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TO RESTORE THE DIGNITY OF MAN

TABLE OF CONTENT

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EDITORIAL

We have decided to release this third issue of Volume 42 on this first day of November 2023 (01/11/2023) in order to soothe the overstretched anticipation of authors who just cannot wait to see their articles published in a *"brand new"* Nigerian Journal of Technology. I say "*brand new*" in the sense that this will be our first publication since our Journal was accepted for indexing in Scopus by the Elsevier Content Selection and Advisory Board (CSAB).

Indeed, it has been a very long *trek* to Scopus indexing. This arduous task did not start with the present Editorial Team – it started in 1975 when the first issue was published with only seven articles, thus laying the foundation for the intellectual clearing house that NIJOTECH has now become. Though it started as a print only Journal with chequered publication history in the early days, it has maintained an unbroken publication record in the past twenty-three years (2000 – date). Another important milestone which provided the launch pad for Scopus indexing was the transition from print only to online publishing in 2012 with Prof. J. C. Agunwamba as Editor-in-Chief and Prof E. S. Obe as Editor. As a result of this laudable move, the visibility and popularity of NIJOTECH rapidly assumed an upward trajectory both in Nigeria and beyond.

The first attempt to secure indexing in the Scopus database was made in June 2019, followed by a second attempt in April 2022. So, when on the eve of 2022 we started preparing for yet another application, the Editorial Team went into overdrive mode just to ensure that no stone was left unturned in achieving this critical milestone. It also became obvious that we needed to overhaul and upgrade the Journal website as well as the content. The first green light came when in June 2023, we were upgraded from 1-star to 2-star on a scale of 3 by the Journal Publishing Practices Standards (JPPS) Framework on the premise that the Journal had recorded significant improvements. After almost one year of relentless efforts, we finally dared to start the application again in August 2023 – for the third strenuous time. We submitted the application on August 4, 2023 and went back to work. One thing was sure – whether we were accepted for indexing or not, we were determined to keep pushing our beloved Journal to the next level.

Then on September 30th September 2023, the long *trek* to Scopus indexing was relieved. It was announced in a terse email from Elsevier CSAB – "***Congratulations, your Nigerian Journal of Technology has been accepted for Scopus***". There were a few other things, but this was the most important message.

Before I wrap up this editorial, there is need to bring clarity to the implication of this milestone for both the Journal and authors. The most frequently asked question has been "will the indexing cover all back issues"? We thought it wise to pass on the question to Elsevier for a reliable answer. While waiting for a response, I decided to do a bit of research and then I learnt that if a journal is accepted for indexing at the first application, then coverage will include all articles published in the Journal minus four years from the year of indexing. This means that if a journal is accepted for indexing in 2023, coverage will start with all articles published from 2019. However, if a journal has been declined before, then this rule will not apply. For more details visit CP-Scopus-FAQs-EXTRNL.pdf (widen.net). My email to Elsevier was finally replied yesterday stating that coverage for NIJOTECH will cover all articles published in 2023 and forward. I am also sure that authors would like concrete evidence that our Journal has been accepted for indexing in Scopus. One evidence is the Scopus title suggestion tracker -https://suggestor.step.scopus.com/progressTracker/?trackingID=87AEB0D2DB8706F3 and the second is the list of accepted titles on Scopus website - https://www.elsevier.com/?a=91122. Once indexing process is complete, we shall be animating our CiteScore on our website.

On a final note, we would like our authors and readers to note that Scopus indexing is not and has never been our destination. We are on the long haul to excellence. Hence, we will keep pushing boundaries and exploring new frontiers. We will soon roll out our new guide for authors which we expect that authors will adhere strictly to. Once again, ***congratulations*** and thank you for your continued support. Enjoy your reading.

Prof. Chidozie Charles Nnaji
Editor-in-Chief
01/11/2023

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SETTLEMENT, SLOPE STABILITY AND SEEPAGE ANALYSES BY NUMERICAL MODELLING METHOD AND THEIR APPLICATIONS IN PRACTICE

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Abstract

The encountered situations during the design process of a gully erosion control site in Kano State are discussed in this article. The project was to design a rectangular concrete lined drainage channel with short side walls to efficiently convey flood water and prevent embankment erosion. Because of the embankment depth and soil type on the site which are mostly silty/clayey sand, settlement of the huge concrete channel, seepage and the unprotected embankment slope were issues of major concern. Settlement, slope stability and seepage analyses and designs were some of the several activities undertaken for the project. The anticipated total settlement prediction was performed by numerical simulation from which the differential settlement was then calculated. The prediction of the safety factor to determine the stability of the slope was performed by numerical simulation using SLOPE/W. The hydraulic velocity and rate of seepage prediction was performed by numerical modelling using SEEP/W. The use of numerical technique was specifically recommended by the consultants of the funder of the project, the World Bank. It was observed that numerical modelling technique provided accurate results of settlement, factor of safety, hydraulic velocity and rate of seepage and was therefore recommended for both research and practical applications.

1.0 INTRODUCTION

It is a common understanding that the responsibility of a civil engineer is to develop reliable, safe and effective systems for the society by mitigating risk and avoiding failure. These responsibilities includes forecasting, predictions and prevention against catastrophes due to human activities and natural hazards. Natural hazards, when occurred, cause enormous damage on human life and economic loss. In all engineering systems, cost effectiveness must also be put into considerations. Prediction of the anticipated total and differential settlement of shallow foundations in cohesive and cohesionless soils is prone to several uncertainties such as variations in soil properties with lateral and axial distances, perfection in the laboratory experimental results, etc. Numerous methods have been developed to predict the settlement of shallow foundations in soils. With advancement in technology and development of sophisticated numerical methods such as finite element method, the consideration of the constitutive behavior of soils has become a subject of wide discussion [1]. The constitutive behavior governs the response of soil under the footing and therefore majorly determines the value of bearing capacity and settlement [2 - 3].

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Numerical modelling is a powerful simulation and mathematical tool that makes it possible to solve complex engineering problems. In a study on the constitutive behaviour of soils, Salahudeen and Sadeeq [4] observed that soils can be successfully modelled with numerical analyses using some basic soil properties as input data. It was also discovered that it is realistic to idealize the material behaviour of the soil, which is non-linear with plastic deformations and stress-path dependent, in a more realistic approach [5]. The slope stability and seepage analyses in geotechnical engineering have followed nearly the developments in soil and rock mechanics. Slopes are either engineered or occur naturally. To minimize these enormous damages, especially those caused by geohazards, an appropriate preventing techniques are needed and reliability analysis relating geohazards should be adopted [6].

To quantitatively assess the stability of a slope in an engineered or naturally occurring slope stability failure mechanisms analysis, a parameter known as factor of safety (F) is used which is simply the ratio of the resistance forces to the gravity forces parallel to the slope. A value of F greater than 1 indicates stability, whereas F less than 1 implies instability. F value of 1.5 is generally reported to be satisfactory in the literatures [7]. Thus, the transition between stability to collapse may be envisaged computationally as a decrease in the factor of safety to values below unity. The quantitative determination of the stability of slopes is necessary in a number of engineering activities, such as: (a) the design of earth dams and embankments, (b) the analysis of stability of natural slopes, (c) analysis of the stability of excavated slopes, (d) analysis of deep-seated failure of foundations and retaining walls, (e) open pit mining, (f) road cuts. Conventional forms of slope stability analysis are limited to simplistic problems in the scope of application, encompassing simple slope geometries and basic loading conditions, and as such, provide little insight into slope failure mechanisms [8].

Soil slope stability problems involve complexities relating to geometry, material anisotropy, non-linear behavior, in-situ stress and the presence of several coupled processes (e.g. pore pressure, seismic loading, etc.). To address these problems, numerical simulation methods have been proved to provide more accurate solutions, which is a major limitation in the conventional techniques. Advances in computational methods and the availability of commercial numerical modelling codes means that the simulation of potential soil slope stability failure mechanisms could, and in many cases should, form a standard component of a soil slope investigation [7, 9 - 10]. In this study, the slope stability analysis of an earth dam embankment was performed using SLOPE/W in GeoStudio. It is good to note that the reliability of numerical modelling software and their limitations with respect to field application largely depend on the expertise of the modeler.

Flood channels, just like earth dams have always been associated with seepage as they impound water in them. The water seeks paths of least resistance through the embankment. Seepage will become a bigger problem if it carries materials along with it. Seepage must be controlled to prevent the erosion of embankment or its foundation. Different methods like analytical, electrical analogy and flownet have been used to study and monitor seepage in dams and embankments [11]. In this study, the seepage analysis of the earth dam embankment was performed using SEEP/W in GeoStudio.

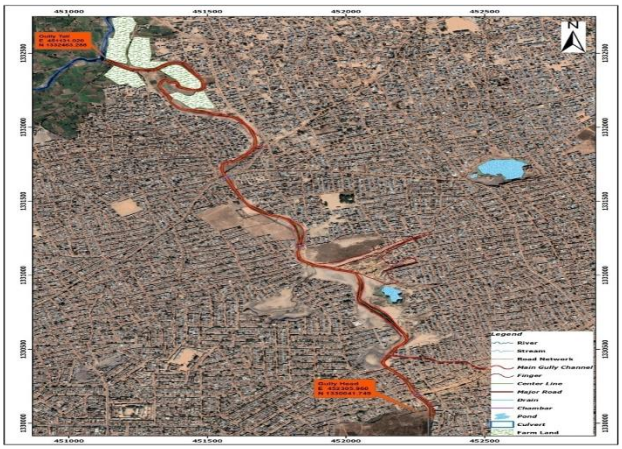

Figure 1: Satellite Imagery of the Site

Some of the important factors causing failure of embankments are slope failures, settlement and seepage through the embankment materials and hence their analysis in embankment dam design is of greater importance. Recently, Finite Element Method (FEM) is being used by geotechnical engineers analysis of geotechnical problems and designs [12 - 16]. Olonade and Agbede [17] performed a computer simulation of the groundwater flow through a porous medium in the Northern region of Nigeria. The results of the simulation was within acceptable limits. The objective of this study is to analyze the settlement, slope stability and seepage potential of a concrete lined flood channel with erosion problem and its embankment in order to ensure both safety and sustained economic development of the community. These analyses of the design parameters are very vital for the safety, stability and economic or optimal

design of the flood channel to mitigate the flood and erosion problems.

2.0 MATERIAL AND METHODS

2.1 Material

The geotechnical investigation works for the site (located at Latitude 1330041.749N and Longitude 452305.960E of the gully head and 1332463.288N and 451131.020E of the gully tail) involves seven (7Nos) boreholes to depths of 10.0m (BH1 and 2) and 5.0m (BH3 - 7) and 9 Nos trial pitting to depth of 3.0m explored to characterize the subsoil for the purpose of settlement, slope stability and seepage analyses and design. The site is located at Bulbula, Kano State, Nigeria (see Figure 1 for the site map and Figure 2 for pictures).

Figure 2: Site Photographs

The test borings were drilled using the rotary drilling machine. In each test bore, Standard Penetration Tests (SPT) was conducted at 1.5m interval where samples were also taken. The sampling procedure consisted of driving a standard split spoon as set forth in ASTMD1586-1990 and BS 5930. The laboratory tests were conducted in accordance with the relevant British Standard as Specified in BS 1377 [18]. This was by repeated blows of hammer of 63.5kg weight falling through 760mm height. Average values of the parameters used for modelling the soil and the foundation element are presented in Table 1. Values of Young's modulus and Poisson's ration were obtained fron set of tables presented by Das [19].

Table 1: Average parameters for modelling and general computations

Parameter	Unit	Soil	Concrete
Bulk unit weight	kN/m^3	18.0	24
Dry unit weight	kN/m^3	17.3	--
Friction angle	Degree	24	--
Dilatancy angle	Degree	0.0	--
Cohesion	kN/m^2	10	--
Permeability	m/sec	1.2×10^{-5}	--
Young's modulus	kN/m^2	10200	2.74×10^7
Poisson's ratio	--	3.324	0.2
Soil model	--	Mohr-Coulomb	
Material behavior	--	--	Linear (Isotropic)

2.2 Methods

2.2.1 Laboratory experimental procedure

The results presented in Table 1 and 2 were obtained through the following experimental procedures. The laboratory tests were performed to determine the index and strength properties of the soil in accordance with BS 1377 [18]. The experimental tests conducted include sieve analysis, consistency limits, density, permeability, specific gravity and direct shear test for strength. The strength test was conducted using the direct shear method. The permeability test was conducted using laboratory constant head hydraulic conductivity procedure. The specific standards used in conduction the tests presented in Table 2 has been detailed in the last column of the table.

2.2.2 Settlement modelling

Total settlement

The total settlement prediction was done using PLAXIS software package. Prediction of maximum total anticipated settlement of the channel structure was done on the lined rectangular channel with concrete at different chainages along the gullies based on structural applied loads at embedment depth of 0.6 m. A maximum applied foundation pressure of 40 kN/m^2 was used and point loads of 20 kN representing each side wall of the rectangular channel. Plaxis 2D (plane strain model) is a finite element package used for two-dimensional analysis of deformation and stability analysis in geotechnical engineering. It uses advanced soil constitutive models for the simulation of the non-linear, time dependent and anisotropic behaviour of soils. Plaxis portfolio models the structure, the soil and the interaction between the structure and the soil. Soil layers and foundation structure parameters are inputted into Plaxis and the construction stages, loads and boundary conditions are defined in an already defined geometry cross-section containing the soil model. Plaxis then automatically generates the unstructured 2D finite element meshes with options of global and local mesh refinements. Using its calculation facilities, Plaxis undergoes a calculation process and presents the calculation and model outputs which can be accessed in animation and/or numerical forms. The input parameters used in modelling the embankment are the derived soil parameters from both the SPT and laboratory results which include the cohesion, friction angle, dilatancy angle, modulus of elasticity, Poisson's ratio, hydraulic conductivity, bulk and dry unit weights and plasticity index. Further details can be found in Plaxis 2018 Version manual [20].

Differential settlement analysis

The differential settlement was computed using the angular distortion approach based on the total settlement computed by the numerical modelling method.

$$\Delta S = S_T / l \quad (1)$$

Where ΔS = Differential Settlement, S_T = Total Settlement and l = distance between the two points under consideration.

Slope stability modelling

The SLOPE/W package for slope stability simulations in GeoStudio was used for modelling the slope stability of the gully site embankment. SLOPE/W is a two-dimensional axisymmetric finite element software product that can be used to perform stress, and stability analyses of embankments. Its comprehensive formulation makes it possible to analyse both simple and highly complex problems like a simple linear elastic deformation analysis or a highly sophisticated nonlinear elastic-plastic effective stress analysis. In SLOPE/W, finite elements numerical modelling methods translate a set of differential equations into matrix equations for each element, relating forces at nodes to displacements at nodes. Further details can be found in GeoStudio 2020 Version manual [21].

Geo-Studio software portfolio includes simulation of soil and soil-structure interaction. Geo-Studio is an axisymmetric finite element package used for two-dimensional analysis of deformation and stability in geotechnical engineering. It uses advanced soil constitutive models for the simulation of the non-linear, time dependent and anisotropic behaviour of soils. Geo-Studio portfolio models the structure, the soil and the interaction between the structure and the soil. Soil layers parameters are inputted into Geo-Studio and the construction stages, loads and boundary conditions are defined in an already defined geometry cross-section containing the soil model. Geo-Studio then automatically generates the unstructured 2D finite element meshes with options of global and local mesh refinements. Using its calculation facilities, Geo-Studio undergoes a calculation process and presents the calculation and model outputs which can be accessed in animation and/or numerical forms. The input parameters used in modelling the embankment are the derived soil parameters from the laboratory results which include the cohesion, friction angle, bulk and dry unit weights.

Seepage modelling

The seepage analysis in this project was performed to determine the seepage loss and the hydraulic conductivity of the soil which is necessary for estimating the quantity of underground seepage under various hydraulic conditions and for making stability analyses of river slopes as they are subject to seepage forces. When water channels convey flood water, there will be penetration of water into the earth embankment and therefore analysis of the seepage hydraulic velocity and flux is inevitable. The seepage analysis was performed at different locations along the gully. The selected sections of the gully for which analysis was performed are those locations with concerned features based on soil properties, slope height, channel width and location. Seepage simulations was performed using SEEP/W in Geo-Studio package. The working system of Geo-Studio has been described in slope stability modelling subsection. The input parameter used in modelling the flow in embankment is majorly the hydraulic conductivity of the soil obtained from laboratory constant head hydraulic conductivity test and presented in Table 1.

3.0 RESULTS AND DISCUSSIONS

3.1 Average Geotechnical Properties of the Site

The Stratigraphy of the subsurface deposits as observed from the logs of test bores performed at this site exhibited slight variations in strata from one location to the other, but there are some similarities in nature and in strength characteristics of soil strata encountered. The subsoil formation at the boring locations consists of silty sand, clayey sand, clayey sandy silt, sandy silty clay, laterite and weathered rock. The results in Table 2 show range of values of soil properties from the laboratory test results on samples from the test borings. Figure 3 shows the average particle size distribution.

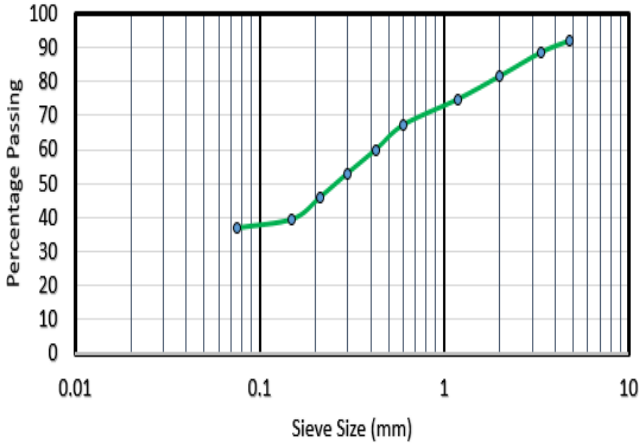

Figure 3: Average particle size distribution of the site soil

Table 2: Range of values of laboratory test results

Soil Property	Minimum	Maximum	Standard
Natural Moisture Content(%)	7	20	BS 1377 (1990) – Part 2
Liquid Limit (%)	21	32	BS 1377 (1990) – Part 2
Plastic Limit (%)	NP	15	BS 1377 (1990) – Part 2
Plasticity Index (%)	NP	17	BS 1377 (1990) – Part 2
Passing # 200 Sieve (%)	2.65	75.23	BS 1377 (1990) – Part 2
Bulk density (kN/m^3)	15.50	19.0	BS 1377 (1990) – Part 2
Permeability (m/sec)	$2.95x10^{-7}$	$1.29x10^{-3}$	BS 1377 (1990) – Part 5
Specific Gravity	2.60	2.64	BS 1377 (1990) – Part 2
Apparent Cohesion (kN/m^2)	0	3	BS 1377 (1990) – Part 8
Angle of Internal Friction (Ø)	22	36	BS 1377 (1990) – Part 8

3.2 Settlement

The results of settlement analyses are presented in Table 3 while samples of the model plates used for numerical simulations are presented in Figures 4 and 5. Conventionally, the allowable settlement value of 25 mm is generally recommended for sensitive engineering structures like buildings as stipulated by the European Committee for Standardization otherwise known as Eurocode 7. However, this allowable value is 50 mm for structures founded on sands [22 - 23]. Eurocode 7 [24] recommended limiting values for maximum acceptable foundation settlement as: limiting values for total settlement of 25 mm for isolated shallow foundation and 50 mm for raft foundation. Since the bottom slab of the concrete channel is designed as raft footing, which spread the loads over a wise area, the limiting value of 50 mm for raft foundation was considered for this project. Eurocode 1 [25] recommended a maximum allowable differential settlement and angular distortion of 20mm and 0.00333 respectively for serviceability limit state in rafts founded on sand. The observed settlement and differential settlement values in this project are mostly within the acceptable limits. However, there are locations in which the limiting conditions were not met. Therefore, mechanical predensification and/or special treatments (mixing with coarse grain materials) [26-29] of the soils is recommended at these locations using soil compaction machines to reduce the compressibility of the soil before placing the concrete channel's foundation. This settlement problem is an issue of major concern at Chainages 1+000 - 1+600 and 2+200 - 3+000 as obvious from Table 3. The use of rectangular concrete channel has the advantage of wide spread of load over a large area thereby mobilizing a larger soil surface for bearing the load and thereby minimizing the anticipated settlement.

