autogas. These programs provide financial support and facilitate the conversion process. One example is the "Egypt Vehicle Conversion Initiative," which offers financial incentives and support to vehicle owners who convert their vehicles to run on Autogas (Akin-Tepede, 2010).
- Awareness Campaigns: Egypt has conducted awareness campaigns to educate the public about the benefits of Autogas, including its environmental advantages and cost savings. These campaigns have involved public advertisements, workshops, and targeted outreach programs to reach vehicle owners and promote the adoption of Autogas (Akin-Tepede, 2010).

Insights for Nigeria: Nigeria can learn from Egypt's Autogas adoption strategy by promoting market liberalization and encouraging private sector participation in Autogas infrastructure development. Implementing targeted conversion programs, similar to the "Egypt Vehicle Conversion Initiative," and conducting comprehensive awareness campaigns can also help increase acceptance and adoption of Autogas among vehicle owners.

C. **India:** India has been actively promoting the use of Autogas as a cleaner and more affordable fuel option. Some key elements of India's Autogas adoption strategy include:

- Government Incentives: The Indian government provides incentives, such as tax benefits and subsidies, to encourage vehicle owners to switch to Autogas. For instance, the government has implemented the "Pradhan Mantri Ujjwala Yojana" scheme, which offers financial assistance to below-poverty-line households for the conversion of their cooking fuel from traditional sources to Autogas (Swain & Mishra, 2020).
- Collaborative Approach: India has adopted a collaborative approach involving various stakeholders, including government agencies, oil companies, and vehicle manufacturers, to create a supportive ecosystem for Autogas adoption. For example, the government has collaborated with oil marketing companies to establish Autogas refueling stations at their existing petrol stations, leveraging their infrastructure and distribution networks (Ranjan & Singh, 2020).
- Awareness and Training Programs: India has conducted extensive awareness and training programs to educate the public, fleet operators, and mechanics about the benefits of Autogas and the conversion process. These programs include workshops, seminars, and skill development programs to equip mechanics with the necessary knowledge and skills for Autogas conversions (Ranjan & Singh, 2020).

D. **Italy**: Italy is another country that has successfully adopted Autogas as an alternative fuel. The Italian government has implemented policies to encourage the conversion of vehicles to Autogas and the installation of Autogas refueling stations. These initiatives have been supported by collaborations between government bodies, research institutions, and industry partners. For example, universities and research centers have contributed to technological advancements in Autogas systems, while industry players have invested in infrastructure development. This collaborative evidence can be a lesson pathway for Nigeria to drive Autogas market.

4.0 Nigeria's adoption strategy using the triple helix model.

The triple helix model anchors on the collaboration of the government, academia, and industry to unlock the production capability of any economic sector.

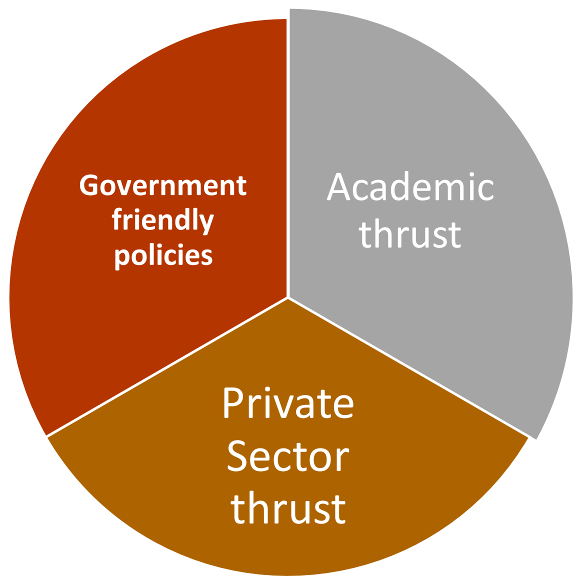

Fig 1 Triple helix model

1. **Government thrust**: Nigeria can take inspiration from India's Autogas adoption strategy by implementing government incentives, similar to the "Pradhan Mantri Ujjwala Yojana" scheme, and collaborating with key stakeholders to create a conducive environment for Autogas adoption. Pathways through which government can create the enabling environment for investment inflows include.

A. Tax holidays incentives

B. Duty waivers for Gas related equipment

C. Security of gas assets

D. Policy to encourage indigenous Oil & gas companies to invest on gas utilization projects that are targeted at the transport sector.

E. Policy to encourage OEM companies to target producing gas vehicles for the Nigerian market.

F. Special tax on PMS users. Road worthiness for vehicle using PMS should be renewed at N7,000 while gas fueled vehicles should be renewed at N5,000. Currently, commercial vehicle road worthiness is renewal every six months while other salons are renewed yearly except for vehicle on special exemption. (Highwaycode,2023)

Table 1: Proposed Road worthiness rate

ITEMS	OLD RATE	NEW RATE
ROAD WORTHINESS	5,500	7,000
GAS FUEL RATE	NA	5,000
DIFFERENCE		**2,000**

The tax gain of N2,000 can generate 20 billion naira per annum assuming 10 million vehicles using PMS. This tax gain can be plowed into more infrastructural development of fuel gas distribution outlets.

2. **Accademia thrust**: Conducting awareness and training programs would be crucial in educating vehicle owners, mechanics, and other relevant stakeholders about Autogas benefits and promoting its use. More critically is educating the populace through specialized academic programs to implant in the consciousness of key players on the economics of transition using gas resources. Like India, Nigeria through her educational institutions can create new knowledge channels to ensure the needed capacity to unlock the gas value chain is visible within her human resources. These channels may include.
    A. Targeted academic programs & research
    B. Strategic Seminars
    C. Skill acquisition programs
    D. Energy conferences
3. **Private sector thrust**: Investors fund will naturally flow to where returns are guaranteed. Partnership with the private sector in providing single digit credit facilities and allowing them to drive businesses around the gas sector which will unlock the entire gas value chain. This collaborative approach is visible in both the Indian and Iran case studies; therefore, Nigeria can take a cue to develop her huge gas asset to power her transport sector. Egypt's example of promoting market liberalization can benefit Nigeria. Oil companies should be encouraged to run all their fleets of vehicle on Autogas as a show of good faith and encouraged along with other private industry players to drive the market.

Conclusion

In conclusion, this research aimed to explore Autogas adoption strategies of Iran, Egypt, and India, as a prelude

to jumpstart Nigeria's auto gas adoption using the triple helix model.

Comparisons of Autogas adoption strategies in these countries provided valuable lessons for Nigeria. Government subsidies, infrastructure development, conversion programs, market liberalization, and awareness campaigns were identified as key elements that contributed to successful Autogas adoption in these countries. Nigeria can draw inspiration from these strategies by considering the implementation of government incentives, developing a widespread Autogas refueling infrastructure, promoting market liberalization, and conducting comprehensive awareness campaigns.

The findings of this research underscore the potential of Autogas as a promising alternative to traditional automotive fuels in Nigeria. Autogas offers advantages such as reduced emissions, cost savings, and energy efficiency. However, it is essential to acknowledge the limitations of the literature review methodology, which relies on existing studies and publications, and the inherent variations in quality, methodologies, and perspectives. The findings should be considered within the context of the reviewed literature and the limitations of the methodology.

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DECISION SUPPORT MODEL FOR THE MAINTAINABILITY OF STEAM POWER PLANT

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Abstract

This study focused on the development of a Decision Support Model (DSM) for the maintainability and management of a steam power plant, and the model was validated using actual data from a typical organisation in Port Harcourt with a steam power plant. The Time Before Failure (TBF) and Time To Repair (TTR) data set was collected and analysed using the Statistical Package for the Social Sciences (SPSS) to determine the best-fit distribution, which was used to determine the reliability, maintainability, and availability of the steam power plant. A reliability-centered maintenance (RCM) programme was developed for the plant's fire-tube boiler, water treatment plant, condenser, steam distribution system, waste disposal system, turbo-alternator, feed-water pump, and turbine based on the findings. On the implementation of the DSM model, the steam power plant achieved a 90% reliability with a maintenance time interval of 529.28hours for the Waste Disposal System (WDS), 1104.6 hours for Fire Tube Boiler (FTB), 1300.51 hours for Water Treatment Plant (WTP), 1280.78 for the Turbo-Alternator (TUA), 4692.87hours for the Feed Water Pump (FWP), 2164.77hours for the Steam Distribution System (SDS), 5029.28hours for the Turbine (TUR) and 3542.20 hours for the Condenser (CON). The study can conclude therefore that the developed model is feasible and has been able to address all the reliability related challenges considered in the study. Some of which include frequency equipment down time, availability of the equipment and the maintainability of the steam power plant subsystems.

Key Words: Decision support, Steam Power Plant, Reliability-Centered Maintenance.

Introduction

Since steam power plants are used to generate energy as well as for a variety of other purposes, their importance and contribution to the expansion of the global Gross Domestic Product (GDP) cannot be exaggerated, currently, *more than 80% of global electricity production* is contributed by thermal power plants [27]. Meanwhile, electricity is the backbone of automated business. To a reasonable extent, human beings depend on the wealth generated by automated businesses. The supply of electricity and transportation are two fundamental elements that promote businesses and human pleasure. Recently, various robotics and other systems have been produced to mitigate human physical involvement in production outfits. But when there is a breakdown in any of these systems, production efficiency is often grossly affected; according to [1], who assert that a major breakdown in a system affects production and quality of products.

This may also have a negative impact on the organization's integrity, leading to the end user losing trust in the organization.

System failure and organisational losses become crucial factors for producers when assessing the quality and dependability of products. Beyond these, the aggressive competition among businesses and organisations has intensified the struggle for existence as stated by [2]. According to [3], the majority of manufacturers are motivated to cut back on production lost time, expense, and safety. Any company running a steam power plant must maintain a safe working environment while offering its clients dependable and high-quality service at an affordable price in order to stay in business. In the end, the cost of running a steam process plant keeps going up, and maintenance expenses, which can account for 15% to 70% of total operating expenses, are one of the major drivers of operational costs as narrated by [4]. Therefore, every effort must be made to minimise maintenance costs so as not to jeopardise environmental safety, system availability, safety, or reliability. The following maintenance system components should be optimised in order to achieve this.

1. Risk assessment
2. Maintenance strategy selection
3. Maintenance strategy interval determination

Risk generally results from a system's likelihood of failing and the consequences of that failure. Each component of the steam power plant will be subject to a risk assessment, and the maintenance approach most suited for probable failure mitigation implications will be selected based on the level of risk indicated. The operation of a steam power plant can be maintained using a variety of maintenance techniques. Corrective maintenance, preventive maintenance, and condition-based maintenance are the three categories into which the maintenance strategies are divided. According to the corrective maintenance philosophy, equipment should be run until it breaks down before any corrective action is taken. A strategy known as preventive maintenance involves routinely carrying out scheduled maintenance tasks, such as replacement or overhaul. In condition-based maintenance, the maintenance task is carried out in accordance with the equipment condition that has been noticed. The two main methods for assessing the state of a piece of equipment are continuous and periodic, according to [5]. Because periodic monitoring is less expensive than continuous monitoring, it is most preferred. The next phase in the maintenance management system is to establish the suitable interval for carrying out the maintenance work after the optimal maintenance strategy for each piece of equipment has been established.

Up until recently, testing and analysis of test findings was the method used to determine reliability. It is now apparent that this approach does not help the organisational effort to keep the process plant facilities maintained. The focus should be on anticipating the factors that led to system failure and working out how to remedy them in order to further prevent a recurrence, as claimed by [6].

Reliability-Centered Maintenance (RCM) takes system functions, failures, safety, and maintenance cost effectiveness into account. RCM is a procedure that can indicate what needs to be done to ensure a machine's functionality and availability. According to [7], the use of RCM is an efficient preventive maintenance (PM) optimisation strategy. This technique has lately gained popularity in process plant setups. The goal of preventive maintenance (PM) is often to calculate the likelihood of having an unscheduled repair, which is frequently expensive.

Historical overview of Reliability, Availability and Maintainability (RAM)

RAM, an acronym for "reliability, availability, and maintainability," has been in use as a standalone system for about fifty years. According to [8], reliability is defined as the extent to which an item fulfils its intended purpose when subjected to a particular set of environmental and operating conditions over a certain period of time. The concepts of maintainability and availability are related yet distinct. Plant availability is a function of the reliability and maintainability i.e., A = f (R, M). The definition of availability makes it clearly understandable that a process engineer can increase the plant's availability during the design stage by increasing the dependability or maintainability of the plant, or both. According to recent research from [8].

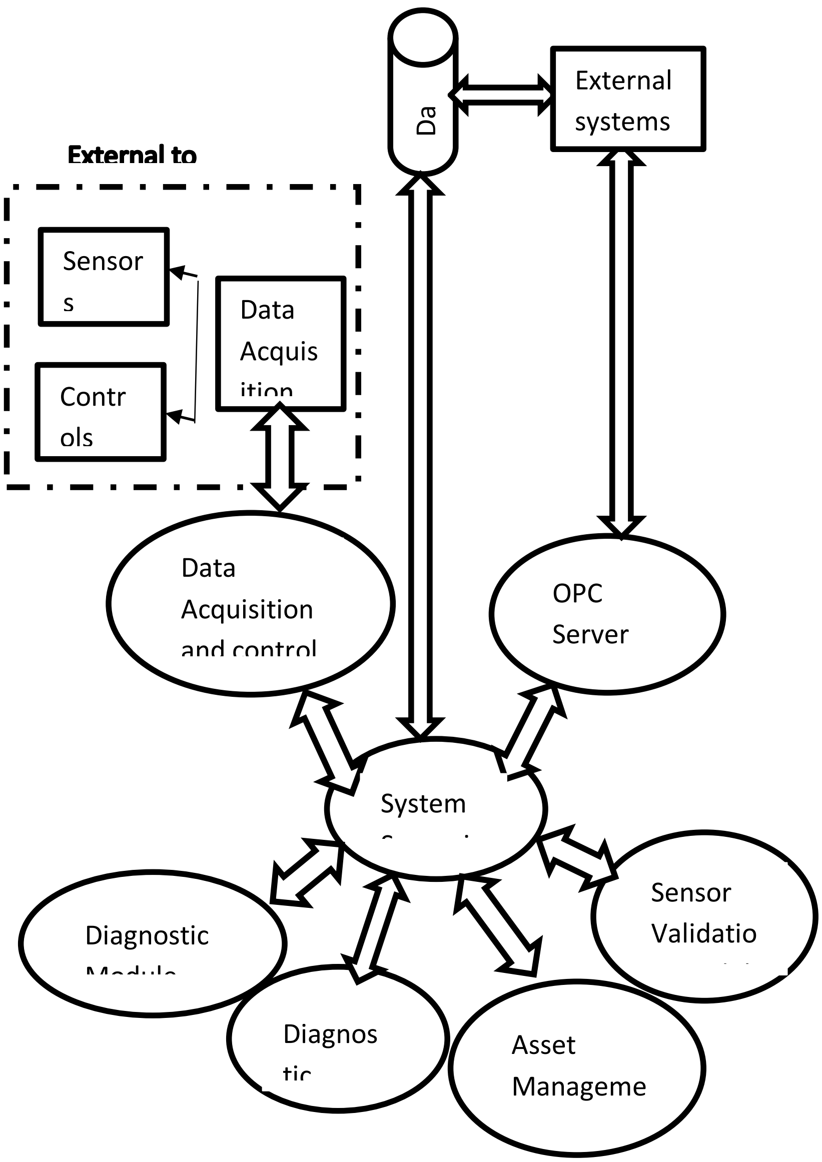
A real-time reliability evaluation model based on automatic partition and the time-varying Markov chain was proposed by [9] to address the challenges of scientific state number selection and time-varying properties description using the Markov process's state transition matrix. In order to build a full analytic network process model, [10] created multiple criteria decision support. The purpose of this model was to make visible all of the connections and dependencies between the various parts of the problem, a process that is notoriously difficult to accomplish. The expenses of sustaining an asset were thoroughly examined by [11], who then utilised a genetic algorithm to optimise those costs in order to boost the asset's performance (i.e., its availability). Using gamma and exponential failures, [12] proposed a competing risk model. Age-related failures are represented by the gamma distribution, while failures with an exponential distribution are indicative of random failures.

A thorough review of the literature on reliability engineering was conducted by [8] and found that several recently developed methods, software, techniques, and models had substantial potential. These included Petri nets, Markov models, the Artificial Bees' Colony (ABC) algorithm, and Optimal Computing Budget Allocation (OCBA). The method for multi-objective optimisation suggested by [13] is based on evolutionary algorithms and explicitly accounts for uncertainty in the parameters. [14] created a model for planning periodic preventive maintenance on systems that is based on a simulated annealing strategy. The sugar company's feeding unit implemented a Decision Support System to rank the importance of servicing its numerous components. This action was taken to ensure the smooth functioning of the feeding machine. For risk assessment of generic networks like transportation, water supply, sewers, telecommunications, electrical, and gas networks, [15] proposed a non-simulation-based network reliability analysis method based on the Recursive Decomposition Algorithm (RDA). [16] used petri nets to deals with the availability analysis which is of a Lube oil system used in a combined cycle power plant. A Generalised Stochastic Petri Net (GSPN) is utilised to represent the system, with common failure mechanisms and partial subsystem failures both taken into account in the study.

The usage of a genetic algorithm is the research that [17] carried out which was aimed at improving the overall efficiency of a milk processing plant. A probabilistic method is utilised to build the mathematical formulation, and the birth-death process developed by Markov was put to use in order to produce differential equations. [18] offered a stochastic analysis as well as a performance evaluation of the steam generator system found in a thermal power plant. At the beginning, a transition diagram was built up in order to portray the operational behaviour, and the Markov technique was utilised in order to find a solution to the issue. It has been determined that the availability of each system has been examined, and condition-based maintenance approaches have been presented. [19] have dealt with the mathematical modeling and performance optimization for the paper making system in a paper plant using genetic algorithm. [20] was the one who developed the procedures that are used for studying system dependability, and a substantial amount of these approaches are dependent on failure data. Also focuses on establishing a method that evaluates the dependability of a system that possesses extraordinarily reliable components and systems, for which failure data is difficult to get. This method's primary goal is to reduce the amount of time spent gathering and analysing failure data. In order to find a solution to a problem involving several objectives for optimisation, [21] suggested using a method that was based on genetic algorithms (GA). This strategy was conceived with the objective of lowering the costs associated with repairable parallel-series systems while at the same time increasing the availability of repairable versions of such systems. A new method that is based on finite element equations was developed by [22], for the goal of conducting a systems dependability research on mechanical and hydraulic systems. This method was first introduced for this purpose. [23] presented a method for evaluating the dependability and availability of HRSGs, which may be found in these types of power plants. The design of a failure mode and impacts analysis, as well as the development of a functional tree for the steam generator, comprised the first phase of the process. This phase also marked the beginning of the process.

Decision Support Model for Maintainability of a Steam Power Plant (DSMMSPP)

A Decision Support Model for Maintainability (DSMM) computing architecture with Commercial off The Shelf (COTS) components is shown in Figure 1. This COTS consists of a database management system (DBMS), a graphic user interface (GUI) for data display, and other data analysis applications that may leverage the data and information provided by DSMM. The Object Linking and Embedding (OLE) for Operating Process Control (OPC) Server Module, the Sensor Validation Module, the Asset Management Module, the Diagnostic/Prognostic Module, and the Data Acquisition and Control Interface are all components of the modular DSMM Software System. The System Supervisor interfaces with internal data management and execution control for the remaining modules. Data transfer between the DSMM software system and other external independent Systems is made possible by the OPC Server Interface. Before being used by the System, the Sensor Validation Module evaluates and qualifies process parameter data.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1.1 Figure: 1. Decision Support Model for Maintainability of a Steam Power Plant (DSMMSPP)

In order to meet demand, the Asset Management Module will track process demand and suggest the best configurations for process components. The Diagnostic Module carries out diagnostics and prognostics at the component level of processes. The internal operations of the DSMM Software System and the data acquisition and control hardware are managed via the data acquisition and control interface. Data acquisition, sensor validation, diagnostic, and data archiving algorithms are started by the system supervisor. These algorithms should ideally operate independently, cooperatively, and synchronously. The System Supervisor also initialises intricate data structures, database interfaces, and Data Acquisition Systems (DAS). The system manager also moves data to and from databases, external systems, and DAS (using the OPC server module). By integrating supporting diagnostic and interface modules, managing the transfer of data between the modules and the database, including management of complex data structures, and implementing and managing communication with the OPC server module, the System Supervisor, in short, performs the various integrating and control functions required for proper interaction and synchronisation of the specialised modules.

The System Description

Figure 2 below shows the steam power plant's structural layout. A fire-tube boiler (FTB), a feed-water pump (FWP), a condenser (CON), a turbine (TUR), a turbo-alternator (TUA), a water treatment plant (WTP), and a steam distribution system (SDS) make up a steam power plant. The pulverised coal is supplied into the fire tube boiler (FTB) at the steam power plant, where it is burned in the furnace. High pressure steam is created when the water in the boiler drum is changed. High pressure steam was sent from the boiler to the super-heater, where it was once again heated to dryness. Through the steam distribution system (SDS), this superheated steam quickly contacts the turbine blades, causing the turbine to quickly begin whirling. The rotor of the turbine (TUR) is connected to a Turbo Alternator (TUA), and while the turbine turns, the Turbo Alternator also revolves at the same speed. The turbine's mechanical energy is transformed into electrical energy via the turbo-alternator. Steam enters the condenser (CON) after leaving the turbine after being struck. With the aid of the cooling tower's cold water, the steam is condensed. Water from the water treatment plant (WTP) is fed into the feed water pump (FWP). With the aid of the feed water pump, the condensed water is introduced into the economizer of the fire tube boiler. The boiler's efficiency is increased by this water heating. After burning of the coal in the furnace of the boiler, the ash is transported to ash handling plant and finally to the ash storage through waste disposal system (WDS).

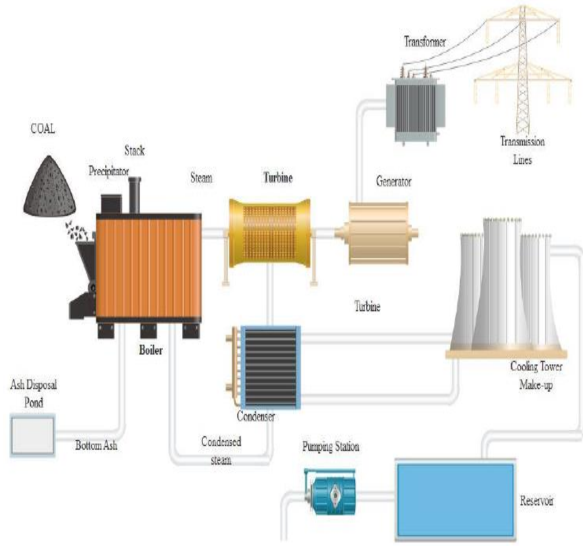

Figure: 2. A Typical Steam Power Plan

(Adopted from [24])

Functional Analysis

According to [25], reliability is primarily determined by the failure rate and time, but it can also be modelled using a variety of distribution functions. The exponential, lognormal, Poisson, and Weibull are often used examples. To choose the best model, one needs a thorough understanding of the system's operation, particularly its failure behaviour. In this dissertation, the Weibull distribution was the best fit distribution of the failure pattern.

The equation for reliability as per Weibull distribution according to [26] are as stated below.

$$R_{(t)} = e^{-(\frac{t}{\theta})^{\beta}} \tag{1}$$

Where, β is the shape parameter and θ is scale parameter.

$$R_{(t)} = \prod_{i=1}^{n} R_i(t) \tag{2}$$

The plant maintainability analysis was done using the equation below:

Maintenance Function (M(t)) are used to forecast the probability that a plant repair, starting at time t = 0, will be completed in a time t. Mathematical expression of maintainability according to [26] is

$$M_{(t)} = 1 - e^{-(\frac{t}{\theta})^{\beta}} \tag{3}$$

Where, β is shape factor and θ is scale parameter

The inherent availability (A_{in}) and operational availability (A_{op}) for all subsystem was computed using the equation below.

$$A_{in} = \frac{MTBF}{MTBF + MTTR} \quad (4)$$

$$A_{op} = \frac{MTBF}{MTBF + MDT} \quad (5)$$

Identification of Critical Subsystems and Failure

The Table 4.1 shows the identification of critical subsystems of a steam power plant and the number of failure for the period of the investigation. The fire tube boiler with code FTB is one of the critical subsystem of the steam power plant and the number of failure experience is 21, also, Condenser code is CON and the number of failure is 7, while the Steam distribution system is coded with SDS and the number of failure is 9. The turbine which is one of the critical subsystem with code TUR was identified with 11 failures, also, waste disposal system with code WDS was identify with highest number of failure for the period under investigation which is 38 failures, feed water pump with code FWP is also with 8 number of failure, Turbo-Alternator and Water treatment plant with code TUA and WTP respectively are with 10 and 14 number of failure respectively.

Table 1. Critical Subsystems and Failure Identification

No	Sub-System	Code	Frequency	Cumul. Hrs
1	Fire Tube Boiler	FTB	21	100,000
2	Condenser	CON	7	98,000
3	Steam Distribution System	SDS	9	98,000
4	Turbine	TUR	11	94,000
5	Waste Disposal System	WDS	38	92,000
6	Feed Water Pump	FWP	8	96,000
7	Turbo-Alternator	TUA	10	105,000
8	Water Treatment Plant	WTP	14	95,000

It is observed from the above

graph in Figure 4.1 that the most frequent failure occurrence takes place in the waste disposal system (32.20%), which is followed by fire tube boiler (17.79 %). So these subsystems need to be inspected for maintenance more than the other subsystems.

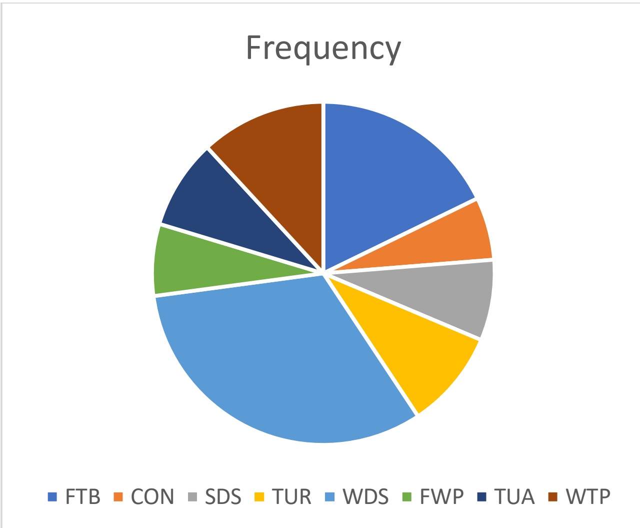

Figure 3 Failure characteristics of the power plant subsystems.

Estimation of the Reliability Parameters

Parameters of Weibull distribution was being estimated analytically using IBM SPSS. Table 4.10 shows that TBF data set of all the subsystem WDS, FTB, WTP, SDS, TUR, CON, TUA and FWP follows Weibull distribution.

Table 2. Best-Fit Distributions and their Estimated Parameters for Time Before Failure

S/N	Sub-System	Best-Fit Distribution	Parameters
1	FTB	Weibull	θ= 5334.971 hrs. β=1.432
2	CON	Weibull	θ= 16288.044 hrs. β=1.478
3	SDS	Weibull	θ= 12565.483 hrs. β=1.451
4	TUR	Weibull	θ= 10701.221 hrs. β=2.984
6	WDS	Weibull	θ= 2678.138 hrs. β=

			1.191
7	**FWP**	**Weibull**	**θ= 13671.545 hrs. β= 2.113**
8	**TUA**	**Weibull**	**θ= 11091.622 hrs. β=1.042**
9	**WTP**	**Weibull**	**θ= 7109.110 hrs. β=1.326**

As shown in Table 2. The shape parameter (β) of TUR and FWP is more than two, which indicates increasing failure rate due to aging process. Therefore, there is need for decision support model to be used to determine whether predictive or preventive maintenance system will be suggested for these subsystems. Shape parameter of WDS is 1.191 which is a little above one, indicating a constant failure rate as they reach useful life or steady state condition. Shape parameter of TUA is 1.042 which is almost one indicating decreasing failure rate, which indicates that it is in its early life or debugging period. Thus, for all the sub-system of the steam power plant, decision support model is necessary for the determination of the maintenance strategies to be used.

Power Plant Reliability Estimation

According to the data gathered on their time before failure, the theoretical reliability for each subsystem of the steam power plant at the conclusion of various mission times has been estimated. For Weibull distribution neglecting location parameter, reliability has been calculated according to equation 1 as stated in above. Equation 2 was used to calculate the whole plant's reliability. Table 3 below displays the calculated reliability values for the subsystems and the entire steam power plant.

Table 3 Reliability of the Power Plant at the End of Different Time Intervals

Time (hrs)	WDS	FTB	WTP	TUA	FWP	SDS	TUR	CON	TOTAL PLANT
0	1	1	1	1	1	1	1	1	1
400	0.9999	0.9758	0.9782	0.9691	0.9994	0.9933	0.9999	0.9958	0.9142
800	0.9996	0.9361	0.9463	0.9375	0.9975	0.9818	0.9996	0.9884	0.8032
1200	0.9985	0.8887	0.9098	0.9062	0.9941	0.9674	0.9985	0.9790	0.6878
1600	0.9965	0.8367	0.8708	0.8755	0.9893	0.9510	0.9966	0.9681	0.5770
2000	0.9933	0.7824	0.8302	0.8455	0.9829	0.9329	0.9933	0.9559	0.4749
2600	0.9854	0.6996	0.7684	0.8021	0.9705	0.8131	0.9854	0.9358	0.3092
300	0.97	0.64	0.72	0.77	0.96	0.88	0.97	0.92	0.27

0	77	50	72	41	02	24	78	12	09
4000	0.9483	0.5158	0.6272	0.7079	0.9282	0.8270	0.9483	0.8821	0.1394
5000	0.9019	0.4020	0.5341	0.6467	0.8875	0.7690	0.9019	0.8398	0.0647
6000	0.8370	0.3063	0.4500	0.5903	0.8391	0.7103	0.8370	0.7956	0.0270
7000	0.7544	0.2287	0.3754	0.5385	0.7842	0.6519	0.7544	0.7505	0.0101
8000	0.6543	0.1676	0.3105	0.4861	0.7241	0.5949	0.6576	0.7049	0.0033
9000	0.5456	0.1207	0.2548	0.4474	0.6614	0.5400	0.5507	0.6596	0.0010
10000	0.4418	0.0855	0.2076	0.4075	0.5966	0.4512	0.4418	0.5412	0.0002

According to Fig. 4. above, all the subsystems are functionally grouped in a series manner. This denotes that the power plant is only in its operational state when all of the subsystems are performing effectively.

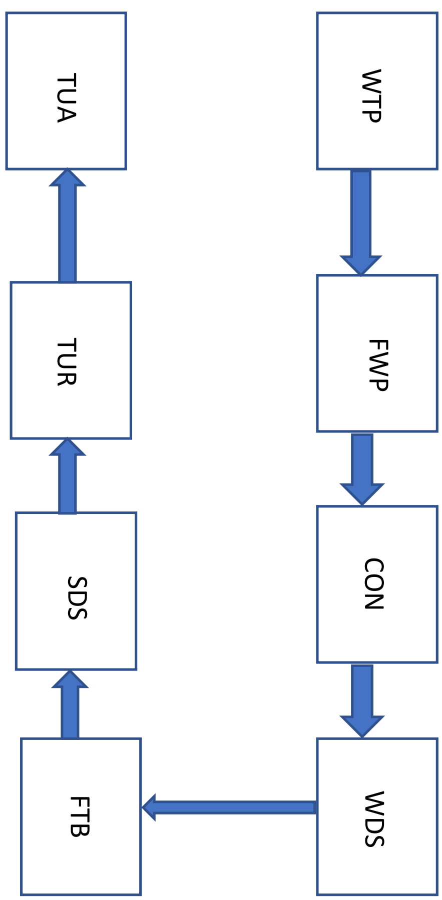

Figure 4 The Series Configuration of the Steam Power Plant Subsystem

Table 4 shows all the parameter of the TTR data set of all the subsystem WDS, FTB, WTP, SDS, TUR, CON, TUA and FWP using Weibull distribution.

Table 4 Best-Fit Distributions and their Estimated Parameters for Time To Repair

S/N	Sub-System	Best-Fit Distribution	Parameters
1	WDS	Weibull	θ = 45.925 hrs. β= 1.037
2	FTB	Weibull	θ = 43.555 hrs. β= 1.797
3	WTP	Weibull	θ = 52.086 hrs. β= 2.575
4	TUA	Weibull	θ = 28.779 hrs. β=4.713
5	FWP	Weibull	θ = 34.398 hrs. β =2.392
6	SDS	Weibull	θ = 42.241 hrs. β =2.020
7	TUR	Weibull	θ = 27.663 hrs. β =6.192
8	CON	Weibull	θ = 38.991 hrs. β =2.312

The Maintainability of the Power Plant

The theoretical maintainability (M) for all the subsystems of the power plant at the end of different given time (t) has been estimated according to the best-fit distribution of their time to repair data collated. The maintainability of the subsystems has been calculated according to equations 3.3 for the Weibull distribution of TTR data collated. The calculated maintainability of all the subsystems as well as of the whole power plant for different given time interval is tabulated in Table 4.21. From Table 5, it is seen that the maintainability of FTB and WDS is lower than other subsystems. So special attention is required to improve their maintainability as well as of the whole plant by the use of Decision Support Model to reduce maintenance time with proper resource allocations like skilled manpower, spare parts etc.

Table 5. The Maintainability of the Power Plant at Different Given Time Interval

Time (hrs)	WDS	FTB	WTP	TUA	FWP	SDS	TUR	CON	T.P
10	0.186	0.069	0.014	0.007	0.051	0.053	0.002	0.042	0.000
20	0.345	0.219	0.081	0.165	0.239	0.198	0.126	0.192	0.000
40	0.580	0.576	0.398	0.991	0.762	0.591	0.765	0.901	0.040
60	0.733	0.831	0.763	1.000	0.977	0.901	0.886	0.933	0.338
80	0.831	0.949	0.951	1.000	0.999	0.973	1.000	0.995	0.731
100	0.894	0.988	0.995	1.000	1.000	0.997	1.000	0.999	0.876
200	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.989
300	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999
400	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999
500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

The Availability of the Power Plant

Finally the inherent availability (Ain) and operational availability (Aop) for all subsystems of the steam power plant has been computed by using equations 4 & 5 respectively and subsequently tabulated in Table 6. The Table 6 shows that the availability of WDS and FTB is less than that of the other subsystems and is critical. The Decision Support System will improve the availability of the WDS and FTB which will in turn improve the availability of the whole power plant.

Table 6 The Availability of the Power Plant

Sub sys	Total No, of Fail.	Cum. TBF (hrs.)	Cum. Down Time	Cum. TTR (hrs.)	MTBF (hrs.).	MDT (hrs.).	A_{op}	MTTR (hrs).	A_{in}

WDS	38	92000	3214	1600	2421.05	84.58	0.97	42.11	0.98
FTB	21	100000	1984	600	4761.90	94.48	0.98	28.57	0.99
WTP	14	95000	963	390	6785.71	68.79	0.99	27.86	1.00
TUA	10	105000	753	150	10500	75.30	0.99	15.0	1.00
FWP	8	96000	475	180	12000	59.38	1.00	22.5	1.00
SDS	9	98000	642	270	10888.88	71.33	0.99	30	1.00
TUR	11	94000	563	300	8545.45	51.18	0.99	27.27	1.00
CON	7	98000	253	230	14000	36.14	0.99	32.86	1.00

From table 6 above, it can be seen that the inherent availability for WDS is 97% while its operational availability is 98%. Also, the inherent availability for FTB is 98% while its operational availability is 99%, the inherent availability for WTP is 99% while its operational availability is 100%, the inherent availability for TUA is 99% while its operational availability is 100%, the inherent availability for FWP is 100% while its operational availability is 100%, the inherent availability for SDS is 99% while its operational availability is 100%, the inherent availability for TUR is 99% while its operational availability is 100% and finally, the inherent availability for CON is 99% while its operational availability is 100%. it is shows that the availability of WDS and FTB is less than that of the other subsystems and is critical. The availability of the WDS and FTB has to be improved using decision support model for the maintainability of steam power plant in order to improve the availability of the whole power plant.

Resultant Effect of DSM on the Reliability of the Steam Power Plant

The application of the Decision Support Model determined the maintenance time intervals for different expected levels of reliability as shown in Figure 5.

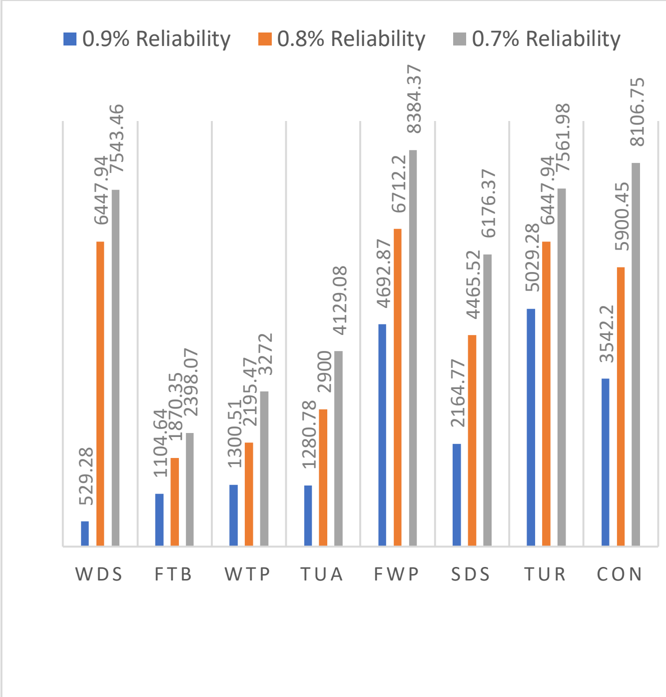

Figure 5 DSM Effect on Maintenance Time Interval on the Reliability of the Steam Power Plant

From the above table 4.23, the decision support model affected the maintenance time interval of the subsystem on the reliability of the steam power plant. For 90% reliability (R = 0.90) of the steam power plant, the maintenance interval of the subsystem varies as waste disposal system (SDS) maintenance time interval is 529.28 hrs, Fire Tube Boiler (FTB) is 1104.64 hrs, Water Treatment Plant (WTP) is 1300.51 hrs, Turbo-Alternator is 1280.78 hrs, Feed Water Pump (FWP) is 4692.87 hrs, Steam Distribution System (SDS) is 2164.77 hrs, Turbine (TUR) is 5029.28 hrs and Condenser (CON) is 3542.20 hrs. The Decision support model operating principle is based on the operating characteristics of the power plant where cost data is neglected, but the reliability and the availability of the steam power plant is of the ultimate consideration which will eventually save cost by preventing unexpected breakdown of the steam power plant. For 80% reliability (R = 0.80) of the steam power plant, the maintenance interval of the subsystem varies as waste disposal system (SDS) maintenance time interval is 6447.94 hrs, Fire Tube Boiler (FTB) is 1870.35 hrs,

Water Treatment Plant (WTP) is 2195.47 hrs, Turbo-Alternator is 2900.00 hrs, Feed Water Pump (FWP) is 6712.20 hrs, Steam Distribution System (SDS) is 4465.52 hrs, Turbine (TUR) is 6447.94 hrs and Condenser (CON) is 5900.45 hrs. This maintenance interval is used for inspection, repair, servicing, condition monitoring or replacement depending upon the safety implications and cost–benefit considerations. For 70% reliability (R = 0.70) of the steam power plant, the maintenance interval of the subsystem varies as waste disposal system (SDS) maintenance time interval is 7543.46 hrs, Fire Tube Boiler (FTB) is 2398.07 hrs, Water Treatment Plant (WTP) is 3272.00 hrs, Turbo-Alternator is 4129.08 hrs, Feed Water Pump (FWP) is 8384.37 hrs, Steam Distribution System (SDS) is 6176.37 hrs, Turbine (TUR) is 7561.98 hrs and Condenser (CON) is 8106.75 hrs.