Table 3: Results of total settlement and differential settlement

Test Point Vicinity	Total Settlement (mm)	Differential Settlement (mm)	Angular Distortion	Deflection Ratio	Remark
0+000	12.25	9.41	0.00004705	0.000032935	Satisfactory
0+200	25.87	13.62	0.0000681	0.00004767	Satisfactory
0+400	10.1	15.77	0.00007885	0.000055195	Satisfactory
0+600	17.39	7.29	0.00003645	0.000025515	Satisfactory
0+800	14.51	2.88	0.0000144	0.00001008	Satisfactory
1+000	67.21	52.7	0.0002635	0.00018445	Not Satisfactory
1+200	14.91	52.3	0.0002615	0.00018305	Not Satisfactory
1+400	100	85.09	0.00042545	0.000297815	Not Satisfactory
1+600	8.55	91.45	0.00045725	0.000320075	Not Satisfactory
1+800	21.56	13.01	0.00006505	0.000045535	Satisfactory
2+000	14.43	7.13	0.00003565	0.000024955	Satisfactory
2+200	84.88	70.45	0.00035225	0.000246575	Not Satisfactory
2+400	14.41	70.47	0.00035235	0.000246645	Not Satisfactory
2+600	80.72	66.31	0.00033155	0.000232085	Not Satisfactory
2+800	86.6	5.88	0.0000294	0.00002058	Not Satisfactory
3+000	29.08	57.52	0.0002876	0.00020132	Not Satisfactory
3+200	14.51	14.57	0.00007285	0.000050995	Satisfactory
3+400	33.21	18.7	0.0000935	0.00006545	Satisfactory

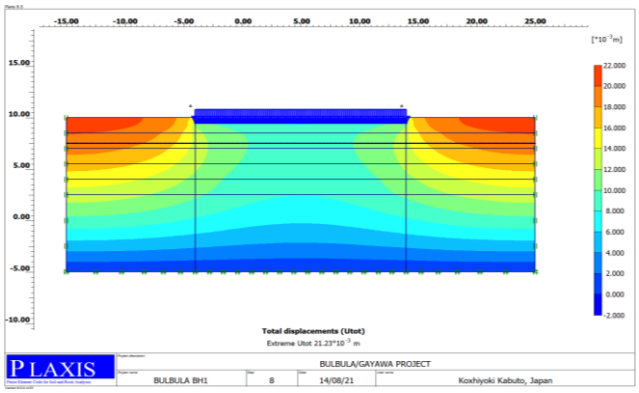

Figure 4: Model of settlement analysis around chainage 0+300

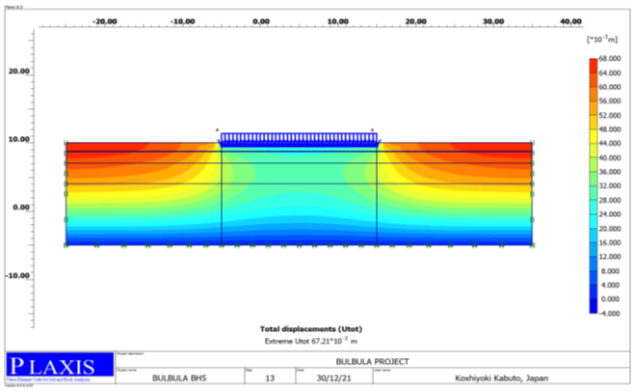

Figure 5: Model of settlement analysis around chainage 1+000

3.3 Slope Stability

Slope stability analysis was performed based on average soil properties within the vicinity of trial pits/boreholes as obtained from the nearest trial pit/borehole. The soil properties of all soil layers encountered during excavation for representative soil samples were considered during the analysis. However, output results are presented for the most critical locations encountered. The analysis was performed for areas with the most observable issues of stability concerns around the vicinity of locations where soil investigation was conducted. The slope stability results for this project are all satisfactory. When an embankment has a factor of safety value of 1.0, it implies that equilibrium is just attained and any value below 1.0 is an indication of certainty of failure. Safety factor value above 1 is an indication of safety but a minimum of 1.5 factor of safety value is conventionally recommended. None of the simulations has safety factor less than the minimum value of 1.5. Detailed results of the slope stability analysis with their corresponding slope heights are presented in Table 4.

The factors of safety first estimated in the unlined channel are very low and seriously below the minimum requirement of 1.5 and therefore not satisfactory and lining the channel with concrete was strictly recommended. However, the concrete lined channels, whichever of rectangular or trapezoidal is favored considering other design criterial is hereby recommended for adequate and efficient solution to the gully problem. To enhance more stability of the slopes, it is recommended that steep slopes be stabilized mechanically by ensuring a gentle slope of the embankments [12, 29]. In the construction of the engineered embankments, a minimum slope of 1:1 (or gentler) should be considered [5, 26] throughout and in cases where this slope cannot be achieved for reasons to be determined by the site engineer, gabion mesh is recommended to compensate the slope for stability. Some of the model plates used for the numerical modelling are presented in Figures 6 and 7.

Table 4: Results of factor of safety for slope stability analysis

Test Point Vicinity	Embankment Height (m)	Factory of Safety	Remark
Around TP1	3.0	3.51	Satisfactory
Around TP2	4.5	4.08	Satisfactory
Around TP3	4.0	5.12	Satisfactory
Around TP4	2.0	3.92	Satisfactory
Around TP5	2.5	4.52	Satisfactory
Around TP6	4.0	5.10	Satisfactory
Around TP7	3.5	5.02	Satisfactory
Around TP8	3.0	5.40	Satisfactory
Around TP9	3.0	5.36	Satisfactory
Around BH1	4.0	3.95	Satisfactory
Around BH2	2.0	4.71	Satisfactory
Around BH3	3.7	2.75	Satisfactory
Around BH4	2.9	3.34	Satisfactory
Around BH5	4.1	3.02	Satisfactory
Around BH6	3.5	2.78	Satisfactory
Around BH7	3.1	4.65	Satisfactory

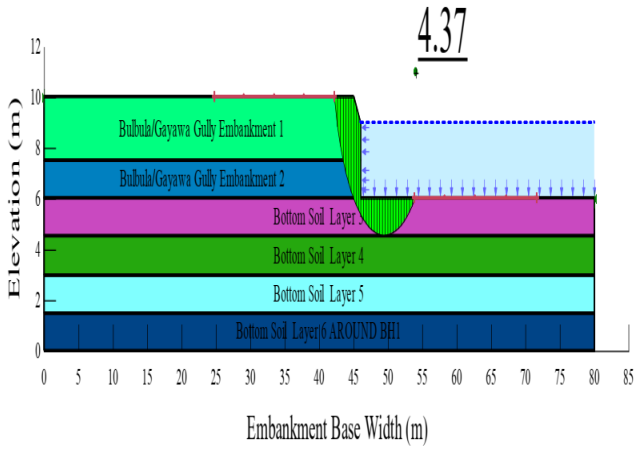

Figure 6: Model 1 of slope stability analysis

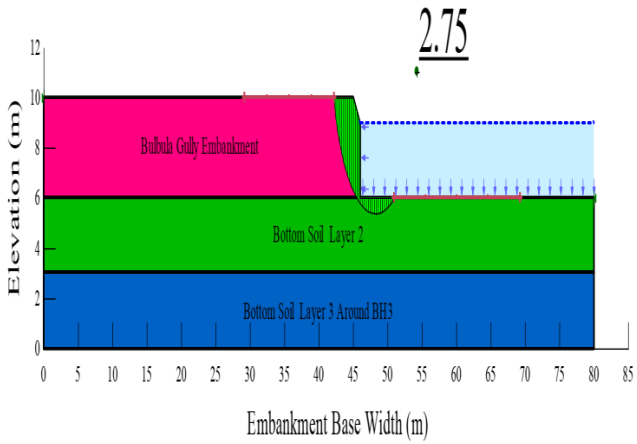

Figure 7: Model 2 of slope stability analysis

3.4 Seepage

Results of seepage analyses show that the maximum hydraulic velocities and flux at most of the sections around the locations of the embankments considered are not satisfactory, thereby necessitating the use of concrete lining. For the construction of embankments, the coefficient of permeability is generally used to qualify the suitability of a particular soil horizon. Dikes and embankments without any impermeable clay core may be built from soils having a coefficient of permeability less than 1×10^{-4} m/s. In any case, the coefficient of permeability greater than 1×10^{-6} m/s is considered rapid [30]. Also, an average seepage rate of 1.157×10^{-4} to 2.315×10^{-4} m^3/s is considered acceptable, but corrective measures should be taken to reduce soil permeability when higher values exist. The most serious concerns are for internal erosion or piping within an embankment when the signs of

distress are often hidden until severe internal damage has occurred [30].

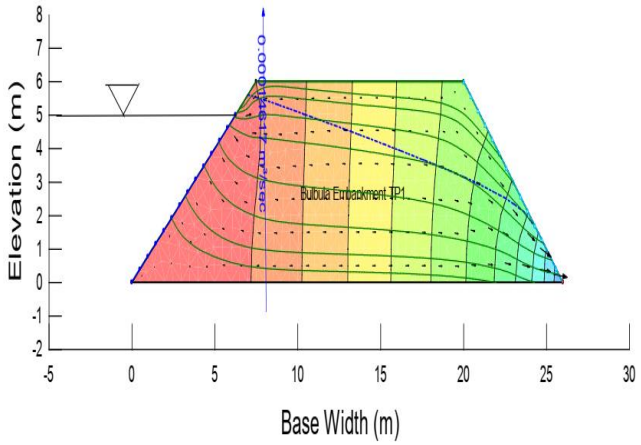

Figure 8: Model of seepage analysis around chainage 0+000

It is reported in the literature that there are two major procedures for quickly alleviating a seepage problem: reduce the hydraulic head and pressure causing the problem (reservoir drawdown) or control the exits of the seepage. For this particular project, controlling the exits of the seepage is the applicable of the two options. Constructing sandbag or other types of ring dikes around sand boils can be used to control the seepage exit. Seepage exits can also be controlled with a weighted filter (e.g. geotextile) constructed by placing a layer of filter material over the seepage exit and overlaying that with pervious drainage material. Meanwhile, providing a concrete channel is a better alternative that provides a permanent solution to the seepage problem which will also aide the slope stability. Summary of the seepage analysis results are presented in Table 5. Based on these results, it is highly recommended that the gully channel be lined with concrete due to the highly permeable soil type which is highly susceptible to collapse and erosion.

Figure 9: Model of seepage analysis around chainage 3+500

Table 5: Results of maximum hydraulic velocities and flux

Test Point Vicinity	Max. Hydraulic Velocity (m/s)	Max. Hydraulic Flux (m^3/s)	Remark
Around TP1	1.266×10^{-4}	1.462×10^{-4}	Satisfactory
Around TP2	4.576×10^{-3}	7.350×10^{-3}	Not Satisfactory
Around TP3	2.532×10^{-3}	4.100×10^{-3}	Not Satisfactory
Around TP4	5.614×10^{-4}	4.151×10^{-4}	Not Satisfactory
Around TP5	2.341×10^{-6}	1.630×10^{-6}	Satisfactory
Around TP6	4.001×10^{-4}	6.040×10^{-4}	Not Satisfactory
Around TP7	7.455×10^{-4}	8.925×10^{-4}	Not Satisfactory
Around TP8	5.514×10^{-3}	6.254×10^{-3}	Not Satisfactory
Around TP9	3.756×10^{-4}	4.038×10^{-4}	Not Satisfactory
Around BH1	3.043×10^{-5}	4.639×10^{-5}	Satisfactory
Around BH2	5.657×10^{-5}	4.072×10^{-5}	Satisfactory

The hydraulic velocities and flux estimated in the unlined channel are very high and not satisfactory. Therefore, concrete lining is highly recommended for adequate and efficient solution to the gully problem. Some of the model outputs are presented in Figures 8 and 9.

4.0 CONCLUSION

Based on the results and observations of the study, it is concluded that numerical modeling technique of predicting the total settlement of foundations in geotechnical engineering is effective and more accurate than the conventional methods that are based on approximations. It was also concluded that numerical modeling technique of predicting the safety factor of natural or engineered slopes in geotechnical engineering yielded reliable factor of safety results. From the results of hydraulic velocity and rate of seepage obtained in this study, it was obvious that the numerical simulation technique is highly recommended for all geotechnical seepage analysis.

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GROUNDWATER QUALITY ASSESSMENT OF ABA URBAN AREA

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Abstract

This work presents groundwater quality assessment of Aba Urban area and its sources of Contaminants within Aba Urban Area. Aba area was divided into nine parts using a 3x3 grid. Water samples were taken from each of these 9 parts of Aba. Five water samples were taken from household boreholes while four samples were taken from boreholes drilled and cased at the remaining four parts in the course of carrying out this research. Site and laboratory tests were conducted to determine the values water parameters in the samples. The parameters analysed in the laboratory include the Phosphate, ammonium, Lead, cadmium, Manganese, Copper, Mercury, Chromium, and magnesium, Electric conductivity (EC), Dissolved oxygen (DO), Total dissolved solid (TDS), Acidity, Turbidity, Alkalinity, oxidation-reduction potential (ORP), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and E-Coli. It was discovered that more than 75% of the water samples are contaminated by E-Coli. Umuagu sample has Manganese value of 0.775mg/l. This more than the limiting value of 0.4mg/l. The values 252, 524 and 472 mg/l of Magnesium in samples from Estate, Abia Polytechnic and Osisio Ngwa respectively are more than the limiting value of 150mg/l. The DO (mg/l) values of 6,4 and 9 from Ariaria Junction and Abia Polytechnic are outside the range limiting of 6.5mg/l – 8.0 mg/l. The values of TDS, ORP and BOD recorded in all the samples are below the limiting values of 600 mg/l, 357 mV and 1mg/l respectively.

1.0 INTRODUCTION

Aba is one of the commercial nerves of South-East Nigeria. It houses many people of different walks of life. It is densely populated with an estimate of 1,189,000 people in 2023 [1]. Ninety five per cent of this population depend on ground water obtained by drilling boreholes at various locations. There is dare need to determine if the ground water at Aba, which is a commercial city, is directly or indirectly affected by the enormous quantity of solid, liquid and gaseous waste products produced therein.

Static water level (SWL) in Aba area is shallow. The work of [2] shows that SWL is as low as 4.57m in Ukwa East. The range of Static water level for some LGA within Aba area are shown on Table 1. According to United States Environmental Protection Agency (EPA) [3], there are three types of private drinking water wells. They are Dug/Bored wells, Driven wells and Drilled wells. The depth of dug wells is within 3 to 9 meters deep whereas that of driven well is within 9 to 15m. Both dug well and driven well can be easily contaminated because their water is drawn from aquifers that are near to the ground

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surface. Drilled well is more than 15m deep and is less likely to get contaminated because it water is drawn from aquifer that is not near the ground surface and the well uses continuous casing.

Some of the parameters to be looked out for include Anions (Phosphate and Ammonia), Cations (Lead, Cadmium, Manganese, Copper, Mercury and Magnesium), Electric conductivity (EC), Dissolve oxygen (DO), Total dissolved solid (TDS), Acidity, Turbidity, Alkalinity, Oxidation-Reduction Potential (ORP), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Escherichia Coli (E-Coli). Some scholars and Bodies like World Health Organization gave limiting (permissible or allowable) values for these parameters in drinking water. These standard values would be used to compare with the values measured in this work to establish if the sample meets the standard for drinking water or not. The standard values are presented on Table 2.

Table 1: Static water level in some LGA within Aba area

Local Government Area	Static water level (m)
Aba North	29.86 to 30.45
Aba South	18.25 to 35.97
IsialaNgwa North	19.0 to 97.5
IsialaNgwa South	23.70 to 50.52
ObiomaNgwa	17.7 to 36.0
Ukwa West	7.8 to 26.52
Ukwa East	4.57-19.20

Source: [2]

1.1 Location and Brief Geology of Study Area

Aba is located on the world map within the following geographical coordinate points - 5° 12’ latitude to North and 7° 20’ longitude to East; 5° 7’ latitude to North and, 7° 27’ longitude to East; 5° 2’ latitude to North and 7° 20’ longitude to East; 5° 7’ latitude to North and 7° 17’longitude to East. The elevation is 205m. See Figure 1. According to [4] , Aba falls into tropical climate considered as AM in Köppen-Geiger climate classification [5]. AM stands for the warmest climate with short dry season. It is mostly referred to as a tropical monsoon and trade-wind littoral climate.

The average annual temperature in Aba is 26° C with peak and lowest temperatures of 33° C and 22° C respectively. Precipitations of up to 200mm are recorded for the months of April to October every year. December, January and February are the driest months with average precipitation of 57mm. The months with more than 6 hours of day light include December, January, February, March, April and May. Other months have average of 5 hours of sunlight a day [4].

Aba is one of the commercial hub cities in the South Eastern Nigeria. Lots of commercial and industrial activities go on in Aba on daily basis. According to [6], the waste generation in Aba is estimated at 236,703 tons/month. The typical municipal solid waste management technique used by ASEPA (Abia State Environmental Protection Agency) include: storage by the producers, collection by ASEPA, transportation and disposal at dumpsites and Incineration [7].

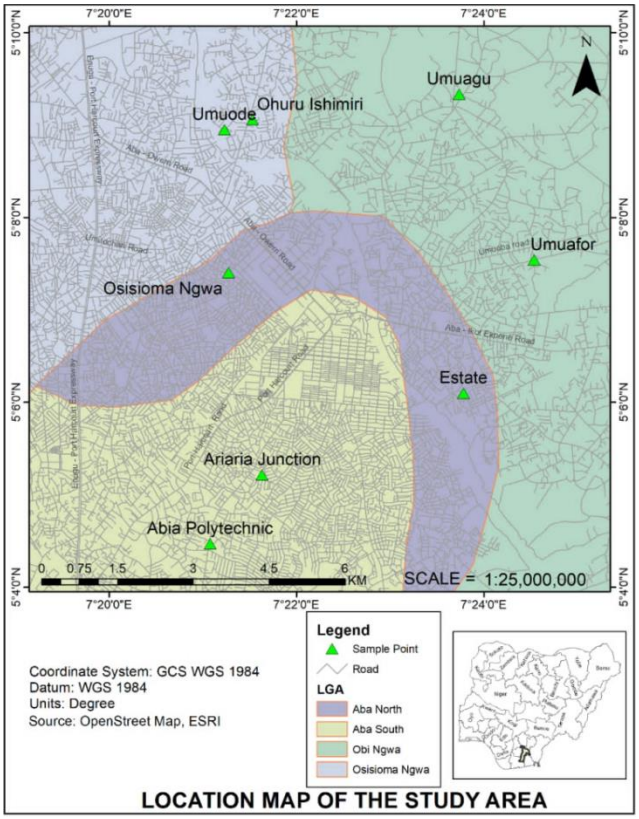

Figure 1: Map of Aba city, Nigeria
Legend: ΔThis indicates area where water sample was collected

The nearest cities around Aba include Owerri (North-west), Umuahia (North-East), Akwa-Ibom (South-East) and Port Harcourt (South-West). The nearest airports to Aba are Sam Mbakwe Airport (QOW), which is 39.40km away, Port Harcourt International Airport (PHC), which is 47.40km away and Margaret Ekpo International Airport (CBQ), which is 110.05km.

The plan area of Aba is roughly 72 km^2. The average population density of Aba is 36,111.11/km2. Aba has no municipal water supply. Residents of Aba rely on direct rain water, river (stream) water and groundwater (shallow well or deep well). However, they all rely on deep well (aquifer well) for drinking water. Benin formation composed of shale and

sandstone underlies Aba. This formation is composed of shale/sand sediments sandwiched among clay beds ([8],[9]]).

Table 2: Standard (Limiting) values of parameters

Parameter	Unit	Guideline Value	Guideline Reference
pH	-	6.5-8.5	[10]
Electrical conductivity	µ/cm	2500	[13]
Turbidity	NTU	1	[10], [13]
Dissolved Oxygen	mg/l	6.5 to 8.0 (80%-120%)	[14], [15]
Oxidation Reduction Potential ORP	mV	357 to -25	[16]
Total dissolved solid (TDS)	mg/l	600 (1500)	[12] ([14])
Phosphates	mg/l	0.015	[17]
Ammonia	mg/l	1.5	[12]
E-Coli	MPN/100ml	0	[11], [14]
Lead	mg/l	0.01	[11], [14]
Cadmium	mg/l	0.03 (0.05)	[11] ([14])
Manganese	mg/l	0.4 (0.1)	[11] ([14])
Copper	mg/l	1	[11], [14]
Mercury	mg/l	0.006	[11]
Chromium	mg/l	1	[11]
BOD after 5 days	mg/l	1	[18]

2.0 METHODOLOGY

Aba area was divided into 9 parts using a 3x3 grid. A water sample was taken from each of these 9 parts of Aba. Five water samples were taken from household bore holes while four samples were taken from boreholes drilled and cased at the remaining four parts in the course of carrying out this research. The coordinate locations (lat., long.) of the nine boreholes are 1-Estate (Latitude 5.101°N and Longitude 7.39°E), 2-Umuagu (Latitude 5.15°N and Longitude 7.39E°), 3-Alaoji (Latitude 5.18°N and Longitude 7.55°E), 4-Ariaria Junction (Latitude 5.08°N and Longitude 7.36°E), 5-Umuafor (Latitude 5.12°N and Longitude 7.40°E), 6-Abia Polytechnic (Latitude 5.07°N and Longitude 7.35°E), 7-Osisioma Ngwa (Latitude 5.12°N and Longitude 7.35°E), 8-Ohuru Ishimiri (Longitude 5.15°N and Longitude 7.35°E) and 9-Umuode (Latitude 5.14°N and Longitude 7.35°E).