The Reliability, Maintainability and Availability of the Steam Power Plant and the Subsystem

From the tables and the data results presented above, the reliability, maintainability and availability of a steam power plant has been critically analyzed and evaluated. All the Time Before Failure and the Time To Repair data of the power plant's subsystems are found to be independent and identically distributed. Weibull distribution signifies the best fit, in all the cases, to Time Before Failure datasets of Waste Disposal System (WDS), Fire Tube Boiler (FTB), Turbine (TUR), Water Treatment Plant (WTP), Turbo-Alternator (TUA), Feed Water Pump (FWP), Steam Distribution System and Condenser, so the Decision Support Model for the maintainability of the power plant will enable predictive and preventive maintenance for these subsystem.

From Table 6, it can be observed that the availability of the Waste Disposal System (WDS) and the Fire Tube Boiler (FTB) both the operational and inherent availability are lesser compare to the other sub system availability. This implies that this will also affect the availability of the whole plant. So, the availability of the WDS and FTB has to be improved using decision support model for the maintainability of steam power plant in order to improve the availability of the whole power plant.

The case study shows that Waste Disposal System and Fire Tube Boiler are critical from reliability point of view. Hence the main focus should be on improving the reliability of Waste Disposal System and Fire Tube Boiler by applying Decision Support Model for proper maintenance strategy. As seeing in Figure 6, to maintain a 90% reliability for the subsystem of the steam power plant, the maintenance interval for some of the subsystem was high while some was low. Introducing Decision Support Model for inspection and maintenance interval at 70% reliability level, prior to failure of the subsystems actually improve the Mean Time Before Failure. Fire Tube Boiler and Steam Distribution System are critical from maintainability point of view; hence special attention should be provided for improvement of their maintainability that is, reduction of Mean Time To Repair by proper resource allocation. Therefore, availability of the subsystems as well as of the whole power plant will increase by the improvement in Mean Time Before Failure and subsequent reduction in Mean Time To Repair.

1.2 Conclusion

The application of Decision Support Model in Reliability Centered Maintenance management framework of Steam Process Plant helps to explore the use of sophisticated technical solutions. The application of this developed sophisticated technology in maintenance and operations of power production facilities will bring huge benefits in terms of reducing risk and enhancing profitability. The potential benefits of this model include:

(i) Improvement in terms of more effective and efficient management of potential occurrences and incidents that could result in operational failures.

(ii) Widely acknowledged by maintenance experts as the most economical method of creating top-notch maintenance plans. Decision support in RCM improves plant availability and reliability, product quality, safety, and environmental integrity quickly, consistently, and significantly.

(iii) More realistically modelled, analysed, and predicted system behaviour (removes ambiguity in maintenance planning). Deal with the difficulty of evaluating qualitative criteria that are

(iv) Employed in traditional analytical procedures in a direct, quantitative manner.

(v) Aids in a quick assessment of the rankings of multiple maintenance activities so that appropriate maintenance practices and strategies can be planned for enhancing system performance.

(vi) Helps to eliminate over/under maintenance.

(vii) Helps to find out hidden causes of failure.

(viii) Agreement on how operational risk areas would be addressed, leading to increased system readiness

It is uncommon for maintenance optimisation models to be used successfully. The main challenges in using the model are those related to computation, data collection, and failure distribution modelling. It is crucial to conduct a thorough investigation to develop a methodology for modelling the failure distribution or degradation process of equipment that takes into account the data needed for modelling, how to obtain that data, how to estimate the model parameters, and how to update the model as new data becomes available.

The conclusion of the findings showed a high likelihood evolution of a digitalized power system and the application of data analytics and big data management. The use of Decision Support Model has demonstrated how maintenance methods and results are likely to change in the steam power plant. It is anticipated that RCM will use the data to discover patterns, underlying causes, and make judgements for the improvement of the steam power plant's maintainability through the use of a decision support model.

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Optimal Placement of Short Circuit Current Limiters for Upgrade of Trans-Amadi 132/33kV Network Using Series Reactors

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Abstract

As advancements in power generation and transmission systems persist, the consequential increase in fault current levels poses a substantial challenge to the stability of electrical grids. Elevated fault current magnitudes have the potential to disrupt existing protection mechanisms and circuit breakers, thereby jeopardizing the overall health of the electrical grid. To address this pressing issue, this research paper focuses on evaluating the efficacy of current limiting reactors (CLRs) in mitigating fault current levels within electrical grids. This study delves into the impact of CLR deployment on fault current reduction and delves into the optimal placement of these devices within the grid infrastructure. This research unequivocally demonstrates that the utilization of CLRs serves as a highly effective strategy for reducing fault current levels. Moreover, the precise positioning of these reactors within the grid emerges as a pivotal factor influencing overall performance. Through comprehensive analysis, this research employed advanced power analysis software for meticulous modelling, strategically integrating optimally sized Current Limiting Reactors (CLRs) within the Trans-Amadi 132/33kV Network, in order to mitigate against power outages and costs incurred from frequent replacement of network protection equipment due to excessive fault current-induced thermal and mechanical stress.

Keywords: Series Reactors, Short Circuit Limiters, Power System.

INTRODUCTION

When faults arise in power systems, they can lead to the flow of large currents. A particularly concerning scenario is a dead short circuit occurring at the bus bars or terminals, where the currents can escalate to enormous levels, resulting in severe mechanical and thermal stresses. This can cause substantial damage to equipment and operating facilities. Replacing existing switchboards with higher-rated short circuit capability might not be feasible due to production constraints and cost limitations.

In certain situations, dividing bus bars or splitting the network isn't a viable option, especially when concerns about power reliability and security arise, as is the case with the 132/33kV Trans-Amadi Network. Moreover, installing patented current limiters in existing switchboards and substations can pose challenges due to space and installation constraints. In such scenarios, the utilization of series current limiting reactors presents an effective solution to mitigate short circuit currents.

The case study for this research work focuses on the Trans-Amadi 132/33KV Network, which receives power from Alaoji and Afam generating stations, and the Trans-Amadi injection substation, before distributing power to the Rumuosi substation. This network plays a crucial role in the Port Harcourt electrical power system, making it

essential for fault analysis and fault limitation efforts.
The primary goal of the research is to design an efficient short circuit current limiting scheme for the 132/33kV Trans-Amadi Network by implementing Series Reactors while ensuring optimal reliability. To achieve this, the research aims to: model the network using the Electrical Transient Analyzer Program (ETAP) software application, select and size the appropriate Current Limiting Reactor, determine the optimal positioning of the Current Limiting Reactor and analyze the benefits of implementing fault current limitation.
The significance of this study lies in the ability to accurately size and position series current limiting reactors within the electrical network, thereby reducing the magnitude of fault current during short circuit faults. By doing so, it aims to prevent power outages and safeguard equipment against adverse damage, thus saving costs associated with equipment replacement.

MATERIALS AND METHODS

In medium and high voltage installations, the short-circuit current amount is dependent on the voltage and inductive reactance of the distribution power system. To restrict the short-circuit current at a voltage level, the only option is to increase the inductive reactance present at the fault location. This is achievable through two methods: either by increasing the circuit's inductance or by eliminating certain parts of the circuit from the fault path. Reactors can be added to increase inductance, while current limiters can be utilized for the latter option (Chen, Y et al. 2017).

The first step in the methods needed for the Network improvement involves modeling the Single Line Diagram (SLD) of the existing power system using the Electrical Transient Analyzer Program (ETAP) 19 software. Data and parameters obtained from various verified sources will be inputted into the ETAP model to ensure accuracy and relevance. The existing network will undergo Short Circuit Analysis using the Electrical Transient Analyzer Program (ETAP) 19 software application to identify potential fault scenarios and fault current magnitudes. The proposed Current Limiting Reactor will be sized using the fault current per- unit calculation method, considering existing fault currents to determine the appropriate reactor rating for effective fault current limitation. Current Limiting Reactors will be integrated into the power system model, and their placements at different positions within the Substation will be experimented with to find optimal positions for fault current limitation. Subsequently, a second round of Short Circuit Analysis will be performed on the modified network using the ETAP software to assess the impact of the Current Limiting Reactors on fault currents throughout the system. The results of the Short Circuit Analysis for the power system with reactors at various positions will be compared with the results from the analysis of the existing system to evaluate the effectiveness of the proposed enhancement and the extent to which the current limiting reactors mitigate fault currents. By following these methods, the distribution network can be significantly improved, leading to enhanced power system reliability and reduced risks associated with fault currents.

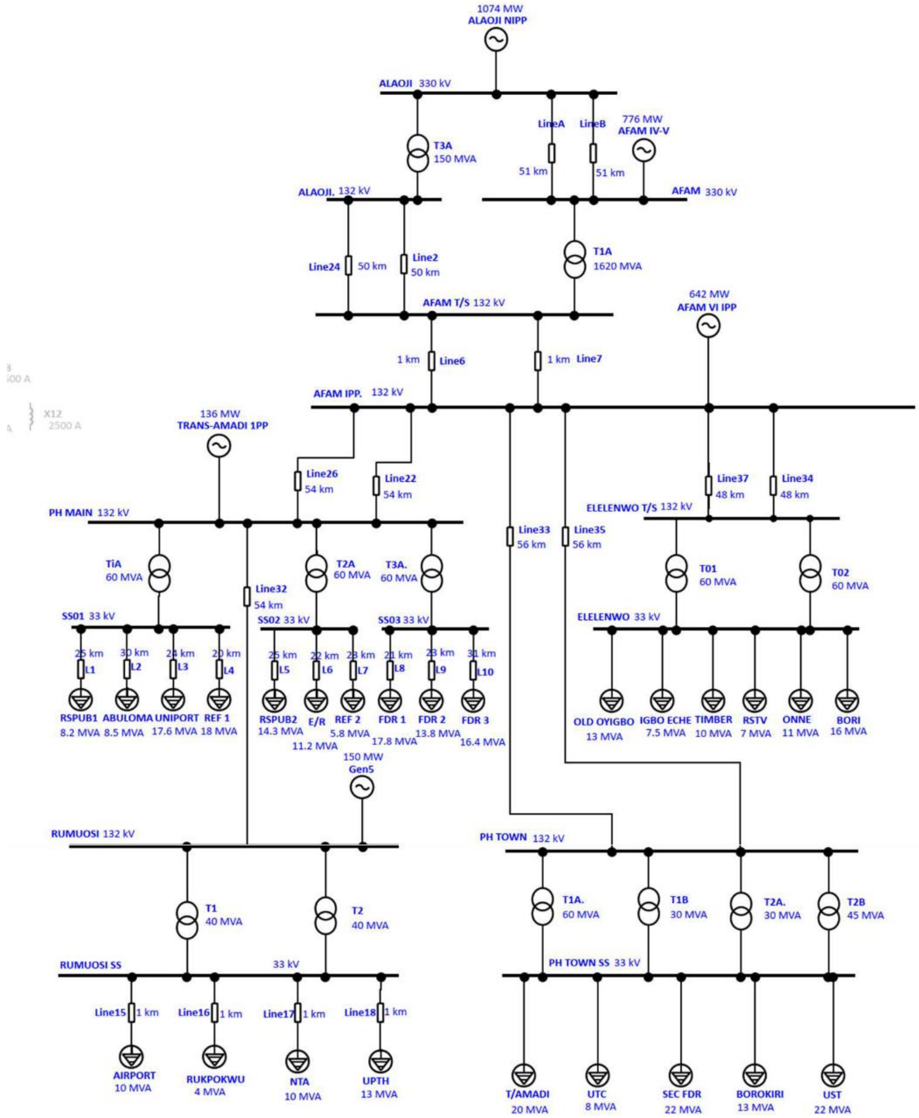


Fig 1: Single line diagram of existing Trans - Amadi 132 / 33 kV power network

1. RESULTS AND DISCUSSION

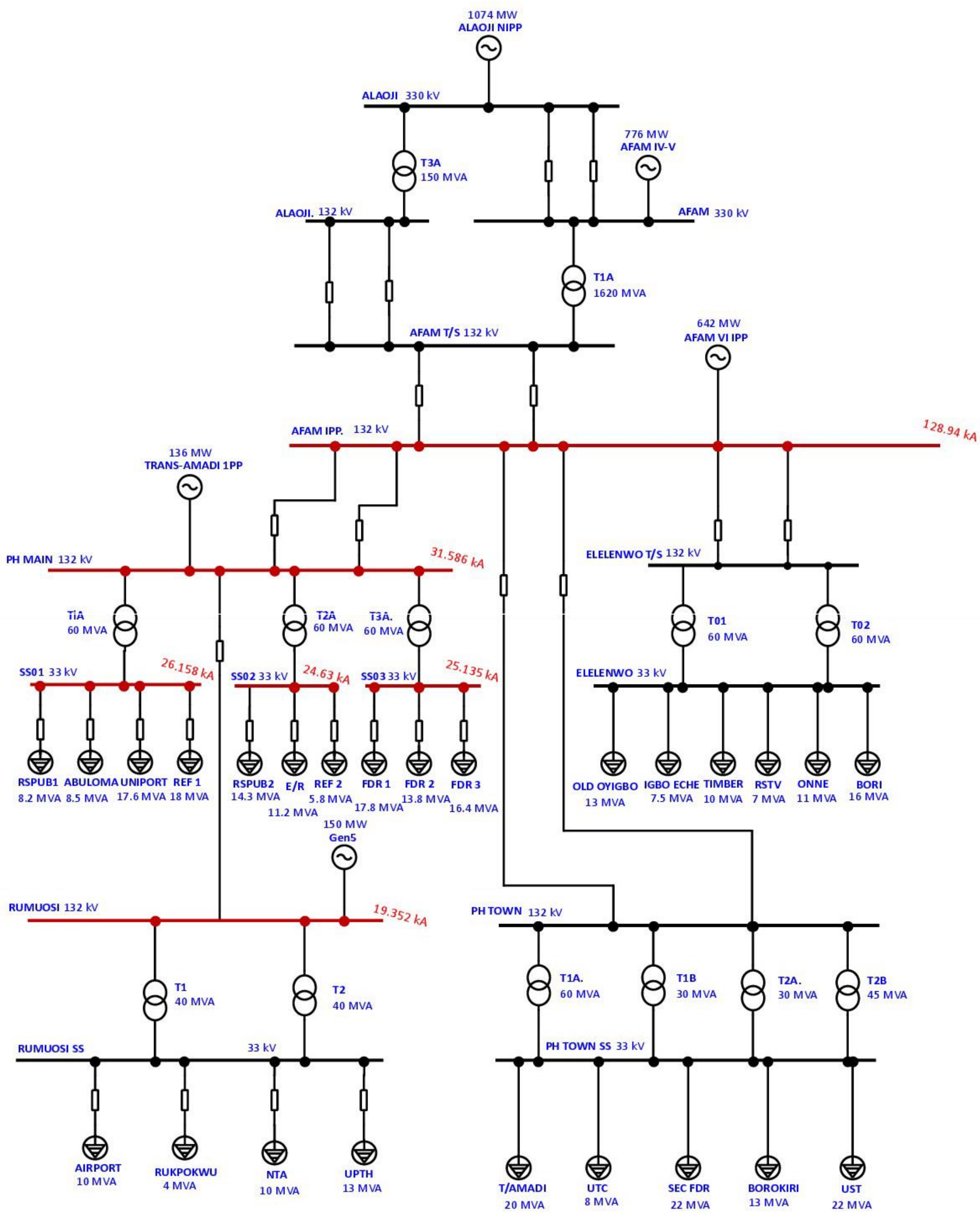


Fig 2: Short circuit analysis results of existing Trans - Amadi power network

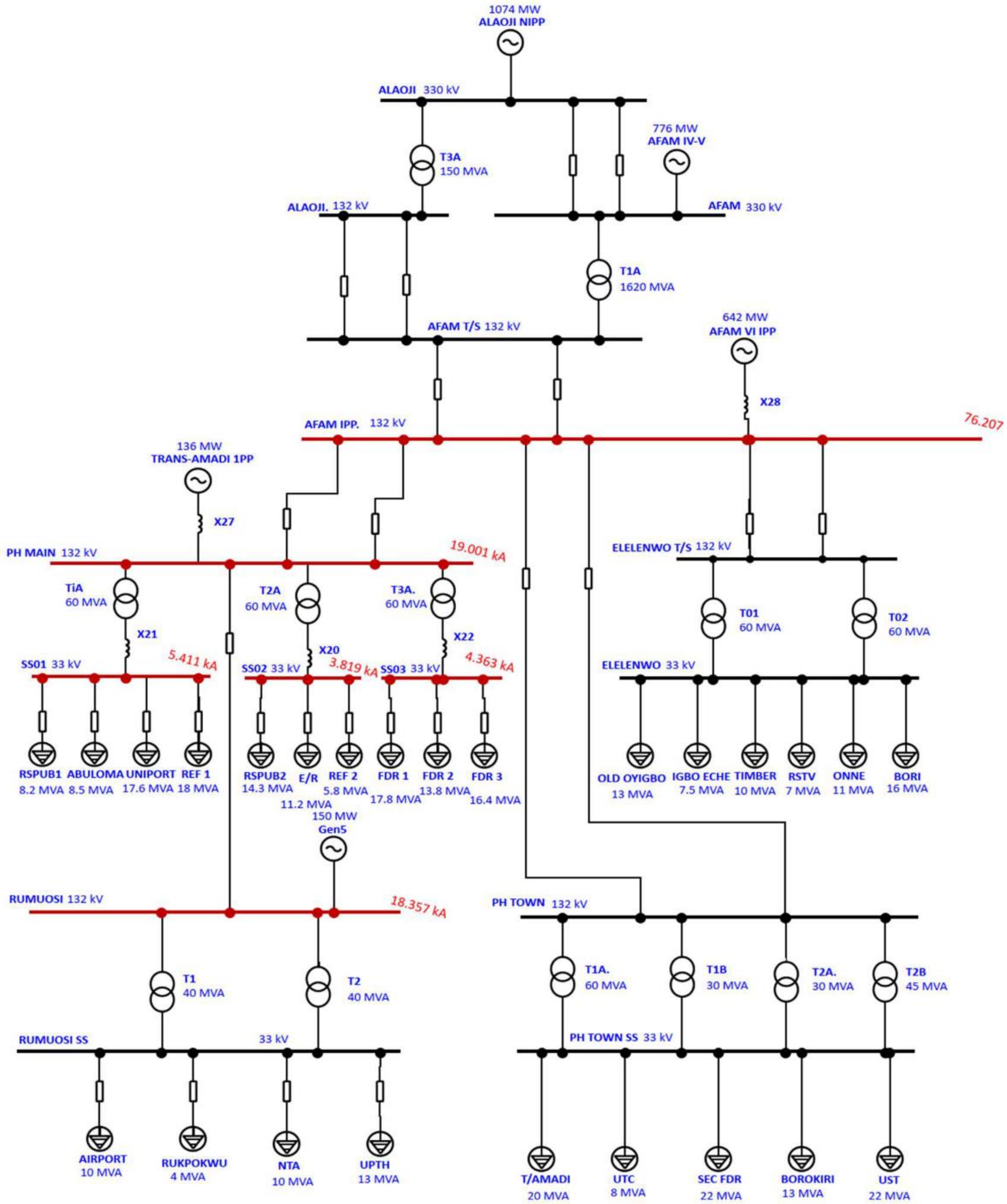


Fig 3: Short Circuit analysis results for placement of current - limiting reactors in series with incoming feeders

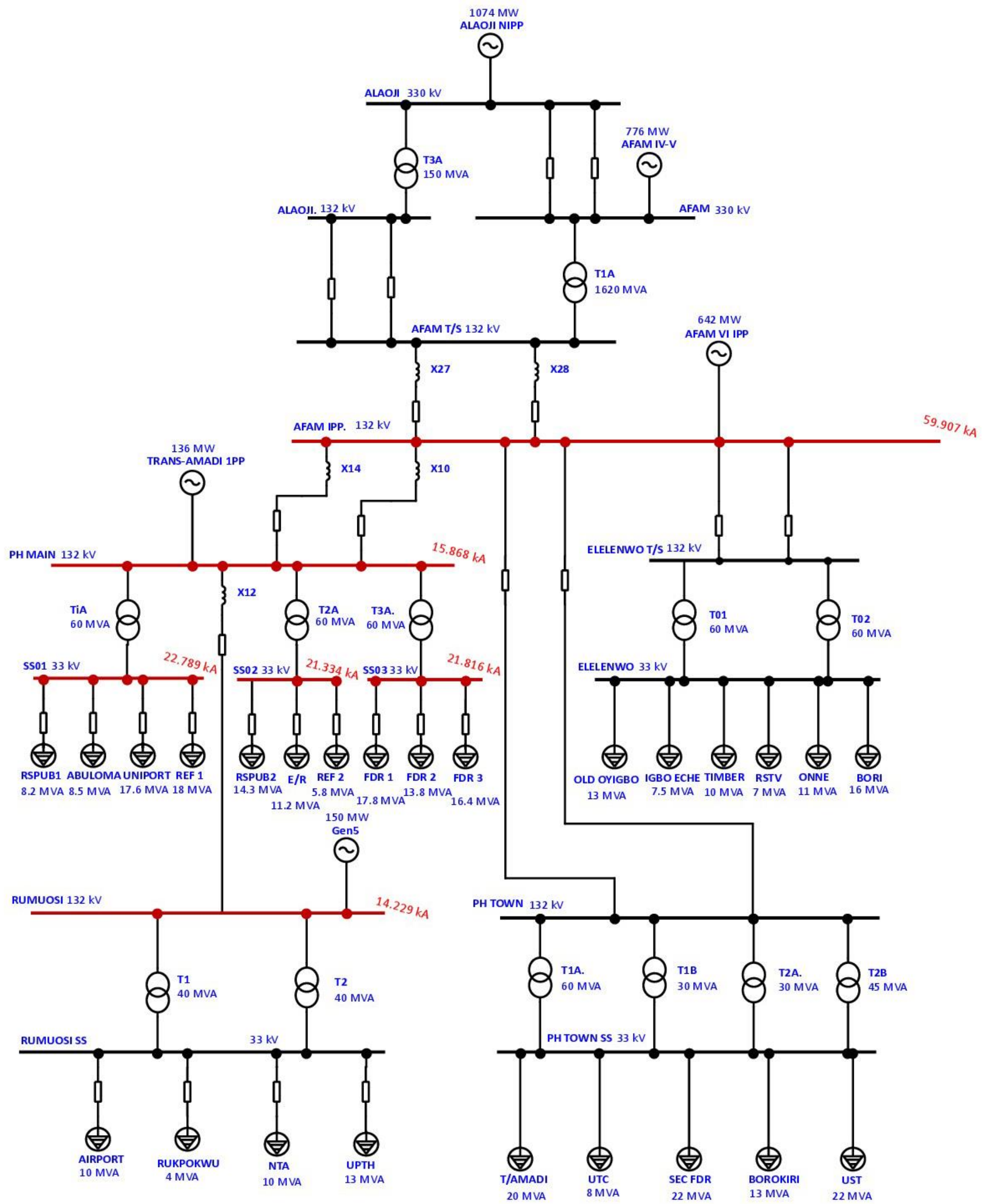


Fig 4: Short Circuit analysis results for placement of current - limiting reactors in series with outgoing feeders

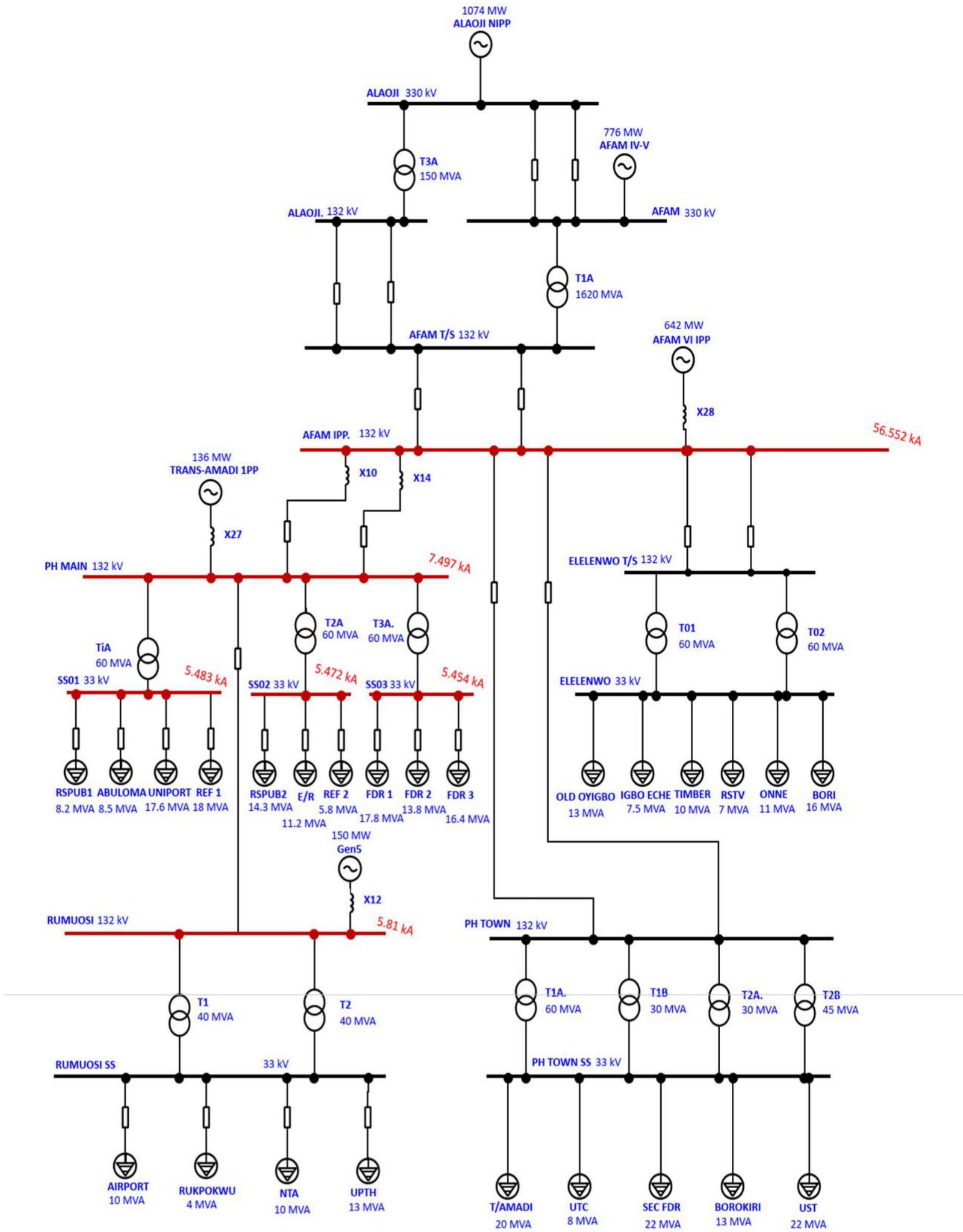
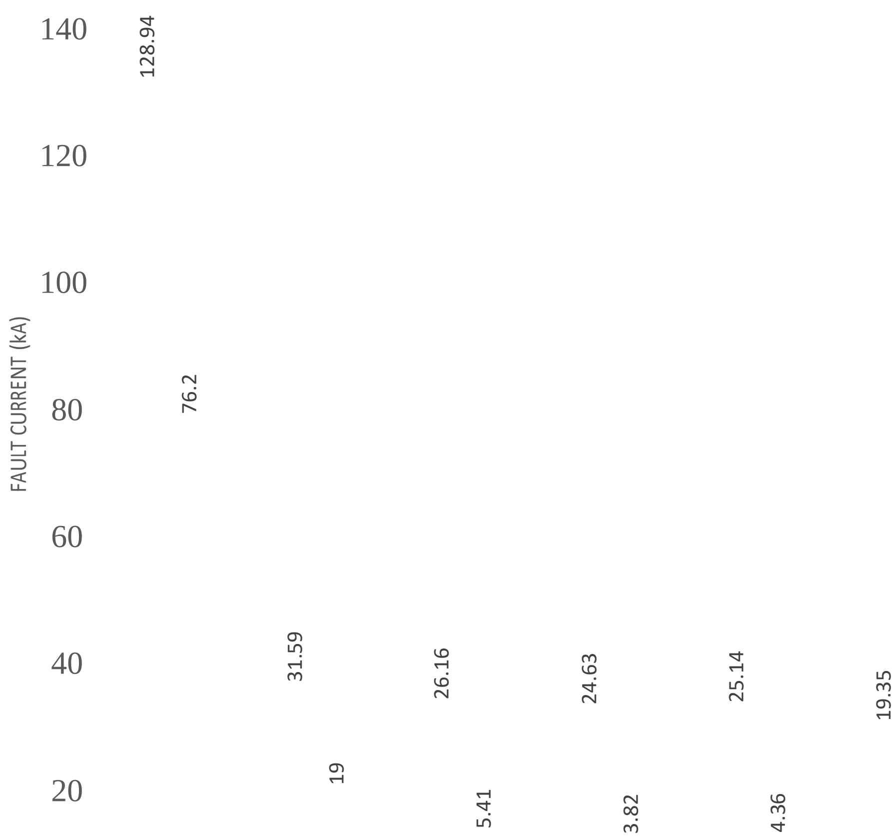


Fig 5: Short Circuit analysis results for placement of current - limiting reactors partly in series with incoming and outgoing feeders

Table 1: Comparison of fault currents at different buses without fault current limiters and with fault current limiting reactors in line with incoming feeders

Bus	Voltage (kV)	Fault Current At Bus - Without FCL (kA)	Fault Current At Bus - With FCL In Line With Incoming
AFAM IPP	132	128.94	76.2
PH MAIN	132	31.59	19
PH SUBMAIN 1	33	26.16	5.41
PH SUBMAIN 2	33	24.63	3.82
PH SUBMAIN 3	33	25.14	4.36
RUMUOSI	132	19.35	18.387



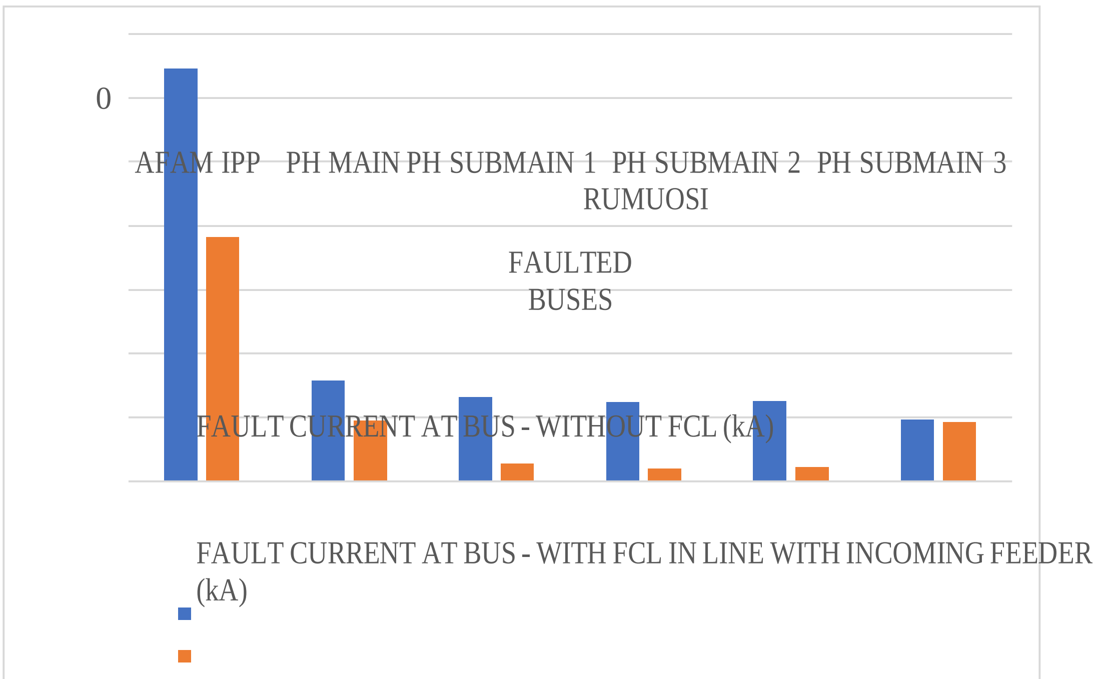


Fig 6: chart showing comparison of fault currents at different buses without fault current limiters and with fault current limiting reactors in line with incoming feeders

Table 2: Comparison of fault currents at different buses without fault current limiters and with

Bus	Voltage (kV)	Fault Current At Bus - Without FCL (kA)	Fault Current At Bus - With FCL In Line With Outgoing Feeder (kA)
AFAM IPP	132	128.94	59.91
PH MAIN	132	31.59	15.87
PH SUBMAIN 1	33	26.1	22.7
PH SUBMAIN 2	33	24.6	21.4
PH SUBMAIN 3	33	25.1	21.8
RUMUOSI	132	19.35	14.23

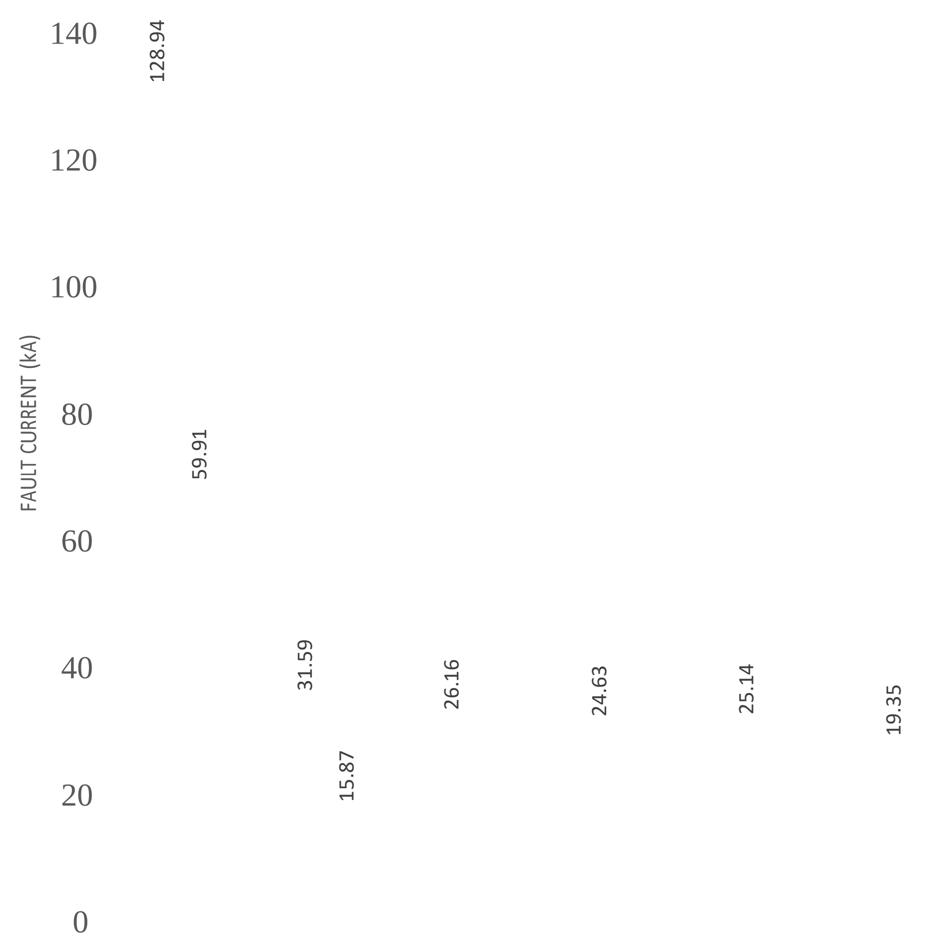


Table 2: Comparison of fault currents at different buses without fault current limiters and with

AFAM IPP PH MAIN PH SUBMAIN 1 PH SUBMAIN 2 PH SUBMAIN 3
RUMUOSI

FAULTED
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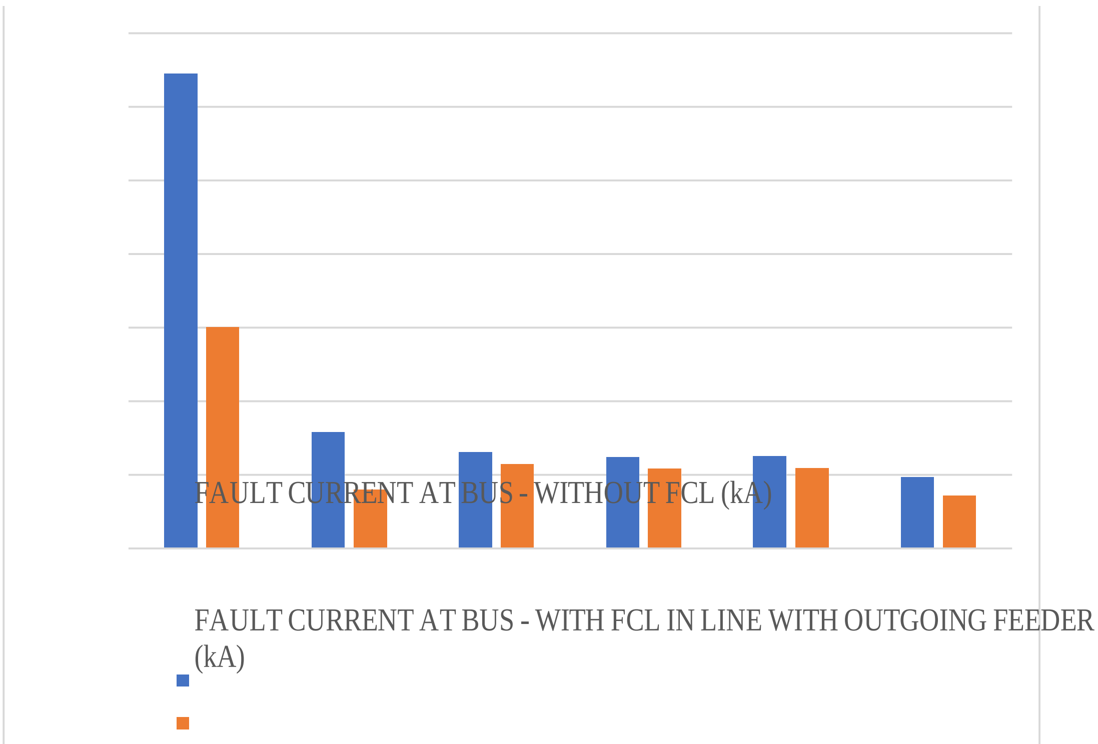

Fig 7: Chart showing comparison of fault currents at different buses without fault current limiters and with fault current limiting reactors in line with outgoing feeders

Table 3: Comparison of fault currents at different buses without fault current limiters and with

Bus	Voltage (kV)	Fault Current At Bus - Without FCL (kA)	Fault Current At Bus - With FCL partly in Line with Incoming Feeders and Outgoing Feeders (kA)
AFAM IPP	132	128.94	56.55
PH MAIN	132	31.59	7.50
PH SUBMAIN 1	33	26.16	5.48
PH SUBMAIN 2	33	24.63	5.47
PH SUBMAIN 3	33	25.14	5.45
RUMUOSI	132	19.35	5.81

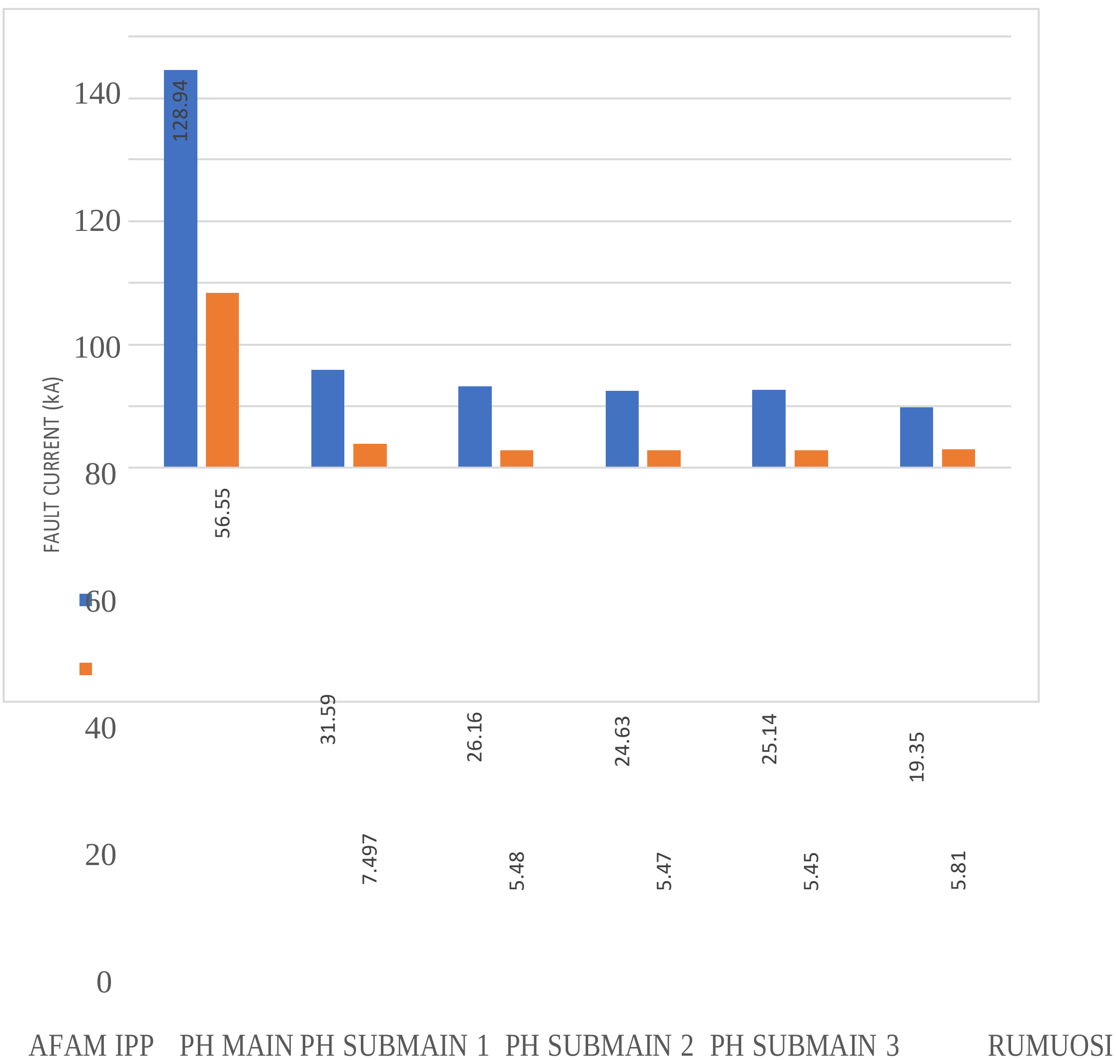

Table 3: Comparison of fault currents at different buses without fault current limiters and with

FAULTED BUSES

FAULT CURRENT AT BUS - WITHOUT FCL (kA)

FAULT CURRENT AT BUS - WITH FCL PARTLY IN LINE WITH INCOMING FEEDERS AND OUTGOING FEEDERS (kA)

Fig 8: Chart showing comparison of fault currents at buses without fault current limiters and with fault current limiting reactors partly in line with incoming feeders and outgoing feeders

Table 4: Comparison of fault currents at buses without fault current limiters and with fault

Bus	Voltage (kV)	Fault Current At Bus - Without FCL (kA)	Fault Current At Bus - With FCL In Line With Incoming Feeder (kA)	Fault Current At Bus - With FCL In Line With Outgoing Feeder (kA)	Fault Current At Bus - With Fcl Partly In Line With Incoming Feeders And Outgoing Feeders (Ka)
AFAM IPP	132	128.94	76.2	59.91	56.55
PH MAIN	132	31.59	19	15.87	7.497
PH SUBMAIN 1	33	26.16	5.41	22.79	5.48
PH SUBMAIN 2	33	24.63	3.82	21.44	5.47
PH SUBMAIN 3	33	25.14	4.36	21.82	5.45
RUMUOSI	132	19.35	18.387	14.23	5.81

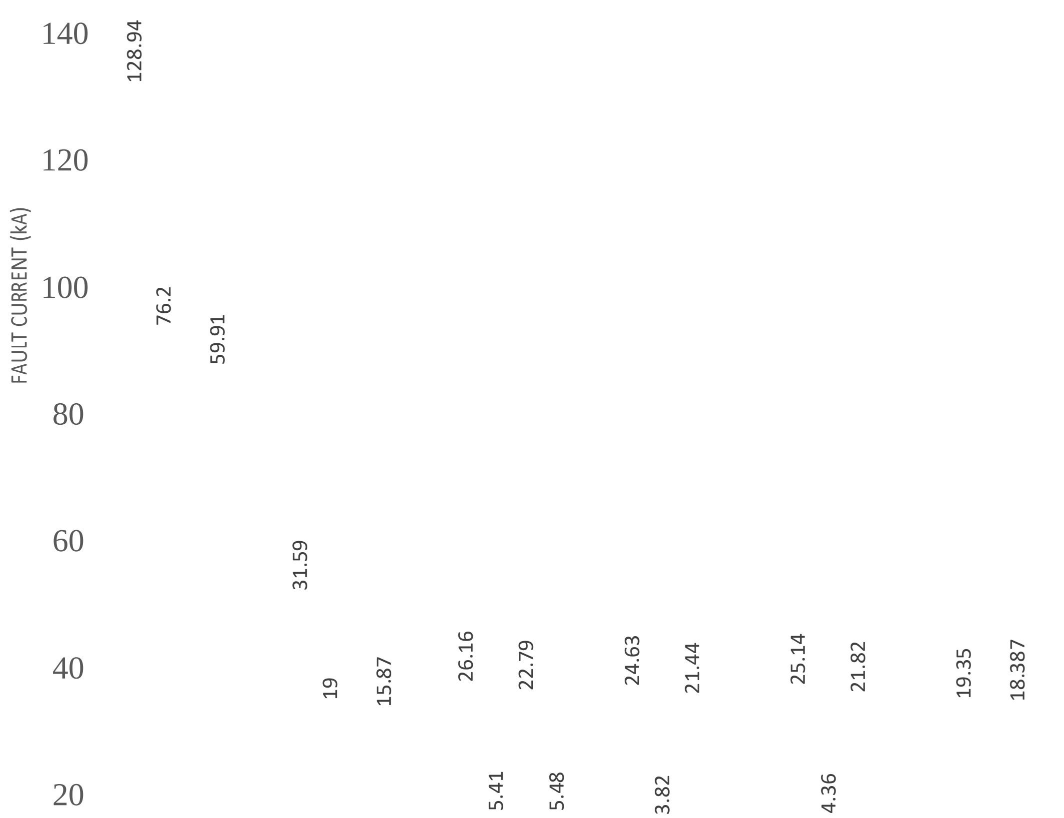

Table 4: Comparison of fault currents at buses without fault current limiters and with fault

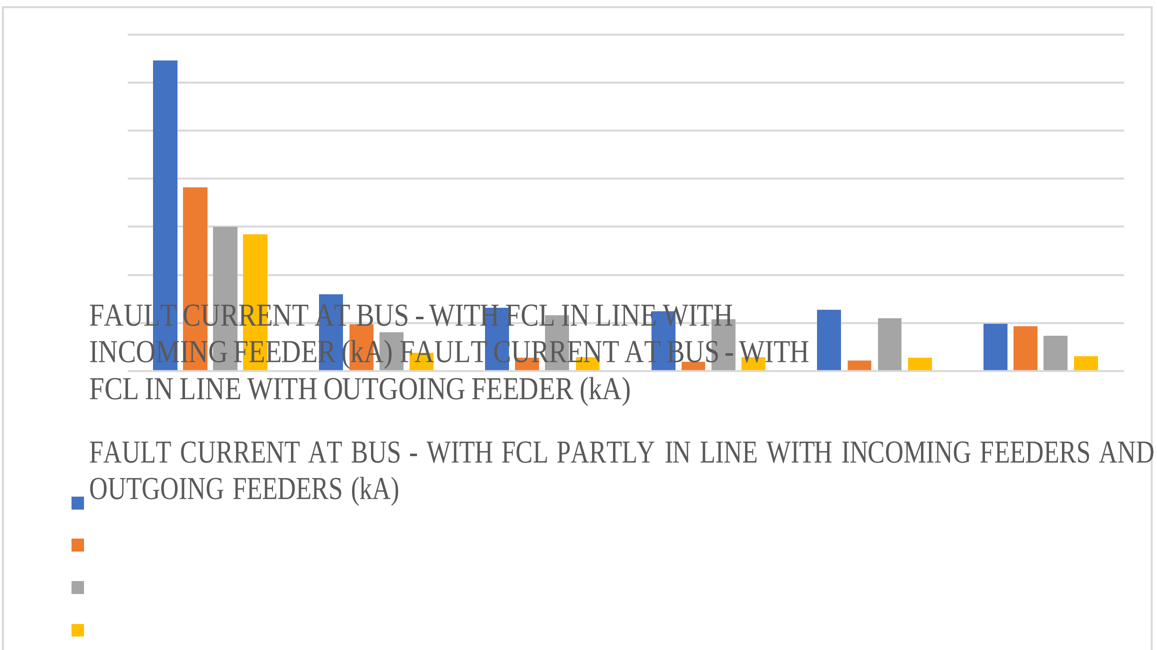

Fig 9: Chart showing comparison of fault currents at buses without fault current limiters and with fault current limiting reactors for all three conditions

SUMMARY, CONCLUSION AND RECOMMENDATIONS

The research considered the existing state of electric power network for Trans - Amadi 132/33KV network in Port Harcourt as a load centre. The scope of the network in consideration consists of five (5) generating stations; Aloaji NIPP, AFAM IV-V IPP, AFAM VI IPP, Trans
- Amadi IPP and Rumuosi. The feeders considered in the short circuit fault analysis consists of six (6) buses; AFAM IPP (132kV), PH MAIN (132kV), PH SUBMAIN 1 (33kV), PH SUBMAIN 2 (33kV), PH SUBMAIN 3 (33kV) and Rumuosi (132kV).

The distribution network is modeled and simulated in Electrical Transient Analyzer Program (ETAP) with short circuit studies. Short Circuit analysis was also conducted for the existing conditions by using collected data with subsequent investigations. A validation test between the existing state of the power system short circuit fault current and the proposed upgrade was also conducted for assurance purposes.

A total of five (5) current limiting reactors rated 2500A for 132kV buses and 1000A for 33kV buses were introduced into the power system and the placements were done in three different scenarios. The first scenario was the placement of all five reactors in series with incoming feeders, the second was the placement of all five reactors in series with outgoing feeders and in the final scenario, 3 out of the 5 reactors were placed in series with incoming feeders while 2 were placed in series with outgoing feeders.
The short circuit analysis helped in determining the peak short circuit current when three phase fault duty was introduced on the six selected buses in the network. Based on the analysis and simulation results obtained using the ETAP software, it is evident that the placement of current limiting reactors can significantly reduce fault currents in the power system. In the first scenario where reactors were placed in series with incoming feeders, fault currents reduced by an average of 29% for critical 132kV buses and 82% for 33kV buses. In the second scenario where reactors were placed in series with outgoing feeders, fault currents decreased by an average of 43% for critical 132kV buses and 13% for 33kV buses. The third scenario, which involved placing reactors partly in series with incoming feeders and partly in series with outgoing feeders, resulted in an average fault current reduction of 67% for critical 132kV buses and 78% for 33kV buses.

Overall, the analysis results suggest that incorporating the placement of current limiting reactors partly in series with incoming feeders and partly in series with outgoing feeders is the best strategy for fault current limitation, especially for critical 132kV power systems. This approach could help to reduce losses and optimize fault current limitation. This research introduces an advanced methodology for modeling electrical distribution networks using modern Power Analysis software. This contributes to knowledge by showcasing a systematic approach to accurately represent complex networks digitally. This knowledge can benefit both academia and industry professionals seeking more effective tools for network analysis and optimization.

The research also presents a systematic framework for the optimal integration of Current Limiting Reactors (CLRs) within a transmission network. This contribution enhances the understanding of how CLRs can be strategically placed to effectively mitigate short-circuit fault currents. This knowledge can guide network engineers, researchers, and utility companies in making informed decisions about improving fault current management.

It is important to note however that current limiting reactors can also have some drawbacks, such as higher network reactance and lower power factor, which can affect power system regulation. It's crucial to choose the right reactor type and carefully consider their placement in the power system to minimize these effects.

In addition, short circuit analysis studies alone are not sufficient to determine whether integrating current limiting reactors into a power system is the best solution. More detailed studies, including long-term cost savings analysis, equipment reliability analysis, and equipment layout studies, should be conducted before the power system is integrated with short circuit current limiting reactors. These studies will provide a more robust engineering framework for the upgrade of the Trans-Amadi 132/33kV network.

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Performance characteristics of *Clarias gariepinus* fingerlings fed *I. batatas* leaf inclusion meals

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Abstract

This study aimed to evaluate the performance characteristics of *Clarias gariepinus* fed *Ipomoea batatas* leaf inclusion meals. Fresh *I. batatas* leaves were harvested and prepared for analysis by standard methods. Feeds were formulated using the Pearson's square standard method. A total of two hundred and seventy (270) fingerlings were used in the study and grouped into six (6) groups of forty-five (45) each and administered feeds as follows: Group 1-(control 1-Coppens feed), Group 2-(control 2-ARAC feed), Group 3-(10% *I. batatas* leaf), Group 4- (20% *I. batatas* leaf), Group 5-(30% *I. batatas* leaf) and Group 6- (100% *I. batatas* leaf). The fishes were administered the respective diets *ad libitum* for a period of 90 days. Physicochemical parameters of the water were determined using LaMotte Fresh Water Aquaculture Test Kit (USA), lengths and weights of the fingerlings were measured using a graduated ruler and electronic weighing balance respectively. Proximate composition was by standard methods while performance characteristics were obtained by calculation. Proximate composition of the formulated fish feeds showed the following ranges: protein (35.16±0.23% to 43.75±0.30%), lipid (6.18±0.60% to 11.93±0.13%), moisture (6.04±2.13% to 9.33±0.82), ash (5.39±0.36% to 9.44±0.12%), NFE (19.41±0.87% to 34.23±0.40%) and fibre (2.15±0.76% to 7.98±0.14%). Proximate content of *I. batatas* leaf was as follows: crude protein (16.60±2.13%), crude fat (0.16±0.00%), moisture (40.62±3.16%), ash (11.92±0.54%), crude fibre (12.28±1.22%) and carbohydrate (18.42±2.17%). Proximate composition of the experimental feeds showed the following ranges: protein (35.16±0.23 to 43.75±0.30%), lipid (6.18±0.60 to 11.93±0.13%), moisture (6.04±2.13 to 9.33±0.82%), ash (5.39±0.36 to 9.44±0.12%), NFE (19.41±0.87 to 34.23±0.40%) and fibre (2.15±0.76 to 7.98±0.14%). Physicochemical parameters (pH, temperature, dissolved oxygen, ammonia, nitrite and total hardness) of the water used for the study were within acceptable limits for fish survival and optimal growth. Performance indices (feed conversion ratio, protein efficiency ratio, specific growth rate, nitrogen metabolism) were very good for all groups of fish. Condition factor (K) of the fish was better at 10% concentration than the ARAC control group while survival rate of 94% at 10% concentration was the best among the formulated feeds. The results support the potential use of *Ipomoea batatas* leaves as a nutritious and sustainable feed ingredient, promoting efficient growth and improved overall health in *C. gariepinus* farming.

Keywords: *Clarias gariepinus*; *Ipomeoa batatas;* fingerlings.

Introduction

Aquaculture, the farming of aquatic organisms, has become an increasingly important sector in global food production. The sustainability of aquaculture relies on the responsible sourcing and formulation of feed. Recent research has focused on reducing the dependence on wild-caught fishmeal and fish oil in aquafeeds by exploring alternative protein and lipid sources, such as plant-based ingredients, microbial-derived proteins, and insect meal (Rawles *et al.*, 2021). These alternative feed ingredients not only help to alleviate pressure on marine resources but also contribute to improved feed efficiency and reduced environmental impacts.

Fish feed plays a crucial role in aquaculture, ensuring the growth, health, and productivity of farmed fish. Recent studies have focused on exploring alternative feed ingredients for fish feeds, aiming to reduce dependence on marine resources and enhance feed sustainability. Various plant-based protein sources, such as soybean meal, canola meal, and pea protein concentrate, have been investigated as viable alternatives to fishmeal (Tacon *et al*., 2020). In addition, microorganisms, such as bacteria and yeast, are being explored as potential feed ingredients due to their high protein content and nutritional value (Yúfera *et al*., 2021). The formulation of fish feeds has also evolved, employing a combination of ingredients to meet the specific nutritional requirements of different fish species and life stages. Understanding the nutritional requirements of farmed fish is essential for formulating balanced and efficient feeds. Recent research has focused on optimizing the protein-to-energy ratios, lipid content, and amino acid profiles of fish feeds to support growth, feed utilization, and overall fish health (Glencross *et al*., 2021). The use of advanced techniques, such as molecular biology and metabolomics, has provided valuable insights into the nutrient utilization and metabolic pathways in fish, contributing to improved feed formulations. Feed additives play a crucial role in enhancing feed performance and fish health. Recent studies have explored the use of functional additives, such as probiotics, prebiotics, and immunostimulants, to improve feed efficiency, disease resistance, and gut health in farmed fish (Togun *et al*., 2019). Additionally, natural additives derived from plant extracts, seaweeds, and herbs have shown potential in promoting growth, disease prevention, and stress tolerance in fish (Yan *et al*., 2021). The development of sustainable and environmentally friendly additives is a focus area for future feed innovation.

Clarias gariepinus is a member of the *Clariidae* family and is native to freshwater habitats in Africa (Moehl *et al*., 2016). It has a robust body structure, with an elongated shape and a streamlined head and exhibits sexual dimorphism, with males typically displaying a larger body size and the presence of specialized breeding tubercles (Ng *et al*., 2001). *C. gariepinus* has a broad ecological tolerance, allowing it to colonize diverse habitats, including rivers, lakes, swamps, and man-made reservoirs. The natural distribution of *C. gariepinus* spans across many African countries, including Nigeria, Egypt, Sudan, Zambia, and South Africa (Eyo *et al*., 2013).

C. gariepinus

However, due to its adaptability and commercial value, it has been introduced to other regions, such as Asia, Europe, and the Americas. This widespread distribution reflects its ability to thrive in varying climatic and environmental conditions. *C. gariepinus* is considered an opportunistic and omnivorous feeder, displaying a versatile diet. In its natural habitat, it consumes a wide range of food sources, including insects, crustaceans, small fish, plant matter, and detritus (Okwundu *et al*., 2018). This adaptability in feeding habits enables *C. gariepinus* to exploit various food resources in different environments.

Ipomoea batatas (sweet potato), has gained attention as a potential feed ingredient in fish feed formulation. *I. batatas* is a rich source of carbohydrates, fiber, vitamins, and minerals and studies have revealed its nutritional composition, including high starch content, moderate protein levels, and a variety of essential micronutrients (Oduro *et al*., 2018). The presence of bioactive

I. batatas. Several studies have investigated the inclusion of *I. batatas* in fish diets and its effects on growth performance. Osman *et al*., (2021) reported that *I. batatas*-based diets have shown positive effects on growth, feed utilization, and body composition of tilapia (*Oreochromis spp*.). The presence of essential nutrients, along with the bioactive compounds, may contribute to improved fish growth and overall health. *I. batatas* has been reported to possess anti-inflammatory, anticancer, immunomodulatory, antidiabetic, anti-microbial, cardiovascular and antioxidant properties (Ayeleso *et al.* 2016; Elgabry, *et al.* 2023). Several studies have demonstrated the positive effects of incorporating *I. batatas* in fish diets on the immune response and disease resistance. In Nile tilapia (*Oreochromis niloticus*), supplementation with *I. batatas* extracts enhanced immune parameters and resistance against bacterial infections (Jayasankar *et al.*, 2020). These findings suggest the potential of *I. batatas* to improve fish health and disease resistance. The use of *I. batatas* in fish feeds holds potential sustainability benefits in that it is a widely available and inexpensive crop, making it a promising alternative to conventional feed ingredients. This study therefore is aimed to investigate the performance characteristics of *C. gariepinus* fingerlings fed *I. batatas* leaf inclusion diets.

Materials and methods

Fresh *I. batatas* leaves were harvested from Aluu community in Ikwerre L.G.A. of Rivers State, Nigeria in April 2020 and identified at the Department of plant science and biotechnology herbarium, University of Port Harcourt by Mr. Ekeke (reference number: UPH/V/1332). All chemicals and reagents used were of analytical standard.

Experimental Design: Two hundred and seventy (270) fingerlings were grouped into six (6) groups of forty-five (45) each and administered feeds as follow: Group 1 (control 1)-(Coppens feed), Group 2-(control 2) (ARAC feed), Group 3-(10% *I. batatas* leaf inclusion diet), Group 4-(20% *I. batatas* leaf inclusion diet), Group 5-(30% *I. batatas* leaf inclusion diet) and Group 6-(100% *I. batatas* leaf inclusion diet). The fishes were administered the respective diets *ad libitum* for a period of 90 days and all analysis was carried out in triplicates to minimize error.

Method of Feed Composition: The composition of the feeds used in the study where formulated based on the skeleton formula (table 1) and the percentage composition of the various ingredients were calculated using the Pearson's square and substituted into each formulation.

Table 1: The Skeleton Formula

Ingredients	**Percentage**
Wheat bran	?
Soya bean meal	?
Fishmeal	?
Palm oil	5
Garri	5
Premix	0.25
Methionine	0.15
Vitamin C	0.1
Total	**= 100%**

N/B: Ingredients 1-3 were the protein component of the feed making up the 45% protein requirement of the feed. Also, the proportion of the 1^{st} 3 protein ingredients is (100 – 10.5) % = 89.5%.

The Pearson's square: The feeds were formulated using the Pearson square method (fig. 1) and the percentage of the various ingredients calculated suing formula.

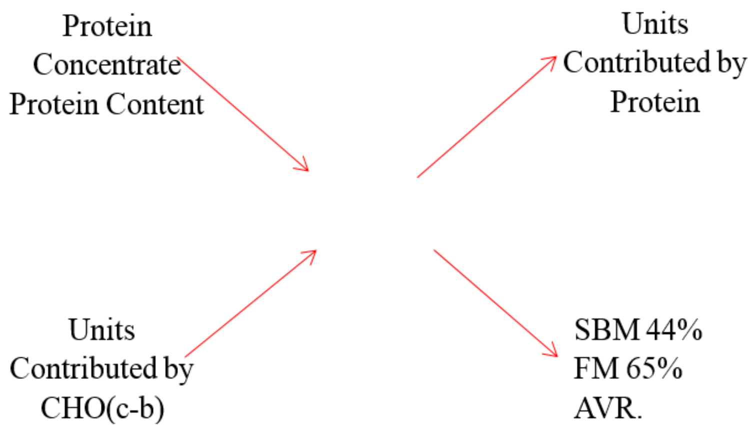

Fig. 1: Pearson's square

Total units contributed by CHO and protein concentrates = (c-b) + (c-a)

The following formulas were applied in the calculation of the percentage of each unit:

$$\% \, CHO = \frac{c-b}{(c-b)+(c-a)} \times 89.5$$

$$\% \, Protein \, Concentrate = \frac{c-a}{(c-b)+(c-a)} \times 89.5$$

Where 89.5 is the proportion of the 3 protein-containing ingredients that go into the square.

Table 2: Formulation of test feeds

Ingredients	**ARAC (control)**	*I. batatas* leaf inclusion feeds **10%**	**20%**	**30%**	**100%**
I. batatas leaf	0	3.9845	7.969	11.9535	39.845
Wheat bran	9.81	9.81	9.81	9.81	9.81
Soyabean meal	39.845	35.8605	31.876	27.8915	39.845
Fishmeal	39.845	39.845	39.845	39.845	0
Palm oil	5	5	5	5	5
Garri	5	5	5	5	5
Premix	0.25	0.25	0.25	0.25	0.25
Methionine	0.15	0.15	0.15	0.15	0.15

Vitamin C	0.1	0.1	0.1	0.1	0.1

N/B: 15kg of each feed was produced based on the percentages shown above

Proximate analysis of *I. batatas* leaves and compounded fish feed

Proximate composition of samples (moisture, ash, lipid, crude fiber and crude protein) were determined by standard procedures.

Analysis of water quality parameters in the experimental tanks: The temperature was measured using a mercury-in-glass thermometer. The physicochemical parameters of the water in the experimental tanks were determined using LaMotte Fresh Water Aquaculture Test Kit (USA) following the instructions on the kit leaflets. Each test had a specific code as follows- pH (Code 3633-01), Dissolved oxygen (DO) (Code 3633-05,), Ammonia-nitrogen (NH_3-N) (Code 3633-05., Nitrite-nitrogen (Code 3633-05) and total hardness (Code 0633-05, USA).

Determination of growth parameters of fish: The lengths of the fingerlings were measured using a graduated ruler and weighed using an electronic weighing balance (Kerro, India). To determine the average and percent weight gain, the fish were weighed at the beginning and end of study after starvation. Growth performance of fingerlings was evaluated using standard formulae.

$$\text{Weight gain \%} = \frac{(\text{Final weight} - \text{Initial weight})}{\text{Initial wieght}} \times 100$$

$$\text{FCR} = \frac{\text{Total dry feed intake (g)}}{\text{Weight gain}}$$

$$\text{Specific growth rate \%/day} = \frac{(\text{In. final wt. of fish} - \text{In. initial wt of fish})}{\text{Trial day}} \times 100$$

$$\text{Food Specific growth rate (\%/day)} = \frac{(\text{In. final wt. of fish} - \text{In. initial wt of fish})}{\text{Trial day}} \times 100$$

$$\text{Protein efficiency ratio} = \frac{\text{weight gain (g)}}{\text{Protein intake (g)}}$$

$$\text{Nitrogen metabolism (NM)} = \frac{(\text{b} - \text{a}) \times 0.54 \times \text{h}}{2}$$

Where a and b=initial and final weights of fish, h =experimental period in days and 0.54=experimental constant

$$\text{Condition factor (K)} = \frac{100\text{W}}{l^3}$$

Where W=average weight of fish at various stages and l=average standard length of fish at various stages.

Statistical analysis

Data were expressed as means and standard deviations. The data was subjected to analysis of variance (ANOVA) using SPSS (version 21) and significant differences determined at $P<0.05$.

Results and discussion

Aquaculture plays a crucial role in meeting the increasing demand for seafood while striving for sustainability and resource conservation. The conventional feed sources used in aquaculture, such as fishmeal and soybean meal, are facing challenges in terms of cost, availability, and environmental impact. As a result, there is growing interest in exploring alternative feed ingredients, including leaves from various plant sources. Leaves from different plant species, such as *Moringa oleifera*, *Azolla pinnata*, and *Ipomoea batatas*, have been investigated for their nutritional composition. These leaf meals are known to be rich in proteins, essential amino acids, vitamins, minerals, and dietary fiber, making them suitable candidates as alternative feed ingredients (Leng, 2017). Leaf meals often contain a balanced nutrient profile that can meet the dietary requirements of various cultured fish species. Studies on the inclusion of leaf meals in fish feed have shown promising results regarding growth performance and feed utilization efficiency. *I. batatas* leaves have gained attention due to their nutritional composition, cost-effectiveness, and potential as a viable feed ingredient for fish. Studies have shown that *I. batatas* leaves are very nutritious and have good potential to serve as a valuable dietary supplement for fish (Xu *et al*., 2018; Silva *et al*., 2020). The protein content of fish feed is a critical factor in promoting growth and development. Studies have shown that the inclusion of *I. batatas* leaves in fish feed can significantly increase the protein content. A study by Nguyen *et al*. (2020) observed that the protein content in Asian sea bass (*Lates calcarifer*) feed increased from 30% to 36% when supplemented with 10% *I. batatas* leaf meal. Similarly, Olaoye *et al*. (2022) reported an increase in protein content from 25% to 31% when Nile tilapia (*Oreochromis niloticus*) feed was supplemented with 15% *I. batatas* leaf meal. Lipids play a crucial role in providing energy and essential fatty acids for fish growth and overall health. The lipid content of fish feed can be influenced by the inclusion of *I. batatas* leaves. Togun *et al*. (2019) found that the lipid content in Nile tilapia (*Oreochromis niloticus*) feed increased from 8% to 12% when supplemented with 10% *I. batatas* leaf meal. However, in another study by Fernandez *et al*. (2019), no significant change in lipid content was observed in Asian sea bass feed supplemented with 5% *I. batatas* leaf meal. Carbohydrates serve as an energy source in fish diets thus the inclusion of *I. batatas* leaves in fish feed can influence the carbohydrate content. Silva *et al*. (2020) reported an increase in carbohydrate content from 35% to 42% when Asian sea bass feed was supplemented with 20% *I. batatas* leaf meal. In contrast, Xu *et al*. (2018) found that the carbohydrate content remained relatively constant in Nile tilapia (*Oreochromis niloticus*) feed supplemented with 10% *I. batatas* leaf meal. Ash content in fish feed reflects the mineral composition, including essential elements like calcium and phosphorus. The inclusion of *I. batatas* leaves in fish feed can influence the ash content. Nguyen *et al*. (2021) reported a significant increase in ash content from 10% to 15% in Asian sea bass feed supplemented with 5% *I. batatas* leaf meal. Similar finding has been reported in the current study.

Water quality is a crucial factor in successful fish farming as it directly impacts the health, growth, and overall well-being of fish. Monitoring physicochemical parameters is essential to ensure that the aquatic environment is suitable for fish survival and growth. Temperature influences the metabolic rate, feeding behavior, and reproductive activities of fish. Different fish species have specific temperature ranges in which they thrive hence temperature fluctuations beyond the preferred range can lead to stress, reduced growth, and increased susceptibility to diseases (Huner, 2005). Dissolved oxygen is vital for fish survival as it is essential for aerobic respiration. Low dissolved oxygen levels can result from overstocking, excessive organic matter, or algal blooms and insufficient oxygen can lead to fish mortality, especially in intensive fish farming systems (Noga, 2010). The optimal dissolved oxygen levels vary between species, but generally, levels above 5 mg/L are considered suitable for most fish. The pH level of water indicates its acidity or alkalinity and affects the physiological processes of fish. Fish species have specific pH tolerance ranges, and deviations from their preferred range can cause stress and affect nutrient absorption. Most freshwater fish prefer a pH range of 6.5 to 8.0, but some species may have more specific requirements (Boyd, 2019). Regular monitoring of pH levels and appropriate corrective measures are necessary to maintain a stable and suitable environment for fish. Ammonia is produced by fish excretion and decaying organic matter. High ammonia levels are toxic to fish, as they can damage gills and impair the fish's ability to excrete waste. In fish farming, ammmonia levels should be kept below 0.02 mg/L to avoid adverse effects on fish health and growth (Timmons *et al.*, 2002). Proper water exchange, filtration, and nitrification processes are essential for managing ammonia levels. Nitrite and nitrate are intermediate and end products of the nitrification process in the nitrogen cycle. Elevated nitrite levels are toxic to fish, causing methemoglobinemia or "brown blood disease," which reduces oxygen-carrying capacity (Rakocy *et al*., 2006). The quality of water in this study was within acceptable levels.

After a 90-days feeding period, the mean weight gain of the fish showed the following trend: group 1 (coppens feed)> group 3 (10% *I. batatas* inclusion feed)>group 2 (ARAC)>group 4 (20% *I. batatas* inclusion feed)>group 5 (30% *I. batatas* inclusion feed)>group 6 (*I. batatas* inclusion feed). Specific growth rate (SGR), nitrogen metabolism (NM) and condition factor (K) of the fish was also better at 10% concentration than the ARAC control group indicating better performance when leaf meal is included at that concentration. There were no significant differences in mean weight gain of fishes except in 100% concentration where weight grain was not rapid as other groups. The 100% concentration group has a significant difference ($P<0.05$) mean weight gain from the control groups. There was no significant difference in PER across dietary groups except in group 6 which recorded a significantly different ($P<0.05$) PER compared to control groups. There was no significant difference ($P<0.05$) in nitrogen metabolism in all groups except group 6 which recorded a however value compared to control groups. Fish growth is measured in units of weight and length, and is best described as SGR (Labh, 2020). Several studies have investigated the growth rate of *C. gariepinus* fed diets containing *I. batatas* leaves. Togun *et al*. (2019) conducted a study on African catfish (*C. gariepinus*) and observed that fish fed diets with up to 15% *I. batatas* leaf meal exhibited improved growth rates compared to those fed with traditional diets. Similar findings were reported by Olaoye *et al*. (2022) in a study on *Heterobranchus longifilis,* where the inclusion of 10% *I. batatas* leaf meal led to enhanced growth rates. These studies suggest that the supplementation of fish feed with *I. batatas* leaves positively influence the growth performance of *C. gariepinus*. Feed utilization efficiency is a crucial factor in aquaculture as it directly impacts production costs and environmental sustainability. Studies have investigated the feed utilization efficiency of *C. gariepinus* fed *I. batatas* leaf-supplemented fish feed. Silva *et al*. (2020) reported that juvenile channel catfish (*Ictalurus punctatus*) fed diets containing up to 20% *I. batatas* leaf meal showed improved feed conversion ratios (FCR) compared to the control group. This indicates that the incorporation of *I. batatas* leaves in *C. gariepinus* diets can enhance feed utilization efficiency, potentially leading to cost savings and reduced environmental impact. The findings of this study on percentage weight gain and SGR of fish were similar to the reports of other researchers (El-abd *et al*. 2019; Labh, 2020; Tabassum, *et al*. 2021). The increase in length and weight obtained in this study indicates that the formulated feed was nutritionally adequate to support growth and fish survival.

Condition factor and survival rate are essential indicators of the overall health and well-being of fish in aquaculture. The use of alternative feed ingredients, such as *I. batatas* leaves, has been studied to understand their impact on condition factor and survival rate of *C. gariepinus*. Conditions factor (K) which is the overall wellbeing of the fishes in water was not significantly different ($P<0.05$) in all dietary groups which indicates the fishes adapted well to their environment and the food formulated was palatable and well accepted by the fishes while survival rate of fishes in all dietary groups recorded above 90% except group 6 which recorded a 78% survival rate. The fishes in this study had a survival rate of 94% at 10% concentration as close to the coppens feed which recorded a 96% survival rate. Studies have examined the condition factor of *C. gariepinus* fed diets containing *I. batatas* leaves. Silva *et al*. (2020) conducted a study on juvenile channel catfish (*Ictalurus punctatus*) and reported that fish fed diets containing up to 20% *I. batatas* leaf meal showed significantly improved condition factors compared to the control group. This suggests that the inclusion of *I. batatas* leaves in *C. gariepinus* diets positively affects their health and overall condition. Survival rate is a critical parameter in aquaculture, as it directly reflects the ability of fish to withstand various stressors and challenges. Nguyen *et al*. (2021) investigated the effects of *I. batatas* leaf meal supplementation on the survival rate of African catfish (*Clarias gariepinus*) and found that fish fed diets containing 5% *I. batatas* leaf meal showed higher survival rates compared to the control group. The findings of this present study were similar to literature. This indicates that the inclusion of *I. batatas* leaves in *C. gariepinus* diets can improve their resilience and survival, potentially reducing mortality rates in *C. gariepinus* farming systems.