These coordinates were obtained using handheld GPS receiver. The four boreholes drilled in the course of this research were flushed two times a day (4 hours each time) for four consecutive days to ensure that any impurity introduced into the wells was removed before collection of samples. The water samples were collected directly from the boreholes using 27 rinsed sterilized plastic containers. Three samples were collected from each location. The temperature and pH of the water collected from the boreholes were measured and recorded, before taking the samples to Laboratory. One per cent (1%) of Trioxonitrate (V) acid (HNO_3) was used to acidify the samples for main cations analysis in order to stabilize trace metals with pH~2. At the same time, Boric acid H_3BO_3 was used to acidify the samples for nitrate analysis. All the samples were put in an ice container and stored below the temperature of 4° C while being conveyed to the Laboratory. The parameters analysed in the laboratory include the Anions (phosphate and ammonia), Cations (lead, cadmium, manganese, copper, mercury, chromium and magnesium), Electric conductivity (EC), Dissolve oxygen (DO), Total dissolved solid (TDS), Turbidity, pH, oxidation-reduction potential (ORP), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and E-Coli.

Nephelometric turbidimeter was used to measure Turbidity of the water samples. It expresses turbidity in NTU (Nephelometric Turbidity unit). However, one Turbidity unit is equivalent to 1 mg/L of silica in suspension [19]. Electrical conductivity was measured using an electrical conductivity meter (EC meter) that has a probe which consists of two metal electrodes spaced 1 cm apart. (the unit of measurement is microsiemens per centimeter (µS/cm)) [19]. Winkler titration method was used to measure dissolved oxygen in water samples. It is measured in mg/l [19]. Total dissolved solids (TDS) was measured using a TDS Meter. It is measured in mg/l [19]. The pH of the water samples was measured using a pH meter. pH is used to measure the acidity or alkalinity of water. It is a dimensionless quantity measure on a scale of 1 to 14 [19]. Oxidation-Reduction Potentials of the water samples was measured using ORP meter. It is measured in millivolts (mV). Higher values of ORP indicates higher presence of oxygen [19]. Biochemical oxygen demand (BOD) was measured using Winkler titration method. BOD is the difference in dissolved oxygen measured at the beginning and that measured after 5 days period at a temperature of 20°C in the dark. It is measured in mg/l [19]. Chemical oxygen demand (COD) was measure using the COD colorimeter. Strong oxidizing agent (potassium dichromate), tetraoxosulphate (vi) acid and heat were employed in the test. It is measured in mg/l [19].

3.0 RESULTS AND DISCUSSIONS

The values of the parameters measured at site and in the laboratory are summarized on Table 3. From Table 3 the pH value (a logarithmic measure of the concentration of hydrogen (H+)), which indicates the degree of acidity of the water samples collected ranges from 4.35 (Osisioma) to 8.50 (Alaoji). Apart from Umuagu (pH = 8.05), Alaoji (pH = 8.50) and Ariara (pH = 6.59) the pH values for other places are more acidic than the neutral (pH = 7).The acceptable pH for drinking water is between 6.5 and 8.5 [10]. It could be seen that water at Osisioma is the most acidic and the

one from Umuagu is most alkaline. The electrical conductivity of the water samples ranges from 15 μS/cm (Alaoji) to 311 μ/cm (Umuagu). Another high value of 133 μ/cm is recorded at Umuafor. The high value of electrical conductivity implies high dissolved salt in the water and the low values imply that the dissolved salts minimal. However, they are all low compared to the standard value of 250 µS/cm set by [10], which is 2500 μ/cm. This indicates that the water samples are not aggressive.

The temperature of the wells as measured at site ranges from 28.6°C (Abia Poly and Umuode) to 28.9°C (Umuagu and Alaoji). They all indicate that the water samples are all at ambient temperature, which is expected.

The turbidity (a measure of the muddiness of water due to suspended clay or silt, effluents or microbes in water) is lowest at Umuafor and Ariaria Junction (0 NTU each). The highest turbidity of 4 NTU was obtained at the Estate. The sample from Umuafor and Ariara Junction are the clearest indicating that the wells are in pure sandy-gravel aquifer. WHO [10]recommended the allowable turbidity of 1NTU. Beyond this value the disinfection of water will be ineffective.

The dissolve oxygen (DO) values range from 6.0 mg/L (Osisioma Ngwa and Ohuru Ishimiri) to 9.0 mg/L (Abia Poly). Dissolved oxygen less than 4.0mg/l is not good for aquatic life and dissolved oxygen more than 5.0mg/l is not good for steel and iron conduit [15]. When the dissolved oxygen is more than 5.0mg/l, it leads to fast corrosion of iron. In this case iron and iron alloys shall not be recommended as pipes for the water. For drinking water, dissolved oxygen should be in the range of6.5mg/l – 8.0 mg/l (equivalent of 80% - 110%). The water is contaminated and not good for drinking if DO falls below 6.5 mg/l [15].

High oxidation-reduction potential (ORP) in water is an indication of high dissolved oxygen in water and vice versa. The limiting range of ORP in water according to [16] is from -25 mV to 357mV. The measured values of ORP from all the water samples fall within this range. No values was below -25 mV and none was above 357 mV. They are positive and less than 357 mV. This indicates that the water is good for consumption.

Total dissolved solids (TDS) value of 600 mg/l is considered good for drinking water [9]]. Water becomes unpalatable for drinking when TDS is more than 1000 mg/l. The measured values of the TDS for all the soil samples are below 600mg/l. Thus, all the water samples are palatable and good for drinking. Water samples from Estate (29 mg/l)) and Alaoji (66 mg/l) are the most palatable of all the water samples as they contain less TDS.

According to Lehigh Environmental Initiative [20], Phosphates value less than 1.0 mg/L is considered excellent especially for aquatic and plant life. However, Kotoski[17]gave the limit of phosphate for water supply as 0.015 mg / L. Only the water samples from Estate (0.05 mg/L), Umuafor (0.04 mg/l), Osisioma (0.05 mg/l), Ohuru Ishimiri (0.01 mg/l) met this requirement for drinking water. The maximum allowable value of ammonia in drinking water is given by [12] as 1.5 mg/l. All the water samples collected met this requirement. Estate (0.17 mg/l), Alaoji (0.10 mg/l), Ohuru Ishimiri (0.10 mg/l) are the most suitable for drinking. According to [18] the allowable limit of Biochemical Oxygen Demand (BOD5) is 1 mg/l. The water sample obtained from Umuagu fell short of this criterion. Other water samples met the requirement.

Standard limit value of E-Coli in drinking water, according [11] and [14] is 0 MPN/100 ml. From the samples tested, only the samples obtained from Alaoji (0 MPN/100 ml), Ariara Junction (0 MPN/100 ml) met this requirement. The rest of the samples fell short of this criterion. It is advisable to treat water from these boreholes with Chlorine before drinking them.

Standard value of lead contamination in drinking water is 0.01 mg/l. This is according to both [11] and [14]. The water samples from all the boreholes tested have lead contamination less than 0.001 mg/l. This implies that all the samples met the criterion of lead contamination. Hence, drinking of water from these boreholes will not lead to lead poisoning.

The standard value of Cadmium in drinking water, according to both [11] and [14] are 0.003 mg/l and 0.005 mg/l respectively. However, the value of cadmium measure from all the water samples are less than 0.001 mg/l. The water samples cannot lead to Cadmium poisoning. According to [11] and [14], the standard values for Manganese in drinking water are 0.4 mg/l and 0.1 mg/l respectively. All the water samples tested with the exception of Umuagu (0.775 mg/l) have Manganese contamination less than 0.034. This means that water from Umuagu can lead to Manganese poisoning whereas the rest cannot lead to poisoning. These contaminations may be due to the

generated solid and liquid waste within the Aba environs.

Limiting value of copper in drinking water is 2 mg/l according to [11] and 1 mg/l according to [14]. However, the values of copper found in the water samples are all less than 0.001 mg/l. thus, the water obtained from the boreholes whose samples were tested cannot lead to copper poisoning.

The standard value of Mercury in drinking water, according to both [11] is 0.006 mg/l. However, the values of Mercury measure from all the water samples are less than 0.001 mg/l. The water samples may likely lead to Mercury poisoning if taking continuously for a very long time. Thus, there is need to treat them before consumption. Limiting value of Chromium in drinking water according to [11] is 1 mg/l and according to [14] is 0.05 mg/l. The water samples from all the boreholes tested are less than 0.001 mg/l. Thus, water from the boreholes cannot lead to Chromium poisoning. Threshold value of Magnesium allowed in drinking water according to [14]is 150mg/l. any value more than this may not be tolerable. With the exception of Estate (252 mg/l), Abia Poly (524 mg/l) and Osisioma Ngwa (427 mg/l) whose Magnesium values are more than 150 mg/l, the rest of the water samples have value that are less than the threshold value of 150 mg/l.

Analysis of variance (ANOVA) test for a statistically significant difference between the means of nineteen parameters in nine different locations was carried as shown on Table 4. The Null hypothesis is "there is no significant statistical difference between the means of the nineteen parameters measured in nine different location at 95% confidence level". The alternative hypothesis is "there is significant statistical difference between the means of the nineteen parameters measured in nine different location at 95% confidence level".

Table 3: Summary values of parameters in the water samples from the boreholes in Aba area

	Samples from various locations – 1, 2, 3, 4, 5, 6, 7, 8 and 9								
	1-Estate	**2-Umuagu**	**3-Alaoji**	**4-Ariaria Junction**	**5-Umuafor**	**6-Abia Polytechnic**	**7-Osisioma Ngwa**	**8-Ohuru Ishimiri**	**9-Umuode**
PH Value	4.72	8.05	8.5	6.59	6.25	4.5	4.35	5.46	6.25
Cond. (μS/cm)	52	311	15	28	133	87	40	90	20
Temp. (°C)	28.8	28.9	28.9	28.7	28.8	28.6	28.9	28.7	28.6
Turbidity (NTU)	4	3	2	0	0	1	5	1	1
DO (mg/l)	7.5	7.2	7.3	6.4	8.6	9	6	6	7.2
ORP (mV)	212	252	195	181	197	211	223	181	220
TDS (mg/l)	29	171	66	73	128	101	300	350	161
PO_4^{3-} (mg/l)	0.05	0.25	0.36	0.17	0.04	0.28	0.05	0.01	0.28
NH_4^+ (mg/l)	0.17	0.43	0.1	0.35	0.68	0.75	0.24	0.1	0.35
BOD_5 (mg/l)	0.12	1.17	1	0.42	0.46	0.17	0.25	0.13	0.25
COD (mg/l)	0.18	1.75	1.5	2	1.19	0.81	0.38	0.19	1.19
E-Coli (MPN/100ml)x10^2	0.7	0.8	0	0	1.3	0.2	1.6	0.8	0.2
Pb (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mn (mg/l)	0.033	0.775	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cu (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hg (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg (mg/l)	252	44	62	65	39	524	427	51	68

Table 4: Analysis of variance for mean of nineteen parameter in nine locations

	Sum of squares, SS	**Degree of freedom, df**	$\boldsymbol{Mean\ Square = \frac{SS}{df}}$	$\boldsymbol{F = \frac{MSB}{MSW}}$
Between Group, B	727599.9	19 – 1 = 18	MSB = 40422.22	13.81
Within Group, W	444880.8	9*19 – 19 = 152	MSW = 2926.847	

The sum of squares between parameters (SSB) and the sum of squares within parameters (SSW) are respectively given as Equations 1 and 2:

$$SSB = \sum n_k (\bar{Y}_k - \bar{Y})^2 \quad (1)$$

$$SSW = \sum (Y_i - \bar{Y}_k)^2 \quad (2)$$

Where; k is the number of parameters, n_k is the number of locations for a parameter, $\bar{Y}_k$ is the average value of the parameters in the nine locations, $\bar{Y}$ is the overall average of all the parameters in the nine locations and Y_i is the value of the parameter in each location.

The degree of freedom between parameters (dfb) and degree of freedom within parameters (dfw) are respectively given as Equations 3 and 4:

$$dfb = K - 1 \quad (3)$$

$$dfw = N - k \quad (4)$$

Where; N is the product of number of parameters and number of locations given as Equation 5:

$$N = k \times n_k = k.n_k \quad (5)$$

Substituting Equation 5 into Equation 4 gives the equation for degree of freedom within parameters:

$$dfw = k.n_k - k = k.(n_k - 1) \quad (6)$$

The F taken from statistic table at confidence level of 95%, dfb of 18 and dfw of 152 is 1.6697. Since the calculated F (that is 13.81) is greater than the F from the statistical table (that is 1.6696) then the Null hypothesis is rejected. Hence, there is significant statistical difference between the means of the nineteen parameters measured in nine different locations at 95% confidence level.

4.0 CONCLUSIONS

From the results obtained in this work it is obvious that the majority (up to 75%) of the water samples obtained within Aba area cannot be taken without treatment. The contain E-Coli. Thus, treating them with chlorine before drinking is ideal. This is because Chlorine is capable of eliminating the E-Coli from water. Drinking water obtained from Aba area, which is not treated with chlorine is not encouraged. Boiling the water can also be recommended since the E-Coli may not survive at a temperature above 70°C. Treating the water within Aba area with chlorine is recommended. Apart from eliminating E-Coli and improving the Oxidation Reduction Potential of the water, it is capable of precipitating Magnesium, which is dominant in majority of the water samples) out of the water. The chlorine can also precipitate Manganese out of water. Recall that value Manganese in the water sample from Umuagu (0.775 mg/l) is more than the standard value of 0.1 mg/l.

Since the values of E-Coli obtained from the ground water at Aba area are more than zero it will be concluded that faecal contamination is rampant. This is an indication that most people may be using pit latrine instead of septic tank toilet system in Aba. It is the pit latrine that is capable of transporting faecal contaminant into the ground water this is true because the distance from the base of the latrine and the ground water in Aba is small. The ground water level in Aba is shallow. The work of [2] shows that static water level in some area is as low as 4.57m. Some pit latrine can be as deep 5 to 6m. With this, it is obvious that in any area within Aba where they practice the use of pit latrine, the water from the boreholes there will be affected by faecal contaminants like E-Coli. So government should make legislation to ban and discourage the use of pit latrine within Aba area to avoid outbreak of water borne disease.

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SYNTHESIS AND CHARACTERIZATION OF ALKYD RESINS FROM RUBBER SEED/SOYBEAN OIL BLENDS

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Abstract

The polymerization and properties of environmentally friendly resin binders applicable in the surface-coating industry were studied. Rubber seed oil (RSO) and RSO blended with 10% and 20% soybean oil (SBO)-based alkyd resins were synthesized by alcoholysis-polyesterification of the oil with glycerol and phthalic anhydride. Physicochemical properties (such as colour, specific gravity, acid value, saponification value, iodine value, and drying schedule) of the alkyd resins were determined to establish the possible industrial potential of the resins. The saponification value and iodine value ranged from 250.19 mgKOH/g to 279.55 mgKOH/g and 29.58 gI_2/100g to 33.77 gI_2/100g respectively. The drying schedule and chemical resistance of the blended alkyd resins to water, salts, acids, and alkalis were also studied. The blended resins were found to be resistant to water, salt, and acid media, except for alkali media. The colour properties were enhanced as the percentage of the blend increased. FT-IR spectroscopic study of the oil and alkyd resin samples further corroborates our findings. Therefore, the potential of rubber seed oil blended with soybean oil to produce light-coloured alkyd resins could be exploited as raw materials for the Nigerian surface coating industry.

1.0 INTRODUCTION

Alkyd resins are a group of polyesters synthesized by the polycondensation reaction of triglyceride oils (or fatty acids), dibasic acids (or acid anhydrides), and polyols with hydroxyl functionality greater than two [1]. They are widely used as important binders in the coatings and paint industries. Recent estimations revealed that alkyd resin contributes approximately 70% of the conventional binders used in surface coatings today [2]. They can also be used as raw materials for the production of industrial and household finishes [3]. The versatility of alkyd resins as vehicles for coatings is largely due to their unique properties such as film hardness, durability, gloss and gloss retention, resistance to abrasion, and compatibility with other resin systems [4]. The properties of the resins depend on the drying ability of the triglyceride oil used during their manufacture.

Drying oils owe their ability to polymerize after application on materials surfaces to form tough, adherent, impervious, and abrasion resistant films to the level of unsaturation of the triglyceride oils [5]. Similarly, The fatty acid chains in the polymer backbone are known to improve the flexibility,

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adhesion, and chemical resistivity of alkyd resin [6]. Vegetable oils like soybean oil, linseed, soybean, canola, tall oil, coconut oil, and sunflower oil are conventional oils used as benchmarks for alkyd resin synthesis[7, 8]. Similarly, non-conventional vegetable oils such as rubber seed oil, jatropha seed oil, karanja oil, nahar seed oil, African locust bean seed oil, etc. are well reported as alternative non-traditional vegetable oils with properties similar to the traditional oils used as potential sources of triglyceride oil for alkyd resin synthesis [7, 9-11]. Other, non-conventional drying oils are available locally but have remained untapped and are the subject of investigation.

Alkyd resins synthesized using drying oils had superior appearance, chemical resistance, and outstanding physical properties. Several vegetable oils reported in literature used in alkyd resin production are semi-drying in nature. The properties of the resins are mainly dependent on the type of drying oil. However, several diverse and stringent end-use applications of alkyd resins, such as farter drying and improved colour have necessitated special treatment of oil to meet these requirements. Consequently, physical and chemical modifications of vegetable oils in order to enhance their quality have been carried out over the years. For instance, non-drying oils can be transformed into drying oils through modification by dehydration [12]. Similarly, monomer modification through malenisation, fumarisation, acrylation of the oils[10], and resin from oil blends [13] have all been reported.

In our previous studies [14], we reported the potential of rubber seed oil (RSO) in the production of alkyd resins suitable as binders in solvent-borne and water-reducible coatings. This paper reports the modification of RSO to enhance its use in producing bright-coloured coatings by partially blending with soybean oil. Previous studies have shown that rubber seed oil alkyd resin is darker in colour [10]. The coloured nature of the resin may not be suitable for the formulation of non-pigmented coatings where brighter colour is a necessity. Although, several reports have shown that RSO based alkyd resins are valuable raw materials in formulating dark coloured non-pigmented coatings [14]. Since soybean oil is brighter in colour (light yellow) can be used in formulating bright coloured alkyd resin. Soybean oil is an edible oil that cannot solely be used in the production of alkyd resin since higher food prices pose an immediate threat to the food security of poor net food buyers [15]. In a recent study, alkyd resin prepared from RSO blended with linseed oil (LSO) was reported [13]. The result from that study showed that alkyd resin samples[13] synthesized from RSO blended with LSO exhibited good resistance to brine, water, and acid with improved drying properties.

Similarly, studies on the properties of alkyd resins synthesized from blends of RSO and SBO [16]. Both studies showed that alkyd resins with better properties can be produced by blending other oil types with RSO. In both studies, lead oxide was used as a catalyst, and the studies focused on blending RSO with a high proportion of SBO or LSO [13, 16]. This contradicts the objective of production cost reduction, where demand for more expensive traditional oil could be reduced. Also, the alcoholysis stage in alkyd resin production is normally catalyzed by Brønsted bases such as lithium, sodium hydroxides, calcium, and lead oxides [17, 18]. Lead oxide was reported to be detrimental to the production of bright coloured resins [17]. Also, a higher percentage of SBO used as a blend will put unnecessary strain on the demand for food commodities. The implications, opportunities, and limits of crops applicable as resources for food, industrial, and technical productions and possible consequences of the global food price spike are reviewed [15, 19]. Although, there have been knowledge gaps over the years on the global capacity for sustainable plant-based polymer production while maintaining food security. Therefore, the effect of rubber seed oil blended with a small proportion of soybean oil on the physicochemical properties, drying performance, and chemical resistance of its derived resins were investigated.

2.0 MATERIALS AND METHOD

2.1 Materials

Rubber seeds were collected from the plantation of Rubber Research Institute of Nigeria, Iyanomo, Benin City and soybean seeds were obtained from Oba market, Benin-City, Nigeria. The oils were soxhlet extracted from the milled seed using *n*-hexane as the extracting solvent. Laboratory grade glycerol and analytical grade phthalic anhydride were all obtained from Aldrich Chemicals. All of the chemicals were used without further purification.

Table 1: Recipe for the Formulation of Alkyd Resins

Component (g)	I	II	III	IV
RSO	178.85	166.50	148.00	-
SBO	-	19.20	38.40	178.85
Glycerol	76.64	76.64	76.64	76.64
Phythalic anhydride	119.94	119.94	119.94	119.94

2.2 Methods

2.2.1 Physicochemical properties of rubber seed oil and soybean oil

The physicochemical properties properties, like specific gravity (Ta 1b-64), acid value (Cd 3a- 63), saponification value (Cd 3–25) and iodine value (Cd 1–25) of rubber seed oil (RSO) and soybean oil (SBO) were determined by American Oil Chemists' Society (AOCS) methods [20].

Alkyd resin preparation

Four samples of alkyd (I–IV) comprising of (I- 100% RSO, II: 90% RSO + 10SBO, III: 80% RSO + 20% SBO, IV: 100% SBO) were prepared with RSO, SBO and RSO blend with SBO, glycerol and phthalic anhydride according to the formulation in Table 1. All the alkyds were formulated to an alkyd constant of about 1.0. Two different samples of RSO blends were prepared by thoroughly mixing RSO with (A) 10% and (B) 20% SBO (w/w).