Table 3: Proximate composition of control and compounded fish feeds

Parameter	Control feeds		Compounded feeds (% *I. batatas* leaf inclusion)			
	Coppens	**ARAC**	**10%**	**20%**	**30%**	**100%**
Protein	43.75±0.30^{b}	43.32±1.57^{b}	42.55±0.41^{b}	35.16±0.23^{a}	39.32±0.15^{a}	37.86±0.52^{a}
Lipid	11.93±0.13	6.75±0.36^{a}	6.88±2.02^{a}	7.02±0.47^{b}	6.18±0.60^{b}	8.23±1.40^{b}
Moisture	8.1±0.27	7.16±2.15^{a}	7.25±0.29^{a}	9.33±0.82^{b}	7.19±0.31^{a}	6.04±2.13^{b}
Ash	9.44±0.12	6.29±0.34^{a}	5.39±0.36^{b}	6.28±0.38^{b}	8.77±0.01^{a}	7.99±0.53^{b}
NFE	19.41±0.87	29.33±0.60^{a}	30.08±0.70^{b}	34.23±0.40^{b}	31.48±0.30^{b}	33.72±0.65^{b}
Fibre	7.42±0.62	2.15±0.76^{a}	7.85±1.27^{b}	7.98±0.14^{b}	7.06±0.53^{b}	6.16±0.22^{b}

NFE-Nitrogen Free Extract; ARAC-African regional Aquaculture centre; Values are presented as mean ± standard deviation (n=3); Values with different superscript letters in same row differ significantly (P<0.05).

Table 4: Physicochemical properties of water in the experimental tanks

Parameters	Tank					
	1	**2**	**3**	**4**	**5**	**6**
pH	6.69 ± 0.01^{c}	6.70 ± 0.02^{c}	6.68±0.01^{c}	6.69 ±0.01^{c}	6.68±0.01^{c}	6.69±0.02^{c}
Temperature(°C)	27.27±0.01^{c}	27.28±0.01^{c}	27.28±0.02^{c}	27.27±0.01^{c}	27.29±0.02^{c}	27.28±0.01^{c}
Dissolved Oxygen (mg/l)	6.62±0.02^{c}	6.71±0.01^{c}	6.59±0.02^{c}	6.63±0.02^{c}	6.59±0.01^{c}	6.54±0.01^{c}
Ammonia(mg/l)	0.11±0.01^{c}	0.10±0.01^{c}	0.11±0.02^{c}	0.12±0.01^{c}	0.10±0.01^{c}	0.10±0.02^{c}
Nitrite(mg/l)	0.28±0.01^{c}	0.29±0.01^{c}	0.28±0.01^{c}	0.29±0.01^{c}	0.29±0.01^{c}	0.29±0.01^{c}
Total Hardness(mg/l)	43.47±0.02^{c}	43.47±0.01^{c}	43.47±0.02^{c}	43.46±0.01^{c}	43.46±0.01^{c}	43.47±0.02^{c}

Values are presented as mean ± standard deviation (n=3); Values with different superscript letters in same row differ significantly (P<0.05)

Table 5: Weight gain and specific growth rate

Group	Length (cm)		Weight (g)		Weight gain(g)	Weight gain (%)	SGR (%)
(% inclusion)	Initial	Final	Initial	Final			

1(Coppens)	15.30 ±0.75	37.60 ±0.17	67.10 ±0.11	473.10 ±5.66	266.07 ±143.69	356.19 ±218.36	2.98 ±0.04
2(ARAC)	15.88 ±0.59	34.87 ±0.55^{a}	67.12 ±0.56^{c}	432.10 ±10.50^{a}	245.18 ±133.06^{a}	343.43 ±212.30	2.22 ±0.08^{a}
3(10%)	15.44 ±0.10^{c}	34.00 ±0.68^{a}	66.45 ±0.96^{c}	461.08 ±9.88	248.27 ±136.98^{a}	345.51 ±231.17	2.23 ±0.16^{a}
4(20%)	15.20 ±0.86^{c}	33.97 ±0.77^{a}	67.15 ±0.88^{c}	404.12 ±0.55^{a}	222.60 ±112.44^{a}	316.48 ±281.94^{a}	2.26 ±0.09^{a}
5(30%)	15.60 ±0.12^{c}	30.23 ±0.56$^{a, b}$	66.40 ±0.90^{c}	397.02 ±11.04$^{a, b,}$	215.07 ±126.16^{a}	303.12 ±268.80^{a}	2.13 ±0.13^{a}
6(100%)	15.42 ±0.90^{c}	28.01 ±0.03$^{a, b}$	67.33 ±0.60^{c}	282.78± 8.67$^{a, b}$	190.05 ±110.56$^{a, b}$	261.50 ±230.10^{a}	1.65 ±0.17$^{a, b}$

SGR-Specific Growth Rate (%); ARAC-African regional Aquaculture centre; Values are presented as mean ± standard deviation (n=3); Values with different superscript letters in same row differ significantly (P<0.05)

Table 6: Performance characteristics

Diet group	Feed conversion ratio	Protein efficiency Ratio	Nitrogen metabolism
1(Coppens)	1.28±0.70	2.11±0.66	3978.15±3506.67
2(ARAC)	1.18±0.68^{c}	2.07±0.45	3655.70±3546.88^{a}
3(10%)	1.19±0.77^{c}	2.07±0.78	3674.08±3754.84^{a}
4(20%)	1.16±0.54^{c}	2.05±0.89	3886.74±3608.77
5(30%)	1.16±0.76^{c}	1.96±0.66^{a}	3698.09±3200±3766.67^{a}
6(100%)	0.88±0.14^{a,}	1.12±0.73$^{a, b}$	2671.05±2004.562.07^{a}

ARAC-African regional Aquaculture centre; Values are presented as mean ± standard deviation (n=3); Values with different superscript letters in same row differ significantly (P<0.05)

Table 7: Condition factor and survival rate

Group (% inclusion)	Condition factor (g/cm^{3})	Survival rate (%)
1(Coppens)	1.01±0.13^{c}	96.56±5.78^{b}

2(ARAC)	1.07±0.62[c]	93.04±2.79[b]
3(10%)	1.07±0.35[c]	94.11±7.93[b]
4(20%)	1.10±0.04[c]	93.55±3.41[b]
5(30%)	1.23±0.07[c]	91.06±3.88[b]
6(100%)	2.08±0.15[a]	78.76±1.07[a]

ARAC-African regional Aquaculture centre; Values are presented as mean ± standard deviation (n=3); Values with different superscript letters in same row differ significantly (P<0.05)

Conclusion

In this research article, we investigated the performance characteristics of *C. gariepinus* fingerlings fed fish feed supplemented with *I. batatas* (sweet potato) leaves. The study aimed to evaluate the potential of *I. batatas* leaf meal as an alternative feed ingredient in enhancing the growth and overall performance of the catfish fingerlings. The results of our study demonstrated promising outcomes regarding the performance of *C. gariepinus* fingerlings fed *I. batatas* leaf-supplemented fish feed. The inclusion of *I. batatas* leaf meal positively influenced the growth rate of the fingerlings, as evidenced by a significant improvement in weight gain and specific growth rate (SGR). The observed enhancement in growth parameters indicates the suitability of *I. batatas* leaves as a valuable dietary supplement for young *Clarias gariepinus*. Moreover, the feed utilization efficiency of the fingerlings improved when supplemented with *I. batatas* leaf meal, as reflected by favorable feed conversion ratios (FCR). This finding suggests that the inclusion of this alternative feed ingredient can lead to improved nutrient utilization and reduced feed wastage, potentially contributing to cost-effective and sustainable aquaculture practices. Beyond growth performance, our study also evaluated the health and condition of the *C. gariepinus* fingerlings. We observed a positive impact on the condition factor, indicating overall good health and well-being of the fish fed *I. batatas* leaf-supplemented fish feed. Additionally, the survival rate of the fingerlings was significantly higher compared to the control group, signifying the resilience and adaptability of the fish to the experimental diet. Overall, the results of this study provide valuable insights into the potential benefits of *I. batatas* leaf meal as a supplementary feed ingredient for *C. gariepinus* fingerlings in aquaculture. The improved growth performance, feed utilization efficiency, and health indicators observed in the fingerlings fed with *I. batatas* leaf-supplemented fish feed suggest the viability of incorporating this alternative feed ingredient into commercial catfish diets.

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EVALUATION OF LOCALLY-DERIVED SURFACTANT SWEEP IMPROVEMENT EFFICIENCY.

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ABSTRACT

The test of displacement efficiency of oil using local materials as an agent to improve oil recovery involves utilization of alkaline-surfactant-polymer. These materials were selected based on their high oil displacement efficiency, enhancing the movement of oil and residual oil saturation reduction. The materials were gotten from blending of Palm Bunch Ash (PBA) referred to as alkali (A), Mouse Ear Cress (MEC) also called surfactant (S) with Ogbono (OGB) as polymer (P) termed ASP. Core flooding displacement test experiment was done. The data were collected using concentration of 0.005, 0.01, 0.02, 0.03 and 0.05 wt%. The mobility ratio was computed for PBA-MEC-OGB at 0.05wt% giving 87.5% optimum Recovery Factor (RF) with viscosity (μ) 1.7837 cp, a mobility ratio (M) of 0.2481.The control was also formulated as NaOH as alkali (A),Tween-80 as surficial reducing agent (S) and hydrolyzed polyacrylamide (HPAM) as polymer (P) called ASP with R.F (88%) at 0.05 wt%, μ(10.8318cp) and M(0.1044). In relative terms the locally source alkaline-surfactant-polymers competed favorably compared to synthetics ASP.

KEYWORDS: Alkaline, Mobility ratio, Displacement Efficiency.

INTRODUCTION

Due to the decline in prospecting for new oil fields and the continuous increase in the demand of hydrocarbons, the significance of enhanced oil recovery (EOR) has improved greatly over the years. The oil Industry is in a continuous research to find a new, better, efficient, viable and profitable technique of recovering all the oil conceivable from the established or mature oilfields. In this context, oilfield development and production have advanced through stages: Enhancing Oil recovered, Primary, Secondary, and Tertiary. Improving oil recovery involves the use of chemical to flood oil presence in the reservoir, this sort of improved oil recovery process uses chemicals namely: alkali, surfactants, and polymers to generate more oil than can be recovered by secondary recovery methods (Mandal, 2015).The effectiveness of oil recovery can be high when the injection fluid contains polymer, due to the nature of polymer and surfactant. The utilization of locally sourced materials (alkaline and polymer), to improve recoverable oil using various masses dissolved in solution was also the subject of a flooding experiment undertaken, Ayere *et. al*. (2022).

Ojukwu *et al*., (2013) formulated a reagent containing Irvinga Gabonensis, Lecithin and Palm bundle ash (PBA). Irvingia Gabonensis (Ogbono a biopolymer) in combination with aggregated wild bush mango seeds (Ogbono, a biopolymer) were employed (polymer). This biopolymer possess similar to qualities of the Xanthan gum. Lecithin is a phospholipid, a surfactant extracted from soya bean used for oil recovery using in-situ saponification experiment to recover oil initially in place. They opines that PBA is both an agricultural waste product and an alkali. In this work the 25 percent of the oil was recovered (OIP). In this case, the surfactant reduced interfacial tension, aiming at expelling extra oil from sand void spaces at the recovery of 23.3% OIP. The polymer employed here improved mobility and gradually swept the oil entrapped in the pores, resulting in a 22.7% OOIP increase in oil recovery. Combining the various reagents used revealed that ASP flood achieved a recovery rate of 27.7% with a 17.8% increase over flooding caused by water. A comparison of synthetic and natural polymer for better oil recovery was conducted by Obuebite et al., (2021). Pectin, Jute leaf (Corchorus), and Terminalia mantaly were identified as local polymers while polyacrylamide was identified as a standard synthetic polymer. These polymers were both subjected to laboratory analysis under reservoir conditions in the presence of divalent ions. Their research revealed that mechanical breakdown of the polymer caused by high temperature and the presence of divalent ions reduced the polymer's sweep efficiency. However, Termanalia mantaly, a regional polymer, is less susceptible to reservoir conditions and aids in increasing viscosity. During polymer flooding, this polymer can take the place of polyacrylamide. A significant issue with the surfactant polymer flooding is surfactant adsorption. To address this issue, numerous additives have been employed. In their study from, Kesarwani *et al.* 2021 evaluated the impact of temperature and nonionic surfactant concentration on the critical micelle concentration of anionic surfactant. A very low interfacial tension of 0.0097 mN/m was produced by the binary surfactant combination. Utilizing a chemical slug made up of a binary surfactant and polymer, 76% of the entire oil was recovered. It's interesting to note that Belhaj *et al.*, (2020) stresses the use of chemical EOR approaches, this involves injecting various surfactant constituents into a porous and permeable rock unit to increase the entire displacement of the oil to the production well. They contend that CEOR techniques utilizes by lowering the interfacial tension between oil-water interface and move lingering oil more to the production wells is initiated by surfactant flooding.

They continuously emphasized how difficult it is to choose a surfactant that is appropriate for the reservoir conditions. Fan Zhang et al., (2018) presented evidence of enhanced production caused by spontaneous imbibition when surfactant was added to completion fluids. During hydraulic fracturing treatment, the surfactant molecules interact with the rock surface, changing its wettability from oil-wet to water-wet causing spontaneous imbibition of water via the rock matrix, expelling oil out of the pore space, and interfacial tension reduction.

The flooding of surfactant can be utilized to release trapped residual oil in the reservoir (Abbas *et al*., 2018). The occurrence of high alkali, do have a negative influence towards the efficiency of polymer, even though ASP flooding indicates an improvement in oil recovery in a field. More polymers are added to overcome this and get desired viscosity, Elaries *et al.*, 2011). SHELL ENORDET (2013) emphasize that local polymers when tested for enhanced oil recovery two different concentration must be sampled. Before surfactant flooding pre-flush is injected to pre-condition the reservoirs. The pre-flushed contains sacrificial reagents like Sodium Tripolyphosphate (Enordet, 2013). Non-ionic surfctants possessed polar head categorized as carboxylates, phosphate, sulfonates and sulfate. (Kronberg, 2014). Due to possibility of making charges more effective for reservoir rock systems, sandstones reservoir are compatible when flooded with anionic surfactants whereas cationic surfactants such be used in carbonates reservoirs. (Esmaeilzadeh et al., 2011).Ogolo e*t al., (*2015) demonstrated experimentally the displacement efficiencies whose result shows indicated the performance of the conventional EOR agents was superior to the domestic EOR agents.

This technique aid in the reduction of viscosities and increasing permeability of crude oil using formulation of palm bunch ash (alkali), mouse ear cress (Non-ionic surfactant) and Irvingia Gabonensis (polymer) to improve sweep efficiencies of oil in the oilfield in Niger Delta. In a bid to improve oil recovery, the reservoir engineers are faced with certain challenges. Some of these challenges are, very high oil viscosities and low permeability that are beyond the direct control of the producer, design of suitable EOR agents that will be effective under reservoir condition, reducing the requirements for EOR agents (Cheaper to source for), to reduced loses of EOR agents, recovery of crude oil characterized by lower API value , containing high asphaltene and wax at the vicinity of wellbore, flow-lines, surface oil facility and the utilization of synthetic chemicals which is cost effective for the enhancement of recoverable oil.

The overall interest of this work is to evaluate the use of locally sourced surfactant to improve sweep efficiency of an oilfield in Niger Delta. The specific objectives of this work are to investigate the viscosities and permeability of crude oil using palm bunch ash (NaOH and KOH), Mouse Ear Cress (Arabidopsis Thaliana) and Irvingia Gabonensis (Bush Mango) (Ogbono), (ASP) to improve sweep efficiency as a local sourced surfactant and the formulation containing sodium Hydroxide (NaOH), Tween-80 (Non-ionic Surfactant) and Polyacrylamide (Polymer) as control at the proportion of 0.5:0.25:0.25. The basic interest of this is on evaluation of surfactant (locally sourced) to improve sweep efficiency by reducing the viscosity and increasing permeability of crude oil using combination of palm bunch ash (NaOH and KOH) , Mouse Ear Cress (Arabidopsis Thaliana) and Irvingia Gabonensis (Bush Mango) (Ogbono), (ASP) locally and the formulation containing sodium Hydroxide (NaOH), Tween-80 (Non-ionic Surfactant) and Polyacrylamide (Polymer) as control at the proportion of 0.5:0.25:0.25. The major setback in this work was funding for the analysis of samples. The wettability alteration analysis was impossible to achieve due to a lack of funds.

METHODOLOGY (MATERIALS AND METHODS)

Under certain temperature and salinity circumstances, the surfactant was screened to account for restrictions to determine interfacial tension (IFT) reduction, surfactant adsorption into the crevices of rocks in the porous and permeable formation, wettability alteration constituted by contact angle measurement. Surfactant flooding was carried out using the approved chemical flooding technique (EOR). Through the combination of its flooding processes, this strategy increased oil recovery. Reduction of Interfacial tension (IFT) and wettability modification were all taken into consideration as parameters. The workflow for this work is shown in Figure 1 below.

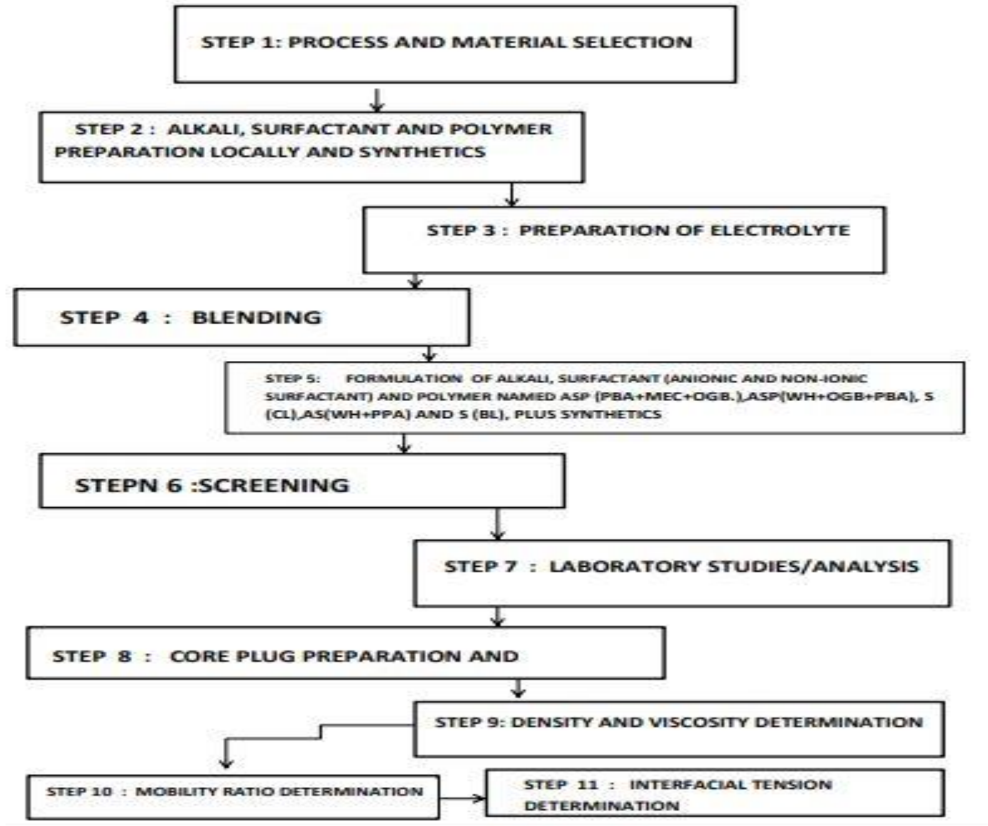


Figure 1 Workflow Chart Adopted for the Research (This study, 2023).

The dataset for this work was acquired using laboratory analysis of the experimental set-up for core-flooding displacement test. Measurement of the flow (lines) dead volumes were recorded and taken for the computation of the material balance. The performance of each chemical flooding was taken based on increment in oil recovery. (Alcazar-Vara *et al.*, 2015). The steps used for core-flooding test includes:-

A. **Core Plug Preparation**: First, methanol or toluene were used as cleaning solvents on the core samples. The core was then dried at 120^0C for at least 24 hours. The clean core plug was installed for flooding into a typical core holder made by the laboratory assistant Attendance. The flooding took place at 29^0C, average core pressure of 95 psi and overburden pressure of 1300 psi., the overburden pressure was obtained by adjusting the instrument . An Agbada sandstone from Niger Delta were used consisting of 100 wt.% of SiO_2. The dimension of core plug was 5.3 cm in length, and 3.7 cm in diameter consisting of 100%. The silicon (IV) oxide, Sio_2, gotten from Agbada sandstone formation in Niger Delta of absolute permeability of 485.83 md measured from the core plug and the ratio of the volume of the void-to-bulk volume (porosity) was 23.5 % (where pore volume was 13.4 cm^3, bulk volume 57.0 cm^3).
B. **Waterflooding (WF) stage:** Sodium chloride (NaCl) brine with a 2.7 weight percent sodium chloride content was used. Here, brine was flowing through the core plug at a rate of 1.2 ml/min, saturating it. By infusing brine at a steady flow rate of 1.2 ml/min, one of the secondary oil recovery (SOR) procedures known as waterflooding was carried out. A centrifugal flask was used to collect the recovered fluids. It was read and recorded what the core pressure was. At the location where little to no oil was recovered, the residual oil

saturation (Sor) was measured. The computation of oil recovery (% OOIP) was done utilizing the material balance with respect to time.

C. **Surfactant Flooding (SP) stage:** The variable pump was connected to the accumulator which pushes the surfactant into the core holder and drains the oil into the collecting vessel/cylinder. The oil collected was recorded in milliliters (ml). After saturating the core sample in a machine called a saturator which build in the core sample to attain a certain pressure. This saturator then is used to saturate the core samples which then is loaded inside the saturator, brine is then poured inside to full the saturator container after-which was locked up. This was then connected to the pressure equipment called cylinder, when the pressure got to 2000 psi, it was locked, kept for 48 hours, after this time the core sample was fully saturated, then weighed and loaded into a core flooding equipment and locked. The pressure needed was 1000, 2000 and 3000 psi, connected to the accumulator, which is the source of the crude oil, after loading, flow it by switching on the pump, this pump begins to push the diaphragm of the accumulator towards the other ends, this causes the crude oil to come out through the line called pipe flowing down to the outlet (collecting vessels) also called measuring cylinder.

After this, the accumulator was loaded with the brine and the process was repeated. The recovery at this phase is called water flooding or secondary recovery.

The same experiment was repeated for alkaline polymer surfactant or a combination of the three. The reading was taken from the measuring cylinder and recorded. After the first experiment, toluene was used to wash the core sample.

This was achieved by pouring the toluene inside the accumulator, then flowing with a flow rate, pump was connected to electricity or power source. On completion of the flow with toluene, brine preparation commence, here brine was saturated inside the accumulator and allowed to flow again with a known flow rate to saturate the core sample, for about an hour or two between 200-400 ml. After wetting the system, next we flood the accumulator with the crude oil and begins to flow it. Note it must be one after the other i.e. the surfactant. At the end recovery of oil was recorded in-terms of OOIP.

The approach put forth by Isehunwa and Olubukola (2012), will be used in this study as a model linking degree of hotness /coldness (temperature), brine solution (salinity) and oil viscosity to compute for interfacial tension in oil-brine systems. Utilizing the algorithm (equation 1).

$$Y = a + bx_1 + cx_2 + dx_3 \qquad \text{(Eqn. 1)}$$

Interfacial tension is denoted by Y measured in dynes/cm, while temperature is denoted by X_1 in degrees Celsius, X_2 represent the salt content (ppm) and X_3 indicates for viscosity (cp).

As indicated in the table 1 below, a, b, c, d are empirical constants established utilizing response of surface methods.

TABLE 1

Showing Crude Oil constants for various classes of crude. (Isehunwa *et al.*, 2012)

Oil Sample	**a**	**b**	**c**	**d**
A	3.5040	-0.0170	-14.4896	0.0429
B	3.6626	0.0506	-39.4118	0.0058
C	11.4459	-0.0489	5.9472	0.1585
D	11.1350	-0.0166	-1.1300	0.5806
E	24.2263	-0.0647	-58.6613	0.4100
F (AGO)	20.3605	-83.9374	0.3043	0.0763

TABLE 2

Average physical characteristics of crude oils (samples). (Isehunwa *et al*., 2012)

Oil Sample	API	Density (g/cm3)	Viscosity (cp)	Specific gravity	pH	Classification
A	21	0.9275	49.0	0.9276	6.5	Heavy
B	39	0.8316	2.5	0.8317	5.2	Light
C	29	0.8796	6.5	0.8798	6.2	Medium
D	34	0.8556	6.0	0.8557	7.5	Medium
E	15	0.9634	50.5	0.9635	7.6	Heavy
F	32	0.8675	4.0	0.8676	7.4	AGO

Note: 1 Dyne/centimeter = 1 mN/m and 1000000ppm =1.0 g/ml

The physical properties of the samples were determined using a temperature of 29^0C as shown in Table 2.

The crude oil samples labelled A, B, C, D, E showed a decrease in interfacial tension as temperature increased. This validates Taha Oshaka and Al-Shiwaish's (2009) showing that brine salinity an impact on interfacial tension shown in the Saudi Arabian reservoir.

Again it is worth to note that, decrease in IFT can be shown in the heavy crudes A and E. Sample F AGO (diesel) shows increased in interfacial tension that varies directly with degree of hotness/coldness, followed by irregular drop in interfacial tension when brine rises in concentration proposed by Princen *et al.*, (1967). The IFT of engine oil rebuke this assumption/condition since the contains additives.

Mobility Ratio: The mobility ratio is the comparison of the mobilities of the injected and displaced fluids, such as oil and water, respectively. The following is the mobility ratio of a flood of water:

$$M = \frac{k_w \mu_o}{k_o \mu_w} \quad \text{(Eqn.2)}$$

The mobility ratio is the comparison of the mobilities of the injected and displaced fluids, such as oil and water, respectively. The following is the mobility ratio of a flood of water.

All the samples densities were determined using density bottles.

Density Determination: The density bottle when emptied and when filled with water were weighed and recorded. Next, when filled with the alkaline, surfactant and polymer mixture were also weighed and result, noted taken and recorded. This was then used to calculate the density using algorithm thus:

$$Density(\rho) = \frac{M_A - M_E}{M_{H2O} - M_E} \quad \text{(Eqn.3)}$$

Where M_A stands for mass of fluid (alkaline- Surfactant-Polymer, surfactant or Alkali-surfactant) mixture added to the mass of empty density bottle

M_E stands for mass of empty density bottle and M_{H_2O} stands for the mass of density bottle when filled with water added to the mass of empty density bottle.

Capillary Tube Viscometer Test Method : In this technique, the sample of oil was inserted in the glass capillary U- tube , here samples were drawn from the tube via suction till they got to gets to the start level shown on the tube's side. At this point, the suction is released to allow the sample to flow back through the tube under gravity. The section of capillary tube, narrow , controls the oil's flow rate , higher viscous grade of oil takes more time to flow than less viscous (thinner grades) oil.

The test measures oil kinematic viscosity with a unit centistoke (cSt), equivalent to mm^2/S in S.I. units, and it determines the flow rate based on the resistance of the oil flowing under gravity through the capillary tube. This measurement was made using a calibration constant allocated for each tube to calculate the time it takes for the oil to flow from the starting point to the stopping point. To state, oil viscosity must always be measured by noting the temperature at which the viscosity was taken. The samples were degassed for 30 min. at 300^0C. (Sexena *et al*., 2019). The dynamic adsorption experiment was carried out using 200ml. The U-tube viscometer were also adopted to estimate the time taken to drain the solutions of various surfactant mixture at varying (0.5g in 100 ml of water,1.0 g in 100 ml of water, 2.0 g in 100 ml of water, 3.0 g in 100 ml of water, and 5.0 g in 100 ml of water) concentrations. These times were all converted into seconds. The time recorded was multiplied by a viscometer constant at room temperature (29^0C) which was 0.03641492. Computation of kinematics viscosity was done thus:

$$V = constant\ taken\ @\ 29^0C\ \ X\ \ time\ in\ seconds$$

The relationship between dynamic viscosity to kinematics viscosity using density is given as :

$$\mu = V\ X\ \rho \qquad (Eqn. 5)$$

Where μ stands for dynamic (absolute) viscosity. V stands for kinematic viscosity and ρ represents the density of fluid $kg/m^{3.}$

Recovery Test: Oil recovery tests were carried out by fluid flowing through the core – adsorbent (Figure 2). Earlier than the recovery tests, they were dehydrated by heating to 120^0C for 18 hours to drive off water. The surfactant quantity used in the recovery exercise was tested at 65^0C above the CMC, with the target to inject the solution in the form of micellar.

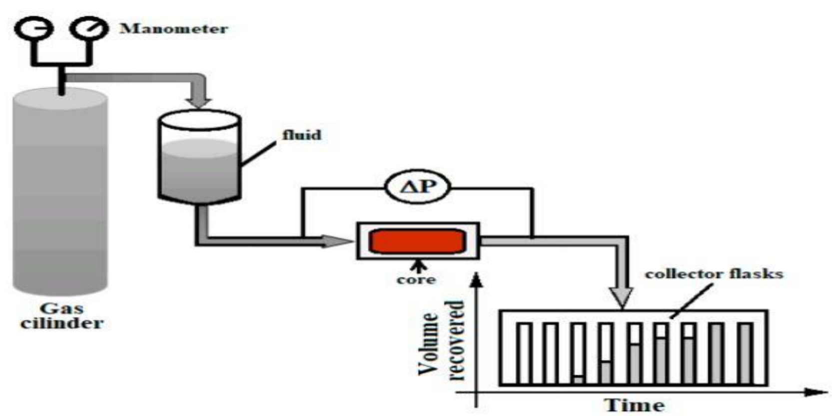


Figure 2: Experimental design to recover oil using Core adsorbent. (Curbelo, *et al*.,2020).

The oil recovered was carried out using brine injection (at 35 psi) in the countercurrent direction of oil production, until a total saturation was reached. During the oil injection stage, the same pressure was maintained with a viscosity of 7.7396 cp and density $0.9941g/cm^3$ at a room temperature of 29^0C. The core flooding was done with oil till no brine was produced (irreducible water saturation). The residual oil volume in the core was estimated using mass balance. The injection of displaced fluid (EOR technique) targeted on residual oil recovery (RO) sticks to the pores of the rock body, hence reducing the interfacial tensions and surfactants (Palm Bunch ash, Mouse Ear Cress and Irvingia Gabonensis, water hyacinth, palm bunch Ash and Irvingia Gabonensis, and finally the recovery factor (RF) were estimated using mass balance according to equation 6 below:

$$RF_{total} = (V_{inj.} - V_{prod.}) * {}^{100}/_{V_{inj.}} \qquad (Eqn. 6)$$

Where RF_{total} stands for total recovery efficiency (%) and $V_{inj.}$, $V_{prod.}$ Stands for volume injected (ml) and the volume produced (ml) accordingly.

Oil samples used were gotten from the Agbada oilfield, Niger Delta.

Preparation of Samples: The sample used in formulating local materials and chemicals for the flooding were given below: NaOH and KOH (alkalis), Tween-80 (Non-ionic surfactant) and Polyacrylamide (polymer) were prepared for various concentrations (0.5 , 1.0, 2.0 , 3.0 and 5.0) grams in 100ml of water, weighed in $g/cm^{3.}$ The breakdown of its proportion was as follows:

(a.) NaOH (0.125g) + Tween-80(0.125ml) + Polyacrylamide(0.25 g) = 0.5 g
NaOH (0.25 g) + Tween-80 (0.25ml) + Polyacrylamide (0.5 g) =1.0 g
NaOH (0.5 g) + Tween-80 (0.5ml) + Polyacrylamide (1.0 g) = 2.0 g
NaOH (0.75 g) + Tween-80 (0.75ml) + Polyacrylamide (1.5 g) = 3.0 g
NaOH (1.25 g) + Tween-80 (1.25 g) + Polyacrylamide (2.5 g) = 5.0 g

Also, the locally sourced surfactant was formulated as follows:

1. PBA (0.125 g) + MEC (0.125 g) + Ogbono (0.25 g) = 0.5 g
PBA (0.25 g) + MEC (0.25 g) + Ogbono (0.5 g) = 1.0 g
PBA (0.5 g) + MEC (0.5 g) + Ogbono (1.0 g) = 2.0 g
PBA (0.75 g) + MEC (0.75 g) + Ogbono (1.5 g) = 3.0 g
PBA (1.25 g) + MEC (1.25 g) + Ogbono (2.5 g) =5.0 g

RESULTS AND DISCUSSION

The formulation of palm bunch ash (alkali), mouse Ear Cress (Non-ionic surfactant) and Ogbono (polymer) at varying concentrations were 0.005 , 0.01,0.02,0.03 and 0.05 wt % concentrations, density (1.00461 g/cm^3), highest (Table 3), the dynamic viscosity at 0.02 wt % concentration shows a value 1.814849g/cm^3, pH of 9.6 seen to be more alkaline (Table 3). The plot of recovery efficiency versus concentration indicated the optimum recovery at 0.05 wt% concentration (figure 3) shown to be 82.5% recovery. This was confirmed in the plot of viscosity versus recovery factor, (Figure 5).

TABLE 3: Showing Kinematic and dynamic viscosities obtained in the laboratory for PBA+MEC+OGB.

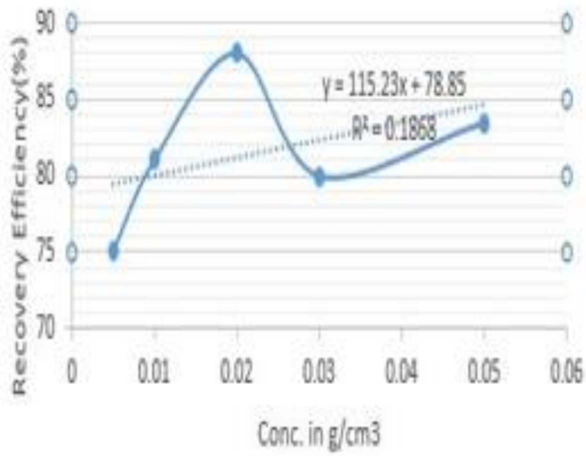
Mass(g)	Conc. (g/ml)	Time (s)	V= const. X Time	Density (ρ) in g/cm3	$\mu = V\ X\ \rho$	pH
0.5	0.005	60.74	2.185197	1.0014	2.188256276	8.8
1	0.01	50.46	1.83775	1.0030	1.843263929	9.0
2	0.02	49.60	1.80642952	1.00381	1.814848809	9.6

3	0.03	46.10	1.678959695	1.0028	1.683660782	9.1
5	0.05	48.75	1.775472563	1.004614	1.783664593	8.9

However the plot of recovery efficiency versus concentration reveals that at 0.05wt % concentration recorded recovery factor (87.5%) (Table 5) (Figure 5). From the plot of recovery efficiency versus viscosity, at moderate viscosity recorded the highest recovery efficiency (87.5 %) shown in figure 3. The mixture of palm bunch ash (alkali), mouse ear cress (Non-ionic surfactant) and Ogbono (polymer) at various proportions (polymer 50%, alkali and surfactant 25% each). The display of the plot of recovery efficiency (%) to viscosity, reveals optimum production at 1.81Ns/m^2 viscosity (Figure 4), beyond this point production drops showing that at higher viscosity >1.81 Ns/m^2 the oil recovery drops.

TABLE 4: Showing Primary, Secondary and Tertiary oil recovery with computed recovery efficiencies for PBA+MEC+OGB.

Mass (g)	Conc. (g/ml)	Primary Recovery(ml)	Second. Recovery (ml)	Tertiary Recov.(ml)	Recov. Eff.(%)
0.5	0.005	10	6	3	75
1	0.01	9	5	3	75
2	0.02	10	5	4.2	84
3	0.03	8	4	3.2	80
5	0.05	11	7	3.5	87.5



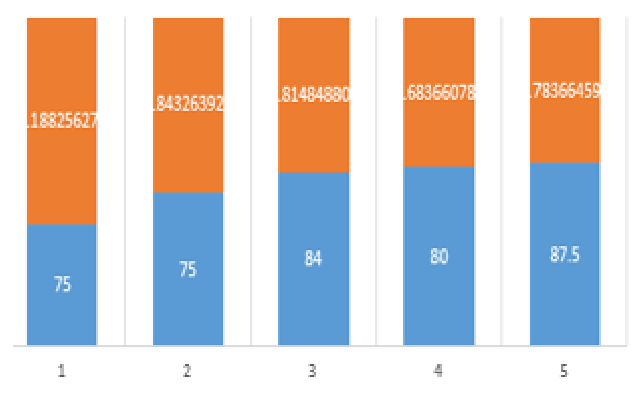


Figure 3 Plot of concentration versus recovery efficiency for PBA, MEC and OGB.

Figure 4 Plot of viscosity versus recovery efficiency for PBA+MEC+OGB.

Note: Recovery efficiency is indicated by brown bars

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In this analysis, control was established using the formulation containing sodium Hydroxide (NaOH), Tween-80 and polyacrylamide at the proportion of 0.5:0.25:0.25.

The plot of recovery efficiency versus viscosity was done to obtain 88% recovery factor at 0.05 wt% concentration. The pH of this mixture read highest at 11.5 indicating more alkaline solution. (Table 5). The density for the samples was determined showing the highest at concentration 0.05wt% whose density (1.01275 g/cm^3) (Table 5).

The plot of recovery efficiency (%) versus concentration reveals optimum recovery at 0.05 g/cm^3 with a recovery of 88%. (Table 6). The plot of viscosity versus concentration reveals at concentration of 0.03wt% oil recovered attended the optimum level, after this threshold the produced oil attained a plateau stage, hence production at this stage became stable, and this was confirmed to record recovery of 88% at 0.05 wt%. (Figure 5). The plot of recovery efficiency versus viscosity shows at viscosity of 1.5 Ns/m^2 the recovery reads above 80 % (figure 5). Also shown in figure 6, the plot of recovery efficiency (%) versus viscosity (μ) in Ns/m^2, read optimum recovery (82.5%) at the viscosity of 1.8 Ns/m^2. The formulation of NaOH, Tween-80 and polyacrylamide.