The reactions were carried out in a 1-L three-necked-round-bottom flask. The flask was fitted with a mechanical stirrer and a Dean–Stark apparatus carrying a water-cooled condenser. Nitrogen gas was bubbling through the reaction medium to create an inert atmosphere. Xylene (10% w/w) was employed as the cooking solvent. In a typical reaction, RSO, a catalyst (calcium oxide) and glycerol were heated with continuous stirring. The reaction temperature was raised and maintained at 230 ^{0}C for about 2.5 h under nitrogen. The reaction was stopped when the sample of the alcoholysis product formed a clear solution in anhydrous methanol (1:3 w/v oil:methanol). The reaction was allowed to cool to about 120°C, phthalic anhydride was added, and the temperature was quickly raised to 250 ^{0}C for the polycondensation reaction. The efflux was drained into the Dean–Stark apparatus, in which xylene was separated from the water of condensation and returned to the reaction flask through an overflow point. The progress of the reaction was monitored by the determination of the acid values of aliquots of the reaction mixture until an acid value below 10mg KOH/g was achieved [14].

Preparation of alkyd coatings

The RSO, SBO and blended alkyd samples were thinned to 50% with xylene in which cobalt and calcium drier (0.5% weigh of alkyd) were added and applied on thin glass panels at room temperature. The drying schedule of the samples in terms of time of set-to-touch and dry through was determined. The films were considered dry through when there is no loosening, detachment, wrinkling, or distortion of the film [10].

Chemical Resistance of the Alkyd Resins

The chemical resistances of the dried films were determined using the dried film on the test panel prepared above. The test panels were assessed for their resistance to different service media by immersion method for a period of 24 hours. The service media used were distilled water, 5% (w/v) sodium chloride solution, 0.1M KOH and 0.1M H_2SO_4 solutions [10] (ASTM D1308-57).

FTIR spectroscopy

Infrared spectra of the RSO, SBO and its derivates were recorded with SHIMADZU, FTIR-8400S spectrophotometer. The samples were spread over NaCl cells, and their spectra were recorded. IR spectra were recorded in the range 4000–400 cm^{-1}.

3.0 RESULTS AND DISCUSSION

3.1 Physiochemical Properties of the Oils

The physicochemical properties of the oils (RSO and SBO) are listed in Table 2. The percentage oil yield of RSO is higher than SBO. The colour of RSO was yellow compared with that of the light-yellow obtained SBO. The value of the specific gravity of RSO is 0.908, which is comparable to the value of 0.901 observed for SBO. The acid value indicates the level of free fatty acids formed from hydrolytic decomposition of glycerides to free fatty acids [21]. High levels of free fatty acids are usually caused by age, storage conditions, and an increase in the extraction temperature of oils. The high content of free fatty acids in oils has been attributed to a reduction in oil quality [21, 22]. The acid value of 48.28, obtained for RSO, was higher than 0.44 obtained for SBO in this study. These values translate into 23.68 and 0.20 free fatty acid of RSO and SBO respectively. The acid values obtained in this study show that both RSO and SBO are good starting materials for the production of oil paints and varnishes.

Table 2: Physico-Chemical Properties of the Oil

Properties	RSO	SBO
Yield (%)	41.30	15.82
Colour	Yellow	Light Yellow
Specific Gravity [30^{0}C]	0.908	0.901
Acid Value [mg KOH/g]	48.28	0.44
Saponification Value [mg KOH/g]	185.30	202.20
Iodine Value [gI_2/100g]	122.45	127.56

Table 3: The Main FT-IR Peaks and their corresponding functional group of RSO and SBO

Frequency (cm^{-1})		Assignment	Remark
RSO	SBO		
3010	3009	C-H	Stretching frequency of non-conjugated unsaturation
2854	2854	C-H	Stretching frequency of alkane
1747	1745	C=O	Stretching frequency of carbonyl group
1653	1654	C=C	Stretching frequency of alkene

1464	1464	-C-H	bending frequency of unsaturated alkene
1240	1230	-C-O	Stretching bending
1165	1161	C-O	Stretching frequency of esters
1099	1099	-C-O	Stretching frequency of ester
723	723	$-(C-C)_n-$	bending frequency of saturated carbon atom

Similarly, the iodine values for the oils were 122.45 and 127.56 $gI_2/100g$ for RSO and SBO, respectively. The iodine value recorded in this study was also indicative of the high unsaturated fatty acid content of both oils. The iodine value is a measure of the unsaturation of triglyceride oil [23] and is useful for predicting the drying properties of oils. The iodine value of the RSO obtained in this study was slightly lower than that recorded for SBO. The iodine values of both RSO and SBO reported in this study fall within the range of semi-drying oil, which is a potential raw material in the paint, resin, polyol, and lubricating oil industries [12]. This observation is further corroborated by the FTIR study of both RSO and SBO, which supports the presence of unsaturated acyl groups in the oils presented in Figure 1. The results in Table 3 show that the functional groups present in RSO are similar to those in other vegetable oils [24].

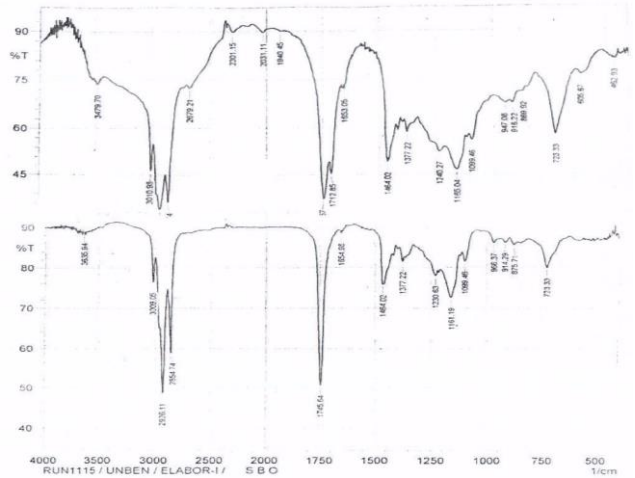

Figure 1: IR spectra of RSO and SBO

The characteristic absorption frequency observed between 3010 and 3009 cm^{-1} of the oils showed C-H stretching vibration of the olefinic functional group, and the stretching frequency of alkene C=C was observed at approximately 1654 cm^{-1} [24]. The level of unsaturation as well as the iodine value of vegetable oil have been determined using the ratios of intensities of the observed (νC=C) bands at 1650 cm^{-1} and δCH2 at 1464 cm^{-1}, as well as ν=C-H at 3010 cm^{-1} and 2853 cm^{-1}, which are well reported in the literature [25, 26]. Soybean oil is a commercial vegetable oil used as an industrial standard for alkyd resin production, where a moderate drying rate and good colour retention are desired [27]. The physicochemical characteristics of RSO and SBO obtained in this study are similar and comparable to those of the seed oils currently used in the commercial production of alkyd resins.

3.2 Properties of Alkyd Resins

The acid values, reaction time and water evolved for the finished alkyds were monitored until the values fell below 10 mgKOH/g to ensure complete reaction with corresponding higher degree of polymerization, as presented in Table 4. Alkyd resins with acid numbers less than 10 mg KOH/g are suitable for paints, as reported in the literature [10, 14]. The acid values of the prepared resins ranged from 3.4 to 4.8 mgKOH/g. The reaction time decreased with increasing SBO content. However, the reverse is true for the acid value, except for the neat RSO alkyd. The esterification reaction time ranged from 4 h 50 min to 5 h 15 min. It appears that the time required for the complete reaction of the SBO-based alkyds was lower than that of the RSO-based alkyd. The average volume of water evolved during the polyesterification reaction was approximately 14.4 ml (Table 4). The variation in the volume of water evolved during the polyesterification reaction was attributed to the variation in the agitation rate of the reaction mixture and the contribution of glycerol and xylene [28]. The volumes of water released during esterification are generally lower than the calculated 22.0 ml of water evolved during the polycondensation reaction of these resins. This observation is attributed to the difficulty of the polycondensation reaction hardly gets to completion before termination of the reaction [28].

Table 4: Parameters of the alkyds

Samples	Sample Code	Reaction Time (Hour)	Acid Value (mgKOH/g)	Water Evolve (ml)
RSO	PI	5hr 15mins	4.10	15.0
90%RSO+10%SBO	PII	5hr 10mins	3.40	13.5
80%RSO+20%SBO	PIII	5hr 10mins	4.85	12.0
SBO	PIV	4hr 50mins	4.74	17.0

Table 5: The main FT-IR Peaks and their corresponding functional group alkyd resins

Frequency (cm^{-1})				Assignment	Remark
PI	PII	PIII	PIV		
3497	2431	3497	2431	O-H	Stretching frequency hydroxyl group
3009	3009	3009	3009	=C-H	Stretching frequency of unsaturation
2854	2854	2854	2854	-C-H	Stretching frequency of alkane
1732	1732	1732	1732	C=O	Stretching frequency of carbonyl group
1599	1600	1599	1600	C=C	Stretching frequency of alkene
1284	1284	1284	1284	C-O	Stretching frequency of ester
856	866	856	866	C-H	Stretching frequency of alkane

3.3 Structural Analysis of Alkyd Resins

The IR spectra of the RSO alkyd compared with those of the blends and neat SBO alkyd are presented in Figure 2. The major functional groups are listed in Table 5. The IR spectra of the resins were identical and similar in all aspects. Consequently, the spectra support the presence of ester, aromatic, and hydroxyl groups and olefinic double bonds in the alkyd resins. The IR spectra of the alkyd resins (Figure 2) show a strong band at 1732 cm^{-1} characteristic of the stretching frequency of the carbonyl group. A sharp absorption band (doublet) appearing around 1599 and 1578 cm^{-1} are characteristic of the unsaturation of the aromatic group on the alkyd resin backbone. The broad band between 3431 and 3510 cm^{-1} present in all the alkyd resins confirms the presence of OH groups and has been shown to be characteristic of alkyd resins [1, 17]. This hydroxyl band is completely absent in both RSO and SBO, which are used as starting materials in the synthesis of resins. A strong absorption due to the asymmetrical C-O-C stretching band at 1284 cm^{-1} and a symmetrical band at 1072cm^{-1}, attributed to the stretching of the ether group, were also observed [1, 29]. Similarly, out-of-plane aromatic C-H bends around 773 and a ring C-C band at 705 were observed [29]. The additional bands within this region are due to ring-bending vibrations [29].

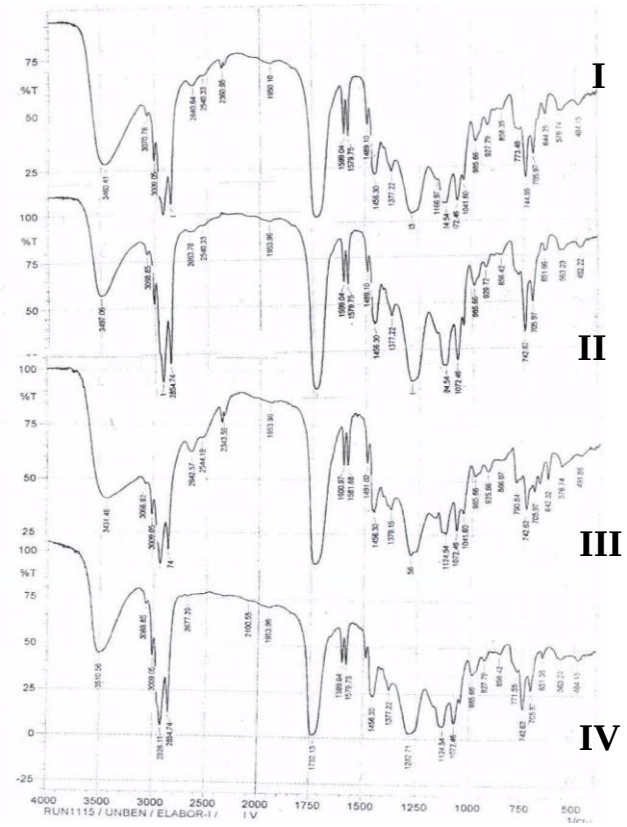

Figure 2: IR spectra of RSO alkyd (sample I), RSO alkyd blends (samples II and III) and SBO alkyd (sample IV).

3.4 Physiochemical Properties of Alkyds

The physicochemical properties of these alkyds are listed in Table 6. The pure RSO alkyd resin was darker than the alkyd resins prepared from RSO blended with SBO. The colour of the SBO alkyd resin was brighter than that of the corresponding RSO alkyd resin and its blends, indicating that blending RSO with SBO enhanced the colour properties of the alkyd samples. The saponification values of the samples of RSO alkyd increased with the SBO content and were lower than the saponification value of the pure SBO alkyd resin. In addition, the saponification values of the PI and PIV resins were higher than those of the corresponding starting oils. The alkyd resin PIV exhibited the highest saponification value (279 mgKOH/g). The saponification value of the alkyd resins increased marginally with an increase in the blend content. Similarly, the iodine values of samples PI to PIII increased with the SBO content and were higher than that of the pure SBO alkyd resin. The iodine values of the alkyds were lower than those of the oils, with values of 29.58 gI_2/100g PI, 31.58 gI_2/100g for PII, 33.77gI_2/100g for PIII and 30.21gI_2/100g for PIV respectively.

The drying properties of the alkyd films were measured in terms of set-to-touch, dry-to-touch, and dry-through. The application of resins as binders is due to their ability to dry, where a thin layer of alkyd resin film dries faster upon exposure to air [30]. Therefore, thin films of the alkyd samples were air-dried in this study. The drying properties (i.e., set to touch and dry to touch) increased as the SBO content in the resin increased (Table 6). Therefore, the RSO alkyd resin exhibited the lowest drying ability. The drying time of the synthesized resins was enhanced when blended with soybean oil compared to the neat RSO alkyd resin. The fast-air-drying ability observed in this study can be attributed to the mechanisms of drying, which are mainly through evaporation of the solvent and oxidative polymerization by the crosslinking of double bonds bond [1, 30]. This observation was supported by the iodine values of the alkyd resin samples used in the coating.

Table 6: Physico-Chemical Properties of the alkyds

Properties	**PI**	**PII**	**PIII**	**PIV**
Colour	Dark Brown	Brown	Brown	Light brown
Acid value (mgKOH/g)	4.10	3.40	4.85	4.74
Saponification value (mg/KOH/g)	250.19	252.68	261.51	279.55
Iodine value(gI_2/100g)	29.58	31.58	33.77	30.21
Drying property				
Set to touch (min)	21	17	13	10
Dry to touch (min)	65	60	56	45
Dry through	Overnight	Overnight	Overnight	Overnight

PI: Pure RSO alkyds, PII: 90% RSO + 10% SBO alkyd (blend), PIII: 80% RSO + 20% SBO alkyd (blend), PIV: Pure SBO alkyd.

3.5 Chemical Resistance of the Alkyd Resins

The performance characteristics of the alkyd resins in different service media are presented in Table 7. The results showed that none of the alkyd resins were affected by acid and salt solutions. Similar results were obtained in water, except for the neat SBO alkyd (PIV), where a slight whitish colouration that disappeared upon drying was observed. All the alkyd films presented in Table 7 showed poor resistance to alkali, which can be attributed to the hydrolyzable ester groups in the alkyd film backbone. It can be deduced that alkyd resin samples have potential applications in which resistance to alkali is not the main requirement [10]. RSO seed oil alkyds and their blends (Table 7) exhibit excellent resistance to water, acid, and salts and have potential for applications in which resistance to water, acid, and salts is necessary. RSO alkyd resins and their blends can be used for corrosion protection and to prolong the lifespan of marine vessels, offshore structures, and general household coatings and paintings.

Table 7: Chemical resistance of the alkyd film to different media

Media	PI	PII	PIII	PIV
Water	1	1	1	2
NaCl (5%)	1	1	1	1
0.1M H_2SO_4	1	1	1	2
0.1M KOH	4	4	4	4

1: No visible change; 2: Slight whitening which disappear on drying; 3: Wrinkled; 4: Film removed.

4.0 CONCLUSION

The results of this study showed that RSO blended with 10% and 20% SBO enhanced the physicochemical properties and performance characteristics of the finished alkyd resins derived therefrom. These resins are good precursors for surface-coating formulations used in paints, varnishes, and coatings. Future studies should use other non-conventional seed oils, such as jatropha seed oil and African locust bean seed oil, which have similar properties to soybean oil as a blend. This deliberate effort in the long run could expand demand and increase prices for non-conventional seed oil, which may present better opportunities for agricultural and rural development.

5.0 ACKNOWLEDGEMENT

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6.0 CONFLICT OF INTEREST

The authors declare that they have no conflict to interests.

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DEVELOPMENT OF A MULTIGENERATION SYSTEM WITH INTEGRATED HYDROGEN PRODUCTION: A TYPICAL ANALYSIS

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Abstract

Rise in demand for energy and emission from fossil fuels has become a thing of concern to researchers and Engineers. It is one thing to provide the energy needed by the society, and another to produce a clean and eco-friendly power supply. In this study, a thermodynamic and economic modelling of a solar-driven multigeneration power plant (MGPP) integrated with a PEM Electrolyzer for hydrogen production is examined. The performance indicators considered include energy and exergy efficiencies, net work, energetic and exergetic COP, cooling rate. Results of the thermodynamic analysis show that the energy and exergy efficiencies excluding the fuel cell was 28.57% and 34.79% respectively; when the fuel cell was incorporated, the energy and exergy efficiencies were respectively 24.45% and 34.63%. The energetic and exegetic COP was 0.609 and 0.281 respectively. Additionally, net work, cooling rate, and hydrogen production were respectively 52.75kW, 86.83kW, and 0.0114kg/s. The economic analysis indicates a unit cost of electricity (UCOE) at $0.025/kWh, a life cycle cost of $0.1097 and a payback period of 4years was achieved. The developed multigeneration system is technically and economically viable with net zero CO_2 emissions. It can also serve as an alternative option to fossil-powered plants and sectors with less energy demand.

1.0 INTRODUCTION

One of the indicators of industrialization and economic progress, and sustainable development is energy accessibility. Following the global projection to about seven billion, energy demand is expected to increase [1]. The increasing energy demand as well as the declining fossil fuels energy resources have triggered researchers to evolving other proficient energy transformation systems called multigeneration systems (MGS) and likewise finding substitutes to conventional fossil-fuels. Apart from monitoring the environmental complications and cost, MGS have an extraordinary capacity to improve environmental sustainability and augment efficiency [2]. Several academics have offered the application of MGS for power generation. For example, [3] evaluated the thermodynamic performance of an integrated solar-biomass hybrid system for heating and power-cooling production. The work shows a high prospective for the solar-biomass MGS. The thermal efficiency and the economic valuation of a natural-gas-fired plant for mutual energy production was examined by [4]. The study showed an enhancement in energy efficiency calculated at 82% with a decrease in CO_2 emissions of nearly 51.5%. Also, a solar-geothermal multigenera-

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tion system and solar-driven tri-generation plants were proposed by [5]. In the proposed plant, the geothermal-solar plant was nominated for power generation, hot water production, space heating, cooling and heat. In contrast, the solar-driven trigeneration plant was for electricity power generation and space heating. The dual thermal plants reached an exergy efficiency not greater than 36.6% and 24. 66%, respectively.

Furthermore, hydrogen production in recent times has been one of the products in several MGS. Hydrogen (H_2) is considered a future fuel to the global economy because of its eco-friendly capacity and cheap production method. For instance, several methods, which include steam methane reforming, splitting water via photocatalyst, biomass conversion process, Electrolyzer and thermochemical cycles, have been applied to produce H_2 [6]. Other studies on MGSs, which comprise hydrogen production, are establish in the study of [7]. Their system achieved 43% and 65% for energy and exergy efficiencies respectively. The maximum generated power was calculated at 48kW. Also, the cooling capacity was sustained at 28kW, heating 298.5kW and overall CO_2 savings were estimated at 1614 tons of CO_2/year. The present study, thus, is to provide a comprehensive review of current research boundaries and developed a multigeneration plant for power, cooling, heating and hydrogen production with an extended fuel-cell at the bottoming cycle for domestic energy resource. The developed MGS is solar-driven using the localized solar irradiance, followed by thermodynamic and economic evaluation.

From the reviewed literature, conventional power generating turbines can achieve efficiencies up to 60 and 70% for plant capacity of about 100kW**.** Also, the reviewed studies show that multigeneration power cycles and hydrogen production are promising technology to tackle environmental complexities. Nevertheless, adequate experimental studies are needed to authenticate the investigative assumptions. Thus, different cycle's performance must be compared based on reliable definitions of performance indices**.** Secondly, a number of the studies reviewed, show that waste heat recovered emanates from a topping gas turbine plant, engine-based or solar thermal plant have been employed to produce heat, supplementary power, cooling and hydrogen production in the bottoming cycles. The components configurations are critical for satisfactory utilization of the energy source, economics and environmental sustainability. In this study, the system's components are reduced and an additionally fuel cell unit is integrated to sustain power supply due to uncertainties that may exist from solar irradiance fluctuation. Thirdly, studies regarding the solar potential for Calabar in this respect is not common in open literature. Specific data is generated for long term energy projection aid and some policies for deep decarbonization pathways and as a contribution to Nigeria's energy plan.

2.0 METHODOLOGY

2.1 Materials

Daily data on the solar irradiance in Calabar for a period of ten years was obtained from Nigeria Meteorological Centre, Calabar. The average data is used as a basis for choosing simulation data for the proposed MGS and the sub-system of the plant. Additionally, the system modelling was done using Engineering Equation Solver (EES), while secondary data is obtained from open literature and scientific documents made public. Other simulation parameters that may be required based on assumptions include: solar beam irradiation, collector aperture area, volumetric flow rate on the parabolic trough solar collector, receiver inner diameter, receiver outside diameter, working fluid selection, isentropic efficiency of turbine, and isentropic efficiency of pump.