TABLE 6 : Showing kinematic and dynamic viscosities for NaOH + Tween-80 + Polyacrylamide extract as obtained in the laboratory.

Mass (g)	Conc. (g/ml)	Time (s)	V= Cont. X Time	Density (ρ) in	$\mu = VX\rho$	pH

				g/cm3		
0.5	0.005	80.62	2.93577085	1.00053	2.93733	10.5
1	0.01	180.07	6.557234644	1.00248	6.573497	11.4
2	0.02	312.03	11.36254749	1.00691	11.441063	11.5
3	0.03	491.67	17.904123372	1.0116897	18.11341756	11.4
5	0.05	293.71	10.69542615	1.01275	10.83179283	11.3

TABLE 7: Showing primary, secondary and Tertiary recoveries for with computed recoveries efficiencies for NaOH + Tween-80 + HPAM

Mass(g)	**Conc.(g/ml)**	**Primary Recov. (ml)**	**Second. Recov. (ml)**	**Tertiary Recov.(ml)**	**Recov. Eff. (%)**
0.5	0.005	11	6	4	80
1	0.01	11	7	3	75
2	0.02	11	7	3.2	64
3	0.03	10	6	3.4	85
5	0.05	11	6	4.4	88

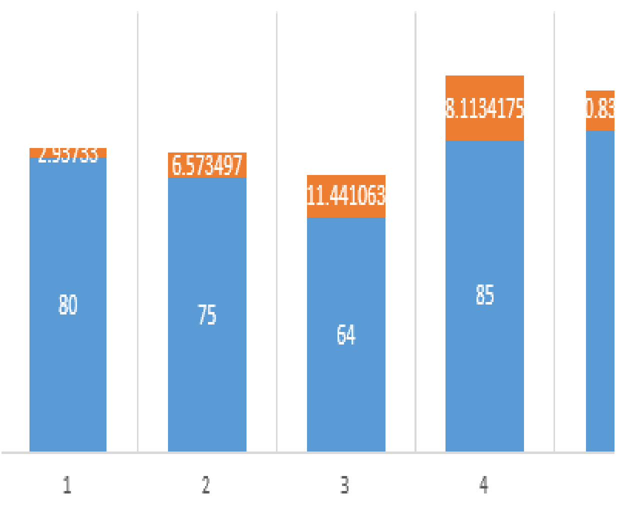

Figure 6 Plot of viscosity and recovery efficiency for NaOH + Tween-80 + Polyacrylamide.
Note recovery efficiency is indicated by blue, viscosity is display by brown bars.

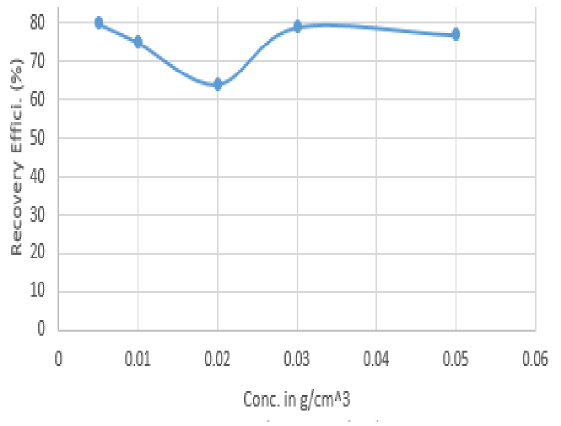

Figure 5 Plot of concentration versus recovery efficiency for NaOH + Tween-80 + HPAM

Sweep Efficiency

The computed mobility ratios for various concentrations and viscosity shows the effect of surfactant on the mobility of crude oil in the reservoir. The mobility ratio was computed based on equation 2. The mobility ratio calculated for all the samples shows that oil leads water.

Importantly, Pba + Mec + Ogb.it effect on mobility ratio can be seen (Table 8 and 9), this is a desirable effect as more oil will be produced. Although the flow rate has to be considered by the reservoir engineer.

TABLE 8

Computed Mobility Ratio PBA+MEC+OGB.

Conc. g/cm^3	**In μ in Ns/m^2**	**m**	**Interpretation**	**Remark**
0.005	2.188256276	0.516692227	Oil leads water	Good
0.01	1.843263929	0.6133983328	Oil leads water	Good
0.02	1.814848809	0.6230023214	Oil leads water	Good
0.03	1.683660782	0.6715456184	Oil leads water	Good

0.05	1.783664593	0.6338944135	Oil leads water	Good

TABLE 9
Computed Mobility Ratio for Control (NaOH+Tween-80 +HPAM)

Conc. In g/cm^3	**μ in Ns/m^2**	**m**	**Interpretation**	**Remark**
0.005	2.93733	0.384926122135	Oil leads water	Good
0.01	6.573497	0.1720020593	Oil leads	Good
0.02	11.441063	0.09882429814	Oil leads water	Good
0.03	18.11341756	0.06242085555	Oil leads water	Good
0.05	10.83179282	0.1043829991	Oil leads water	Good

The control used shows that oil moves faster than water as indicated (Tables 9 and 10). However, due to cost implications of NaOH, Tween-80, Polyacrylamide.

Interfacial Tension

Based on algorithm in equation (1), the interfacial tension was calculated, (Table 11). This express the extent of the force that exist n the interface between the oil and water. It shows that at the concentration of 0.05 wt %, for bitter leaf extract, the interfacial tension 297629.9462 dynes/cm depicts the highest indicating more oil produced. In the case of palm bunch ash, Mouse Ear Cress and Ogbono, the concentration of 0.05Wt % reads 298892.7357 dynes/cm recorded recovery (87.5%) indicating optimum recovery, next to it by performance is 0.02 wt%, recovery (84%), interfacial tension119739.0505 dynes/cm, (Table 10).

Thecontrols considered were formulation of Sodium hydroxide, Tween-80 and Polyacrylamide known as alkaline-surfactant - polymer synthetics, interfacial tension (300326.867 dynes/cm) read highest, at 0.05W %, optimum recovery (88%).This recovery reduces (from 88 -75%) at 0.01wt % the interfacial tension reduces, (from 300326.867 to 30335.59461 dynes/cm), table 11.

TABLE 10
Computed Interfacial tension caused by PBA+MEC+OGB extract

Conc. In g/cm^3	**Conc. In ppm**	**μ in cp**	**X_1 (^{0}C)**	**Y in dynes /cm**
0.005	5000	2188.2562776	29	30218.23562
0.01	10,000	1843.263929	29	60023.55433
0.02	20,000	1814.848809	29	119739.0505
0.03	30,000	1683.660782	29	179424.1251
0.05	50,000	1783.664593	29	298892.7357

TABLE 11

Computed Interfacial tension caused by the synthetic chemicals used as control (NaOH +Tween-80 + HPAM)

Conc. In g/cm^3	**Conc. In ppm**	**μ in cp**	**X_1 (^{0}C)**	**Y in dynes /cm**
0.005	5000	2937.33	29	30335.59461
0.01	10,000	6573.497	29	60773.29627
0.02	20,000	11441.063	29	121264.8055
0.03	30,000	18113.41756	29	182041.0045
0.05	50,000	10831.79283	29	300326.867

In confirmation, Uzoho et al., 2015, emphasized that the blend of ASP with a higher potential of enhanced oil recovery through the combination of positive effects of the three types of EOR agents. Taiwo *et al*.,(2015) in their experiment came up with findings thus: experiment shows Crushed sandstone from the Agbada oilfield in the Niger Delta was used as the adsorbent. The permeability was 485.83 and the average porosity was 23.5%. Tyler series sifting in sieves was adopted to estimate the grain size (particle size distribution) of the crushed core (adsorbent).

Depending on this formulation concentration such as 0.005 wt %, 0.01 wt %, 0.02 wt %, 0.03 wt % and 0.05 wt% , we obtain various recoveries. By combining synthetic chemicals (Tween-80) with alkali chemicals -80 and HPAM (88%) was noted as optimum. KOH, SDS and HPAM (87.5%) at 0.03 wt % . These served as control for the experiment. Although the local surfactants were seen as far cheaper in cost and the recoveries were also very favorable to be used as enhanced oil recoveryagents to aid in extra oil produced.

pH: Surfactant adsorption in the sandstone terrain (Niger Delta) was primarily reduced by the adding alkali (sodium carbonate) to the surfactant solutions, of alkali (Sodium carbonate) to the surfactant solutions. As pH rises, more surfactant is drawn into the solution by electrostatic forces, which improves the anionic charge on the sand surface. Uzoho *et al* (2015), utilizing these plant wastes helps to optimize profit, turn waste into money, and create jobs while also lowering production costs. Flooding with alkaline, surfactant, and polymer (ASP): Alkaline, surfactant, and polymer flooding outcomes. In this instance, there was 30 ml of original oil in the core. Upon water flooding the oil-saturated sand, a secondary recovery of 20.4 ml was attained. A 67.9% recovery resulted from this. 9.8 cc of the oil was not recovered. In order to obtain an extra recovery of 8.35 ml (87.5%), this was then inundated with ASP solution. 28.7 ml of the total volumetric recovery, or 94%, was recovered. The total recovery rate was highest in this particular case.

CONCLUSION: The conclusions arrived at is the combination of PBA, MEC and OGB. (Polymer) also gave 84% oil recovery at 0.02 wt % concentration with mobility ratio < 1 (good) interpreted as oil leads water in the subsurface.

In considering the controls the blending of sodium hydroxide combines with tween-80 and hydrolyzed polyacrylamide as polymer produced a good oil recovery (80%) at 0.005 wt % with interfacial tension (30335.5461 dynes/cm) noted as reduced IFT. The mobility ratio (0.384926122135) interpreted as oil leads water in the reservoir.

RECOMMENDATION: It is recommended with emphasis that other local materials should be looked into whose properties meets up the criteria for selection. Due to challenge, we faced on this work, we recommend that effect of wettability alteration on oil recovery should considered in further research.

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Probabilistic Forecasting of Petroleum Product Demand for Integrated Oil Value Chain Optimization

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Abstract

Optimization energy system models require forecasts of energy demand as a critical input. Traditional approaches to demand forecasting, such as assuming growth factors, developing econometric models, or use of deterministic time series models, introduce uncertainties that affect the recommended resource allocation strategy. To overcome this limitation, this paper uses the @Risk software to make probabilistic time series forecasts of refined petroleum product (RPP) demand. The time series fit function within @Risk is used to model probabilistic demand forecasts for RPP. Based on the historical demand for five products in Nigeria – Liquified Petroleum Gas (LPG), gasoline, kerosene, diesel, and fuel oil – the demand forecasts are modelled. Using the Akaike Information Criteria (AIC), the most representative time series model of the petroleum product demand is chosen. The AIC selects the model that retains the most information (least error) using the most parsimonious representation. The probabilistic time series representation of the refined products demand forecast is produced using the @Risk software an add-in to MS Excel. Gasoline, diesel, and fuel oil are best modelled as first order Auto – Regressive Conditional Heteroskedasticity processes (ARCH1), while LPG and kerosene are modelled as Brownian Motion and Moving Average processes respectively. In summary, this paper demonstrates how the use of @Risk software enables the creation of probabilistic time series forecasts for refined petroleum product demand, which in turn enhances the optimization of resource allocation strategies in an integrated oil value chain.

Keywords: Optimization; Time Series; Machine Learning.

INTRODUCTION

An energy system "…comprises all components related to the production, conversion, delivery, and use of energy". This definition is according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). From this definition, it can be inferred that an energy system is a complex, interacting entity of sub-system components that converts primary energy into forms that drive the economy. To model such a system, modelers must decide how to balance detail with parsimony to depict the energy system realistically and usefully. Deriving meaningful economic and policy interpretation from the empirical model results depends on achieving this balance (Karlsson, *et. al.* 2015). Within the context of an integrated oil value chain, the system modeled captures the production, conversion, and delivery of refined petroleum products to satisfy demand in Nigeria.

For an optimization model of an integrated oil value chain, energy demand is a critical component to be modelled for which several approaches have been developed. Bhattacharyya & Timilsina (2010) observed that for existing energy demand models, the two types of approaches commonly used are econometric and engineering end-use accounting. These are “sophisticated” types of demand models, compared to simpler demand models which rely on single indices such as: “growth rates”, “elasticities” (especially income elasticity), “unit consumption”, and “energy intensity”. Borha & Shah (2020) employ the “unit consumption” method to model Qatar’s total energy demand by sector (residential, commercial, industrial, transport, and agriculture) in their development of an optimization framework for Qatari decarbonization. Dioha & Kumar (2020) also utilize variants of the “unit consumption” and “energy intensity” methods to estimate sector energy demands in their modelling of Nigeria’s transition scenarios to a low-carbon energy system. This method is described by Bhattacharyya & Timilsina (2010) as follows:

$$E_t = [A_t][U_t]$$

Where E_t is the energy demand at time, *t*, A_t is the level of activity at time, *t*, and U_t is the energy requirement or consumption per unit of activity at time, *t*.

Bhattacharyya & Timilsina (2010) are of the view that the engineering end-use accounting (bottom–up) approach is more appropriate for a developing country. This is despite the high level of data intensity associated with the bottom–up approach – a significant drawback, acknowledged by the authors, for a developing country with data availability challenges. Specific to refined petroleum product demand, however, there are several models that have been built utilizing econometric approaches for Nigeria – a developing country. Aliyu, Ariweriokuma, Olaoye, & Bello (2016) employed the Structural Time Series Model to model the demand for gasoline and diesel in Nigeria. They model product demand as a function of real GDP, product price, and population and produce forecasts under different scenarios. Onwioduokit & Adenuga (2000) adopt a trans-log demand model for liquified petroleum gas (LPG), gasoline, and kerosene, using data from 1970 – 1996. Nwakaego, *et. al.* (2020) built models of petroleum product demand for select African countries including Nigeria using the Autoregressive and Distributive Lag Model (ARDL) technique. They model product demand as a function of product price, income, clean energy consumption, population growth, and the global financial crisis. Additionally, consistent with Iwayemi, 2010 and Salisu *et. al.*, 2016, Nwakaego *et. al.* (2020) demonstrates that demand for petroleum products is price and income-inelastic.

To develop an optimization framework for an integrated oil value chain, the significant analytical components include the reference energy system, oil supply models, and refined petroleum product demand models. Generally, however, energy system optimization models tend to rely on deterministic, perfect foresight demand forecasts. This perfect foresight is not reflective of reality, and modelers attempt to overcome this shortcoming by use of scenarios that are intended to capture different demand outlooks. This paper focuses on the development of probabilistic time series models of refined petroleum product demand, to enable forecasts. These probabilistic demand forecasts allow analysts, using the energy system model, to address the question of optimal oil resource allocation to meet uncertain future demand. In probabilistic forecasting, the full predictive distribution of the forecast is of interest and not just a single best realization (Salinas, *et. al.*, 2020). This predictive distribution is used for further decision-making, such as the optimization of an integrated oil value chain (Gbakon, *et. al.*, 2022), or long-range techno-economic analysis (Rogers, *et. al.*, 2023).

MATERIAL AND METHOD

A time-series is a collection of observations made sequentially through time. Forecasts of what the next observation might be made based on data comprising one or more time series are referred to as time series forecasting (Chatfield, 2000). Probabilistic time series forecasting refers to making estimates of the probability distribution of a time series' future given its past (Salinas, *et. al.*, 2020). Several methods have been identified in the literature for probabilistic time series forecasting. Fatema, *et. al.* (2023) identified two approaches adopted in time series forecasting applied to energy demand – statistical and the Artificial Intelligence (AI) (machine learning) methods. Statistical methods such as exponential smoothing, multiple linear regression models, Generalized Autoregressive Conditional Heteroskedasticity (GARCH), and Autoregressive Moving Average (ARMA) are based on linear models. Rodgers *et. al.* (2023) leaning on AI methods deployed an ensemble of 100 neural networks trained on historic commodity price data to project long-term probabilistic prices. Salinas *et. al.* (2022) employed deep learning techniques to train an auto-regressive recurrent network for producing probabilistic forecasts.

Either statistical or machine learning methods can be deployed to yield single-point or probabilistic forecasts. According to Haben *et. al.* (2023), probabilistic forecasts can take three forms thus: (i) Quantile forecast, (ii) Density forecast and (iii) Ensemble forecast. Figure 1 which is extracted from Haben *et. al.* (2023) illustrates the different types of forecasting including the three types of probabilistic forecast.

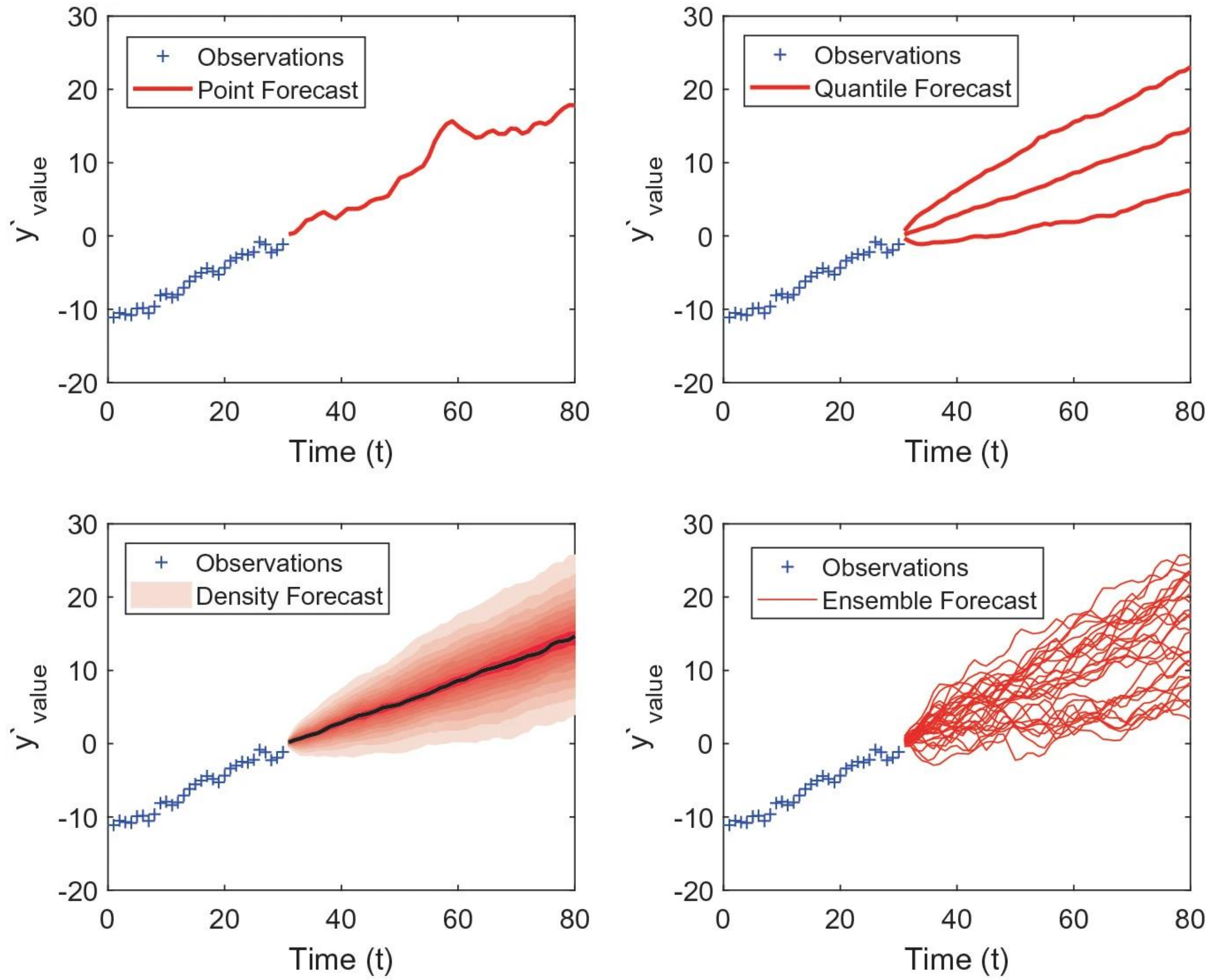

Figure 1: Different types of forecasts, including the three different types of probabilistic forecasts. The blue crosses are historical observations, and the forecasts are in red starting at time step t=31 (extracted from Habben, et. al., 2023)

The quantile forecast shows the 10%, 50% (median) and 90% quantiles where the area enveloped between two quantiles of interest is referred to as the prediction interval. The density forecast captures the full continuous distribution estimated for each time step, while ensemble forecasts provide estimate realisations recognizing the interdependence of values in different time steps.

In this paper, we use the statistical approach to probabilistic time series forecasting to generate density forecasts.

The @RISK software is an add-in tool for Microsoft Excel that aids better decisions through risk modelling and analysis. Using a technique known as Monte Carlo simulation, the software computes and tracks many different possible future scenarios in a risk model, indicating the probability of each scenario occurring.

The time series fit function within @Risk is used to model probabilistic demand forecasts for refined petroleum products. Figure 2 shows the steps followed to deliver a probabilistic time series forecast. In this paper, we will be making forecasts up to 24 time periods (years) into the future.

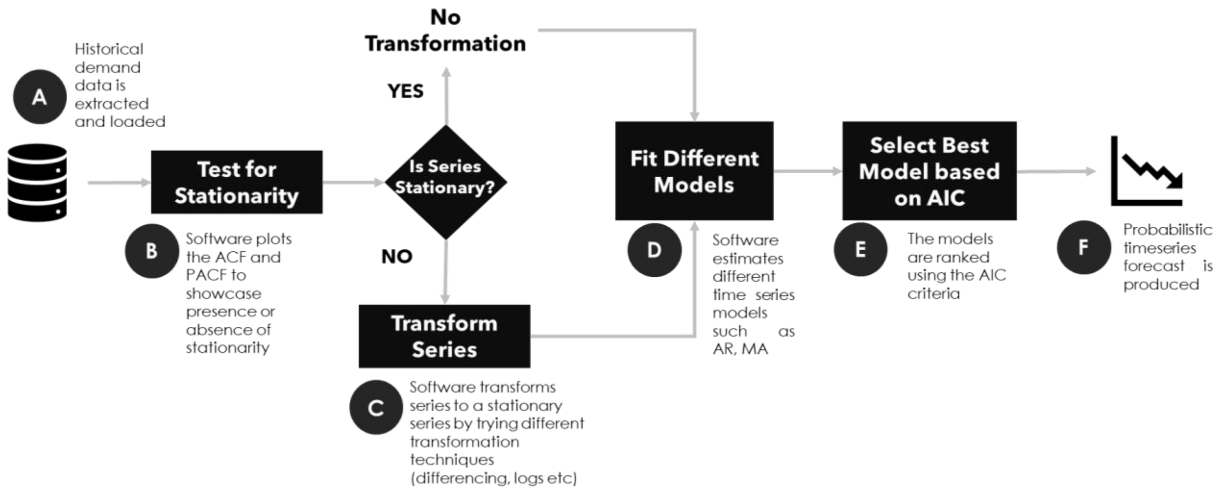

Figure 2: Steps to Model Time Series Forecast in @Risk

After the historical demand data is uploaded, the software performs stationarity tests in Step B. The Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF) plots made in Step B are diagnostic plots from which the characteristics of the time series can be assessed and appropriately modelled. Interpreting the ACF allows the presence of stationarity to be detected. Further, the ACF helps to identify which lags have significant correlations, and understand the trend, seasonality properties of the time series. The PACF is useful to identify the order of an autoregressive process. Together, the ACF and PACF are useful in Step D when the appropriate time series models are fitted.

Depending on the outcome of the time series stationarity tests, the series may be transformed or used in its original form to fit different models in Step D. The most representative time series model of the petroleum product demand pattern is chosen by using the criteria of least AIC (Akaike Information Criteria) seen in Step E. The AIC metric allows for the selection of a best-fit model from a set of candidate models by estimating the models' prediction error and thus establishing their relative quality (Stoica & Selen, 2004). Given that statistical models invariably do not exactly represent the data modelled (due to information loss), the AIC seeks to select the model that retains the most information (least error) using the most parsimonious representation. AIC is calculated using the following:

$$AIC = 2k - 2\ln(\hat{L})$$

Equation 1

Where k is the number of estimated parameters in the model, and $\hat{L}$ is the maximum value of the likelihood function for the model. For each of the models fitted in Step D, the corresponding AIC is calculated and the model with the least AIC is selected as the model most representative of the time series data. The Bayesian Information Criteria (BIC) is another evaluation criteria that which is available in the software for model selection.

Historical Product Demand

The forecast of refined product demand is based on demand data collected and summarized in Table 1. Historical LPG consumption between 2005 and 2020 is assembled from different sources. LPG consumption data from 2005 to the year 2012 is sourced from Global Data Watch[1] while, data for the years 2013, 2016, 2018, 2019, and 2020 is sourced from diverse media reports of PPPRA[2] press releases. The missing data for the years 2014, 2015, and 2017 are interpolated.

Table 1: Historical Annual Refined Product Demand in MMbbls

Year	LPG	PMS	DPK	AGO	FO
1986	-	-	-	-	7.11
1987	-	-	-	-	8.83
1988	-	-	-	-	12.80
1989	-	-	-	-	12.55
1990	-	-	-	-	12.87
1991	-	-	-	-	13.71
1992	-	-	-	-	11.11
1993	-	-	-	-	10.54
1994	-	-	-	-	10.09
1995	-	30.99	13.61	16.94	10.76
1996	-	33.95	15.33	15.51	5.09
1997	-	34.02	14.89	17.26	12.18
1998	-	32.85	14.45	16.57	7.78
1999	-	30.73	13.58	15.48	11.58
2000	-	40.77	9.34	17.01	12.22
2001	-	50.30	12.52	19.93	11.40
2002	-	49.24	15.16	16.95	9.90
2003	-	49.87	11.65	15.34	14.50
2004	-	53.31	11.97	15.91	5.99
2005	0.47	59.97	13.65	14.83	8.75
2006	0.29	57.01	13.21	11.17	8.12

[1] https://www.theglobaleconomy.com/Nigeria/lpg_consumption/
[2] PPPRA, now defunct, is the Petroleum Product and Pricing Regulatory Agency

Year	LPG	PMS	DPK	AGO	FO
2007	0.40	51.98	12.92	8.94	7.06
2008	0.47	59.50	12.70	9.49	5.78
2009	0.29	61.39	9.23	8.80	7.24
2010	1.02	69.90	11.17	13.07	9.48
2011	1.57	78.58	15.91	15.80	-
2012	1.24	88.07	17.41	16.46	-
2013	2.83	99.97	19.45	17.81	-
2014	3.53	103.59	19.35	18.36	-
2015	4.29	111.84	16.02	20.44	-
2016	5.65	109.14	9.13	24.46	-
2017	6.33	115.34	9.49	29.93	-
2018	7.18	123.01	8.76	28.84	-
2019	9.50	-	-	-	-
2020	11.30	-	-	-	-

Historical PMS (gasoline), DPK (kerosene), and AGO (diesel) consumption data are assembled from 1995 to 2018 from the NNPC ASB. Historical FO (fuel oil) consumption data (1986 to 2010) is obtained from the IEA. Note that fuel oil demand data ends in 2010, however, in the absence of any up-to-date data, this series is used as a basis for forecasting.

The demand for LPG, gasoline, and diesel have been on the increase due to population growth, rising level of urbanization, and economic growth. In the decade between 2010 and 2020, LPG consumption recorded the most aggressive demand growth of all the refined products in our dataset – more than 1000% from 1.02 MMbbls/annum in 2010 to 11.30 MMbbls/annum in 2020. Between 2010 and 2018, gasoline consumption increased by 76%, while diesel demand increased by 120%. Kerosene demand however fell by 22% from 11 MMbbls/annum in 2010 to 8.76 MMbbls/annum in 2018. Although the fuel oil data set ends in 2010, the demand trend exhibited volatility between 1986 and 2010.

RESULTS AND DISCUSSION

The model results of each of the five refined petroleum product demands are presented in the following sub-sections.

LPG Time Series Model

Following the stages outlined in Figure 2, the @Risk software is used to estimate the best time series forecast model using the AIC metric. The ACF diagnostic plots shown in Figure 3 decays to near 0 after 5 periods, thus indicating that the LPG series is stationary.

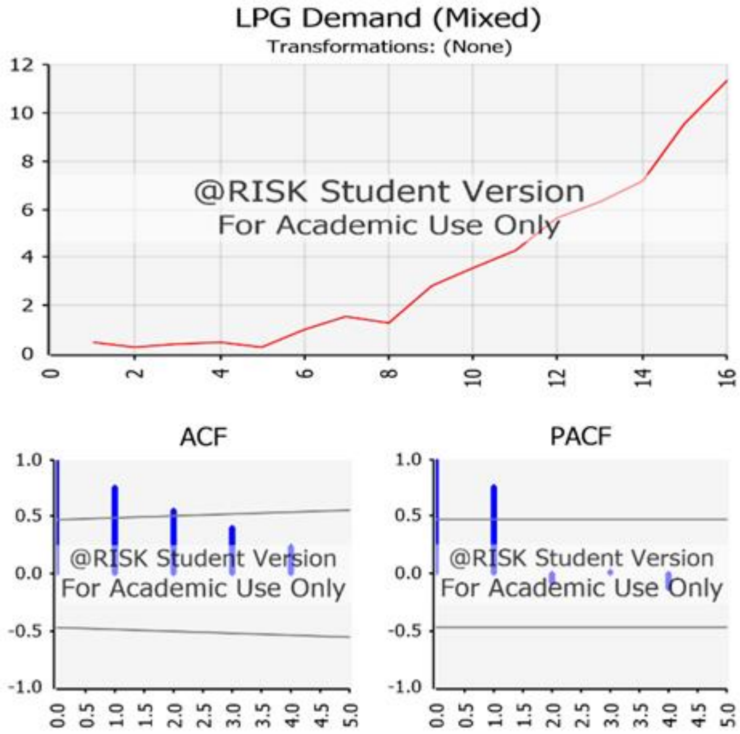

Figure 3: ACF and PACF plot of LPG demand

Table 2 shows the top 5 models ranked by the AIC metric. The shaded column is the top-ranked model for the LPG time series.

Table 2: Top 5 ranking LPG Time Series Models

Model	**AR (1)**	**AR (2)**	**ARMA (1,1)**	**BMMR**	**BMMRJD**
Data Transform	Auto Detect	Auto Detect	Auto Detect	Auto Detect	Auto Detect
Function	None	None	None	None	None
Shift	0	0	0	0	0
Detrend	None	None	None	None	None
Deseasonalize	None	None	None	None	None
Seasonal Period	N/A	N/A	N/A	N/A	N/A
Akaike (AIC) Rank	#4	#2	#3	#5	#1

Model	AR (1)	AR (2)	ARMA (1,1)	BMMR	BMMRJD
Akaike (AIC) Fit	40.99	38.99	40.67	40.99	34.16
No. of Parameters	3	4	4	3	6
Parameter #1	μ	μ	μ	μ	μ
Value	3.60	3.62	3.63	3.60	7544.21
Parameter #2	σ	σ	σ	σ	σ
Value	0.76	0.65	0.69	0.77	0.57
Parameter #3	a1	a1	a1	α	α
Value	0.97	1.47	0.95	0.03	0.00
Parameter #4		a2	b1		λ
Value		-0.52	0.41		0.00
Parameter #5					μ Jump
Value					1173.65
Parameter #6					σ Jump
Value					20.69

The BMMRJD (Brownian Motion with Mean Reversion Jump Diffusion) model ranks top according to AIC to best model the LPG time series. Consequently, LPG consumption forecast is represented as a BMMRJD. The function is expressed thus: $BMMRJD(\mu,\sigma,\alpha,\lambda,\mu_j,\sigma_j,Y_O)$ with the following arguments: μ is drift, σ is volatility, α is the speed of reversion, λ is the jump rate, μ_j is the jump size mean, σ_j is the jump size standard deviation, and Y_O is the value of the data feed at time 0. Figure 4 shows the historical and forecast LPG demand.

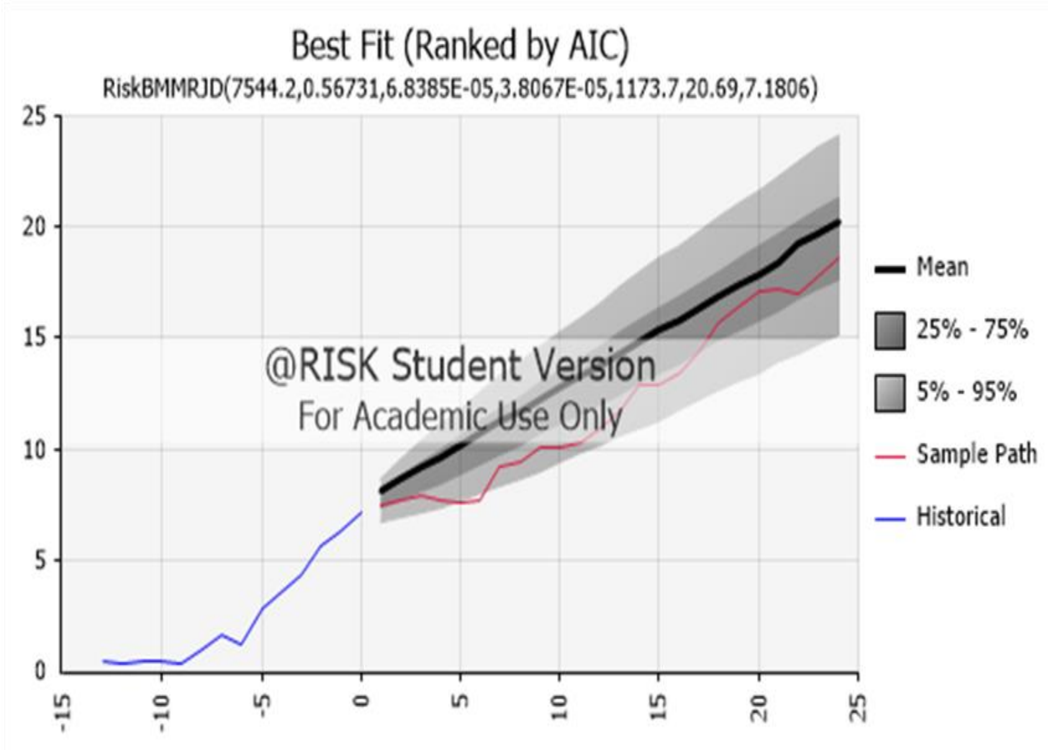

Figure 4: Historical and Probabilistic Forecast LPG demand

LPG mean demand is forecast to increase to 20.2 MMbbls by the 24th period after the historical data ends. However, the shaded band around the mean forecast indicates the confidence interval within which the forecast may lie. Additionally, in a simulation, the red line is a sample path or a likely forecast of LPG demand.

PMS Time Series Model

ACF diagnostic plot of the PMS time series, shown in Figure 5, indicates that the PMS series is non-stationary. The series is first order differenced to make it stationary – note the row labelled "Detrend" in Table 3.

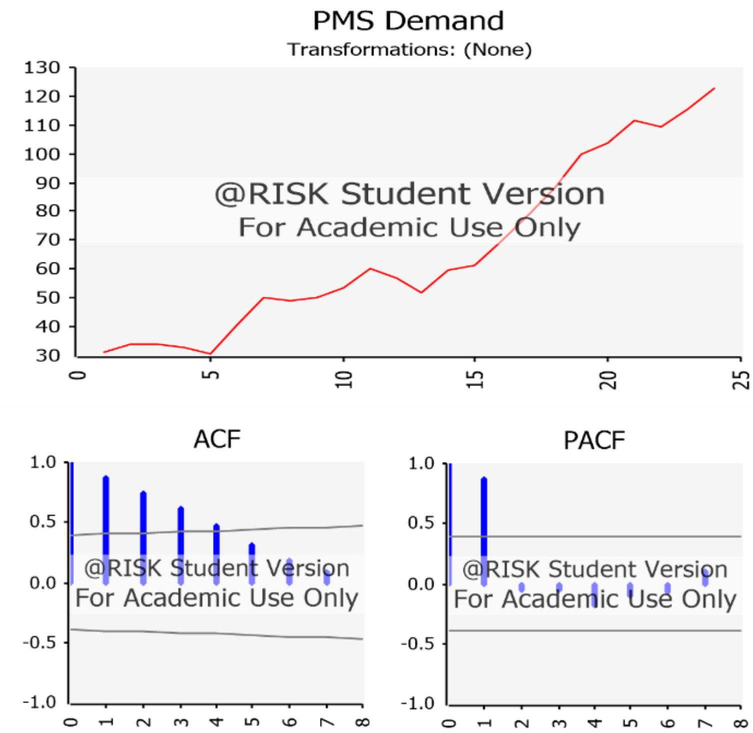

Figure 5: ACF and PACF plot of PMS (gasoline) demand

The best time series forecast model is selected using the AIC metric, following this transformation. Table 3 shows the top 5 models ranked by the AIC metric. The shaded column is the top-ranked model for the PMS time series.

Table 3: Top 5 ranking PMS Time Series Models

Model	**AR (1)**	**MA (1)**	**BMMR**	**ARCH (1)**	**GARCH (1,1)**
Data Transform	Auto Detect	Auto Detect	Auto Detect	Auto Detect	Auto Detect
Function	None	None	None	None	None
Shift	0	0	0	0	0
Detrend	First Order	First Order	First Order	First Order	First Order
Deseasonalize	None	None	None	None	None
Seasonal Period	N/A	N/A	N/A	N/A	N/A
Akaike (AIC) Rank	#4	#3	#5	#1	#2
Akaike (AIC) Fit	143.92	143.84	143.92	139.20	141.20
No. of Parameters	3	3	3	3	4
Parameter #1	μ	μ	μ	μ	μ

Model	AR (1)	MA (1)	BMMR	ARCH (1)	GARCH (1,1)
Value	4.02	4.02	4.02	3.91	3.91
Parameter #2	σ	σ	σ	ω	ω
Value	4.85	4.84	9.46	18.48	18.48
Parameter #3	a1	b1	α	a1	a1
Value	0.16	0.17	1.86	0.29	0.29
Parameter #4					b1
Value					3.44E-15
Parameter #5					
Value					
Parameter #6					
Value					

The best time series model for PMS demand according to the AIC metric is the ARCH1 (Auto – Regressive Conditional Heteroskedasticity of a first order). The function is expressed thus: $ARCH1(\mu, \omega, \alpha_1, Y_O)$ where μ is the mean, ω is the volatility parameter, α_1 is the error coefficient, and Y_O is the value of data feed at time 0. Figure 6 shows the historical and forecast gasoline demand.