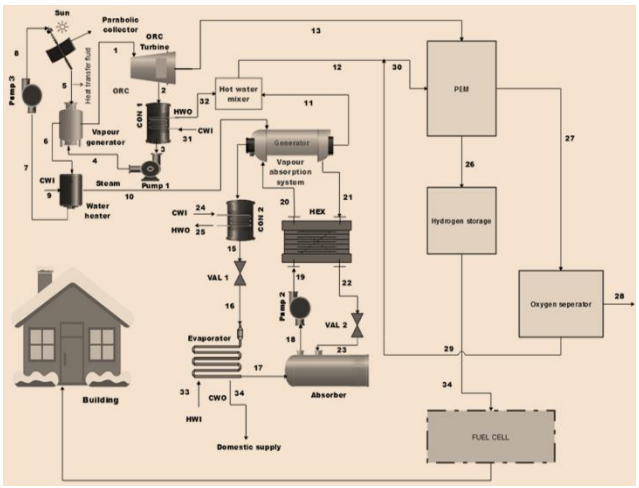

Figure 1: Proposed solar-driven ORC and vapour absorption integrated system

2.2 System Description

The proposed solar-driven combined system is shown in Figure 1. It system encompasses four subsystems which combine to offer the four products namely; cooling, heating, power and hydrogen production. The topping unit is a solar unit, which powers an ORC. Heat from the sun is absorbed by the parabolic collector. The fluid at high temperature flows to the vapour generator (VG) causing the refrigerant (R245fa) in the VG to boil and expand. The expanded fluid enters the ORC turbine at state 1, producing shaft

work and electricity at state 13. Furthermore, the fluid enters the condenser at state 2 and exit at state 3 as saturated liquid. The liquid is pumped to the VG at state 4 to repeat the ORC cycle. Similarly, part of the heat from the VG is used to produce steam at state 10 while the hot fluid returns to the receiver to be reheated. The steam produced is used to power the generator in the VAS (vapour absorption system) to produced refrigerating effect in the evaporator at state 16. The exiting steam from the generator at state 11 and the hot water from condenser 1 at state 32 enters the hot water mixer to produce a single-phase condition. The exiting hot water at state 12 mixed with the hot water from the Oxygen separator entering as hot water to the PEM at state 30 to enhance the hydrogen production. The hydrogen produced is further used to power a fuel cell for continuous electricity production. The bottoming subsystem which is the absorption cooling and heating system is used to provide both cooling and heating loads. The heat input to the absorption system is provided by the steam generated from the water heater at state 10.

2.3 Thermodynamic Modelling

The mass and energy balance of the system is based on the steady state process and conservation of mass as assumed for this analysis. The steady state energy and conservation equations are presented as in [8].

$$\sum_i m_i = \sum_j m_j \quad (1)$$

$$\sum \dot{Q} - \sum \dot{W} = \sum m_j h_j - \sum m_i h_i \quad (2)$$

The energy balancing of the component system for the integrated system is based on Equations (1) and (2). The analysis of the parabolic solar collector (PSC) is presented based on [9].

2.4 Energy of the Parabolic Collector

The useful energy, which is the amount of energy gained by the solar collector can be evaluated from:

$$\dot{Q}_{u=\mathrm{F_R}}\mathrm{R}[S_{col} \times A_a - A_r U_L(T_{in} - T_{amb})] \quad (3)$$

The rate of solar energy delivered from the concentrated solar collector is obtained as:

$$Q_{sol} = A_a S_{col}(Col_r) \quad (4)$$

Where: A_a, S_{col}, A_r, Col_r, F_R, and U_L connotes the aperture area (m^2), Solar Absorptivity (W/m^2), area of receiver (m^2), number of collectors in rows, heat removal factor, and overall heat loss coefficient respectively.

2.5 Exergy Modelling of the Component System

Following the general exergy balance expression:

$$\sum e_{ij} = \sum e_{x,out} + e_D \quad (5)$$

Where; $e_x = \Delta h - T_0$ (6)

The exergy balance efficiencies of components of the system is presented in Table 1.

2.6 Performance Indicators

The following indicators have been considered in order to examine the thermodynamic performance of the proposed MGS.

2.6.1 Thermal efficiency

The Thermal efficiency (energy efficiency) of the proposed MGS without fuel cell η_{th_1} is adopted from that presented by [10] and is given as;

$$\eta_{th} = \frac{\dot{W}_{net} + m_{32}h_{32} - m_{31}h_{31} + \dot{m}_{H_2} \times LHV_{H_2} + Q_{Eva} + \dot{Q}_{WH} + \dot{W}_{PEM}}{Q_{PTSC}} \quad (7)$$

Where $\dot{W}_{net}, \dot{Q}_{WH}, \dot{m}_{H_2}, LHV_{H_2}, Q_{Eva}, Q_{PTSC}$ is the network produced by the ORC sub system, heat generated by water heater, mass flow rate, Lower heating value of hydrogen, refrigerating effect and overall heat input to the system respectively.

The overall energy efficiency of the proposed MGS with fuel cell (η_{th_2}) is given as;

$$\eta_{th_{F,C}} = \frac{\dot{W}_{net} + m_{32}h_{32} - m_{31}h_{31} + \dot{Q}_{WH} + W_{fuelcell} + Q_{Eva} + \dot{W}_{PEM}}{Q_{PTSC}} \quad (8)$$

where; $W_{fuelcell}$ = work done by fuel cell

2.6.2 Exergy efficiency

The exergy efficiency of the system without fuel cell is given as;

$$\eta_{ex} = \frac{\dot{W}_{net} + \dot{E}_{H_2} + \dot{E}_{Eva} + \dot{m}_{32}h_{32} - \dot{m}_{31}h_{31} + Ex_{H_2} + Ex_{WH} + W_{PEM}}{\dot{E}x_{PTSC}} \quad (9)$$

The exergy efficiency of the system including the fuel cell is given as;

$$\eta_{ex_{F,C}} = \frac{\dot{W}_{net} + \dot{E}_{H_2} + \dot{E}_{Eva} + \dot{m}_{32}h_{32} - \dot{m}_{31}h_{31} + Ex_{H_2} + Ex_{WH} + W_{PEM}}{\dot{E}x_{PTSC}} \quad (10)$$

Table 1: Exergy balances and Efficiencies of component of the proposed MGPP

Component	Exergy balance	Exergy of fuel	Exergy of prod.	Exergy efficiency
PTSC	$\dot{E}x_8 = \dot{E}x_5 + E_{solar}$	$\dot{E}x_8 - \dot{E}_5$	$\dot{E}_{solar}$	$\frac{\dot{E}x_8 - \dot{E}_5}{\dot{E}_{solar}}$
ORC turbine	$\dot{E}x_1 = \dot{E}x_2 + \dot{W}_{ORCTURB} + E_{DTURB}$	$\dot{E}x_1 - \dot{E}_2$	$\dot{W}_{ORCTURB}$	$\frac{\dot{W}_{ORCTURB}}{\dot{E}x_1 - \dot{E}_2}$

ORC condenser	$\dot{E}x_2 + \dot{E}x_{31} = \dot{E}x_3 + \dot{E}x_{32} + E_{D,CON1}$	$\dot{E}x_2 - \dot{E}x_3$	$\dot{E}x_{32} - \dot{E}x_{31}$	$\frac{(\dot{E}x_{32} - \dot{E}x_{31})}{(\dot{E}x_2 - \dot{E}x_3)}$
ORC vapour generator	$\dot{E}x_4 + \dot{E}x_5 = \dot{E}x_1 + \dot{E}x_6 + E_{DVG}$	$\dot{E}x_5 - \dot{E}x_6$	$\dot{E}x_1 - \dot{E}x_4$	$\frac{(\dot{E}x_1 - \dot{E}x_4)}{(\dot{E}x_5 - \dot{E}x_6)}$
ORC Pump 1	$\dot{E}x_3 + \dot{W}_{ORCPUMP} = \dot{E}x_4 + E_{D,ORCPUMP}$	$\dot{W}_{ORCPUMP}$	$\dot{E}x_4 - \dot{E}x_3$	$\frac{\dot{E}x_4 - \dot{E}x_3}{\dot{W}_{ORCPUMP}}$
VAS generator	$\dot{E}x_{10} + \dot{E}x_{20} = \dot{E}x_{11} + \dot{E}x_{14} + \dot{E}x_{21} + E_{D,GEN}$	$\dot{E}x_{10} - \dot{E}x_{11} + \dot{E}x_{20}$	$\dot{E}x_{14} + \dot{E}x_{21}$	$\frac{\dot{E}x_{14} + \dot{E}x_{21}}{\dot{E}x_{10} - \dot{E}x_{11} + \dot{E}x_{20}}$
VAS condenser 2	$\dot{E}x_{14} + \dot{E}x_{24} = \dot{E}x_{15} + \dot{E}x_{25} + E_{D,CON2}$	$\dot{E}x_{14} - \dot{E}x_{15}$	$\dot{E}x_{25} - \dot{E}x_{24}$	$\frac{(\dot{E}x_{25} - \dot{E}x_{24})}{(\dot{E}x_{14} - \dot{E}x_{15})}$
VAS Pump 2	$\dot{E}x_{18} + \dot{W}_{VASPUMP} = \dot{E}x_{19} + E_{D,VASP}$	$\dot{W}_{VASPUMP}$	$\dot{E}x_{19} - \dot{E}x_{18}$	$\frac{\dot{E}x_{19} - \dot{E}x_{18}}{\dot{W}_{VASPUMP}}$
Pump 3	$\dot{E}x_7 + \dot{w}_{RCPump} = \dot{E}x_8 + E_{D,RCP}$	$\dot{w}_{RCPump}$	$\dot{E}x_8 - \dot{E}x_7$	$\frac{\dot{E}x_8 - \dot{E}x_7}{\dot{w}_{RCPump}}$
Water heater (WHT)	$\dot{E}x_6 + \dot{E}x_9 = \dot{E}x_7 + \dot{E}x_{10} + E_{D,WHT}$	$\dot{E}x_6 - \dot{E}x_7$	$\dot{E}x_{10} - \dot{E}x_9$	$\frac{(\dot{E}x_{10} - \dot{E}x_9)}{(\dot{E}x_6 - \dot{E}x_7)}$
VAS Heat exchanger	$\dot{E}x_{19} + \dot{E}x_{21} = \dot{E}x_{20} + \dot{E}x_{22} + E_{D,HEX}$	$\dot{E}x_{19} - \dot{E}x_{20}$	$\dot{E}x_{22} + \dot{E}x_{21}$	$\frac{\dot{E}x_{22} + \dot{E}x_{21}}{\dot{E}x_{19} - \dot{E}x_{20}}$
Valve 1(Val 1)	$\dot{E}x_{15} + \dot{W}_{Val\,1} = \dot{E}x_{16} + E_{D,Val\,1}$	$\dot{W}_{Val\,1}$	$\dot{E}x_{16} - \dot{E}x_{15}$	$\frac{\dot{E}x_{16} - \dot{E}x_{15}}{\dot{W}_{Val\,1}}$
Valve 2(Val 2)	$\dot{E}x_{22} + \dot{W}_{Val\,2} = \dot{E}x_{23} + E_{D,Val\,2}$	$\dot{W}_{Val\,2}$	$\dot{E}x_{23} - \dot{E}x_{22}$	$\frac{\dot{E}x_{23} - \dot{E}x_{22}}{\dot{W}_{Val\,2}}$
Absorber	$\dot{E}x_{17} + \dot{E}x_{23} + \dot{E}x_{35} = \dot{E}x_{18} + \dot{E}x_{36} + E_{D,Abs}$	$\dot{E}x_{17} + \dot{E}x_{23}$	$\dot{E}x_{18} + \dot{E}x_{36} - \dot{E}x_{35}$	$\frac{\dot{E}x_{17} + \dot{E}x_{23}}{\dot{E}x_{18} + \dot{E}x_{36} - \dot{E}x_{35}}$
Evaporator	$\dot{E}x_{16} + \dot{E}x_{33} = \dot{E}x_{17} + \dot{E}x_{34} + E_{D,Evap}$	$\dot{E}x_{16} - \dot{E}x_{17}$	$\dot{E}x_{33} + \dot{E}x_{34}$	$\frac{\dot{E}x_{33} + \dot{E}x_{34}}{\dot{E}x_{16} - \dot{E}x_{17}}$

2.7 PEM Energy Modelling

The duty of the PEM Electrolyzer in this MGPP is hydrogen production. As shown in Figure 1, electricity and heat are supplied to the Electrolyzer to perform the electrochemical reactions needed. A chemical reaction takes place and hydrogen is separated from water. The remaining water is returned back to the water supply stream for the next hydrogen production cycle.

The total energy demand for PEM electrolysis is obtained from the relationship in [11];

$$\Delta H = \Delta G + T\Delta S \quad (11)$$

Where $T\Delta S$ is the thermal energy demand (J/mol H_2), and ΔG is the electrical energy demand which refers to the change in Gibb's free energy (J/mol. H_2), with values obtained for hydrogen, oxygen and water in [11].

The outlet flow rate of hydrogen is expressed as follows [11];

$$\dot{N}_{H_2} = {}^{J}/_{2F} = \dot{N}_{H_2O,reacted} \quad (12)$$

Where J is the current density and F is Faraday's constant. $\dot{N}_{H_2O\,reacted}$ refer to the reacted water during the electrolysis process.

The rate of water and oxygen at the PEM Electrolyzer outlet are calculated as [12]:

$$\dot{N}_{O_2,out} = {}^{J}/_{4F} \quad (13)$$

$$\dot{N}_{H_2O,out} = \dot{N}_{H_2O,in} - {}^{J}/_{2F} \quad (14)$$

2.8 Economic Analysis

The feasibility of developing and implementing any power plant depends on the economic importance. In this study the feasibility of implementing the proposed multigeneration power plant is evaluated by calculating the total cost rate of the proposed MGPP, using the model equations developed by [13]; [14]; [15] and [16].

Table 2: Equipment Capital Cost

Component	Cost function ($)
PTSC	4500
ORC Turbine	$4750(\dot{W}_{ORCTURB})^{0.85}$
ORC Condenser	$516.6(A_{ORCCOND})^{0.6}$
ORC Pump	$200(W_{ORCPump})^{0.65}$
ORC Vapour Generator	$309.14(A_{ORCVG})^{0.85}$
Water Heater	$0.3m_9$
PEM Electrolyzer	$1000\dot{W}_{PEM}$
VAS Vapour Generator	$130\left(\frac{A_{VASVG}}{0.093}\right)^{0.78}$
VAS Condenser	$1773\dot{m}_{ref}$
VAS Evaporator	$130(\frac{A_{VASEVA}}{0.093})^{0.78}$
VAS Absorber	$130\left(\frac{A_{VASABS}}{0.093}\right)^{0.78}$
VAS Pump	$400\left(\frac{\dot{W}_{VASpump}}{100}\right)^{0.26}$
VAS Solution heat exchanger	$(\frac{A_{VASHEX}}{A_R})^{0.6}$
VAS Throttle valves	$37(\frac{P_{in}}{P_{out}})^{0.68}$

$A_{R=100m^2}$ source: [17]; [18]; [19]

2.8.1 Equipment cost

The purchased equipment cost (PEC) of the system's component is summarized in Table 2. The total cost of the equipment C_{tot} is determined by adding the annual capital cost (ANCC) and the total annual operation cost (ANOC).

C_{tot} = ANCC + ANOC (15)

ANCC = $TIC \times CRF$

$$CRF = \frac{IR\times(1+IR)^n}{(1+IR)^n-1} \quad (16)$$

Where IR, n is interest rate and is set at 0.9% , and life span of the plant and is set at 25years [17].

2.8.2 Operation and maintenance cost

The annual operating cost (ANOC) of the system is gotten by summing up all the operation cost equation (17).

$$ANOC = C_{Labour} + C_{ins,M} + C_{elect} \quad (17)$$

Where, $C_{Labour}, C_{ins,M}, C_{elect}$ = cost of labour, insurance and maintenance cost, and cost of electrical work respectively.

The unit cost of electricity, UCOE($/kWh) is calculated as;

$$UCOE = [C_{tot} + C_{PTSC}] \times \frac{CRF\times\emptyset}{N\times8760} \quad (18)$$

3.0 RESULT AND DISCUSSION

In this study, thermodynamic and economic assessment of a solar power multigeneration system for production of hydrogen, electricity, heating, and cooling was investigated based on energy and exergy analyses. The Engineering Equation Solver (EES) was used to write the codes for modeling the system with respect to balance equations and performance indicators. Parameters of the thermodynamic state points are depicted in Table 3. From the result obtained, the plant equipment cost is low ($0.1945) with a unit cost of electricity at $0.025/kWh.as compared to the current Nigeria electricity tariff which is $0.10/kWh. The hydrogen produced is not used to generate electricity, but is used as an alternative power supply when needed due to some uncertainties in solar irradiation. So, the overall energy and exergy efficiencies of the system excluding the work of the fuel cell are 28.57% and 34.63% respectively. When the fuel cell is incorporated, the energy and exergy efficiencies are respectively 24.45% and 34.63%.

3.1 Variation in Thermodynamic Properties

3.1.1 Effect of turbine inlet pressure on energy and exergy efficiencies

Figure 2(a) shows variation in turbine inlet pressure. It is observed that by increasing the turbine inlet pressure from 500kpa to 800kpa, the overall energy efficiency of the MGPP without fuel cell decreases slightly from 28.29% to 28.16% This is because an increase in pressure ratio requires high compression work and high mechanical irreversibility, thereby causing a reduction in energy efficiency. Similarly, when the fuel cell is incorporated the energy efficiency decreases from 25.6% to 25.47%. However, the overall exergy efficiency increases by 12.5% without fuel cell and by 12.2% with fuel cell. This is due to the fact that the exergy input into the system increases as the pressure ratio increases thus increasing the system's exergy efficiency.

3.1.2 Effect of turbine inlet pressure on power output and exergy destruction

The effect of turbine inlet pressure on power output and the irreversibility in the multigeneration system are shown in Figure 2(b). It was observed that increase in turbine inlet pressure from 500kpa to 800kpa at a constant inlet temperature of 423K leads to increase in power output from 52.75kW to 70.98kW . This is due to the fact that enthalpy drop across the turbine increases as the pressure ratio increases, thereby causing an increase in the power output. Additionally, as the power output increases, the irreversibility in the multigeneration system decreases by 9%.

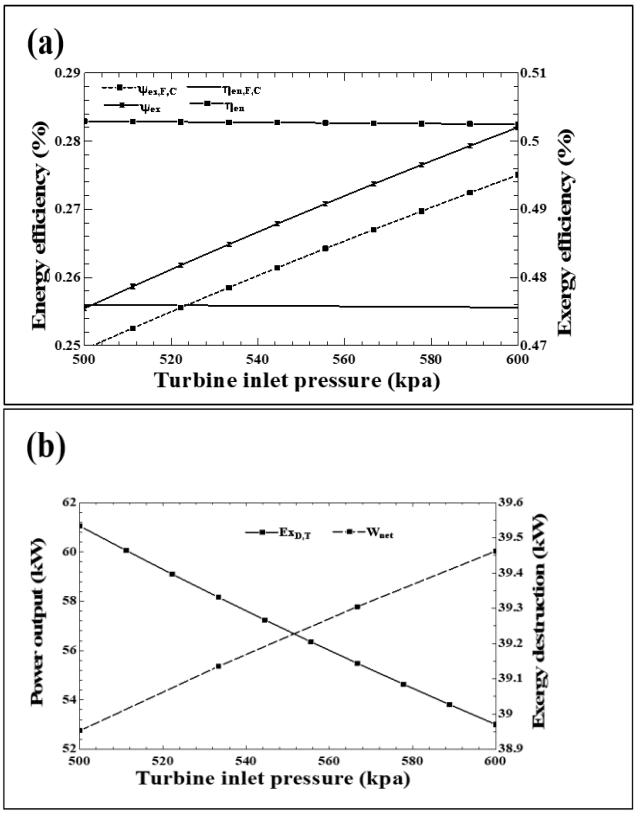

Figure 2: Effect of turbine inlet pressure on (a) energy and exergy efficiencies, (b) power output and exergy destruction

3.1.2 Effect of turbine inlet temperature on energy and exergy efficiencies

Figure 3(a) shows the effect of turbine inlet temperature on energy and exergy efficiencies. It was observed that, as the source temperature increased, there is a greater amount of heat exchange in the ORC vapour generator leading to an increase in the turbine inlet temperature at constant pressure of 500kpa. The increase in temperature leads to an increase in the fluid energy content (enthalpy) thereby increasing the system's efficiencies. The energy efficiency of the MGPP without the fuel cell is increased from 28.57% to 30.22% for turbine inlet temperature mass flow rate of 1.8kg/s. Similarly, the increase in the trend of energy efficiency with fuel cell is the same but the energy values are small. The result indicate that the system decreases in performance with addition of the fuel cell. On the other hand, the exergy efficiency of the system increases from 34.79% to 40.94% for exergy efficiency without fuel cell and that with fuel cell increases by 15%.