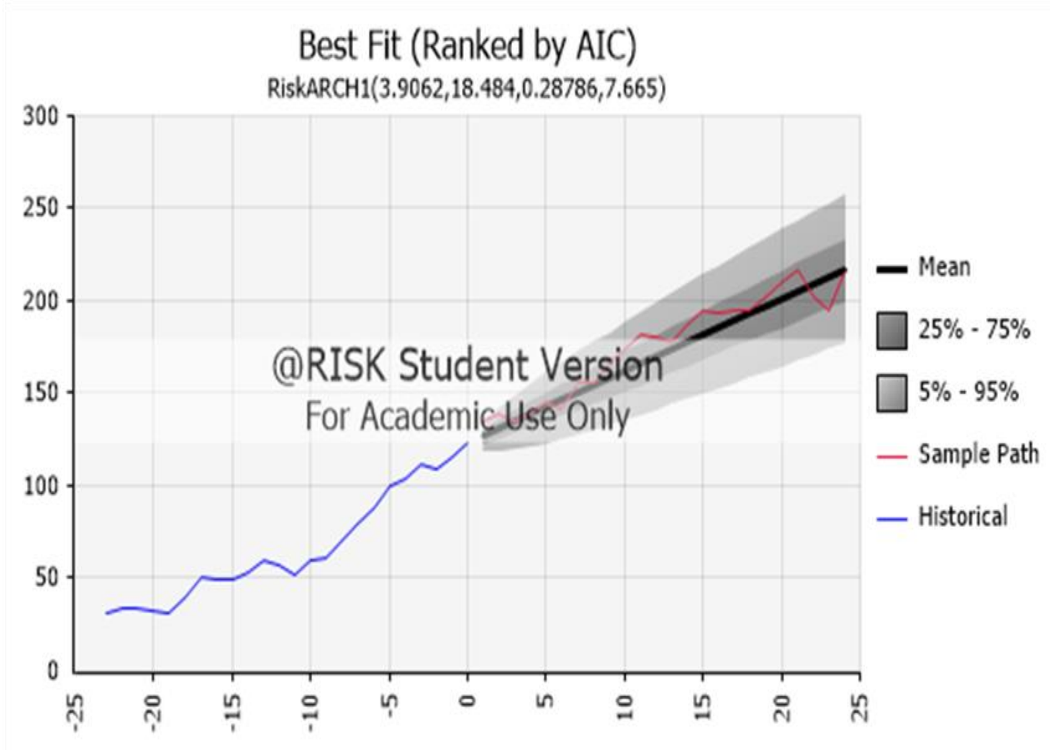

Figure 6: Historical and Probabilistic Forecast PMS demand

The mean forecast demand for gasoline is expected to increase from 126 MMbbls to ~ 220 MMbbls over 24 periods (or years).

DPK Time Series Model

The ACF diagnostic plot of the DPK time series in the Figure 7 is shown to decay to zero over 7 periods thus indicating the DPK series to be stationary.

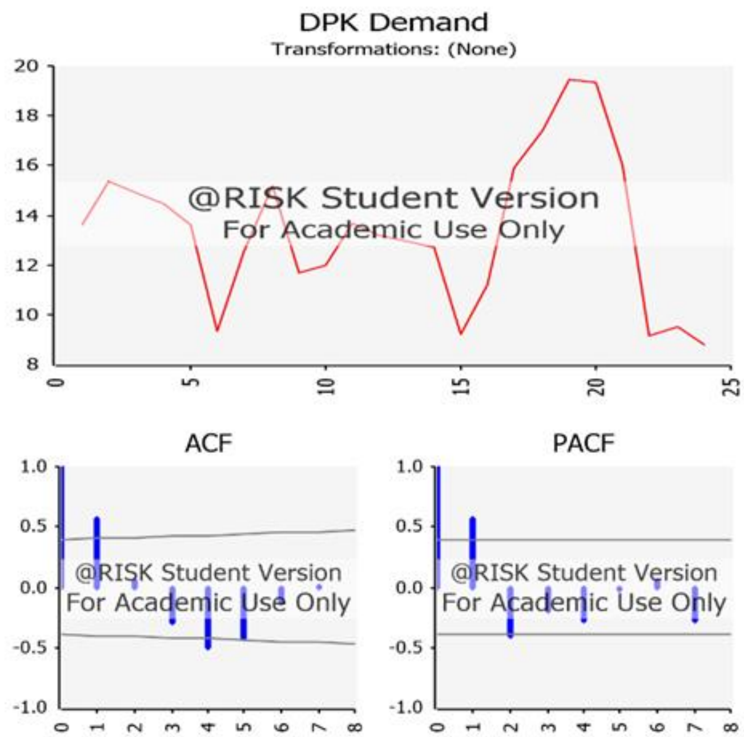

Figure 7: ACF and PACF diagnostic plot for DPK demand

The best-fit time series model, according to the AIC metric is selected. The shaded column in Table 4, showing the top 5 models ranked by the AIC metric, is the top-ranked model for the DPK time series.

Table 4: Top 5 ranking DPK Time Series Models

Model	**AR (1)**	**AR (2)**	**MA (1)**	**MA (2)**	**ARMA (1,1)**
Data Transform	Auto Detect	Auto Detect	Auto Detect	Auto Detect	Auto Detect
Function	None	None	None	None	None
Shift	0	0	0	0	0
Detrend	None	None	None	None	None
Deseasonalize	None	None	None	None	None
Seasonal Period	N/A	N/A	N/A	N/A	N/A
Akaike (AIC) Rank	#5	#2	#1	#4	#3
Akaike (AIC) Fit	115.81	113.41	112.53	113.99	113.80

Model	**AR (1)**	**AR (2)**	**MA (1)**	**MA (2)**	**ARMA (1,1)**
No. of Parameters	3	4	3	4	4
Parameter #1	μ	μ	μ	μ	μ
Value	13.12	13.29	13.20	13.18	13.14
Parameter #2	σ	σ	σ	σ	σ
Value	2.36	2.14	2.14	2.16	2.15
Parameter #3	a1	a1	b1	b1	a1
Value	0.61	0.85	0.92	0.91	0.29
Parameter #4		a2		b2	b1
Value		-0.42		0.21	0.66
Parameter #5					
Value					
Parameter #6					
Value					

The DPK time series is modelled as an MA1 (Moving Average of first order) process, based on which stochastic forecasts will be made. The function is expressed thus: $MA(\mu, \sigma, b_1, \varepsilon_O)$ where μ is the mean, σ is the volatility parameter, b_1 is the moving average coefficient, and ε_O is the initial error term. The plot of historical DPK consumption and the MA1 – based forecast is shown in Figure 8.

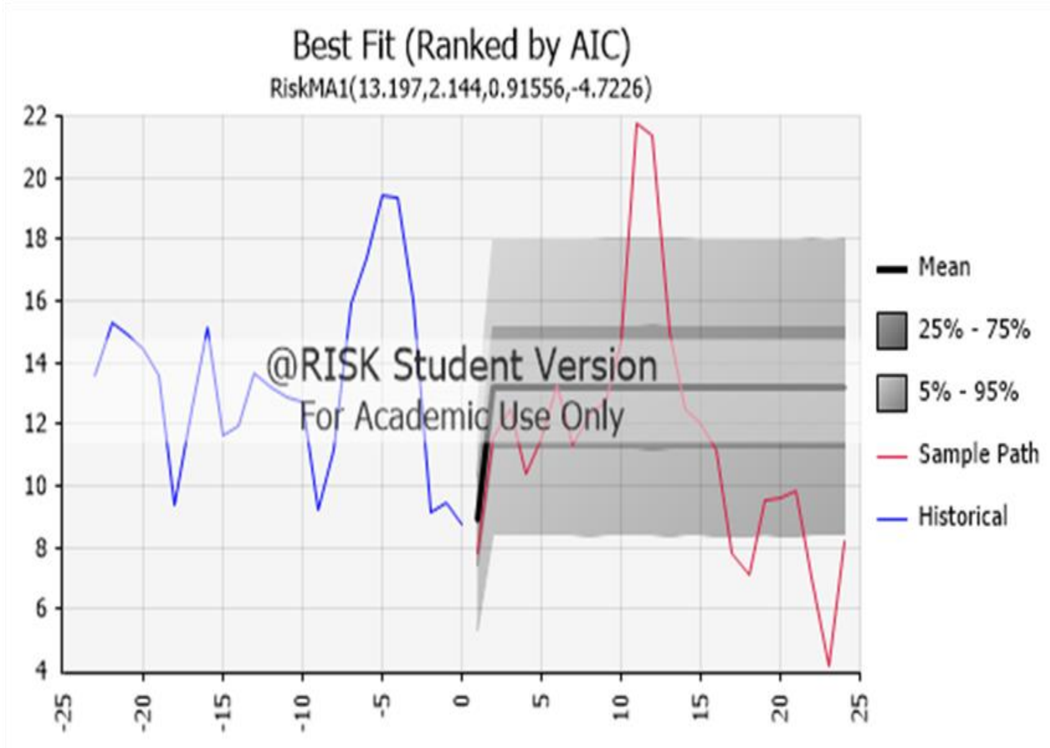

Figure 8: Historical and Probabilistic Forecast DPK demand

Mean DPK demand forecast is 13 MMbbls/annum. In a simulation however, several possible paths for the DPK demand to evolve are generated and in the graphic above, the red line represents one such possible forecast path where demand can spike to 22 MMbbls/annum.

AGO Time Series Model

The ACF diagnostic plot of the AGO time series in the Appendix indicates the series to be non-stationary. Accordingly, the series is first order differenced (see the row "Detrend" in Table 5) and subsequently, as assessed by the AIC metric, the best-fit time series model is the ARCH (1).

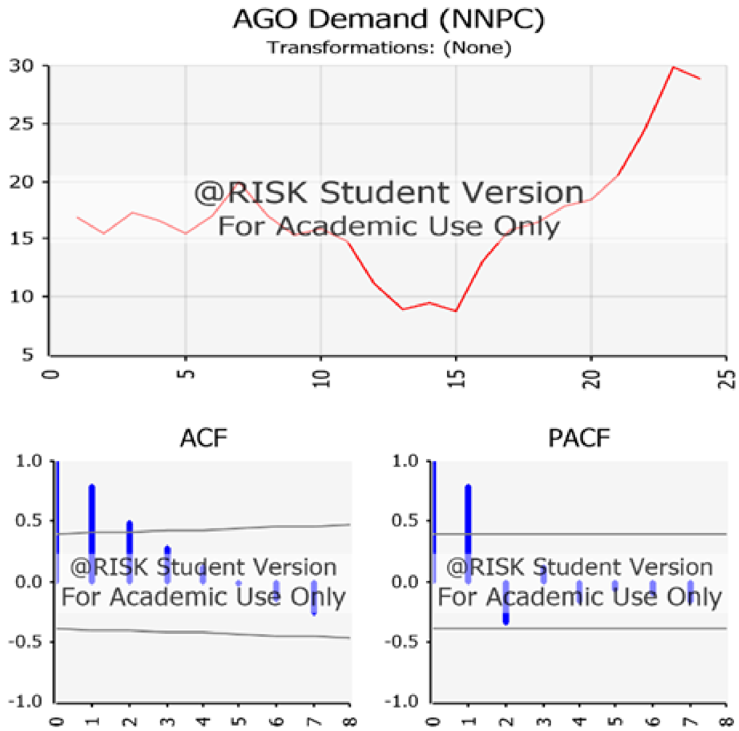

Figure 9: ACF and PACF diagnostic of AGO demand

Table 4 shows the top 5 models ranked by the AIC metric. The shaded column is the top-ranked model for the AGO time series.

Table 5: Top 5 ranking AGO Time Series Models

Model	**AR (1)**	**MA (1)**	**BMMR**	**ARCH (1)**	**GARCH (1,1)**
Data Transform	Auto Detect	Auto Detect	Auto Detect	Auto Detect	Auto Detect
Function	None	None	None	None	None
Shift	0	0	0	0	0
Detrend	First Order	First Order	First Order	First Order	First Order
Deseasonalize	None	None	None	None	None
Seasonal Period	N/A	N/A	N/A	N/A	N/A
Akaike (AIC) Rank	#5	#3	#4	#1	#2
Akaike (AIC) Fit	108.00	107.26	108.00	104.97	106.97
No. of Parameters	3	3	3	3	4
Parameter #1	µ	µ	µ	µ	µ
Value	0.46	0.41	0.46	0.61	0.61

Model	AR (1)	MA (1)	BMMR	ARCH (1)	GARCH (1,1)
Parameter #2	σ	σ	σ	ω	ω
Value	2.22	2.18	3.66	3.69	3.69
Parameter #3	a1	b1	α	a1	a1
Value	0.29	0.42	1.25	0.35	0.35
Parameter #4					b1
Value					1.02E-15
Parameter #5					
Value					
Parameter #6					
Value					

The ARCH (1) time series model, like the gasoline forecast, is also selected to model the forecast of diesel consumption stochastically. Historical AGO consumption as well as the ARCH (1) – based forecast is shown in Figure 10.

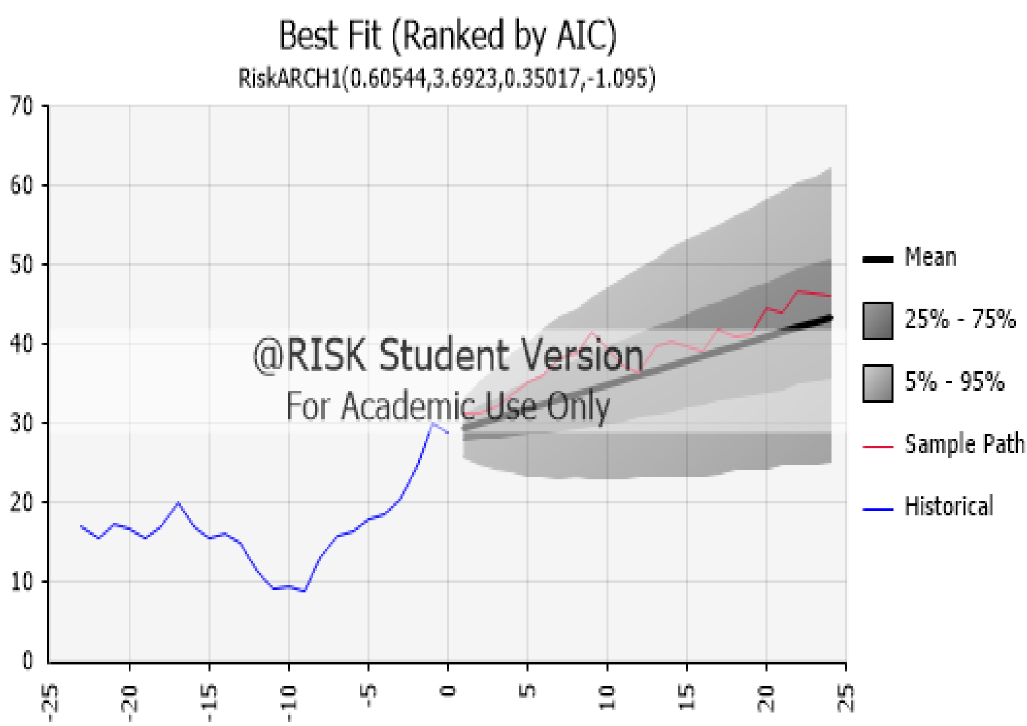

Figure 10: Historical and Probabilistic Forecast AGO demand

The mean demand forecast is from 29 MMbbls to 43 MMbbls after 24 periods (years).

FO Time Series Model

The ACF diagnostic plot of the FO time series indicates that the series is stationary. According to the AIC metric, the best-fit time series model is the ARCH (1).

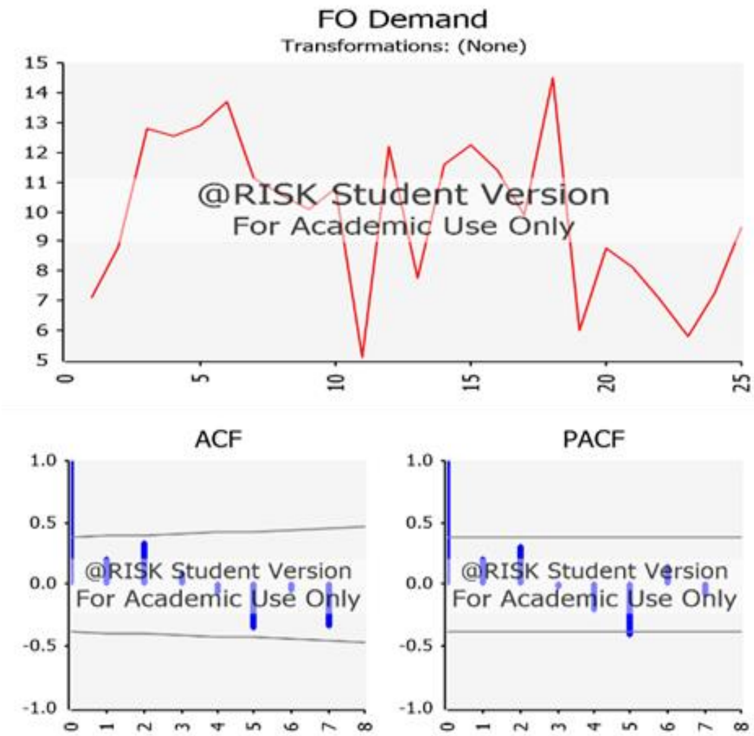

Figure 11: ACF and PACF diagnostic plot for Fuel Oil (FO) demand

Table 6 shows the top 5 models ranked by the AIC metric. The shaded column is the top-ranked model for the AGO time series.

Table 6: Top 5 ranking FO Time Series Models

Model	**AR (1)**	**AR (2)**	**MA (2)**	**ARCH (1)**	**GARCH (1,1)**
Data Transform	Auto Detect	Auto Detect	Auto Detect	Auto Detect	Auto Detect
Function	None	None	None	None	None
Shift	0	0	0	0	0
Detrend	None	None	None	None	None
Deseasonalize	None	None	None	None	None
Seasonal Period	N/A	N/A	N/A	N/A	N/A
Akaike (AIC) Rank	#5	#4	#3	#1	#2
Akaike (AIC) Fit	123.35	122.75	121.70	119.45	121.40
No. of Parameters	3	4	4	3	4
Parameter #1	μ	μ	μ	μ	μ
Value	9.86	9.72	9.77	10.01	10.02
Parameter #2	σ	σ	σ	ω	ω
Value	2.53	2.39	2.32	6.52	6.24
Parameter #3	a1	a1	b1	a1	a1
Value	0.20	0.14	-0.09	0.01	1.26E-15
Parameter #4		a2	b2		b1
Value		0.32	0.57		0.11
Parameter #5					
Value					
Parameter #6					
Value					

The choice model by the AIC metric is a first order ARCH, which is used to produce stochastic forecasts of FO demand in Nigeria. Historical FO consumption as well as the ARCH forecast are shown below.

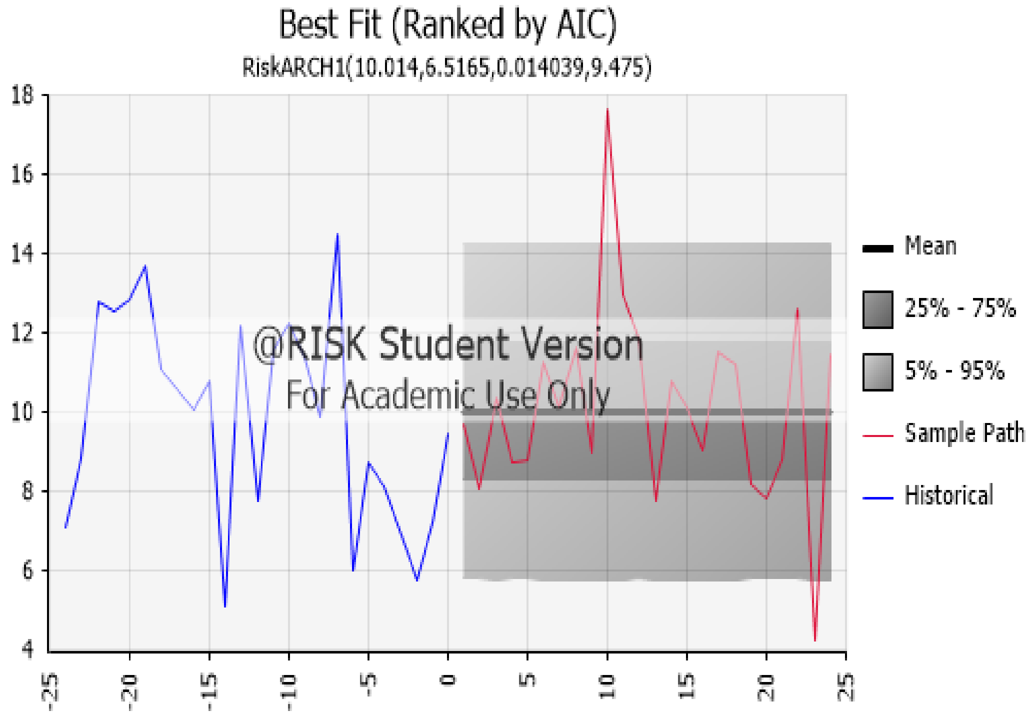

Figure 12: Historical and Probabilistic Forecast FO demand

Mean FO demand forecast is 10 MMbbls. Stochastically, however, the sample path illustrates FO demand could go as high as ~ 18 MMbbls and as low as ~ 4 MMbbls.

Discussion

To summarize, PMS (gasoline), AGO (diesel), and FO (fuel oil) are best modelled as ARCH (1) processes. While LPG and DPK (kerosene) are modelled as Brownian Motion and Moving Average processes respectively. The product demand forecast models, all of which were selected based on the AIC criteria, are provided in Table 7. We note however, that the BIC penalizes the inclusion of more parameters to improve fit and for this reason, some authors recommend its use over AIC (Chatfield, 2000) for deciding between time-series models. For our product demand models however, the BIC, and AIC yielded similar rankings.

The ARCH model is a time series statistical model that specifies the variance of the current error term as a function of the error terms from prior time periods. Mathematically, the ARCH model is thus expressed:

$$Y_t = \mu + \epsilon_t = \mu + \sigma_t N_t \qquad \text{Equation 2}$$

Where:

- μ is the mean of the data series
- $\epsilon_t = \sigma_t N_t$ is the error term; σ_t is the time dependent standard deviation and N_t is a white noise process – samples drawn from normal distribution N (0,1).

The variance is modelled as

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 \qquad \textit{Equation 3}$$

$\omega > 0; \alpha_i \geq 0; \ i > 0$

For a first order model, $q = 1$, the above reduces to

$$\sigma_t^2 = \omega + \alpha_1 \epsilon_{t-1}^2 = \omega + \alpha_1 (Y_{t-1} - \mu)^2 \qquad \textit{Equation 4}$$

The interpretation of Equation 4 is that the variance, is a weighted combination of the volatility parameter, ω, and the square of the previous deviation from the mean.

Table 7: Summary of Product Demand Time Series Models selected by AIC.

S/N	Product	Model Process	Specification of Arguments
1	LPG	Brownian Motion with Mean Reversion Jump Diffusion $BMMRJD(\mu, \sigma, \alpha, \lambda, \mu_j, \sigma_j, Y_O)$	μ = 7544.21 σ = 0.00 α = 0.00 λ = 0.00 μ_j = 1173.65 σ_j = 20.69 Y_O = 11.3
2	PMS	Auto – Regressive Conditional Heteroskedasticity of a first order. $ARCH1(\mu, \omega, \alpha_1, Y_O)$	μ =3.91 ω = 18.48 α_1= 0.29 Y_O = 7.665
3	DPK	Moving Average of first order $MA(\mu, \sigma, b_1, \varepsilon_O)$	μ = 13.20 σ = 2.14 b_1 = 0.92 ε_O = -4.7226
4	AGO	Auto – Regressive Conditional Heteroskedasticity of	μ =0.61

S/N	Product	Model Process	Specification of Arguments
		a first order $ARCH1(\mu, \omega, \alpha_1, Y_O)$	ω = 3.69 α_1= 0.35 Y_O = -1.095
5	FO	Auto – Regressive Conditional Heteroskedasticity of a first order $ARCH1(\mu, \omega, \alpha_1, Y_O)$	μ =10.01 ω = 6.52 α_1= 0.01 Y_O = 9.475

For the Moving Average process, it can be represented mathematically as follows.

$$Y_t = \mu + \epsilon_t + \sum_{i=1}^{q} b_i \epsilon_{t-i}$$

Equation 5

Where

- μ is the mean of the data series
- $b_i \ldots b_q$ are parameters of the model
- $\epsilon_t = \sigma_t N_t$ is the error term; σ_t is the time dependent standard deviation and N_t is a white noise process – samples drawn from normal distribution N (0,1).

For a 1st order process, $q = 1$, the reduces to

$$Y_t = \mu + \epsilon_t + b_1 \epsilon_{t-1}$$

Equation 6

Summary of the mean forecast product demand is in Table 8.

Table 8: Forecasts of Refined Petroleum Product Demand in MMbbls/annum

F'Cast Period	LPG	PMS	DPK	AGO	FO
1	8.12	126.91	8.86	29.44	10.01

F'Cast Period	LPG	PMS	DPK	AGO	FO
5	10.18	142.55	13.20	31.87	10.01
9	12.24	158.19	13.20	34.30	10.01
14	14.81	177.73	13.20	37.33	10.01
19	17.39	197.28	13.20	40.37	10.01
24	20.25	216.82	13.20	43.41	10.01

CONCLUSION

In the applied domain of energy system modelling, energy demand forecasting is critical. Usually, forecasting approaches rely on "growth rates" with reference to a given base where any uncertainties in the future demand are cast as "scenarios" which include variations of the growth rate. For optimizing an integrated oil value chain, forecasting refined petroleum product demand is vital to the optimal allocation of oil and refined products.

In this paper, we have harnessed the value of probabilistic time series forecasting to capture uncertainty. We developed statistical time series forecasts for five refined products which provides a probability range within which time series predictive values can lie. The approach we adopted was to select the best statistical demand model for each of LPG, gasoline, kerosene, diesel and fuel oil based on historical trends, and then project probabilistic future values based on the selected models.

This probabilistic forecast is an important component of optimizing the allocation of future oil production to meet demand for these products. Our approach moves away from the use of pre-determined growth rates for energy demand forecasting to embrace probabilistic forecasts to reflect uncertainty and ultimately deliver more robust optimization results. Further areas of research to be pursued, would be to explore the use of machine learning techniques for refined product demand forecasts.

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COMBINED IMPACT OF MAGNESIUM AND POTASSIUM SULFATE DURING OIL RECOVERY BY WATER FLOODING.

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ABSTRACT
Oil recovery by water flooding is a process that involves using brine solution as displacing fluid to improve the recovery of oil from hydrocarbon reservoir. The process has been known to be cost-intensive intensive. The study therefore investigated the effect of magnesium and potassium sulfate during oil recovery process by water flooding through experimental analysis in Laboratory. This research work involves preparation of brine solution and the flooding process. The experimental analysis was carried out on nine (9) different core samples, and the effect of different salinity of brine solution was observed and recorded throughout the process, that was carried out. The effect of magnesium and potassium sulfates have on recovery was estimated by the recovery percentage of oil trapped in reservoir. Brine ranging from 5 ppm to 15 ppm salinity was used. Subsequently, potassium and magnesium sulfate solutions of different concentrations were used for flooding. Water of 1000 ml was used in preparation of solution of varying weight of salts. Low salinity of brine solution as seen from the experiment, yielded more oil recovery which can be attributed to reduction in interfacial tension, in which both salts of magnesium and potassium sulfate recovered oil. Magnesium sulfate solution of different salinities showed a slight increase while the combined effect of potassium and magnesium sulfate solution has the highest recovery of oil from porous and permeable formation. Therefore, the combination of magnesium and potassium sulfate is recommended for optimum oil recovery.
Key words: Magnesium, Potassium Sulfate, Oil Recovery

INTRODUCTION

Water flooding being a category of secondary process of recoverable hydrocarbon, the driving mechanism required in pushing the crude from the porous and permeable formation into a production well that can be injected from the earth's surface using water. Injecting water usually requires pressure, to boost recovery within this porous and permeable rock unit. This fluid (water) pushes away the oil, hence rate of production can be sustained and it accompanied by force per unit area (pressure). Flooding the injection well with water is an integral component of man induced water drive, as a technique, it is named enhance oil recovery. In a brown field, water flooding remains the most viable and effective driving indices, whose recovery ranges between 40-80% of the Original Oil in place (OOIP) as stated by (Nasralla *et al*.,2011). Also increase in recoverable oil at the range of 2.2-20.4% original oil in place (OOIP) from flooding process according to (Greaser,2010). Water is the main fluid used to maintain the subsurface pressure, noted as the force per unit area of a displacing oil within the porous and permeable formation, also known as reservoirs. The use of brine (saline) water can be used for oil recovery process.

Water injection as a measure for oil recovery can be tested using laboratory experiments. Alteration of salt concentration improves displacement efficiency for silica oilfield with a sandstone reservoir and carbonaceous rocks of carbonate origin. The technique of tertiary recovery is far cheaper and has negligible impact on the production environment. It has been proven that water with salt content when flooded, increases recovery of oil within sandstone and carbonate reservoirs, (Wideroee *et al*.,2010). Therefore, the amount of magnesium and potassium sulfate concentration must be ascertained as this increases the amount of recoverable oil. In this research work, the aim and objective are to determine the combined effect of potassium and magnesium sulfate have on oil recovery and also the amount of recoverable oil on combining increase of magnesium and potassium sulfate salt, in low salinity brine during flooding.

This study is limited to the determination of the effect of potassium sulfate and magnesium salt on recoverable oil, the effect of divalent ions over monovalent ions on the mechanism of oil recovery and increase in combining potassium and magnesium sulfate salt in low-salinity brine during flooding.

This approach designs the flooding experiment to contain the appropriate proportion of ions in water to impact on the minerals aggregates, to sweep the oil in the reservoir, (Dous.*et al.*, (2009). Certain companies such as Exxon Mobil called their altering the ionic content of water as advancing Ionic

Enhanced recovery, attributed to the injection of water and other agents of recovery like salts and polymers helps in increasing production from the porous and permeable rock units (reservoir). The process or method also involves water, to sustain the porous and permeable unit force per unit area (pressure) for the displacement of oil. Conventionally water flooding assist in building up subsurface pressure within the porous and permeable rocks unit, this has a direct effect on improving oil production. The major constituent of injected water is brine or brine contents of the reservoir below the oil zone i.e. hydrocarbon (oil)-water contact (OWC) provided its water drive reservoirs pushes the oil towards the production well. Due to the energy need in West Africa, Nigeria being a highly populous country, there a high demand for enhancing the recoverable oil, boosting oil production has improved for years now due to the drop in prospecting for new green fields, energy demand has tremendously increased (Falls *et al*.,1992). The effect of interfacial tension (IFT): The reduction of interfacial tension (IFT), wettability alteration, emulsifying oil and control of mobility ratios can be achieved during chemical flooding. (Delshad *et al.*,1998) opines that chemical flooding can be limited if inadequacy exists in understanding the mechanisms used in interfacial tension reduction and wettability alteration. Polymer flooding can be achieved by increasing the weight of a molecules (molecular) named polymer to injected water to improve the impact of water flooding. These polymers when added to water to the weight of dissolve mass (concentration), range between 250 to 2010 ppm.

The migration of surfactant to the boundary between oil – water assist in making the two fluid phase miscible. Generally, soap and detergent are the main surfactant known. As the displacement of oil trapped within the pore spaces increases the interfacial tension between oil and water reduces within the rock matrix. Water when flooded in the reservoir known as a secondary process is relatively cheaper in comparison with the tertiary/enhanced recovery process, according to (Fan, *et al*.,2008). When the well is not producing at a sufficient rate, the process to enhance recovery is needed but operational cost can hinder the process of recovery. Therefore, it is necessary to increase production in other to cover the cost involved in production. Reasonable efficiency of recoverable oil can be achieved using water as a source of energy, (Pati *et al.*,2008) determining the water salinity is very necessary. Divalent and monovalent ions present in water concentrated with potassium and magnesium sulfate, proved to increase the recovered oil.

According to various research, flooding with a solution of sodium chloride of low salinity yielded recovery Therefore, there is a need to study the effect of other mineral salts on the flooding process. This experimental study will investigate the combination impacts on magnesium and potassium sulfates concentrations blending with sodium chloride to recover oil during water flooding. Also, they investigated the impact of salt concentration on permeability. The combining impact of potassium sulfate and sodium chloride was demonstrated by flooding three synthetic waters into oil-saturated core samples at concentrations of 10002, 5002, and 1000.01 ppm potassium sulfate (K_2SO_4) and 70,005, 75,003, and 79,002 ppm sodium chloride (NaCl), accordingly. The pH, contact angle, and interfacial tension values were then estimated.

The improvement in recoverable oil caused by a reduction in sodium chloride salt content including a rise in potassium sulfate concentration was linked to two key mechanisms that were developed: altering wettability and reducing interfacial tension (Heal *et al*.,2006).
The interfacial tension and contact angle estimation indicated that when potassium sulfate concentration increased, the interfacial tension (IFT) decreased and the wettability condition moved to a very strong water-wet state. The increase in magnesium and/or potassium levels combined with a reduced sodium chloride concentration promotes recoverable (El-Abbas *et al.*, 2017)
The chosen sodium chloride concentrations (70,002, 75,002, and 79,003 ppm) were much high compared to the values reported for lower salt-content water processes, which are reported to be between 1000 and 5000 ppm and between 300 and 3000 ppm total dissolved solids (Yousef *et al*., (2010) and (Wideroee *et al*.,2010) respectively.

EXPERIMENTAL METHOD.

Overview

This experimental investigation, which looked at the combined effects of magnesium and potassium sulfate concentrations while taking sodium chloride salinity into account, was carried out in nine (9) flood experiments. The following techniques and steps were used to find out how magnesium and potassium sulfate affected oil recovery by water flooding.

The Experimental Method

In this experiment the method is divided into three main groups: the first is the preparation of core samples artificially, using sea sand. The second is the preparation of brine solution, while the third is focus on effect of the solutions of Magnesium sulfate ($MgSO_4$) and Potassium Sulfate (K_2SO_4) on oil recovery during water flooding in low salinity brine, and their effect on permeability.

CORE SAMPLE PREPARATION

Due to the non-availability of original core samples, artificial cores were formed from sand from Etche river, in Rivers state, Niger Delta Region (Agbada Formation).

1. The sandstone was washed, dried and fried.
2. The sieves of various mesh sizes were used to sieve the sand until the required size is achieved.
3. Granulated sand was used to form capsulated core of varying sizes both in length, width, height, and weight.
4. The dry core was measured

Establishing cores saturation

1. A brine solution of 30g was prepared in 1000 ml of distilled water and stirred very well to obtain homogeneity at laboratory temperature of 27.2 ^oC.
2. The cores were saturated for 24 hours to ensure complete saturation.
3. The weight of each saturated core was calculated after the core samples were taken to have a known brine saturation state.
4. After then, the saturated core was placed in a core holder individually in the flooding system apparatus in laboratory as shown in flooding apparatus setup in plate 3.1.
5. 100 ml medium crude oil of API gravity of 22^o and viscosity of 47.7 cP at a 28^{o}C was connected through tubing with a control valve to regulate the flow.
6. Then, the cores were continuously flooded with crude oil to establish an initial-oil-in-place condition.
7. The brine displaced by crude was collected through a measuring cylinder and the original oil in place established.

Brine Solution Preparation

Preparation of brine solution of 5 ppm

1. 5 mg of sodium chloride salts were dissolved in 1000 ml distilled water stirred for about two (2) minutes to obtain homogeneity at a temperature of 28^{o}C.
2. The density of 5 ppm solution of sodium chloride was measured, with respect to the weight of the solution and volume of water.
3. The viscosity and pH of the solution also was measured using the viscometer.

Preparation of brine and potassium sulfate solution of 10 ppm

1. 7 mg of sodium chloride salts and 3 mg of potassium sulfate salts were dissolved in 1000 ml distilled water and stirred for about four (4) minutes to obtain homogeneity at a temperature 28^{o}C.
2. The density of 10 ppm solution of sodium chloride and potassium sulfate was measured, with respect to the weight of the solution and the volume of water.
3. The viscosity and pH of the solution also were measured.

Preparation of brine and potassium solution of 15 ppm

1. 10 mg of sodium chloride salts and 5 mg of potassium sulfate salts were dissolved in 1000 ml distilled water stirred for about six (6) minutes to obtain homogeneity at a temperature 28^{o}C.
2. The density of 15 ppm solution of sodium chloride and magnesium sulfate were measured, with respect to the weight of the solution and the volume of water.
3. The viscosity and pH of the solution also was measured using viscometer.

Preparation 5ppm sodium chloride solution

1. 5 mg of sodium chloride dissolved in 1000 ml distilled water and stirred for about two (2) minutes to obtain homogeneity at a temperature of 28^{o}C.
2. The density of 5 ppm solution of sodium chloride was measured, with respect to the weight of the solution and the volume of water.
3. The viscosity and pH of the solution also was measured using viscometer.

Preparation of 7 ppm sodium chloride and 3 ppm Magnesium Sulfate, 10 ppm TDS

1. 7 mg of sodium chloride salts and of 3 mg of magnesium sulfate salts were dissolved in 1000 ml distilled water stirred for about four (4) minutes to obtain homogeneity at temperature 28ºC.
2. The density of 10 ppm solution of sodium chloride and magnesium sulfate was measured, and calculated with respect to the weight of the solution and the volume of solution and volume of water.
3. The viscosity and pH of the solution also were measured using the viscometer.

Preparation of 10 ppm sodium chloride and 5 ppm magnesium sulfate solution, TDS 15 ppm

1. 7 mg of sodium chloride salts and 3 mg of magnesium sulfate salts were dissolved in 1000 ml distilled water and stirred for about six (6) minutes to obtain homogeneity at a temperature 28ºC.
2. The density of 15 ppm solution of sodium chloride and magnesium sulfate solution were measured and calculated with respect to the weight of the solution and the volume of water.
3. The viscosity and pH of the solution also were measured.