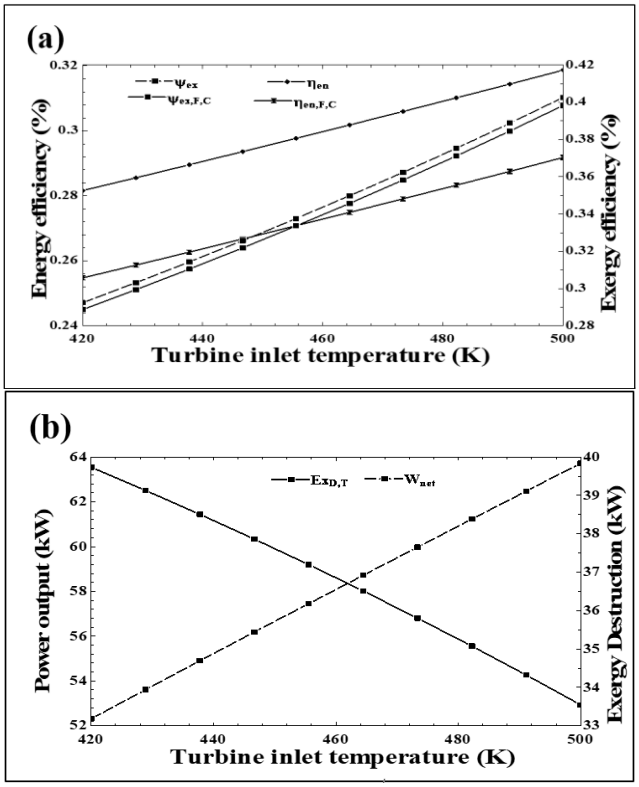

Figure 3: Effect of turbine inlet temperature on (a) energy and exergy efficiencies, (b) power output and exergy destruction

3.1.3 Effect of turbine inlet temperature on power output and exergy destruction

In Figure 3(b), as the turbine inlet temperature is increased from 423K to 470K at a constant pressure of 500kpa and mass flow rate of 1.8kg/s the net power output increases linearly from 52.75kW to 70.98kW. On the other hand, the total exergy destruction of the overall system decreases by 9.4%. This is due to the fact that increasing inlet steam temperature of turbine increases power output nd as such exergy destruction rate reduces leading to a high exergy performance of the overall system.

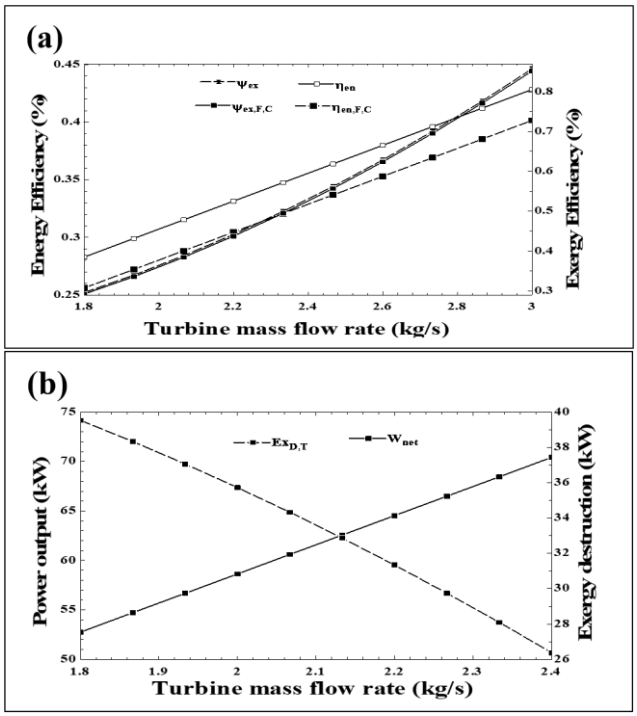

Figure 4: Effect of turbine mass flow rate on (a) energy and exergy efficiencies, (b) power output and exergy destruction

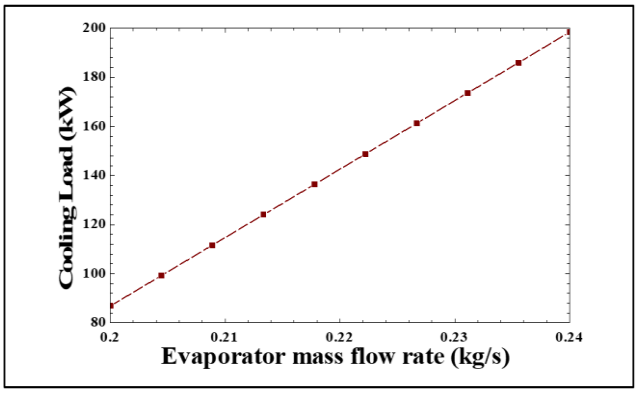

Figure 5: Effect of evaporator mass flow rate on cooling load

3.1.4 Effect of turbine mass flow rate on energy and exergy efficiencies

Figure 4(a) presents the effect of turbine mass flow rate on energy and exergy efficiencies of the overall system without fuel cell and with fuel cell. The energy efficiency without fuel cell increases linearly from 0.28 (28%) to 0.36 (36%) for mass flow rate between 1.8 and 2.4kg/s. the result also shows for 0.07kg/s

mass flow rate increase. The energy efficiency without fuel cell increases by 0.8%.

Similarly, the energy efficiency with fuel cell is the same but the values are small. The increase in efficiency is directly related to the relation between mass flow rate and efficiency in equation 3.26 and 3.28. with constant enthalpy drop. It is important to note that, at higher mass flow rates, temperature drop across the turbine increases, thereby leading to higher efficiency levels at constant pressure.

3.1.5 Effect of turbine mass flow rate on power output and exergy destruction

In Figure 4(b), increasing the turbine mass flow rate from 1.8kg/s to 2.4kg/s produces better rate of heat generated. As a result, net power output increases from 52.75kW at 1.8kg/s to 70.42kW at 2.4kg/s. Increase in mass flow rate leads to increase in turbine work at constant enthalpy triggering an increase in net power production. On the other hand, when the mass flow rate increases from 1.8kg/s to 2.4kg/s, the exergy destruction in the overall system decreases from 39.53kW to 26.37kW due to increase in system's performance.

3.1.6 Effect of evaporator mass flow rate on cooling load

Figure 5 present the effect of evaporator mass flow rate on cooling rate. As can be seen, when the evaporator mass flow rate is increased from 0.2kg/s to 1kg/s the cooling rate increases linearly by 60%. This is due to the fact that increasing the evaporator mass flow rate results in higher cooling generation.

3.2 Validation of Results

The multigeneration power plant was validated and the result compared with that of biomass-based integrated poly-generation power plant as presented in Table 4. Base on energy and exergy efficiency, validated result compared conveniently with that presented in the literature though there were some variations in the present study. This could be attributed to fuel source, heating value of working fluid, and difference in plant configuration. Nevertheless, the energy efficiency of current study's performance is greater than previous study.

Table 3: Thermodynamic Properties of the state points for the combined multigeneration system

State point	Temperature (K)	Pressure (kpa)	Mass flow rate (kg/s)	Enthalpy (kJ/kg)	Entropy (kJ/kg.)K	Exergy (kJ/kg)
1	423	500	1.8	544.5	2.019	87.48
2	392	150	1.8	515	2.019	34.46
3	298	150	1.8	232.3	1.113	11.85
4	298.1	500	1.8	232.5	1.113	12.32
5	453	151.3	2.334	505.9	1.425	200.3
6	403	101.3	2.334	356.9	1.077	94.9
7	348	101.3	2.334	206.3	0.6761	22
8	348	151.3	2.334	206.3	0.6761	22.09
9	293	101.3	1.119	83.3	0.294	0.1986
10	368	101.3	1.119	397.4	1.248	33.42
11	338	101.3	1.119	271.5	0.8916	11.54
12	326.2	101.3	5.176	222.3	0.7435	27.26
13	-	-	-	-	-	-
14	353	7.905	0.2	2649	8.451	27.03
15	314.4	7.905	0.2	172.9	0.5895	0.3473
16	278	0.8635	0.2	172.9	0.6226	-1.626
17	278	0.8635	0.2	2509	9.027	-35.25
18	308	0.8635	7.265	85.03	0.2103	2.095
19	308	7.905	7.265	85.06	0.2103	2.324
20	337	7.905	7.265	144.1	0.3939	33.93
21	353	7.905	7.065	181.8	0.476	63.84
22	318	7.905	7.065	111.3	0.2657	2.072
23	308	0.8635	7.065	91.52	0.2024	8.386
24	298	101.3	3.383	104.2	0.3648	0
25	333	101.3	3.383	250.6	0.8293	26.99
26	326.2	101.3	0.02298	4335	54.67	0.4157
27	326.2	101.3	0.02298	222.3	0.7435	0.121
28	326.2	101.3	0.1824	25.58	0.0822	0.2109
29	326.2	101.3	0.1824	222.3	0.7435	0.9607
30	326.2	101.3	5.176	222.3	0.7435	27.26
31	293	101.3	4.056	83.3	0.294	0.7198
32	323	101.3	4.056	208.8	0.7018	16.85
33	298	101.3	27.37	298.4	5.695	0
34	281	101.3	27.37	281.3	5.636	13.86
35	293	101.3	3.77	83.3	0.294	0.669

36	323	101.3	3.77	208.8	0.7018	15.66

Table 4: Result validation with integrated multigeneration system

Study	References	Energy efficiency	Exergy efficiency	Energetic ORC efficiency	Exegetic ORC efficiency
Technoeconomic assessment of a solar-geothermal multigeneration system for buildings, International journal of hydrogen energy	[6]	17.4	16.6	20.2	49.8
Thermodynamic and Economic modelling of a solar-driven Multigeneration plant integrated with PEM Electrolyzer for hydrogen production	Present study	18.42	37.62	32.75	91.2

4.0 CONCLUSION AND RECOMMENDATION

This research work highlights the potential of solar energy in Calabar. It also provides solutions to clean energy access, environmental sustainability and economic development while attaining reduced GHG emissions. From the study, the MGPP performs optimally within the area of study - Calabar with an average temperature of 29^{o}C and a solar irradiation of 400W/m^2 and a unit cost of electricity (UCOE) of $0.025/kWh as compared to the current tariff of electricity in Nigeria which is $0.10/kWh. The hydrogen production does not interfere with the efficiency of the system, but serve as a fuel for the fuel cell which serves as an alternative power supply during peak periods. In our country like Nigeria and other developing countries of the world with their vast reserve of oil and gas, demand in electricity outweighs power supply due to inadequate or low power generating plants that depend on fossil fuels. The proposed MGPP in this study depend solely on solar energy to generate not just electricity but also produce heating, cooling, hot water for domestic application, and hydrogen gas as a fuel to power the fuel cell at night or during low temperature whether. Also, with the hike in electricity tariff due to high prices of fossil fuels, the proposed MGPP offers a low cost of operation due to availability of solar energy and net zero carbondioxide (CO_2) emission since its only by-product is just water.

In this work, the performance of a MGPP was investigated based on the thermodynamic and economic perspectives considering Calabar area. Further research could be done by considering solar and biomass, or solar and geothermal for the same region – Calabar. It could also be possible to reduce the turbine temperature by choosing a low temperature working fluid for the ORC in order to achieve a more efficient ORC performance.

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DEVELOPMENT OF QUEUE MANAGEMENT MODEL FOR EFFECTIVE SERVICE DELIVERY IN AUTOMOBILE REPAIR SHOPS

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Abstract

In this study, a queue management model/software was developed for automobile repair shops. This software minimizes both waiting time of customers, and idle time of workers. The software groups all jobs done in an automobile repair shop into three sections: mechanical, electrical and air conditioning (A/C) sections. The developed software prioritizes all jobs performed in a typical automobile repair shop in terms of urgency, using the 'shortest processing time' scheduling approach. The jobs are then ranked and assigned to workers based on number of available workstations. Also, expected time of delivery of the job is estimated by the software. The software was tested using data obtained over a two weeks period and percentage reduction in waiting time was found to range between: 0.889-0.122, 0.895-0.25 and 1-0.167 for the mechanical, electrical and A/C sections respectively. In the mechanical section, servicing/replacement of piston and rings and changing/servicing of gear box were discovered to be the jobs with maximum delivery time (15 hrs) while changing of engine belt was seen as the job with the least delivery time (0.3 hrs). For the electrical section, changing of alternator, with delivery time of 3 hrs 30 mins and changing of headlamp and fuse breakage with delivery time of 0.15 hrs are the jobs with maximum and minimum delivery times respectively. For the A/C section, changing of freezer with delivery time of 10 hrs and refilling of gas with delivery time of 0.10 hrs are the maximum and minimum respectively. Implementation of this research will reduce time wastage experienced by customers, idle time at service facilities, frustration caused by unnecessary queue, and encourage allocation of resources accordingly.

1.0 INTRODUCTION

Waiting on queue is an inevitable part of everyday life. Queues are found everywhere; in the market places, on the road, at bus/train stations, in the hospitals, in schools, in the bank etc. Statistics have it that the average person will spend six (6) months of their life waiting in queue [1-5]. Waiting in queue can be exasperating, and to achieve excellent customer satisfaction, queue management has become a priority [6,7]. Optimising the service while reducing the time of the service is an integral part for production [8-13]. The queueing theory helps in understanding the waiting lengths and times, and correlates them with the performance and customer satisfaction [14-20].

Queue management organizes jobs and reduces waiting times, keeping customers engaged and moving through the process, as well as increases the efficiency of the organisation [21,22]. Auto car service is one of the emerging industries in the

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business world, the key factor pertaining to every service-based industry is to provide the best and quality service within the shortest possible time [23-27]. Making a stronger relationship with customers, delivering a high level of service and support, eventually improving the organizational sales and its goodwill are the ultimate aim of such a system [28-30].

The number of cars on our roads are constantly increasing. Consequently, more cars visit mechanic shops frequently. This situation leads to queue at mechanic shops, especially as the number of workshops are not increasing at the same rate. If not managed properly, customers may become impatient and go to competitor's shop. An important factor that needs to be considered when an automobile workshop is already attracting customers is the queuing time [31-33]. The average time in the system, the expected queue length, the expected number of customers served at one time, the expected waiting time in the queue, the probability of balking customers as well as the probability of the system to be in certain states such as full or empty are some of the analyses that can be derived using queuing theory. Waiting lines are common sights in workshops. Hence, queuing theory can be applied in a workshop setting since customers that cannot be served immediately have to queue for service [34].

This work used queuing theory to study the waiting lines at Udo Motors Ltd in Umuahia Abia state, Nigeria and developed a model for queue management.

1.1 Objectives of Study

The main objective of this work is to develop a queue management model for effective customer care service delivery in automobile repair shops.

Specific objectives include:

i. To increase the efficiency of service providers, and improve customer satisfaction through reducing customer waiting time as well as workers idle time
ii. To prioritize all jobs/services performed in a typical automobile repair shop in terms of urgency, using the "shortest processing time" scheduling approach.
iii. To develop a software capable of ranking jobs, assigning jobs to workers, and also estimating the expected time of the delivery of the job.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used in the development, validation and testing of the software are as follows:

i. Questionnaire
ii. Excel spreadsheet
iii. JavaScript programming language
iv. Json server
v. Data generated from Udo Motors Ltd.

2.2 Procedure for Model Development

2.2.1 Model development concept and assumptions

The development of the model/software for assigning jobs to the different sections (mechanical, electrical and air conditioning) in an automobile servicing and repair workshop were based on the following concepts and assumptions:

i. Each section has specified work stations.
ii. One work station specifically handles heavy/long jobs (to avoid lag of long jobs in the system), but can also handle short jobs in the absence of long ones.
iii. No work station should be idle at any given time, provided there is a job to be carried out; therefore, a long job can be assigned to short job station in the absence of short jobs.
iv. A work station should always finish a job before taking on another job.
v. The jobs in the queue should always be shuffled, and arranged in order of priorities (the shortest job should be ranked first, and the longest ranked last).
vi. The software should analyze the job, assign the jobs, and give a range of time, within which the job should be ready (e.g.: your car will be ready in 30mins to 1hour time).
vii. The software should be able to tell the scheduler the work station that are busy and are free for easy assigning of jobs.
viii. Once a work station is through with a job, it should indicate for another job to be assigned to them.
ix. During breaks, the work stations should show busy, so that works will not be assigned to them during the break period.
x. Work must end at exactly closing hours, and unfinished work paused to be continued and completed the next working day.
xi. Work should also be able to be paused on the software. This is also applicable to break time.

2.2.2 Data collection method

Two sets of data were collected. Firstly, for the estimated time for jobs in each section; different types of jobs, time in of the vehicle, time when service begun, and finish time were recorded for a period of time between 8am to 6pm every day for two weeks. The estimated time for each job was found by subtracting the finish time of a job from the time when service begun. The average time a vehicle spends in

the mechanical, electrical and air conditioning sections respectively based on data collected for two weeks are shown in Tables 1-3.

Table 1: Data for average time a vehicle spends in the mechanical section

Day	Sum Total service time	Average Total Service time	Sum Total waiting time	Average Total waiting time	Sum Total time in system	Average total time in system
1	41h 24m	3h 45m	2h 17m	12m	43h 41m	3h 58m
2	34h 19m	3h 07m	1h 54m	10m	36h 13m	3h 17m
3	51h 37	4h 41m	1h 18m	7m	52h 55m	4h 48m
4	44h 56m	4h 29m	1h 12m	7m	46h 08m	4h 36m
5	41h 35m	4h 09m	2h 06m	12m	43h 41m	4h 22m
6	42h 18m	3h 31m	2h 31m	12m	44h 49m	3h 44m
7	43h 46m	4h 22m	1h 47m	10m	45h33m	4h 33m
8	28h 13m	2h 49m	1h 35m	9m	29h 48m	2h 58m
9	28h 11m	2h 49m	1h 43m	10m	29h 54m	2h 59m
10	27h 38m	2h 30m	1h 46m	9m	29h 24m	2h 40m
11	35h 55m	3h 35m	1h 49m	10m	37h 44m	3h 46m
12	28h 20m	2h 34m	1h 41m	9m	30h 01m	2h 43m

Table 2: Data for average time a vehicle spends in the electrical section

Day	Sum Total service time	Average Total Service time	Sum Total waiting time	Average Total waiting time	Sum Total time in system	Average total time in system
1	10h 28m	1h 18m	1h 28m	11m	11h 56m	1h 29m
2	7h 04m	53m	1h 32m	11m	8h 36m	1h 04m
3	8h 29m	56m	1h 20m	8m	9h 49m	1h 05m
4	5h 47m	38m	38m	4m	6h 25m	42m
5	7h 36m	50m	32m	3m	8h 08m	54m
6	7h 34m	50m	35m	3m	8h 09m	54m
7	7h 40m	51m	44m	4m	8h 24h	56m
8	6h 26m	48m	33m	4m	6h 59m	52m
9	8h 29m	50m	39m	3m	9h 08m	54m
10	6h 43m	44m	42m	4m	7h 25m	49m
11	8h 07m	54m	59m	6m	9h 06m	1h 00m
12	7h 36m	57m	1h 06m	8m	8h 42m	1h 05m

Table 3: Data for average time a vehicle spends in the air conditioning section

Day	Sum Total service time	Average Total Service time	Sum Total waiting time	Average Total waiting time	Sum Total time in system	Average total time in system
1	5h 23m	1h 04m	20m	4m	5h 43m	1h 08m
2	17h 06m	2h 51m	23m	3m	17h 29m	2h 54m
3	9h 00m	1h 17m	17m	2m	9h 17m	1h 19m
4	13h 51m	2h 18m	15m	2m	14h 06m	2h 21m
5	3h 47m	37m	0	0	3h 47m	37m
6	6h 55m	59m	46m	6m	7h 41m	1h 05m
7	7h 54m	1h 19m	0	0	7h 54m	1h 19m
8	14h 59m	2h 59m	1h 30m	18m	16h 29m	3h 17m
9	6h 34m	1h 05m	20m	3m	6h 54m	1h 09m
10	5h 49m	58m	1h 31m	15m	7h 20m	1h 13m
11	7h 48m	1h 33m	0	0	7h 48m	1h 33m
12	8h 16m	1h 22m	21m	3m	8h 37m	1h 26m

In Tables 1-3, sum total service time refers to the total time required to complete all the jobs that come into the workshop in day. Average total service time is the average time required to service one vehicle in a day. Sum total waiting time is the total idle time vehicles spend before their servicing commences. Average total waiting time is the average time between when the vehicle enters the workshop and when servicing commences on the vehicle. Sum total time in the system is the time interval between when the first car enters the workshop in a day and when the last car leaves. Finally, average total time in system is the time interval between when a vehicle comes into the workshop and when it leaves the workshop.

The second data set was collected through a questionnaire to obtain the automobile maintenance service details, the number of active work stations in each section and a couple of other information.

2.2.3 Model development

Shortest job first (SJF), is a scheduling policy that selects the waiting job with the smallest completion time to carry out next. It is a non-pre-emptive algorithm.

i. It has the advantage of having a minimum average waiting time among all scheduling algorithms.
ii. It sorts all the jobs according to the arrival time.

iii. It then selects that job which has the least finishing time.
iv. Since it's a non-pre-emptive algorithm, when a new job arrives, the model creates a pool of jobs, then allows the current running job to finish its CPU burst, after which it selects among the pool a job having a minimum burst time.