Preparation 5 ppm sodium chloride solution

- 5 mg of sodium chloride salt was dissolved in 1000 ml distilled water stirred for about two (2) minutes to obtain homogeneity at temperature 28ºC.
- The density of 5 ppm solution of sodium chloride was measured and calculated with respect to weight of solution and volume of water.
- The viscosity and the pH of the solution also was measured.

Preparation of 7 ppm sodium chloride, 3 ppm magnesium and potassium sulfate solution, TDS 10 ppm

1 7 mg of sodium chloride and 3 mg of magnesium and potassium sulfate salts were dissolved in 1000 ml distilled water stirred for about six (6) minutes to obtain homogeneity at temperature 28ºC.

2 The density of 10 ppm solution of sodium chloride, magnesium and potassium sulfate was measured and calculated with respect to the weight of solution and the volume of water.

3 The viscosity and the pH of the solution also was measured.

Preparation of 7 ppm sodium chloride, 4 ppm potassium sulfate and magnesium sulfate solution respectively TDS 15 ppm

4. 10 mg of sodium chloride salts and 5mg magnesium and potassium sulfate salts were dissolved in 1000 ml distilled water stirred for about six (6) minutes to obtain homogeneity at temperature 28ºC.
5. The density of 15 ppm solution was measured and calculated with respect to the weight of solution and the volume of water.
6. The solution viscosity was also measured.

Flooding Process

Core sample G1 was flooded with brine solution of 5 ppm salinity of sodium chloride.

Core sample G2 was flooded with brine solution, 10 ppm salinity of sodium chloride and magnesium sulfate.

Core sample G3 was flooded with brine solution of 15 ppm salinity of sodium chloride and magnesium sulfate.

Core sample G4 was flooded with brine solution of 5 ppm salinity of sodium chloride.

Core sample G5 was flooded with brine solution, 10 ppm salinity of sodium chloride and potassium sulfate solution

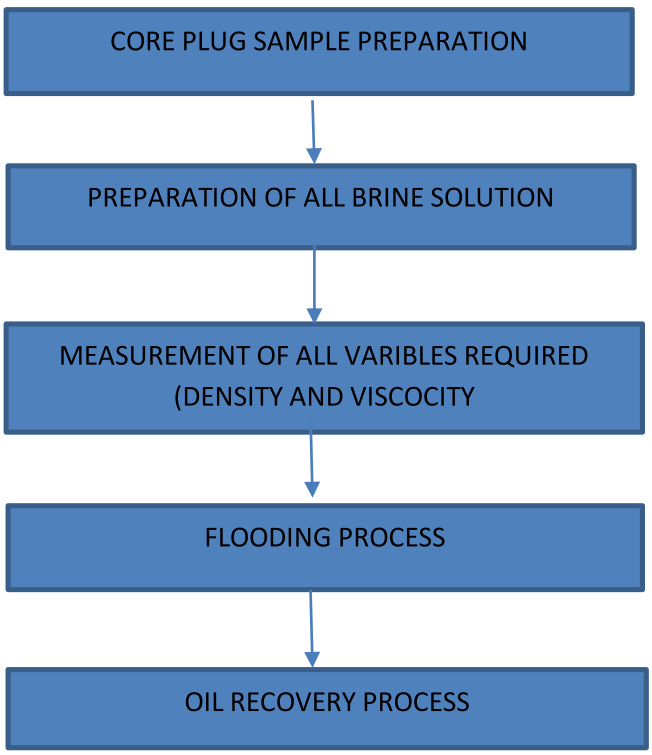
Core sample G6 was flooded with brine solution of 15 ppm salinity of both sodium chloride and potassium sulfate.

Core sample G7 was flooded with brine solution of 5 ppm salinity of sodium chloride.

Core sample G8 was flooded with brine solution of 10 ppm salinity of sodium chloride and of magnesium and potassium sulfate

Core sample G9 was flooded with brine solution of 15 ppm salinity of sodium chloride and magnesium and potassium sulfate of equal proportion.

METHODOLOGY FLOW CHART



Effect of Concentration of 5 ppm Sodium Chloride on Oil Recovery for Core Sample G1 Control Experiment.

The initial experiment was on modification of distilled water by dissolving 5 ppm of sodium chloride salt in 1000 ml of water with a pH of 6.8 at temperature of 28°C, density of 0.9064 g/ml and viscosity of 0.9489 Cp. The core sampled formed has a pore volume of 29.2 ml, porosity in the tune of 29.6%, having a permeability value of 1985.12 mD as base permeability, during water flooding the concentration of sodium chloride with a salinity of 5 ppm was used. The 9.5 ml of 14 ml initial oil trapped in core was recovered, which represents 52.77% of oil recovered after water flooding with concentration of 5 ppm low salinity brine

Effect of Sodium Chloride and Magnesium Sulfate, TDS 10 ppm on Oil Recovery for Core Sample G2

The flooding process using magnesium sulfate in a brine solution, has a high recovery rate when compared with flooding with only brine, it was attributed to the divalent ionic nature of magnesium salt because of the polar nature it interacts with oil-water interface which leads to the reduction of interfacial tension. The composition of injected water are7 mg and 3 mg of sodium chloride and magnesium sulfate respectively in 1000 ml of distilled water with a pH of 7.3, the temperature of 28^oC and salinity 10 ppm of the total dissolved solid ,the core sample formed represent the sand stone reservoir has pore volume of 29.2ml, porosity in tune of 29.6%, initial oil deposit of 20 ml, medium crude of API gravity, 20.22^o, yield 17 ml of oil recovered and percentage recovery of 61.11%, is presented in Table1, having a permeability value of 2010.04 mD at flow rate of 0.22ml/secs.

Effect of Sodium Chloride and Magnesium Sulfate of TDS 15 ppm on Oil Recovery for Core Sample G3

Brine solution with concentration of magnesium sulfate of the total dissolved solid, when used, increases the recovery of oil; scientifically the interfacial tension between the oil and displacing fluid decreases as in low salinity. 10 mg and 5 mg of sodium chloride and magnesium sulfate respectively in 1000 ml of water with pH of 7.3 at temperature of 28^oC and 15 ppm of total dissolved solid, the core sample formed represent the sandstone reservoir with pore volume of, porosity in tune of 29.6%, having a permeability value of 2201.00 mD at flow rate of 0.2 ml/secs. The increase in permeability is a result of a change in the salinity of brine solution. The percentage of oil recovered is 73.68%.

Table 1:Percentage oil recovered with varying salinity of sodium chloride and magnesium sulfate

Core Sample	OOIP (ml)	Salt Proportion (mg) NaCl	$MgSO_4$	TDS (mg)	Salinity (ppm)	oil recovered (ml)	percentage% oil recovered
G1	18	5		5	5	9.5	52.77
G2	18	7	3	10	10	11	61.11
G3	19	10	5	15	15	14	73.68

Effect of 5 ppm salinity of sodium chloride during water flooding for core sample G4

The initial experiment was on modification of distilled water by adding 5 mg of sodium chloride in 1000 ml of water with pH of 6.8 at laboratory temperature of 28^oC, density of 0.9064 g/ml and viscosity of 0.9489 cP. Using brine salinity of 5 ppm: the core sample formed represent the sandstone reservoir has a pore volume of 27.3 ml, porosity in tune of 29.4%, having a permeability value of 2328.6 mD. During water flooding, 8.5ml volume of oil recovered from 17 ml medium crude oil initially trapped inside the core which represents 50% of oil recovered.

Effect of sodium chloride and potassium sulfate of TDS 10 ppm on oil recovery for core sample G5

Brine solution of potassium sulfate and sodium chloride, having a total dissolved solid of 10 ppm, of different concentrations of sodium chloride and potassium sulfate salts of 7 mg and 3 mg dissolved in 1000 ml distilled water having pH of 7.5 at temperature of 28^oC and total salinity of 10 ppm. The core sampled formed represent the sandstone reservoir has a pore volume of 27.3 ml, porosity in tune of 29.4%, having a permeability value of 2341.9 mD, which is attributed to an increase in salinity. 14 ml of oil recovered from initial oil deposit of 19 ml, and percentage recovery of 57.82 %.

Effect of sodium chloride and potassium sulfate of TDS 15 ppm on oil recovery for core sample G6

The experiment was carried out by adding 10 mg of sodium chloride and 5 mg of potassium sulfate to form a solution of 15 ppm of total dissolved solid in the solution, pH of 7.7 at the of 28^oC, density 1.0264 g/ml and viscosity of 1.029 cP. Core sample contained initial oil deposit of 18 ml, medium crude of API gravity of 20.22^o, yield 13 ml of oil recovered and percentage recovery of 72.22%, the core sample has a pore volume of 27.3 ml, porosity in tune of 29.4%, having a permeability value of 2493.3 mD

Table 2: Percentage oil recovered with varying salinity of sodium chloride and potassium sulfate

Core Sample	OOIP (ml)	Salt Proportion (mg) NaCl	KSO_4	TDS (mg)	Salinity (ppm)	oil recovered (ml)	percentage% oil recovered
G4	17	5		5	5	8.5	50.00
G5	19	7	3	10	10	11	57.82
G6	18	10	5	15	15	13	72.22

Effect of sodium chloride concentration on oil recovery for core sample G7

The initial experiment was on modification of distilled water by adding 5 mg of sodium chloride in 1000 ml of water with a pH of 6.8 at temperature of 28^oC, the density of 0.9064 g/ml and viscosity of 0.9489 cP salinity of 5 ppm, a core sampled formed represent the sandstone reservoir has a pore volume of 25.1 ml, porosity of 29.4%, having a permeability value of 2492.0 mD as base permeability, during water flooding in a core that contained 20ml of medium crude of API gravity of 20.22^o, the volume of oil recovered is 8.5 ml, which represent 55.55% of oil recovered.

Combine effect of magnesium and potassium sulfate 10 ppm TDS on oil recovery on core sample G8

Combine effect of magnesium and potassium sulfate in low salinity brine of total dissolve solid of 10 ppm were also considered. The result showed an increment in recovery. 5 mg of sodium chloride and 5 mg of salts of magnesium sulfate and potassium sulfate of total dissolved solid of 10 ppm, 7.9 pH at laboratory temperature of 27.7°C and viscosity of 1.003 cP. The core sample formed represents the sandstone the sand stone reservoir with a pore volume of 25.1 ml, porosity in the tune of 28.5%, a permeability, having a permeability value of 2698.10 mD, the cored used during water flooding has an initial oil deposit of 19ml, the percentage recovery of 68.42%.

Combined effect of Magnesium and Potassium Sulfate 15 ppm TDS on the oil recovery core for sample G9

Combined effect of magnesium and potassium sulfate in low salinity brine of a total dissolved dissolve solid of 15 ppm was also considered. 7 mg of sodium chloride and 4 mg of salts of magnesium sulfate and potassium sulfate respectively, of total dissolved solid of 15 ppm, of 8.1pH at a temperature of 28°C and viscosity of 1.053 cP. The core sampled formed represents the sandstone reservoir with pore volume of 25.1 ml, porosity of 28.5%, having a permeability value of 2765.5 mD. The core used during water flooding contains an initial oil deposit of 18 ml, medium crude of API gravity of 20.22°, yielding 13ml of oil recovered, and a percentage recovery of 77.77%.

DISCUSSION OF RESULTS

Table 3: Percentage of oil recovered by combination of potassium sulfate and magnesium sulfate in sodium chloride of varying salinity

Core	OOIP	Salt Proportion (mg)		TDS	Salinity	oil recovered	percentage% oil recovered
Sample	ml	NaCl	$Mg/K_{(SO4)}$	mg	ppm	ml	
G7	20	5		5	5	11	55.55
			3				
G8	19	7		10	10	13	68.42
G9	18	10	5	15	15	14	77.77

Table 4: Composition of Brine Solutions

Brine Solutions	TDS mg	Salinity PPM	Density g/ml	pH^+	Temperature °C	Permeability mD	Viscosity cP
NaCl	5	5	0.9064	6.8	25	1985.12	0.9489
NaCl +$MgSO_4$	10	10	0.9584	7.3	26	2010.00	0.9834
NaCl +$MgSO_4$	15	15	1.0381	7.7	28	2210.00	1.0010
NaCl	5	5	0.9064	6.8	25	2328.60	0.9489
NaCl+K_2SO_4	10	10	0.9464	7.5	27.3	2341.90	0.9661
NaCl+K_2SO_4	15	15	1.0264	7.7	28	2493.30	1.029
NaCl	5	5	0.9064	6.8	25	2492.00	0.9489
NaCl+$MgSO_4$+K_2SO_4	10	10	1.0264	7.9	26.7	2698.10	1.003

$NaCl+MgSO_4+K_2So4$	15	15	1.0501	8.1	28	2765.50	1.053

In this research, the combination effect of magnesium sulfate and potassium sulfate salts during oil recovery by water flooding was investigated.
Based on experimental analysis, the following conclusions were drawn:
The decrease of sodium chloride concentration in water containing magnesium and potassium sulfate, increases the oil recovery.
The combination of potassium and magnesium sulfate with a decrease in sodium chloride salinity is preferable having the tendency of recovering 77.77% of oil. In addition, it shows there is a reduction in interfacial tension as a result of a slight decrease in salinity, and an increase in wettability has an effect on oil recovery. While change in salinity increases the permeability as seen in the result which also helps in the quantity of oil recovery.

RECOMMENDATION

From the results of this research work, the following recommendations were made:
For oil recovery by water flooding to be effective, there is a need to have good proportion of salts of magnesium and potassium sulfate concentration in sodium chloride solution in other to have more recovery and also to increase oil production.

- ❖ The anticipated concentration ranges of magnesium sulfate, potassium sulfate salts and sodium chloride that yield more increment of oil recovered is required.
- ❖ The use of water containing low salinity of sodium chloride concentration should also be required.
- ❖ pH value of concentrations of salts in water should be maintained at a reasonable maximum value.
- ❖ There is a need to have good knowledge of the energy drive in the reservoir.

Summary

The combination effect of magnesium sulfate and potassium sulfate salts during oil recovery by water flooding was investigated.
Based on experimental analysis the following conclusions were drawn:
Sodium chloride concentration in water containing magnesium or potassium sulfate increases the oil recovery.
Water containing a mixture of magnesium and potassium sulfate recovers more oil during water flooding of sodium chloride.

Conclusion

In conclusion, the combination of potassium and magnesium sulfate with the decrease in sodium chloride salinity is preferable having the tendency of recovering 77.77% of oil. In addition, it shows there is a reduction in interfacial tension as a result of slight decrease in the salinity and an increase in wettability have an effect on oil recovery. While the change in salinity increases the permeability as seen in the result which also helps in the quantity of oil recovered

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GEOTECHNICAL PROPERTIES OF FOUNDATION SUBSOILS IN PARTS OF NIGER DELTA, NIGERIA

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ABSTRACT

The overall objectives of the study was to determine the stratification, comparative analysis and geotechnical index properties of the soils in some parts of Port Harcourt and environs, Rivers State and six Towns in Yenagoa Local Government Area, Bayelsa State. Field study and laboratory studies of soil samples were obtained from 0-20.25m deep. Subsurface soil profiles were delineated followed by the determination of their index and mechanical properties, including Atterberg limits, particle size distribution, undrained shear strength, shear box test and consolidation coefficient. The general soil profiles consists of (from top to bottom) Sandy clay horizon (0- 13.5m thickness) soft to stiff for Port Harcourt and environs, sand horizon (6.75 to 11.25m thickness) fine to medium to coarse for Port Harcourt and environs, upper Silty clay horizon (0.0-5.25m thickness) soft to firm for Yenagoa study areas, Medium silty clay horizon (0.75 to 1.5m thickness) soft to firm Yenagoa study areas, low clayey sand horizon (0.75 to 1.5m thickness) soft Yenagoa study areas, peaty clay (1.0m thickness between 3.0-4.0m) soft Igbogene Yenagoa, upper sand horizon (3.0m thickness) silty sand Etegwe *Town Yenagoa, lower sand horizon (13.5 to 18.0m) silty sand to fine to medium and medium coarse appear in all the boreholes in Yenagoa. The sub-soil in Port Harcourt and environs show clay of low to high plasticity (CLCH) while Yenagoa sub-soil shows clay of high plasticity, silt of intermediate to high plasticity (CH, MI and MH) the unified soil classification system from the results it shows that pad foundation is more suitable in the study areas in Port Harcourt and environs with allowable bearing capacity of the clay ranges from 69-149KN/m*^{2} *while raft foundation is more ideal in the six Towns study areas of Yenagoa with Allowable bearing capacity of the upper clay layer ranges from 23-128KN/m*^{2}*. Axial load carrying capacity for 305, 306mm, 356, 360mm, 406mm, 600and 610mm diameter for bore pile and tubular driven steel cased piles respectively were calculated for all the studies areas.*

Keyword: Geotechnical index properties, Stratification, pile foundation.

INTRODUCTION

The foundation is the lower hidden part of the structure, which carries large amount of load from the superstructure and distributes it to the soil. The foundation should be sound enough to carry the load of the superstructure.

The reason for most collapsed building is ascribed to poor quality building materials, while thus may be true, less attention is paid to the sub-surface soil conditions that bears the foundation (Youdeowei etal., 2019). The need for accurate information and adequate understanding of the geotechnical properties of the foundation of sub-soil cannot be over-emphasized. Geotechnical information is useful in ensuring that the effect of projects on the environment and natural resource is properly evaluated and mitigated where necessary (Nwankwoala etal., 2009).

It is on this basis that this study was undertaken to ascertain the engineering characteristics of the sub-soils.

DESCRIPTION OF STUDY AREAS/ GEOLOGY

The study areas (Fig 1), shows three (3) Local Government Areas in Rivers State, namely Port Harcourt City, Obio/Akpor and Ikwerre Local Government Areas (Fig 2), shows Etegwe, Akenfa-Agudama, Igbogene, Yenegue, Opolo Epie and Ovom, study areas in Yenagoa Local Government Area of Bayelsa state. They are all within the Niger Delta region of Nigeria. The local geology of the locations is composed of sediments which are characteristic of several depositional environments. Deposits are geologically young, ranging from the Eocene to the recent Pliocene. They include river mouth bar, delta front platform, delta slope and open shelf sediments. The detailed geology of the area has been described by Allen (1965), Reyment (1965), Short and Stauble (1967). Litho- stratigraphically, the rocks are divided into the oldest Akata Formation (Paleoceone), the Agbada Formation (Eocene) and the youngest Benin Formation (Miocene to Recent). The wells and boreholes tap water from the overlaying Benin Formation (Coastal Plain Sands). This formation comprises lacustrine and fluvial deposits whose thicknesses are variable but basically exceed 1970 meters (Asseez, 1989). The Benin Formation has lithologies consisting of sands, silts, gravel and clayey intercalations. The area is within the coastal zone. The coastal zone which comprises the beach ridges and mangrove swamps is underlain by an alternating sequence of sand and clay with a high frequency of occurrence of clay within 10m below the ground surface. Because of the nearness of these compressible clays to the surface, the influence of imposed loads results in consolidation settlement.
It lies within a sub-horizontal geomorphologic train with a measure of undulations from uneven surface area erosion. Ground elevation ranges between 15 to 45 meters in River state and 12 to 24 meters in Bayelsa state above mean sea level. There are drainage problems with seasonal and temporary flooding due to heavy rainfall and a rise in groundwater table at okilton drive NTA /Mgbuoba road in Obio/Akpor local government area and in Yenagoa, Bayelsa state.

Study Location Coordinate

The study location coordinate for the various boreholes as shown in Table 1

Table 1: Showing the Coordinates of the studied locations in Rivers State and Bayelsa State.

Location	Northing	Easting
BH1	4º81’48.43”	6º98’43.54”
BH2	4º84’39.72”	6º98’26.01”
BH3	4º46’63.4º	6º58’49.45”
BH4	4º57’53.4”	6º58’10.0”

BH5	4°57’43.1”	6°58’14.2”
BH6	4°57’49.9”	6°58’14.2”
BH7	4°00’62.0”	6°24’30.8”
BH8	4°56’98.4”	6°20’20.3”
BH9	4°57’24.6”	6°21’15.5”
BH10	4°00’33.6”	6°23’11.5”
BH11	4°02’28.9”	6°24’28.7”
BH12	4°02’81,9”	6°24’89,7”

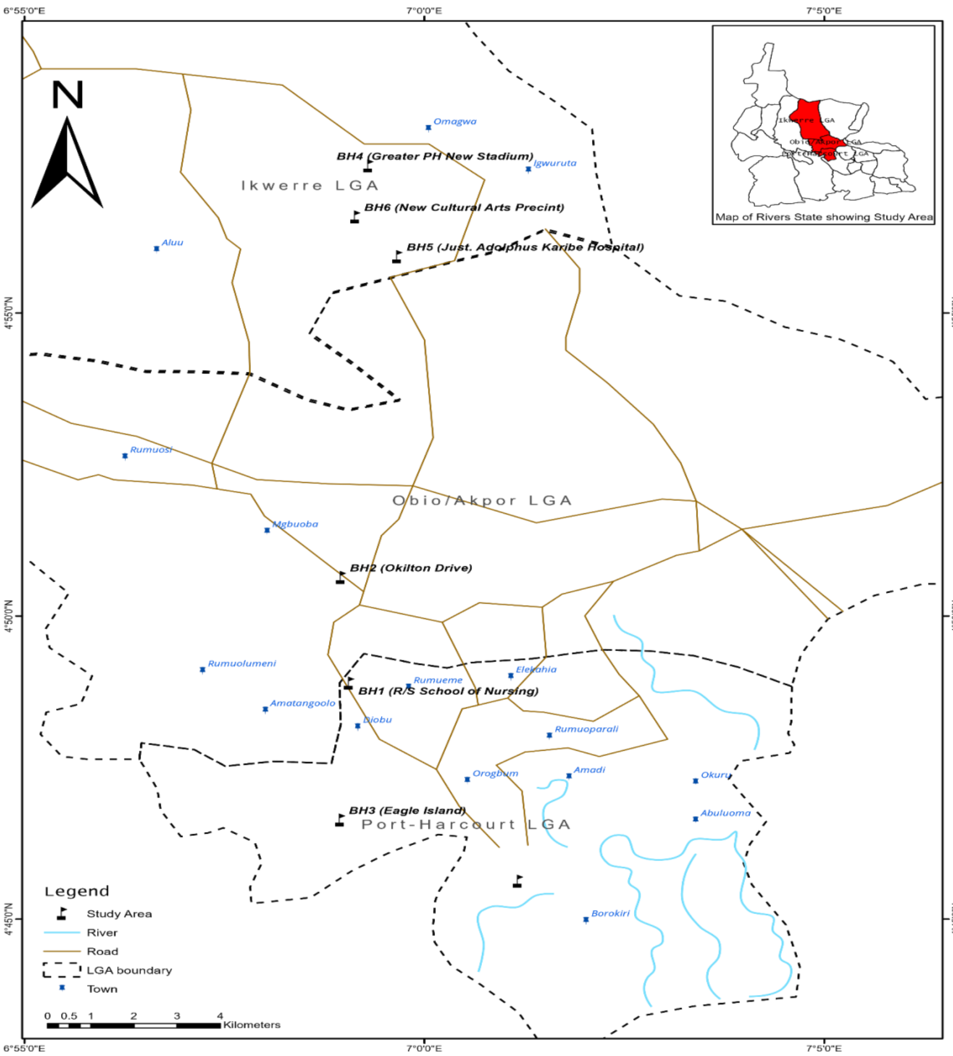

Fig 1.0 Map of the study area in Rivers state

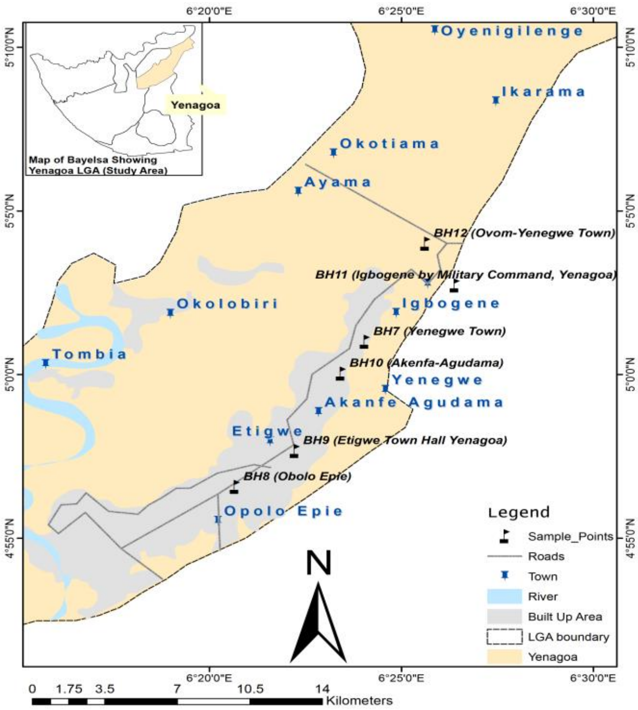

Fig 2.0: Map of the study Area in Bayelsa State

METHODOLOGY

Field Exploration / Laboratory analysis

Subsurface data from six (6) locations: comprising of one (1) from Andoni junction (BH3) in Port Harcourt city local government and one (1) each from Okilton drive NTA/Mgbuoba road (BH2) and formal school of nursing (BH1) all in Obio/Akpor local government area and one (1) each from greater Port Harcourt new stadium (BH4), Justice Adolphus Karibe hospital (BH5) and cultural Arts prescient (BH6) all in Ikwerre local government area, Rivers state, six (6) locations from Yenagoa namely Etegwe (BH9), Akenfa-Agudama (BH10), Igbogene (BH11), Yenegue (BH7), Opolo Epie (BH8) and Ovom (BH12). The study area was studied through ground borings to depths of 20.25m each using a light cable percussion boring rig. Both disturbed and undisturbed soil samples were collected for visual examination, laboratory testing and classification. Also, standard penetration tests (SPT) were carried out to determine the penetration resistance of cohesionless strata at specific depths within the boreholes as the boring progresses. A series of classification and mechanical property tests were conducted on representative soil samples. They include Atterberg limit tests, particle size analysis test, natural moisture content tests, unit weight tests, unconsolidated undrained triaxial test and consolidation test etc. All the tests followed standard procedures for testing soils for civil engineering purposes.

BEARING CAPACITY ANALYSIS FOR SHALLOW FOUNDATION

The ultimate bearing capacity, Qu, for shallow square footing on cohesive soils encountered at the study area using Terzaghi's equation (1954) as modified for shape factor is given below as:

$$Q_u = 0.867cNc + \gamma.D_f.Nq + 0.4\,\gamma.B.N_y \qquad (1)$$

$$Q_u=cNc(1+0.3*B/L)+\gamma.D_f.Nq+0.5\gamma.B.N_y(1-0.2B/L) \qquad (2)$$

Where:

Q_u = Ultimate bearing capacity

C = soil cohesion at the studied depth

D_f = depth of foundation

B = Foundation width

L = length of foundation footing

γ = unit weight of soil at the depth

NC,Nγ, Nq = Bearing Capacity factors

BEARING CAPACITY ANALYSIS FOR DEEP FOUNDATION

The pile bearing capacity, Q_u of bored piles is determined by the equation below derived from American Petroleum Institute API (1998).

$Q_u = Q_s + Q_b$ (3)

$\mathbf{Q_u}$ = fs.As. + f_b.Ab

(4)

$\mathbf{Q_u}$ = δ_v'.K_s.tanØ.A_s + δ_{vb}'N_q.A_b (For sand layers) (5)

$\mathbf{Q_u}$ = α.$ć_u$.A_s + C_u.N_c.A_b (For clay layer)

(6)

Where:

Qu = ultimate axial pile capacity

Qs = ultimate shaft resistance

Qb = ultimate base resistance

fs = unit shaft resistance

f_b = unit base resistance

δ_v = average effective overburden pressure over the soil layer

Ks = coefficient of lateral earth pressure against the shaft wall

α = pile wall adhesion factor

$ć_u$ = average untrained shear strength of the clay over the pile penetration depth considered

δ_{vb}' = effective overburden pressure at the pile base

Cu = untrained shear strength of the clay at the pile base

Ab = cross-sectional area of pile base

Nc, Nq = bearing capacity factors

As = exposed area of pile shaft in the soil layer

δ = effective interaction angle between pile wall and the soil (Ø*75)

SETTLEMENT OF THE UPPER CLAY LAYER

Immediate settlement

Immediate foundation settlement of the different soil was calculated from the expression of Tomlinson (2001)

$S_i = \frac{Bq_n}{E} (1-\mu_s^2) I_p$ (7)

Where,

S_i = immediate settlement

B= breadth of foundation

q_n = net foundation pressure

E = modulus elasticity

μ = poisson ratio

I_p = influence factor

I_f = influence factor is used as proposed by Bowles (1988).

E/cu = 400

Consolidation Settlement on Upper Clay Layer

Consolidation settlement (ρ_c) in the cohesive layer was computed based on the foundation breadth (B) subjected to a bearing pressure of the soil. The induced vertical stress (Δσ) at the centre of the consolidating was used in computing ρc. The settlement value was computed from the expression given by Skempton and Bjerrum (1957) as follows:

$\rho c = \mu_g \rho_{oed}$

(8)

$= m_v \Delta\sigma_z H$

(9)

$= m_v\ 0.55 q_n H$

Where

μg = coefficient which depends on the type of clay

ρ_{oed} = settlement as calculated from oedometer tests

m_v = coefficient of volume compressibility

q_n = net foundation pressure

H = thickness of the considering layer (1.5B)

B = Breadth of foundation.

RESULTS AND DISCUSSION

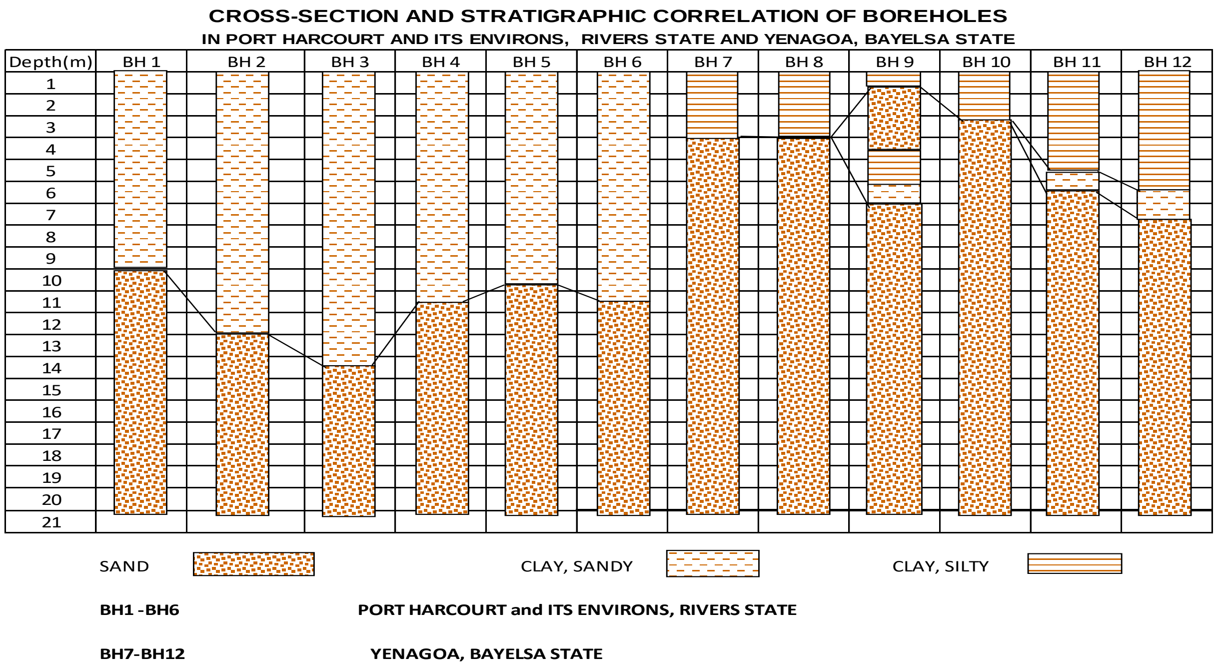

Fig 3.0: Cross section and Stratigraphic Correlation of Boreholes in Port Harcourt and Environs Rivers State and Yenagoa, Bayelsa State.

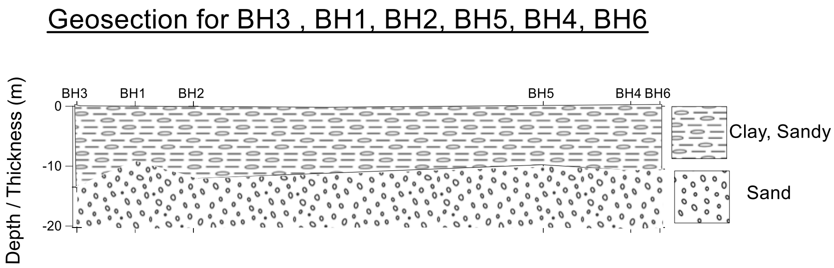

Fig 4.0: Geo-section of the Boreholes

Table 2.0 : Soil Stratigraphy

Description Depth / Thickness (m)	BH7	BH8	BH9	BH10	BH11	BH12
Silty Clay	0.0-2.25	0.0-3.0	0.0-0.75		0.0-3.0	0.0-5.25
			3.75-5.25		4.0-5.25	
Peaty Clay					3.0-4.0	
Clay, Sandy	2.25 -3.0		5.25-6.0	0.0-2.0	5.25-6.0	5.25-6.75
Sand	3.0-20.25	3.0-20.25	6.0-20.25	2.0-20.25	6.0-20.25	6.75-20.25
(Silty, fine , fine to medium grained)						

Engineering Properties of the Soil

The geotechnical characteristics of the soil and the engineering attributes of the properties of the soil were determined from the laboratory and field work at the study area. The relevant index and engineering parameters of the soil are summarized below in Table 3.0 to Table 6.0.