A. Mathematical approach

Let J_1, J_2, J_n be n-process, which are arranged according to how they arrived at the workshop. The queue is a temporal queue, (Q^T).

Also $ST_i;\ i = 1,2,3,..,n$, which are the estimated service time for job completion. Depending on the service time, genuine to each job, (J), the submitted jobs are arranged in a ready queue (pool), Q^R, which is maintained for all processes.

The n-jobs are arranged in ascending order, with respect to their service time (ST)

$$Q_n^R = (J_1), (J_2) \ldots . (J_n) \quad (1)$$

i. Total turn around time:

Total turn-around time for job J_i can be calculated by summing up its total time genuine to the Q^R.

Turnaround time of $J_1 = ST_1$ (2)
Turnaround time of $J_2 = ST_1 + ST_2$ (3)
Turnaround time of $J_i = ST_1 + ST_2 + \ldots + ST_i$ (4)

$$J_i(TAT) = \sum_{w=1}^{i} ST_w - AT_i \quad (5)$$

TAT= Turn Around Time

Average Turn Around Time of a job J_i can be calculated thus:

$$\text{Av. TAT} = \frac{\sum_{w=1}^{b} J_w(TAT)}{n} \quad (6)$$

ii. Total waiting time:

Total waiting time for job J_i $\{J_i(TWT)\}$, can be calculated by summing up total time devoted to job J_i in Q^R.

Waiting time of $J_1 = 0$ (7)
Waiting time of $J_2 = ST_1$ (8)
Waiting time of $J_3 = ST_1 + ST_2$ (9)
Waiting time of $J_i = ST_{i-1} + ST_{i-2} + \ldots + ST_i$ (10)

$$J_i(TWT) = \sum_{w=1}^{i-1} ST_w - AT_i \quad (11)$$

$$\text{Av. TWT} = \frac{\sum_{w=1}^{b} J_w(TWT)}{n} \quad (12)$$

2.3 Software Development Procedure

Project lifecycle refers to the basic steps taken in software development, to ensure that a software is completed from start to finish without bugs. These stages that the software undergoes from start to finish is called project lifecycle. In this work, a modified software development cycle was used because of its numerous advantages which includes: increased flexibility, faster time to market, improved customer satisfaction, enhanced quality and a focus on continuous improvement. The modified software development cycle refers to an adapted or customized version of the traditional software development life cycle (SDLC) that incorporates changes or modifications to better suit specific project requirements or development methodologies. The specific modifications may vary depending on the organization, project or approach being followed. The steps in a modified software development cycle are sequential, systematically proceeding from: analysis to design, coding and unit test, integration and system test. The flow chart for the developed Algorithm is shown in Figure 1.

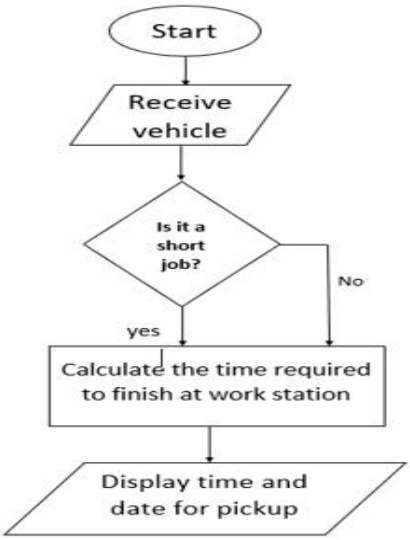

Figure 1: Flow chart for the development of the queue management software

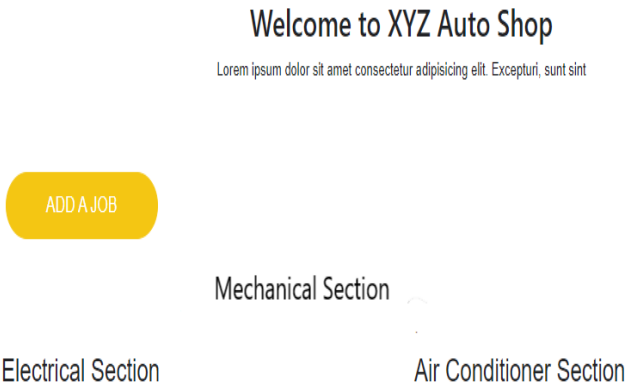

Figure 2: The Queue Management Software user interface

3.0 RESULTS AND DISCUSION

3.1 The Queue Management Software Interface

The software was designed to carry out the queue management process; it calculates the waiting time and turn around using the model generated, and displays the finished time (time of completion of job). The software also displays the car name, car model and job carried out, for easy identification. The name, phone number and e-mail of the customer is also supplied to the software, so as to communicate the customer when the job is successfully carried out and is ready to be picked up by the customer (owner of the vehicle). The software interface is shown in Figures 2 - 4.

Figure 3: Software interface showing details of job added

Figure 4: Software interface showing a completed job

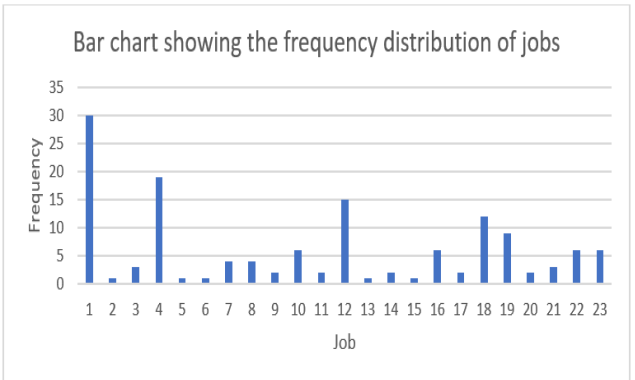

Figure 5: Frequency distribution of jobs within two weeks (mechanical section)

3.2 Classification of Jobs according to their Urgency Level

Results of the frequency of jobs and estimated processing time of the jobs carried out in the mechanical section are shown in Figure 5 and 6 respectively.

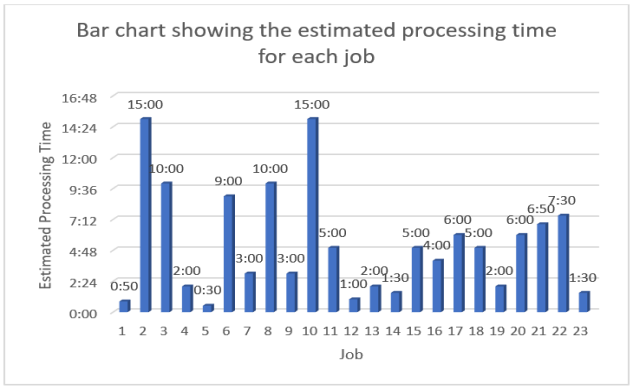

Figure 6: Estimated processing time for each job (mechanical section)

The list of jobs recorded, that were carried out within the two weeks of inspection were:
1. Changing of engine oil, 2. Servicing and replacement of piston and rings, 3. Changing of engine top/gasket, 4. Changing of spark plugs and servicing of nozzles, plug coils, 5. Changing of Engine Belt 6. Changing of oil seals, 7. Servicing of valve cover, 8. Changing of Engine, 9. Changing of radiator 10. Changing/servicing of gear box, 11. Servicing of bottom, 12. Change of brake pad, 13. Bleeding and refilling of brake fluid, 14. Servicing of brake shoe/ hand brake, 15. Servicing ABS 16. Changing of brake disc, 17. Changing of brake master and servo 18. Shock replacement, 19. Linkages and bushings replacement, 20. Transmission shaft maintenance /replacement, 21. Changing of suspension, 22. Changing of camber, ball joints, u-rubber, tyroid, 23. Changing of power steering/pump.

These jobs correspond to the jobs 1-23 on the bar charts. From Figure 6, we see that: jobs 2, 3, 6, 8, 10, have the highest estimated processing time (15 hours, 10 hours, 9 hours, 10 hours, 15 hours, respectively) and we can also see that, they have minimal occurrence, from Figure 5. These jobs are the "long jobs", and have a dedicated work station for processing. These jobs are ranked as "less urgent" jobs.

Also, jobs, 11, 15, 16, 17, 18, 20, 21, 22, have a mid-estimated processing time (a range of 4 hours to 7 hours 30 mins), these jobs are ranked as "urgent jobs"

For the "very urgent" jobs, they have the least estimated processing time, these jobs are jobs, 1, 4, 5, 7, 9, 12, 13, 14, 19, 23.

Results of the frequency of jobs and estimated processing time of the jobs carried out in the electrical section are shown in Figures 7 and 8 respectively.

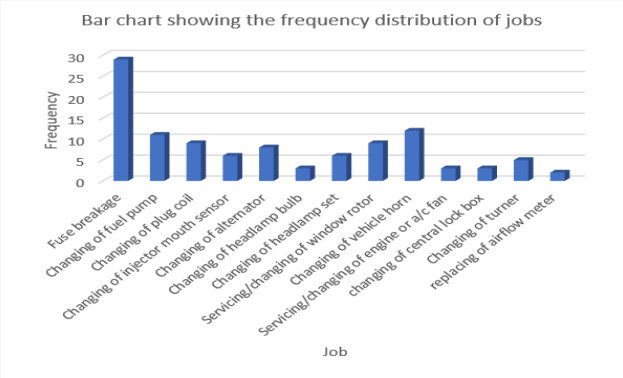

Figure 7: Frequency distribution of jobs within two weeks (electrical section)

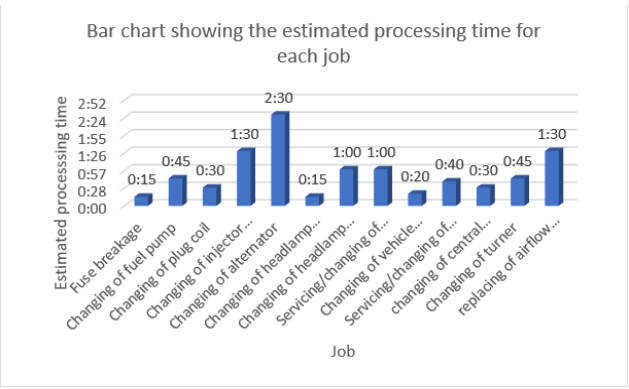

Figure 8: Estimated processing time for each job (electrical section)

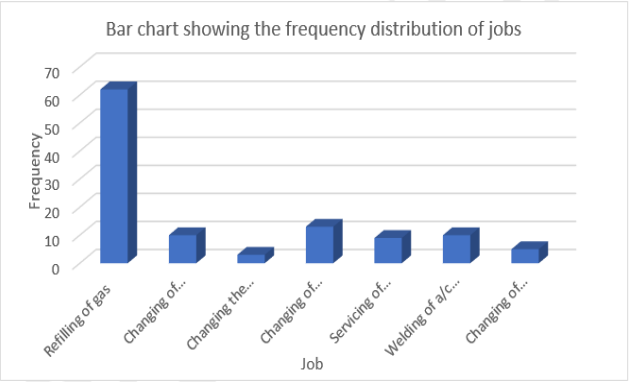

Figure 9: Frequency distribution of jobs within two weeks (A/C section)

From Figure 7, we see some jobs with high occurrence in the space of two weeks, and from Figure 8, we see jobs with estimated processing time of (2 hours 30 mins, 1 hour 30 mins, and 1 hour), these jobs are defined as long jobs and are dedicated to one work station. these jobs are ranked as "less urgent" jobs. Also, jobs with estimated processing time of 45 mins, 40 mins, 30 mins, are ranked as "urgent jobs". For the "very urgent" jobs, they have the least estimated processing time, these jobs have estimated times of 15 mins and 20 mins.

Results of the frequency of jobs and estimated processing time of the jobs carried out in the air conditioning (A/C) section are shown in Figures 9 and 10 respectively.

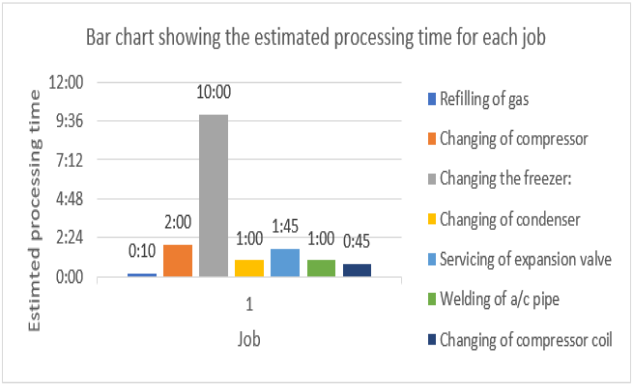

Figure 10: Estimated processing time for each job (A/C section)

From Figure 9, we see some jobs with high occurrence in the space of two weeks, and from Figure 10, we see jobs with estimated processing time of (10 hours), these jobs are defined as long jobs and are dedicated to one work station. these jobs are ranked as "less urgent" jobs. Also, jobs with estimated processing time of less than 2 hours are ranked as "urgent jobs". For the "very urgent" jobs, they have the least estimated processing time, these jobs have estimated times of 10 mins and 45 mins.

3.3 Determination of Percentage Reduction in Waiting Time

The data gotten from the automobile maintenance workshop was inputted into the software to determine percentage reduction in waiting time. The results are shown in Tables 4-6.

Table 4: Percentage reduction in waiting time for mechanical section

S/N	Waiting time (unmodelled)	Waiting time (modelled)	% Reduction in waiting time
1	2h 17m	35 m	0.744526
2	1h 54m	1hr 35 m	0.264516
3	1h 18m	29 m	0.628205
4	1h 12m	1hr 02 m	0.121951
5	2h 06m	14 m	0.888889
6	2h 31m	40 m	0.735099
7	1h 47m	49 m	0.542056
8	1h 35m	41 m	0.568421
9	1h 43m	38 m	0.631068

10	1h 46m	37 m	0.650943
11	1h 49m	44 m	0.59633
12	1h 41m	30 m	0.70297

Table 5: Percentage reduction in waiting time for Electrical section

S/N	Waiting time (unmodelled)	Waiting time (modelled)	% Reduction in waiting time
1	1h 28m	38 m	0.568182
2	1h 32m	49 m	0.467391
3	1h 20m	42 m	0.475
4	38m	04 m	0.894737
5	32m	13 m	0.59375
6	35m	22 m	0.371429
7	44m	33 m	0.25
8	33m	12 m	0.636364
9	39m	25 m	0.358974
10	42m	14 m	0.666667
11	59m	39 m	0.338983
12	1h 06m	26 m	0.606061

Table 6: Table showing the percentage reduction in waiting time for A/C section

S/N	Waiting time (unmodelled)	Waiting time (modelled)	% Reduction in waiting time
1	20m	0	1
2	23m	14m	0.391304
3	17m	12m	0.294118
4	15m	11m	0.266667
5	0	0	0
6	46m	36m	0.217391
7	0	0	0
8	1h 30m	1h 15m	0.166667
9	20m	14m	0.3
10	1h 31m	40m	0.56044
11	0	0	0
12	21m	18m	0.142857

Tables 4-6 show that with the use of the developed software, an appreciable percentage reduction in waiting time of customers was achieved.

4.0 CONCLUSION

A queue management software for effective service delivery in automobile repair shops was developed and tested. This software was designed to reduce both waiting time of customers, and idle time of workers in automobile repair shops. Once a vehicle enters the workshop, details of the work to be done is determined through scan or other physical fault detection techniques. This data is immediately entered into the software and the software automatically calculates how long the repair will take, based on several factors like: type of maintenance to be done, number of vehicles in queue, number of workstations available, etc. The software automatically notifies the customers once their vehicles are ready for pick up, through their mobile phones and emails. Evaluation of the software showed very notable reductions in waiting time in the mechanical, electrical and A/C sections of the workshop. The software has a user-friendly interface, which will be easily understood by anyone who wants to adopt this system in his automobile workshop.

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CHEMICAL AND MINERALOGICAL PROPERTIES OF LEJJA NSUKKA IRON ORE DEPOSITS

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Abstract
The ore deposits obtained from Dunoka, Amankwo and Umuakpo in Lejja Nsukka were found to be iron silicate in nature. They were analysedby XRD, XRF, AAS and the ores were found to contain 60.59% Fe, 64.81%Fe and 64.67%Fe respectively. These ores when compared to those iron ore producing nations, they were classified as medium-grade iron ore. Other elements like titanium, magnesium and manganese were present and could be mined for commercial use. Chemical analysis of the ore samples showed that traces of phosphorous of ≤ 0.0079% and were free from the deleterious elements, sulphur and arsenic.

1.0 INTRODUCTION
Iron and steel industrialisation is crucial in the technological and infrastructural development of a country. Nigeria has vast raw materials of iron ore needed for development of steel such as coal, iron ore, limestone and natural gas [7]. Nigeria has high potentials of becoming West Africa's regional economy. But the economy of the country cannot be vibrant and strong without the development of its iron and steel which is the bedrock of the manufacturing sector [5].

The Government of Nigeria and her mineral sector has been searching for additional and supplementary iron ore deposits to sustain its iron and steel industries. These ores occur extensively in different parts of the country as metamorphic and sedimentary deposits with the large concentration in Kogi state [9]. The Lejja ore is one of the many ores in the South-Eastern Nigeria that belong to the metamorphic types, which occur in bands, popularly referred to as "ferruginous quartzite".

The iron ore, a mineral from the iron ore rocks, can be economically mined to produce metallic iron and steel. They are rich in iron oxides, ranging from bright yellow, dark-grey, rusty red to deep purple [11]. The oxides possess iron-bearing minerals that are readily available, and consist mainly of haematite (reddish), magnetite (blackish), limonite (brownish) and siderite (pale brown) [5]. The Fe content determines the quality of the iron ore. Ores with more than 65% are considered as high-grade ores; a range between 62–64% are classified as medium grade ores and below 58% Fe are regarded as low-grade ores [1]. Nigeria is

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searching for ways to effectively utilise the solid minerals to improve the economy by providing job opportunities.

Several iron ore deposits have been characterised using different analytical techniques. Some of the techniques include the use of scanning electron microscopy (SEM) and optical image analysis, diffuse reflection spectroscopy, Mossbauer spectroscopy and x-ray diffraction (XRD). Characterisation of some Nigeria solid mineral deposits were reported. The characterisation of these ores were analysed by SEM-EDS, XRD and ICP [12].

Characterisation of iron ore is an important step required to establish the potential benefits of the ore for production. The quality, quantity, shape, density and physical characteristics are determined to effectively utilise the economic and technical parameters required to support planning, production and evaluation of the economic viability of deposits [10]. [2] carried out the determination of chemical, mineralogical and liberation size of Ochokochoko iron ore. It was reported that the ore contained 50.60% Fe, 17.70% SiO_2, 0.05% P_2O_5, and 0.03% S which is mostly hematite, magnetite, calcite, alumina, and silica. Raw Materials Research and Development Centre (RMRDC) and Geological Survey of Nigeria (GSN) concluded on mineralogical study that reports that the ore is a replacement of amphibolites and basement gneisses by iron rich solution emanating from granites bodies of older-granite suite of Pan-Africa. An update of mineral reserves of 111,400,000 tonnes has been outlined, with a grade level of about 35% Fe which could be easily upgraded. It is currently being utilised in open pit mining and provides feed for the Delta and Ajoakuta Steel Companies [13; 15].

KotonKarfe iron ore deposit has also been studied by [16] and was reported to have an iron composition of 43.34% with a low silica amount (10.14%). According to them, the content is mainly magnetite, siderite and goethite and some haematite. The work index determined was 11.33kWh/tonne and 17.00kwh/tonne for the calcined and uncalcined samples. [15] reported that Gujeni iron ore deposit ore contains 48.6% Fe, 12.01% Ti, 0.2% Mn, 0.2% S, 2.06% P, 4.4% Al and 6.0% Si. Mineralogically, the ore contained hematite, rutile and goethite in large quantities with, manganese oxide, zirconium, silicate and zincite minerals present in small quantities. The work index was recorded at13.96kwh/tonne.

Iron is regarded as the building block of economic activity, and per capita iron consumption is a well recognized predictor of a nation's degree of development. Although, there are local deposits of iron ore identified at various places in the country, the Nigerian iron industry is dependent on imported raw materials [3]. By establishing the development of commercial amounts of iron ore mineral in the Lejja area, the economic benefits will significantly enhance the local economy there and open up technical job opportunities in the transportation, mining, and manufacturing sectors, guiding the nation towards the achievement of key millennium development goals.

Understanding the essential properties and composition of ores determines how it could be processed. It is an important factor for the exploitation of any mineral. The economics of commercial ore exploitation are frequently determined by the characteristics of minerals [1]. This study's primary goal is to assess the chemical and mineralogical makeup of raw iron ore from the Lejja deposits in Nsukka, Nigeria. The chemical composition of the ore will be compared to those of other ore deposits in Nigeria and major iron ore producing nations to evaluate its quality and determine whether it can be used for commercial purposes (market standards).

The research work will contribute a new and detailed information on the chemical and mineral makeup of the Lejja iron ore deposits. This will guide the ore processing and assist to determine the grade and utilisation of the iron ore in production. This will also create a platform for researchers to understand the behaviour of Lejja iron ore deposits during its utilization.