Table 3.0: Geotechnical Index Properties of Sandy clay in Port Harcourt and Environ

LOCATIONS	BH1			BH2			BH3			BH4			BH5			BH6		
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
Wn %	19.6	25.0	22	22.8	25.4	24.0	20.7	22.8	21.8	18.4	23.6	21	17.5	20.3	19.0	14.2	23.1	16.4
LL %	32.0	37.0	34	47	50	49	38	41	40	45	48	47	49	52	51	45	47	46
PL %	19.0	23.0	21	26	29	28	23	23	23	23	25	24	27	28	28	24	24	24
PI %	14.0	15.0	15	21	22	22	15	18	17	22	23	23	22	24	23	21	23	22
USCS			CL			CI			CI			CI			CI			CI
Cu (KN/m^2)	40	60	50	40	50	45	40	47	44	44	75	60	45	85	65	35	79	57
Ø (°)	4	7	6	3	4	4	3	5	4	5	10	8	4	8	6	3	8	6
Unit Weight (KN/m^3)	20.1	20.5	20.3	18.9	19.8	19.4	20.1	20.6	20.3	19.0	20.5	20	19.4	20.3	19.9	18.6	19.7	19.2
Cv (m^2/yr)	52.35	52.35	52.4	42.4	42.4	42.4	34.7	34.7	34.7	66.5	66.5	66.5	52.6	52.6	52.6	52.8	52.8	52.8
Mv (m^2/MN)	0.21	0.21	0.21	0.23	0.23	0.23	0.20	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19

Table 4.0: Geotechnical Index Properties of Sandy Soil in Port Harcourt and Environ

LOCATIONS	BH1			BH2			BH3			BH4			BH5			BH6		
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
d_{10} (mm)	0.20	0.23	0.22	0.20	0.23	0.17	0.22	0.32	0.27	0.17	0.22	0.20	0.20	0.32	0.26	0.14	0.21	0.18
d_{30} (mm)	0.26	0.33	0.30	0.27	0.30	0.29	0.31	0.44	0.38	0.25	0.37	0.31	0.30	0.50	0.40	0.23	0.35	0.29
d_{60} (mm)	0.34	0.50	0.42	0.36	0.44	0.40	0.46	0.59	0.53	0.36	0.48	0.42	0.48	0.90	0.69	0.35	0.49	0.42
$C_u = \frac{d_{60}}{d_{10}}$	1.7	2.2	1.95	1.8	1.9	1.9	1.8	2.1	1.95	2.1	2.5	2.3	2.4	2.8	2.6	1.6	3.0	2.3
$C_c = \frac{d_{30}}{d_{10}d_{30}}$	0.9	1.0	0.95	0.9	1.0	0.95	0.9	1.0	0.95	1.0	1.3	1.2	0.9	1.0	0.95	0.9	1.2	1.05
Unit weight KN/m3	19.6	20.2	19.9	18.5	20.8	19.7	20.4	20.9	20.7	19.2	19.5	19.4	19.2	19.9	19.6	18.6	19.4	19.0
Dry Unit weight KN/m^3	16.8	17.5	17.2	16.0	17.5	16.8	17.6	17.8	17.7	16.2	16.5	16.4	16.7	16.9	16.8	16.4	16.7	16.6
MC %	16.6	18.5	17.6	15.2	18.7	17.0	16.3	17.4	16.9	15.2	18.5	16.7	15.1	17.9	16.5	13.6	15.8	14.7
Ø (°)	29	33	31	30	30	30	30	31	31	30	31	31	30	30	30	29	30	30
N value	7	45	26	18	33	26	15	19	17	18	22	20	21	25	23	18	30	24

Table 5.0: Geotechnical Index Properties of clay in Yenagoa,

LOCATIONS	BH7			BH8			BH9			BH10			BH11			BH12					
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
Wn %	20.8	20.8	20.8	54.9	54.9	54.9	51.4	51.4	51.4	39.0	39.0	39.0	40	40	40	64.8	64.8	64.8			
LL %	65	65	65	71	71	71	54	54	54	35	51	43	125	125	125	60	60	60			
PL %	37	37	37	36	36	36	33	33	33	18	33	33	69	69	69	32	32	32			
PI %	28	28	28	35	35	35	21	21	21	17	18	18	56	56	56	28	28	28			
USCS			MH			MH				MH	CL		MH			MH		MH			
Cu (KN/m^2)	42	42	42	28	28	28	17	17	17	47	47	47	41	53	47	35	35	35			
Ø (º)	4	4	4	8	8	8	4	4	4	6	6	6	5	7	6	7	7	7			
Unit Weight (KN/m^3)	18.1	18.1	18.1	14.9	14.9	14.9	17.8	17.8	17.8	18.7	18.7	18.7	18.2	19.4	18.8	14.5	14.6	14.6			
Cv (m^2/yr)	18.38	18.38	18.38	3.26	3.26	3.26	3.24	3.24	3.24	10.5	10.5	10.5	10.5	10.5	10.5	4.34	4.34	4.34			
Mv (m^2/MN)	0.38	0.38	0.38	0.59	0.59	0.59	0.65	0.65	0.65	0.30	0.30	0.30	0.32	0.32	0.32	0.80	0.80	0.80			

Table 6.0: Geotechnical Index Properties of Sand in Yenagoa

LOCATIONS	BH7			BH8			BH9			BH10			BH11			BH12		
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
d_{10} (mm)	0.16	0.22	0.19	0.18	0.20	19	0.20	0.22	0.21	0.18	0.22	0.20	0.17	0.22	0.20	0.20	0.23	0.22
d_{30} (mm)	0.23	0.30	0.27	0.26	0.28	0.27	0.30	0.30	0.30	0.29	0.30	0.30	0.23	0.30	0.27	0.30	0.30	0.30
d_{60} (mm)	0.35	0.46	0.41	0.39	0.49	0.44	0.42	0.50	0.46	0.42	0.50	0.46	0.35	0.47	0.41	0.41	0.50	0.46
$C_u = \frac{d_{60}}{d_{10}}$	1.9	4.6	3.3	2.0	2.7	2.4	1.9	2.4	2.2	1.9	2.4	2.2	1.9	2.4	2.15	1.9	2.2	2.05
$C_c = \frac{d_{30}}{d_{10} x d_{30}}$	0.8	2.0	1.4	0.7	1.0	0.8	0.8	1.0	0.9	0.8	1.1	0.95	0.9	1.0	0.95	0.8	1.0	0.9
Unit weight KN/m3	20.0	20.5	20.3	19.2	20.0	19.6	18.5	19.0	18.8	19.2	19.2	19.2	19.0	19.1	19.1	19.4	19.8	19.6
Dry Unit weight KN/m^3	17.3	17.6	17.5	16.3	17.6	17,0	16.0	16.0	16.0	16.6	16.9	16.8	16.7	16.9	16.8	16.8	17.3	17.1
MC %	14.5	15.1	14.8	13.7	17.5	15.6	15.6	18.6	17.1	13.6	15.8	14.7	19.0	19.1	19.1	14.2	15.6	
Ø (º)	28	30	29	29	30	30	30	30	30	29	30	30	30	31	31	30	32	31
N value	6	13	10	8	23	16	11	27	19	14	28	21	7	18	13	14	33	24

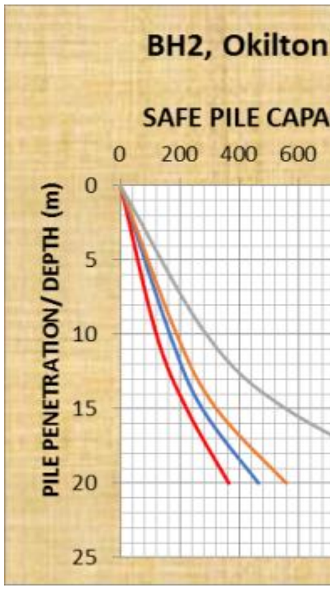

Fig 5.0: Typical Chart for the Safe Load Capacity of Pile for BH 2

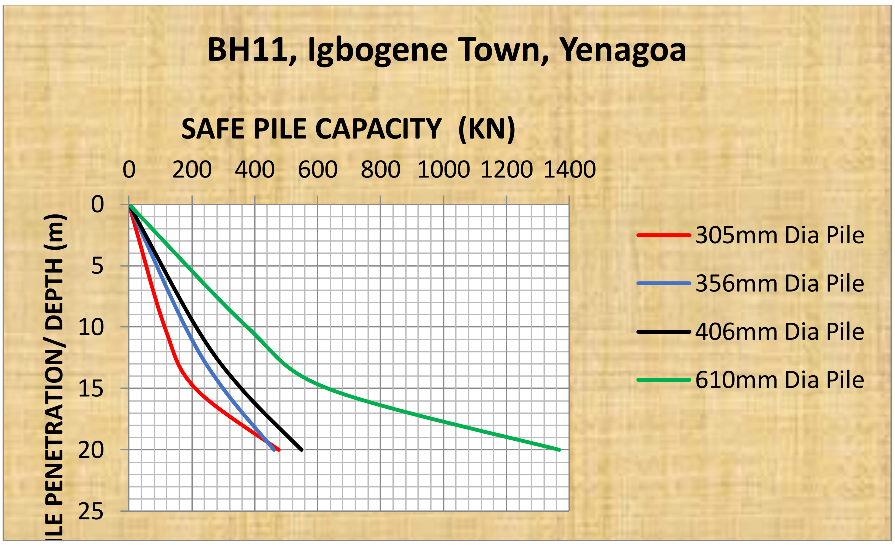

Fig 6.0: Typical Chart for the Safe Load Capacity of Pile for BH 11

Discussion

Soil Classification / Stratification

These results as obtained from the boring data and laboratory tests from the study area in Rivers state and Yenagoa, Bayelsa state, revealed the plastic soils (sandy clay) as generally consisting of soft to firm to stiff, light brown, yellow-brown, sandy clay of low to medium plasticity, underlying the clay is loose to medium dense and dense, fine to medium to coarse grained sand as illustrated in Figure 1.0 and Figure 2.0 above. Underneath the sandy clay is a continuous layer of relatively clean sand which is poorly graded in all the study areas as shown in Table 3.0 and Figure 3.0. The upper layer in Yenagoa is predominately very soft to firm, light to dark gray and light brown formation was encountered and it is observed to possess low to high plasticity which is underlain by various thickness of silty sand and fine to medium to coarse grained, loose, medium dense and dense sand (Table 2.0). The parameters of the clay formation and sand are presented above in Tables 3.0 to 6.0.

Bearing capacity

Both shallow foundation and deep foundation analysis have been carried out for the study area in Port Harcourt and environs, Rivers state and Yenagoa, Bayelsa state. From the shallow foundation analysis, the allowable bearing capacities of the square footing width of 1.0 to 3.0m and depth of 1.0 to 3.0m for Port Harcourt and environ study area are as follows: for (BH1 to BH2) Obio/Akpor local government area reveals allowable bearing capacity ranges from 69 to 101KN/m^2 with settlement range of 16 to 61mm. (BH3) Port Harcourt city local government area reveals allowable bearing capacity ranges from 81 to 88KN/m^2 with settlement ranges of 18 to 74mm. (BH4, BH5 and BH6) Ikwerre local government area reveals allowable bearing capacity ranges from 86 to 160KN/m^2 with settlement range of 18 to 80mm raft foundation with widths of 2,5,15m at different depth of 1.0 and 2.0m was calculated for Yenagoa local government area of Bayelsa state reveals allowable bearing capacity ranges from 87 to 109 KN/m^2 with settlement 20mm to 54mm for (BH7) Yenegwe, 61 to 75 KN/m^2 with 32mm to 103mm for (BH8) Opolo Epie, 100 to 128 KN/m^2 with settlement 35mm to 112mm for Akenfa Agudama, 85 to 107 KN/m^2 with settlement 36mm to 120mm for (BH11) Igbogene, 71 to 89 KN/m^2 with settlement 53 to 159mm for (BH12) Ovom. (BH 9) Etegwe was calculated using layered soils (sand) over the soft clay proposed by Meyerhof and Hanna's, the allowable bearing capacity ranges from 23 to 98KN/m^2 at width 1 to 8m and aspect ratio L/B = 1, 2 and 5. The shallow foundation is guided by the allowable maximum settlement suggested by Skempton and Macdonald for isolated foundation 65mm, 65-100mm for a raft on clay. Pile foundation analysis was also carried out for the soil profile that was encountered in the study areas. Bored piles of diameters of 306,360,406 and 600mm and Straight shaft closed pipe piles with diameters 305, 356, 406 and 610mm were designed for pile compressive resistance for study area Yenagoa. The pile compressive resistance 306mm diameter pile values vary from 121 to 386KN when founded between 10m and 20m depth for Obio/Akpor local government area, 98 to 371KN for Port Harcourt city, 158 to 371KN for Ikwerre. While 406mm diameter values vary 189 to 596KN for Obio/Akpor, 133 to 549KN for Port Harcourt City, and 158 to 493KN for Ikwerre local government area when founded between 10m and 20m depth. The 600mm diameter was observed to give values varying from 290 to 1119KN for Obio/Akpor, 207 to 1032KN for Port Harcourt City and 333 to 1318KN for Ikwerre Local Government Area at the same depth above. Straight shaft closed pipe piles with diameters 305, 356, 406 and 610mm for compressive resistance for Yenagoa local government area were observed to vary from 114 to 540KN, 144 to 674KN, 165 to 819 and 208 to 1536KN respectively found between 10m and 20m depth. The calculated safe load capacity of piles should be used where the bearing capacity is not adequate for the proposed structure or high-rise building is to be built.

CONCLUSION

The following conclusion can be drawn from the study areas in Port Harcourt and environ, Rivers state and Yenagoa, Bayelsa state. The field investigation revealed that the study area comprises two distinct soil layers namely sandy clay and sand and their thickness varies from one study area to another. The soil profile across the six study area in Yenagoa Bayelsa State are not uniform in layer, they vary from one location to another but silty clay and sand are found in all the location. The subsoil in the study area shows low to medium plasticity (CL-CI). The six study areas in Yenagoa sub-soil show low to high plasticity (CL-MH) according to the unified soil classification system. Yenegwe (BH7) and Opplo-Epie (BH8) shows similar soil profile of silty clay, intercalation of clay and sand and sand layer. The shear strength of study areas ranges from firm, and soft in the various boreholes. Evaluated bearing capacity values for (B) width equal 3.0m for Andoni junction Eagle Island (BH3), Justice Adolpus hospital (BH5) and new cultural Art prescient (BH6) not satisfy the maximum allowable settlement for pad footing foundation. Igbogene town lain 1.0m thick peaty clay embedded in the clay between 3.0 and 4.0 depth, this will greatly increase the compressibility of the clay consisting the nature of the intended structure so, pile foundation is recommended to take the imposed load beyond the soft clay layer to the underlying sand stratum. It is recommended that study areas (BH1) formal school of nursing and (BH2) Okilton drive junction by NTA where the groundwater level is between 1.2 and 0.2m respectively, that the foundation should be considered for used raft foundation, if the pad foundation proposed is not suitable for the intending structure. It is suggested that proposed shallow foundation structures in Port Harcourt and environs should be supported by means of pad footing, while the studies areas in Yenagoa local government area of Bayelsa state be supported by means of raft beam foundation within upper clay and sand layer.

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ALLELOPATHIC POTENTIAL of *Mangifera indica* L. LEAVES ON THE GERMINATION AND GROWTH OF *Zea mays* L. SEEDLINGS

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ABSTRACT

The allelopathic potential of the leaves of mango (*Mangifera indica* L.) was test on the germination, and growth of maize seedlings using different experimental setups. The study aimed to explore the inhibitory or stimulatory allelopathic potential of mango leaves on the germination and growth of maize seedlings. Two methods were employed in this study which included two microplot xperiments involving mango leaf extracts and powder. The microplot experiments were conducted concurrently and involved treating maize seeds planted in washed river bed soil (5kg) with mango leaves aqueous extract at concentration of 0g (control), 5g (1% w/v), 10g (2 % w/v), 15g (3% w/v) and 20g (4% w/v). The second microplots experiment involved the incorporation of mango leaf powder into washed river bed soil (5kg) at concentrations of 0g (control), 5g (0.1% w/w), 10g (0.2% w/w), 15g (0.3% w/w) and 20g (0.4% w/w). After 7 days of emergence, the microplots treated with mango leaves aqueous extract were irrigated while those treated with mango leaf powder was moistened with 5ml of water daily. The maize plant was harvested 30 days after planting The result obtained indicated that mango leaves aqueous extract as well as powder at concentration (5g, 10g) did not inhibit the germination, growth, radicle and plumule length of maize. At concentrations (15g and 20g), mango leaves aqueous extract as well as powder showed inhibitory allelopathic potential on the germination, growth, radicle and plumule length of maize. It can be concluded that *M. indica* leaves showed inhibitory allelopathic potential on *Zea mays*. This study aims at determining the allelopathic potential of mango leaves on the germination and growth of maize seeds

Keywords: Allelopathy, Mango Leaves, Maize Seed.

INTRODUCTION

Allelopathy refers to the intriguing phenomenon wherein plants release chemical compounds that profoundly affect the growth and development of nearby plants and microorganisms. This process, known as allelopathy, holds immense significance, especially within agroecosystems, as it influences the growth, quality, and quantity of agricultural yields (Kohli 1998; Singh *et al.*, 2001). Different plant components, including roots, stems, and leaves, contain secondary metabolites, commonly referred to as allelochemicals. These secondary metabolites are synthesized by plants or microorganisms and encompass a diverse range of compounds, including terpenoids, phenolic compounds, organic cyanides, and long-chain fatty acids.

Allelochemicals, generated by a particular crop species, can impact the growth, productivity, and overall yield of other crops, even if they belong to the same species (Batish *et al*., 2001). These allelochemicals possess noxious properties and impact the target species in diverse ways. They can hinder shoot and root growth, interfere with nutrient uptake, or disrupt naturally occurring symbiotic relationships, ultimately compromising the availability of resources for the affected plant. In the context of natural ecosystems, allelopathy acts as a mechanism of interference, where living or deceased plants release allelochemicals that exert either positive or negative effects on associated plants. Therefore, allelopathy plays a vital role in shaping the dynamics of natural ecosystems (Fitter, 2003; Inderjit *et al*., 2003).

Mango is widely cultivated in Nigeria and is highly favored as a garden crop. The use of mango leaf litter as compost is a commendable and environmentally friendly approach to managing organic waste. Plants generate a wide array of phytochemicals, which are organic compounds that do not directly partake in metabolism or possess apparent functions in cellular operations. Initially considered waste products, these compounds actually play crucial roles within the plant. Some of these organic molecules serve as protective mechanisms against herbivores, insects, or pathogens, while others attract pollinators or exhibit allelopathic properties to compete with other plants (Hadacek, 2002).

Maize (*Zea mays* L.) belongs to the family Poaceae (also known as the grass family), which is termed one of the largest and most important plant families in the world. The maize plant is considered the third most crucial cereal crop globally, following wheat and rice (Farooq *et al*., 2013). Often referred to as the "Queen of cereals" due to its widespread cultivation, economic significance, and versatile uses.

Several researchers have conducted studies on mango allelopathy to examine the allelopathic potential of different parts of the mango tree. Mango and maize are two crops that are typically grown together in the same field during a growing season (Ofori and Stern, 1987). Curiously, there is a lack of extensive research on the allelopathic influence of mango on the germination and growth of maize. Consequently, it is crucial to investigate whether mango exhibits allelopathic influence on maize, as such insights can contribute to a deeper comprehension of this system. In this study, water was chosen as the extracting medium due to the fact that allelochemicals are commonly soluble in water and are released into the environment through root exudation (Tawaha & Turk, 2003). Considering the economic significance of maize as a stable crop, this research aimed to shed light on the potential allelopathic effects of mango leaves on the germination and growth of maize and also uncover the potential of crop-to-crop allelopathy

Previous studies and records have provided evidence that the leaves of *M. indica* (mango) sourced from Nigeria contain a diverse array of compounds. Aiyelaagbe and Osamudiamen (2009) documented the presence of diverse compounds, including saponins, steroids, tannins, flavonoids, reducing sugars, and cardiac glycosides. Additionally, El-Rokiek et al. (2010) identified phenolic compounds such as ferulic acid, coumaric acid, benzoic acid, vanillic acid, chlorogenic acid, caffeic acid, gallic acid, hydroxybenzoic acid, and cinnamic acid. It is noteworthy that some of these compounds have been observed to exhibit active allelopathic properties.

MATERIALS AND METHODS

Materials collection: Mature leaves of mango were collected from a mango tree on a farm. These leaves were washed with water to eliminate dust and soil particles. Afterward they were air-dried on a tray for 20 days at room temperature. The dried mango leaves were manually crushed into a powder form and stored in plastic bottles until needed. Seeds of hybrid maize (DK-919) obtained from the Agricultural Development Programme in Port Harcourt, Rivers State, Nigeria, were subjected to surface sterilization using a sodium hypochlorite (NaOCl) solution. Following sterilization, the maize seeds were rinsed with deionized water and stored at room temperature until they were ready for use.

Preparation of plant extracts: The pulverized mango leaves powder was divided into 0g (control), 5g (1% w/v), 10g (2 % w/v), 15g (3% w/v) and 20g (4% w/v) concentrations and transferred to labeled plastic bottles. Each bottle was filled with 500ml of deionized water, and the mixture was continuously agitated before being left at room temperature for 48 hours. Subsequently, the mixture underwent filtration using two layers of cheesecloth and the resulting liquid was collected as the supernatant to obtain extracts at concentrations of 5g, 10g, 15g, and 20g.

Use of Mango leaf powder: Soil-filled planting bags, measuring 15cm in diameter and 11cm in height, were prepared with drainage holes at the bottom. The soil was incorporated with mango leaf powder at different rates: 5g, 10g, 15g, and 20g. In each microplot, 10 maize seeds were sown. The microplot, were appropriately irrigated and maintained free of weeds. Once the seed had sprouted within a period of 7DAP, the excess seedlings were removed, leaving only three plants per bag. The experiment spanned 30 days, starting from the time of sowing. Throughout this period, various parameters such as plant height, number of leaves, fresh weight, and dry weight of the plants were measured and recorded.

Use of Mango leaf extract: In planting bags filled with washed river bed soil, ten maize seeds were sown. Two days after planting, the mango leaf extracts at concentrations of 0g, 5g, 10g, 15g, and 20g were added to each pot on a weekly basis for one month. After 30 days from planting, the same parameters mentioned earlier were measured and recorded.

Experimental Design

The experiments were comprised of five treatments, including an untreated control. A completely randomized design (CRD) was employed in this study, where each treatment was replicated four times. The microplot was randomization.

Parameters understudy:

The following parameters were measured and recorded:

- Plant Height (HOP): The height of the plants was measured in centimeters (cm) using a meter rule.
- Number of Leaves (NOL): The quantification of leaves on each plant was conducted through visual observation, and the count was recorded.
- Biomass of Maize Plant: The fresh weight of the maize plants was measured by weighing them immediately after harvest. Subsequently, the plants were subjected to oven-drying until a constant weight was achieved, and the dry biomass was measured and recorded.

RESULTS AND DISCUSSION

USE OF MANGO LEAVES EXTRACTS

Number of Leaves (NOL): Results obtained from the number of leaves of maize seedlings after 30 days of experimental time are shown in Table (2). The data revealed that the number of leaves significantly increased within concentration after 30 days of planting in comparison to their respective controls. The result also suggests that there were slight variations amongst different concentrations on the number of leaves, which is believed to be a resultant effect of a proportionate increase in concentrations of mango leaf extracts. A noticeable decrease in the number of leaves resulted in treatments of 15g and 20g mango leaves powder

Height of Plant (HOP): The data revealed that the height of the plant significantly increased within concentration after 30 days of planting in comparison to their respective controls. The result also suggests that there were slight variations amongst different concentrations on the height of the plant, which is believed to be a resultant effect of a proportionate increase in concentrations of mango leaf extracts. Minimum inhibition in plant height resulted from treatments of 15g and 20g mango leaf extracts.

TABLE 1: **Effects of different extracts concentration of Mango leaves on the number of leaf (NOL) and height of plant (HOP) of Maize (*Zea mays* L.).**

TREATMENTS (g)	No. of Leaves	Height of plant (cm)
0	5.25^{a}	29.4^{a}
5	5.25^{a}	28.15^{a}
10	5.25^{a}	27.33^{a}
15	4.5^{b}	25.83^{b}
20	4.5^{b}	25.69^{b}
LSD	**0.41**	**1.58**

All such mean which shares a common English letter are non-significantly different from each other at P<0.05

THE USE OF MANGO LEAVES POWDER

Number of Leaves (NOL): The data reveals that the number of leaves significantly increased within concentration after 30 days of planting in comparison to their respective controls. The result also suggests that there were slight variations amongst different concentrations on the number of leaves (NOL), which is believed to be a resultant effect of a proportionate increase in concentrations of leaf powder. A noticeable decrease in the number of leaves (NOL) resulted in treatments of 15g and 20g mango leaf powder.

Height of Plant (HOP): The HOP increased generally with increasing concentration of treatment within experimental time, The data further reveals that the HOP significantly increased within concentration after 30 days of planting in comparison to their respective controls. The result also suggests that there were slight variations amongst different concentrations on the height of the plant, which is believed to be a resultant effect of a proportionate increase in concentrations of mango leaf powder. Minimum inhibition in plant height resulted from treatments of 15g and 20g mango leaf powder.

TABLE 2: Effects of different leaf powder concentration of Mango on the number of leaves and height of plant of *Zea mays* L.

TREATMENTS (g)	No.of Leaves	Height of plant (cm)
0	4.5[a]	29.43[a]
5	4.5[a]	28.52[a]
10	4[b]	26.08[a]
15	4[b]	24.31[b]
20	4[b]	22.65[b]
LSD	**0.28**	**2.84**

All such mean which shares a common English letter are non-significantly different from each other at $P<0.05$

BIOMASS: The biomass of maize plants treated with both mango leaf water extract and powder exhibited clear signs of inhibition, as observed in Tables 5 and 6. The suppression of dry weight in maize plants exhibited significant variation with varying concentrations of mango leaf extract and powder. Notably, the allelopathic effects of mango leaf extracts were most pronounced at a concentration of 15g and 20g, compared to their control group. This indicates that the reduction in biomass increased progressively along the concentration gradient during the experimental period.

TABLE 3: Effects of different extract concentrations of Mango on the fresh and dry biomass of *Zea mays* L. **plant.**

	Fresh weight (g)	Dry weight (g)
LEB	5.72[a]	1.125[b]
LPB	4.31[b]	1.335[a]
LSD	**1.00**	**0.15**

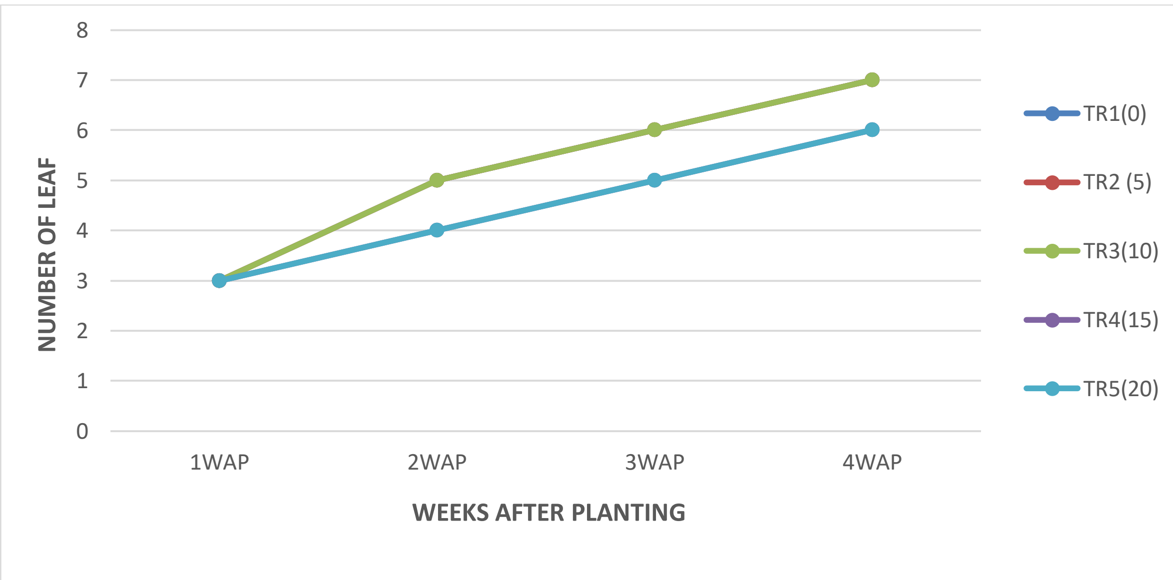

Fig. 1. NOL for ***Zea mays*** **L. treated with mango leaves extracts**

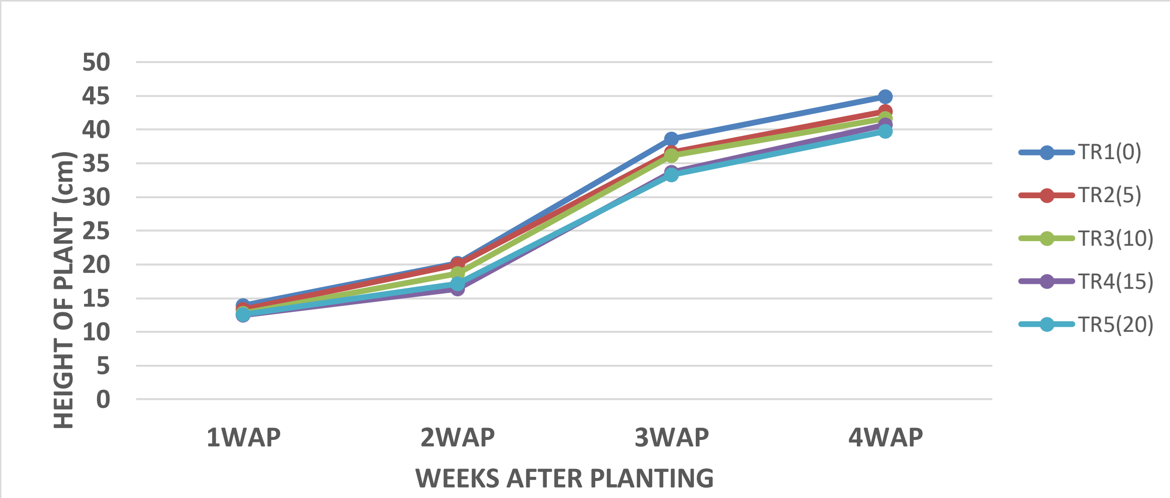

Fig. 2. Showing HOP for *Z. mays* L. treated with mango leaves extracts

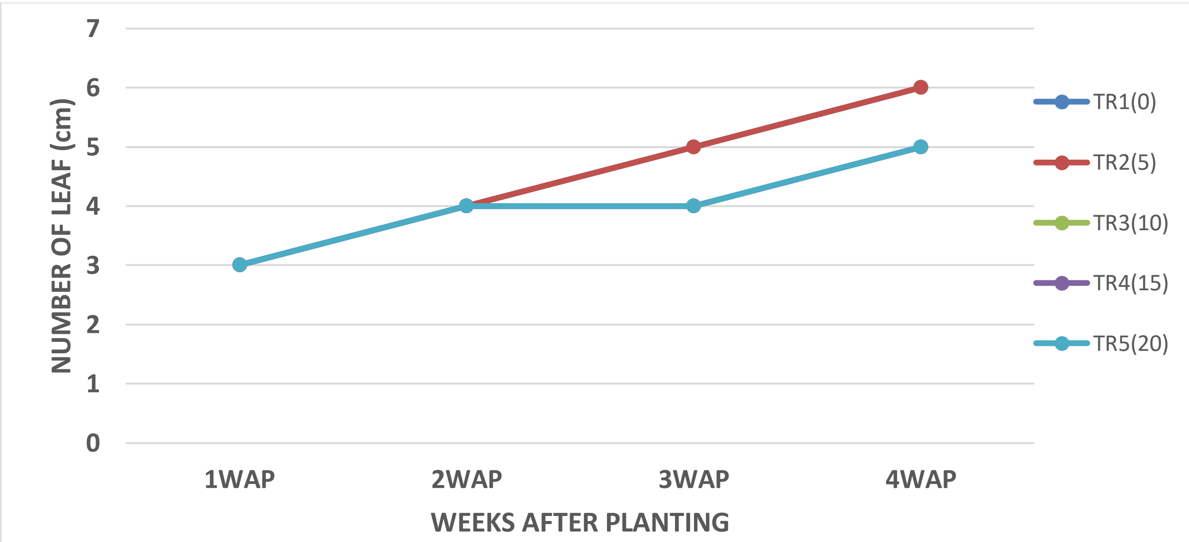

Fig. 3. NOL of *Zea mays* L. treated with mango leaves powder

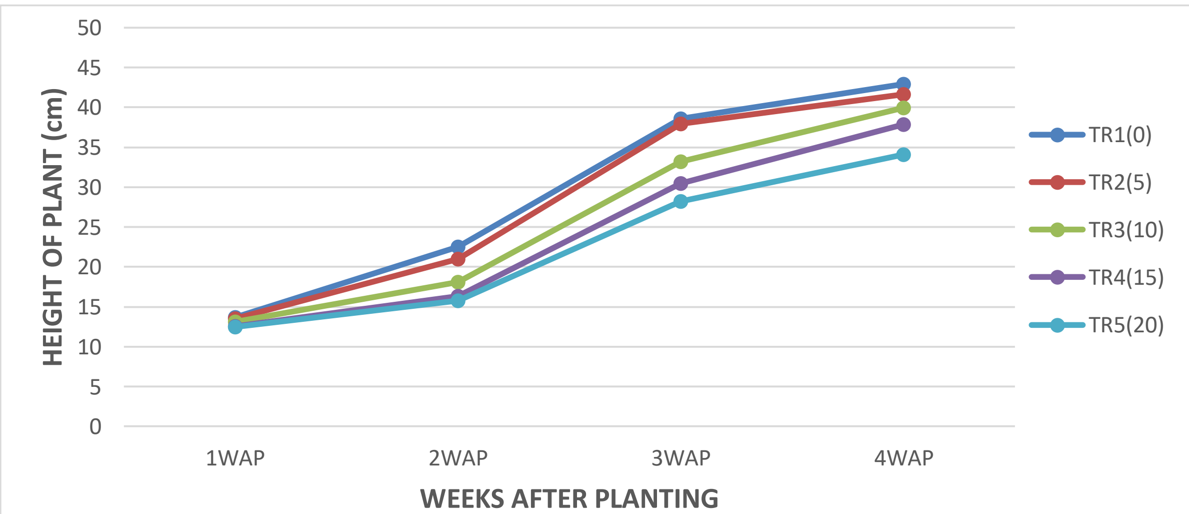

Fig. 4. **HOP for *Zea mays* L. treated with mango leaves powder**

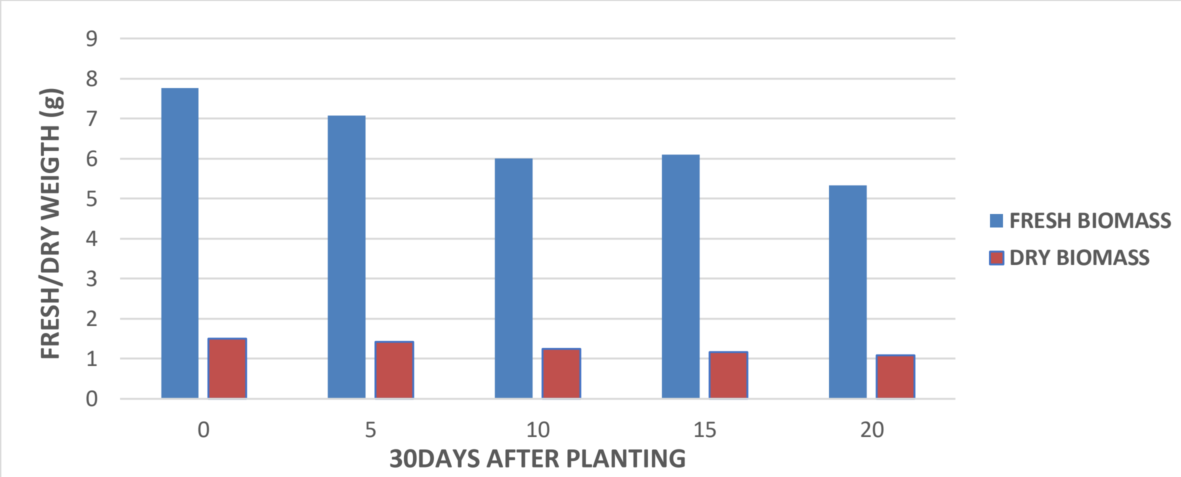

Fig. 5. Leaves Extract Biomass (LEB) for *Zea mays* L.

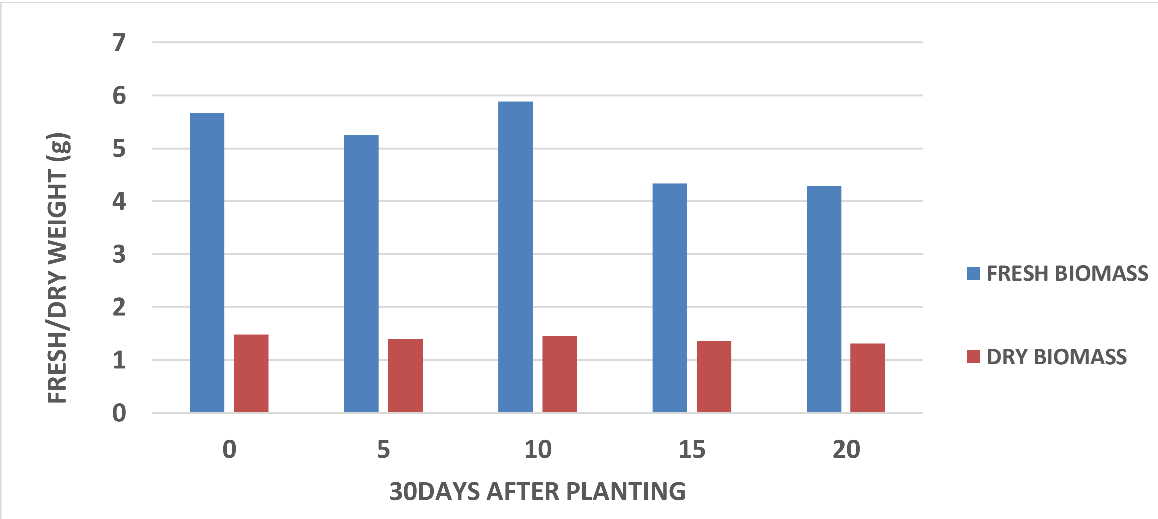

Fig. 6. Leaves Powder Biomass (LPB) for *Zea mays* L.

DISCUSSION

The study revealed that aqueous extracts as well as soil-applied powder of mango leaves negatively affected the HOP of *Zea mays* at higher concentrations. However, the same cannot be said of its effect on the number of leaves within the same concentration levels, which followed a slight increase with increasing duration (WAP). The slight increase in the number of leaves (NOL) for *Z. mays*, despite a reduction in height shows that the inhibitory allelopathic effect of *Mangifera indica* L. may only affect the height of plants without altering the NOL of plants. Though this phenomenon is not fully understood, but the increased NOL was anticipated with time, as the NOL of plants is not established as being dependent on the height of the plant. The above findings corroborate the work of Ochekwu *et al*. (2020), who reported *Juglans nigra* to exhibit a similar allelopathic influence on wheat and rice. It was also observed that the decrease in the concentration of mango leaf extract as well as soil-applied powder did not inhibit the HOP and NOL for maize (*Z. mays*) over time. This result comes as a surprise, as the notoriety of mango (*Mangifera indica* L.) as a negatively allelopathic plant is widely established by different researchers. Therefore, this result goes against the inferences of El-Rokiek *et al*. (2010) and Kamran *et al*., (2013) who reported the allelopathic notoriety of *M. indica* on *Cyperus rotundus* and canary grass germination respectively. But this observation seems to conform with the report of Musiyimi *et al,* (2015) who established that applications of fresh aqueous extracts of *Tithonia diversifolia* increased some morphological growth parameters of *Vigna sinensis*. Musiyimi *et al*. (2015) further asserted that the stimulatory effect on the morphological growth parameters of *V. sinensis* corresponded to an increase in the total chlorophyll content of *V. sinensis.* Similar work has also been carried out by Uzoma *et al.,* (2018) who established that the aqueous extracts of *Axonopus compressus* increased the growth parameters of *Kalanchoe pinnata*. Uzoma *et al.* (2018) further averred that the application of extracts of *A. compressus* increased the phenolic and chlorophyll content of *K. pinnata*, and therefore suggested that the increase in the growth parameters of *K. pinnata* due to the application of the aqueous extract of *A. compressus* could be traceable to an increased chlorophyllase activity. Kamran *et al*. (2013) investigation on mango leaf extract also revealed a moderate stimulatory effect on the growth of wheat. This assertion by Saleem *et al* (2013) corroborate the work of Muhammad *et al* (2019) who averred that sorghum water extract concentrations without adjuvant at low concentrations exhibited the growth-enhancing potential; while higher concentrations of sorghum water inhibited the seedling growth of maize.

The results strongly indicate that the inhibitory effects observed in agricultural crops and weeds within farmlands can be attributed to the release of allelochemicals from mango plant residues. These findings are consistent with the investigations conducted by Chon *et al*. (2003), Singh *et al*. (2003), and Chon and Kim (2004), who have linked the potent allelopathic properties of certain plant extracts to the presence of phenolic acids, including coumarin, α-coumaric acid, p-coumaric acid, benzoic acid, p-hydroxybenzoic acid, ferullic acid, and cinnamic acid.

In this study, the growth of maize seeds under the allelopathic influence of Mango (*Mangifera indica* L.) exhibited significant performance across various concentrations of mango leaves water extract and powder. The extracts and powder derived from mango leaves demonstrated a remarkable ability to enhance the germination and growth of *Z. mays*, with the greatest effects observed at lower concentrations. Specifically, mango leaf ater extract and powder at 5g and 10g concentrations supported the growth of maize without negative effects, while concentrations (15-20g) showed inhibitory effects on the germination and growth of maize seeds.

CONCLUSION

Mango leaves aqueous extract or its powder, at lower concentrations roved best in enhancing the growth and germination of maize. Based on the findings, it can be deduced that maize extracts, as well as its powder in low concentrations can be useful in enhancing the growth and yield of maize as well as other plants with appreciable tolerant levels to mango allelopathy. The practice of leaving the leaf drops to degrade and erode into the soil in these areas by farmers has not in any way recorded an impeding effect on maize cultivation and productivity. However, it might be safe to deduce that areas or farmlands with such practices portend low productivity for maize cultivation within the framework of this research.

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