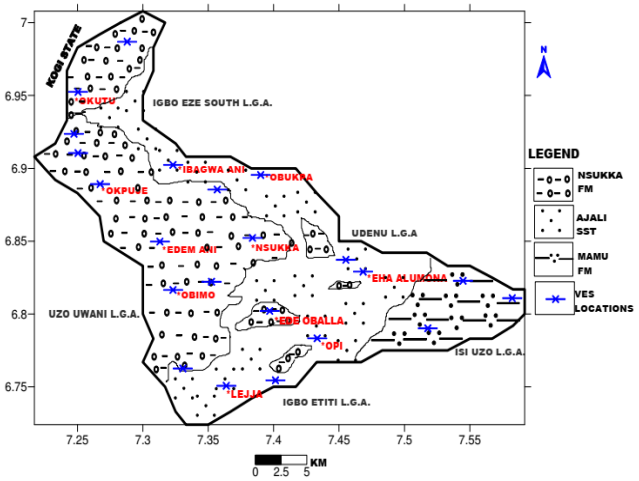


Figure 1: Geologic map of the study area [12].

1.1 Study Area and its Geology

Lejja is a small community about 14km south of Nsukka town in Nsukka Local Government Area of Enugu State, Nigeria. It lies at latitude 6°45^{I}N

and longitude 7°22ᴵE. The hill sites under investigation are Dunoka, Amankwo and Umuakpo villages respectively, in Lejja [16]. It covers roughly 480 km^2 of area. (Figure 1).

The area under investigation has two distinct types of landforms: a high relief zone with residual undulating hills and valleys, and lowland sections (Figure 1); with the residual hills being a remnant of the Nsukka formation constituting the surface layers. The AjaliSandstone is overlying the strata, which are severely weathered and degraded [12]. There are three main geologic formations in this region: the Mamu, Ajali, and Nsukka formations (Figure 1), which are the characteristic of the Eastern Nigeria sedimentary basin in the southern portion of the Benue Trough of Nigeria [8].

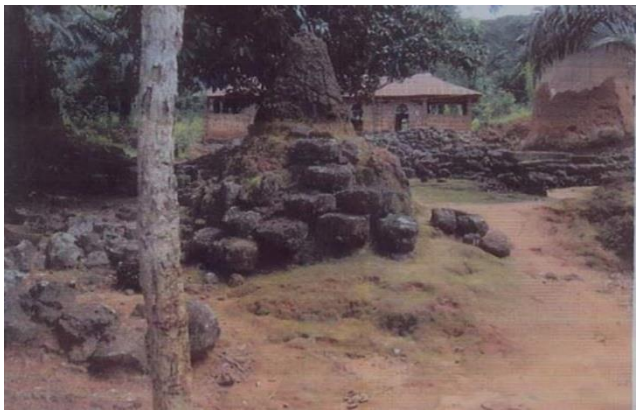


Figure 2: Iron slag visibly scattered at Otobo-Dunoka village square [8].

White to grey, fine to medium-grained sandstones, shaly sandstones, sandy shales, grey mudstones, shales, and coal seams make up the Mamu formation (lower coal measures). The Ajali formation is conformably underlain by this layer, which is around 450 meters thick. The Ajali formation, often referred to as false bedded sandstone, is composed of thick, friable, irregularly sorted, iron-stained, white sandstones. It has a typical thickness of 300 m and is frequently covered in a thick layer of red earth, which is made up of red, earthy sands created by the formation's weathering and ferruginization. The Ajali sandstone conformably rests on the Nsukka formation, which is the upper coal measure. The lithology is extremely reminiscent of the Mamu formation and is composed of a succession of alternating sandstone, black shale, and sandy shale, with thin coal seams at various layers [6]. Eroded remnants of this formation compose of outliers and its thickness averages 250m. At Otobo-Dunoka village (which spans an area of about 500m^2) and environs [8], slag blocks of various sizes and shapes are clearly visible (Figure 2), describing the size of the area's historical iron smelting operations. The abundance of the iron slag has turned the area into an archeological site which confirms the area as a previous iron smelting area [8].

2.0 MATERIALS AND METHODS

The samples of the ores were collected from three hills;Donoka, Amankwo and Umuakpo in Lejjacommunity of Enugu state. Within a 10-meter radius surrounding each hill, samples were taken at random. The initials A, B, and C, respectively, were assigned to the ores from these hills.

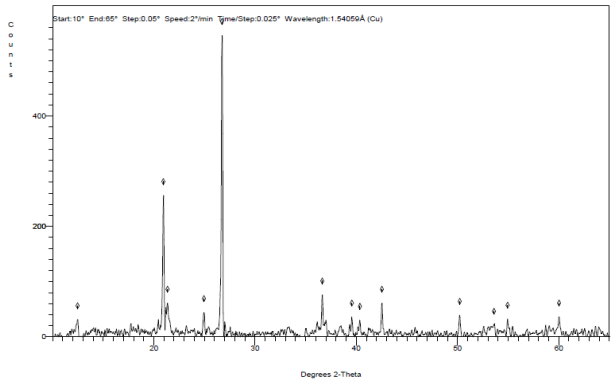
2 kg of each sample was crushed and sieved with a Ro-Tap shaker to 38, 53, 75, 106, 125, 150, 212, 300, 600, and 850$^+$ microns. Samples A, B and C of the ores were crushed with a jaw, cone and roll crushers respectively. The ore fines of sieve size below 100μm were used for mineralogical and elemental analysis. The FeO and other oxides were determined using Perkin-Elmer Model 3100 Atomic Absorption Spectrophotometer (λ = 253.7nm, I = 11mA, bandwidth = 0.7nm) at PRODA Enugu. The elemental composition of element such as Fe, Si, Al, P, Ti, Mg, Mn, Pb, Zn, and Cu were determined using XRF (Philips 2400 XRF) after fusion in $Na_2B_4O_7$. Mineralogical analysis was carried out using an X-ray diffractometer (Bruker D8 X-ray diffractometer) with Ni-filtered Kα Cu-radiation, at 40 kV and 30 mA. It operated at a scan speed of 0.5 with steps of 0.02^0 from 200 to 80^0 2θ range.

3.0 RESULTS AND DISCUSSION

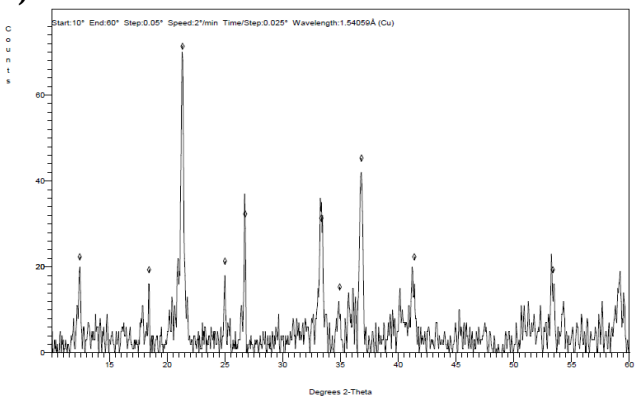
3.1 Mineralogical Analysis Results

The results of X-ray diffraction analysis of iron ores from various ore deposits in Lejja community/town are as shown in Figure 3. The chemical compound observed in Dunoka sample was iron silicate, a common mineral known as isocrite or heptairon silicate hexaoxide {$Fe_7O_{10}Si$ or $Fe_7(SiO_4)O_6$}. Amankwo and Umuakpo samples were analysed to be iron silicate of a common mineral called Fayalite {Fe_2O_4Si or $Fe_2(SiO_4)$}. The major compound observed in the XRD scans of all ore specimens is iron silicate. The main peak appearing at 2θ of 26.85° for Dunoka iron ore, 21.38° for Amankwo and 26.87° for Umuakpo iron ore samples. According to the results obtained, it suggests that all the ores from Lejja community were observed to be iron silicate in nature. Iron ore with high iron composition (65–70% Fe), can be used directly in the blast furnace for production of iron without beneficiation, agglomeration and in direct reduction of iron ore (DRI) process. The ore samples from Dunoka are a compact, bonded crystalline ore varying in colour from grey to black.

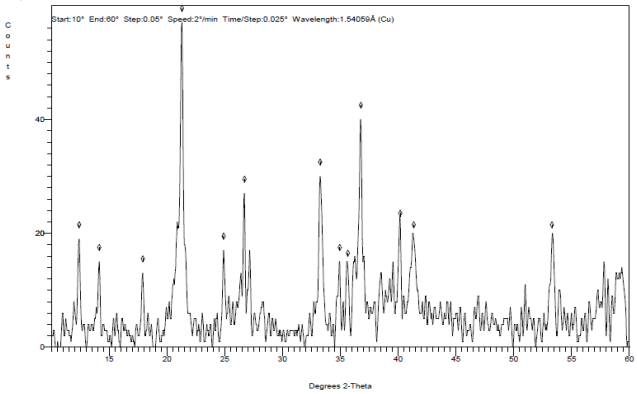
The Amankwo samples consist of aggregates of brown compact and fine-grained particles as compared to report by [14]. That of Umuakpo ore samples are brownish-yellow in colour and fine-grained particles as seen physically.



a) Dunoka ore



b) Amankwo ore



c) Umuakpo ore

Figure 3: XRD Spectra of the iron ores (a, b, and c)

3.2 Elemental and Oxide Analysis Results

The chemical characteristics (AAS and XRF data) of iron ores under investigation are presented in the Tables 1 and 2 respectively. The phosphorous content in all the ores were found to be below the acceptable contents of 0.07% (Table 2), as it follows iron during downstream reduction process, transforming into iron phosphides that makes steel brittle and hence increase the cost of making steel. Therefore, the ores can thus serve as raw materials for iron production. These ores have Fe contents of 60–65% which correlate to the medium-grade ores. Iron ores with high iron content (65–70% Fe) similar to those obtained by [2] and [12] and can be utilised in the direct reduction of iron ore (DRI) process and without beneficiation or agglomeration in the blast furnace for manufacturing iron.

The impurity elements in Dunoka iron ore mainly consist of 1.12% Ti, 0.81% Co, 0.14% Mn and 0.12% Pb. Other elements present in less than 0.1% include Al, Cr, Zn, Ni, V, Mg, K, Ca, and Cu. Phosphorous has 0.0079%. The ore was found to be free from deleterious elements such as sulphur and arsenic. The results from the AAS analysis show that the iron ores obtained from Dunoka hill was rich in iron content (60.59%).

Data from the composition indicated that the impurity elements in Amankwo iron ore mainly consist of 1.58% Ti, 0.64% Co and 0.18% Pb. Other elements present in the ore include Al, Mn, Cr, Zn, Ni, V, Mg, K, Ca, Cu, but are present in less than 0.1%. Phosphorous has 0.0059%. The ore was found to be free from deleterious elements such as: S, As and hence comparable to those of Muko deposits as studied by [1] and GidanJaja in Zamfara state (Nigeria) by [5]. The result shows that the iron ores obtained from Amankwo hill has the richest iron content of 64.81%.

Within the composition of Umuakpo iron ore, the impurity elements mainly consist of 1.37% Ti, 0.55% Co and 0.15% Pb. Other elements such as Al, Mn, Cr, Zn, Ni, V, Mg, Ca, Cu, Ag, are also present in less than 0.1% and 0.0079% P. The ore was also found to be free from deleterious elements such as sulphurand arsenic. The result (as in Table 2) established that the iron ores obtained from Umuakpo hill was also rich in iron content (64.67%). The AAS test results also show the presence of all the above elements as in XRF analysis data (Table 2). Elements such as Titanium, Lead and Cobalt are found to be largely present among the impurities which can be extracted for commercial use. The Lejja iron ore deposits having an iron content of 60-65%, can serve as direct-shippable ore (DSO) and will only need minimal beneficiation.

Table 3 shows the chemical composition of iron ore deposits from Lejja Nsukka communities (Dunoka, Amankwo and Umuakpo) as compared to other deposits in Nigeria. These deposits have much higher iron contents than other deposits as observed in the XRF chemical analysis results.

Table 1: Result of Lejja iron ore in oxide form from AAS Analysis

Deposit	S	FeT	TiO_2	CaO	MnO	MgO	SiO_2	P_2O	Cr_2O_3	CO	Al_2O_3	K_2O	ZnO
Dunoka	UN	60.65	1.12	0.45	1.00	0.98	4.85	Trace	Trace	Trace	0.86	Trace	0.062
Amankwo	UN	65.40	1.62	Trace	0.57	8.81	3.78	Trace	0.035	0.32	0.30	UN	0.060
Umuakpo	UN	64.69	1.45	0.432	0.14	8.20	3.41	Trace	0.006	0.57	0.24	UN	Trace

Where UN= Undetected

Table 2: Elemental analysis results of Lejja iron ore (XRF analysis)

Element	Dunoka	Amankwo	Umuakpo
Mg	0.0100	0.0092	0.0348
Al	0.0858	0.0312	0.0238
Si	0.1995	0.1703	0.1515
P	0.0079	0.0059	0.0063
S	0.0000	0.0000	0.0000
K	0.0154	0.0000	0.0000
Ca	0.0313	0.0201	0.0229
Ti	1.1198	1.5764	1.3650
V	0.0373	0.0485	0.0354
Cr	0.0611	0.0609	0.0613
Mn	0.1378	0.0894	0.0967
Co	0.8063	0.6389	0.5457
Fe	60.5927	64.8108	64.6735
Ni	0.0529	0.0549	0.0560
Cu	0.0232	0.0198	0.0190
Zn	0.0619	0.0523	0.0536
As	0.0000	0.0000	0.0000
Pb	0.1161	0.1759	0.1544
W	0. 0000	0.0000	0.0115
Au	0. 0000	0.0000	0.0000
Ag	0. 0000	0.0000	0.0006
Rb	0.0028	0.0049	0.0050

Table 3: Composition of some Nigerian iron ores as compared to Lejja deposits (AAS analysis).

Deposit	S	P_2O_3	K_2O	CaO	TiO_2	FeT	MgO	Al_2O_3	SiO_2	Cr_2O_3	ZnO
Chocochoko	UN	0.02	0.53	0.15	0.61	34.45	0.18	9.67	44.8	UN	UN
Agbajanoko	0.03	0.01	0.03	0.21	Trace	37.22	0.15	3.39	46.5	UN	UN
Agbaja	0.12	2.08	0.04	0.72	0.37	47.8	0.38	9.60	10.89	UN	UN
Kotun-karfi	0.04	2.14	0.02	0.45	0.25	48.18	0.07	6.70	5.13	UN	UN
Bassange	0.05	2.14	0.02	0.17	0.17	46.9	0.46	10.87	8.28	UN	UN
Itakpe	UN	0.18	0.42	0.3	0.1	36.88	0.2	1.0	44.8	UN	UN
Dunoka	UN	Trace	Trace	0.45	1.12	60.65	0.98	0.86	4.85	Trace	Trace
Amankwo	UN	Trace	UN	Trace	1.62	65.40	8.81	0.30	3.78	0.035	Trace
Umuakpo	UN	Trace	UN	0.432	1.45	64.69	8.20	0.24	3.41	0.006	Trace

Where UN= Undetected, Modified after [4].

4.0 CONCLUSION

The mineralogical and chemical composition characterisation of raw iron ore from the three deposits, Dunoka, Amankwo and Umuakpo in Lejja community, Nsukka Local Government Area of Enugu State were studied. The results show that the ore samples were found to be mainly composed of iron silicate in nature. The results obtained from the analysis of iron ores using XRD analysis well-aligned with chemical composition data (XRF and AAS) of these ores. Iron ore from Dunoka contains 60.59% Fe, Amankwo ore contains 64.81% Fe as the highest and Umuakpo contains 64.67%Fe. When compared to other iron ores from the countries that produce iron, these are considered to be of medium grade. The iron ores can be efficiently exploited to produce steel and iron. There are also other elements like titanium, magnesium and manganese that can be mined for commercial use. Chemical analyses established that all the samples of iron ore under investigated contain trace of phosphorous of < 0.0079 and were free from the deleterious elements, sulphur and arsenic.

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OPTIMIZATION OF LEACHING PARAMETERS FOR THE EXTRACTION OF COPPER FROM HEMATITE-DOMINATED COPPER ORE USING RESPONSE SURFACE METHODOLOGY (RSM)

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Abstract

The optimization of recovery of copper from Akiri hematite-dominated copper ore using hydrometallurgy was investigated in this study. The Akiri copper ore deposit hosts a high-grade copper mineral from which copper metal can be extracted. However, the ore is dominated by gangue minerals that need to be mechanically reduced for efficient copper recovery. The purpose of this study is to optimize the extraction of the metal from hematite-dominated copper ore. The experiments that were carried out in the course of this study include crushing, pulverization,mineralogical and chemical characterizations of the sample and sulpheric acid leaching. Response surface methodology was used to optimize the system parameters namely;temperature, concentration of the leachant and contact time so that an efficient method will be developed for the extraction of copper.Chalcopyrite, covellite and cuprite are the copper minerals while the gangues minerals were quartz ,mica, hematite,etc.on the characterization of the copper ore. The major oxides in the ore are hematite ,copper oxide and silica and revealed that the ore contains 4.61% copper and 65.8% iron. Effect of three independent factors like concentration ,temperature and contact time for copper extraction from the hematite-dominated copper ore was studied.Central composite design method was applied to the proposed quadratic model that connect the factors used for best copper extraction at the best process condition. The work shows that concentration of the acid was the best efficient factor for copper extraction compare to temperature and contact time. This may be as a result of high value of F-statistics for the concentration of the leachant, which effects to high level of copper extraction.Experimental and predicted values for weight loss from the copper ore were obtained as 39.10% and 39.03% at optimum conditions, respectively. The optimum conditions of 1.5M acid concentration, 90^{o}C reaction temperature and 90minutes contact time were obtained and from which 6.64%Cu at recovery of 92.0% and 2.31%Fe was obtained without stirring. Also, the ore was subjected to leaching with stirring at 400rpm with the optimum conditions obtained to know the effect. The grade obtained was 7.84%Cu at recovery of 83.51% and iron content 5.47%. This shows that leaching without stirring is the best option against leaching with stirring to extract the copper and to reduce the iron and other gangues contents in the copper ore.The activation energies were estimated as 13.20kJ/mol and 22.67kJ/mol for liquid film diffusion and diffusion product layer respectively, the values indicate that the leaching rate is controlled by diffusion process.

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1.0 INTRODUCTION

Copper as a metal is a nonmagnetic base type with average concentration in the earth's crust of about 50ppm. The cutoff grade for exploitable concentration level for a deposit of copper is 0.4% based on average crustal abundance [1]. The estimated copper ore deposit in Nigeria is over ten million metric tons, and are distributed across the northern part of Nigeria in

Nasarawa, Bauchi, Plateau, Gombe and Zamfara States. This making it one of the most desired places in the world for buyers from outside the country to buy copper ore [2]. [3] reported that there are over 40 different types of economic minerals in Nigeria including copper found in about 500 locations, spread extensively across the country. Nevertheless, many of these occurrences can just be described as 'mineral showings'with no or little economic potential.

Copper as a base metal has many areas of applications in metallic forms and as well as in alloys form, in industries relating to mechanical, metallurgy, electrical and electronics, military, chemistry, paint and agriculture. The copper products demand globally is on the increase as a result to its growing applications in scientific and technological fields and as well as other innovative applications of the metal industry ([4];[5];[6]). The rising request for copper in the recent years was evident worldwide and the requisition for copper products can validly be due to stay high and keep increasing in the future years [7], This is because, the rising copper request has stimulated the unavoidable exploitation and application of oxide of copper ore. The effective use of oxides of copper from copper deposits is an essential subject of research [8]. The metals recovery from ores that are non-ferrous has been investigated on large-scale and the process determination relies upon both the localization and the ore composition ([9];[10];[11]). Oxides of copper, blended sulphide-oxide ores and copper sulphide ores with low grade, which for profitable cause, can never be improved by froth flotation technique,but can be treated by hydrometallurgical techniques [7].

Nevertheless, hydrometallurgy as a field of study, there have been notable transformation, growth and development for copper production from carbonate group ores of copper, like malachite and azurite ([12];[13]). The leaching media for the processing of copper usually of acids, alkaline, cyanides and inert reagents. Sulpheric acid is an inexpensive leaching agent for oxidized copper ores. [14] reported the origin and characteristics of Akiri copper ore deposit. The chemistry of the ores showed dominantly Cu and Fe with barium in places and the ores contain insignificant Pb and Zn which suggest the absence of the associated galena and sphalerite. The Akiri copper ore deposit hosts a high-grade copper mineral from which copper metal can be extracted. However, the ore is dominated by gangue minerals that need to be mechanically reduced for efficient copper recovery. The Nigerian copper ore has been reported to contain both chalcopyrite and pyrite while the content of pyrite is higher than that of chalcopyrite ([15] and [16]). The implication of these is that the grade of the ore needs to be improved berfore extraction.

Lately many experimental design methods mostly response surface methodology (RSM) is applied in the many engineering sectors for system parameters optimization. Complex variables process optimization in traditional method follows one-parameter at a time. Several tests are needed for normal methods, and these techniques do not describe the interaction effect. In order to estimate optimum level, additional data is required and take a longer period, which is undependable [17]. The purpose of the design of experiment (DOE) method was to know the combined effects among the factors, that will assist factors optimization in the experiment in order to produce the statistical models [18]. The optimization of leaching parameters for coal with hydrofluoric acid for ash reduction has been studied using response surface methodology [19]. From literature, it has been established that few studies have been conducted on statistical optimization of system condition for upgrading of copper and reduction of gangues minerals from copper ore by using hydrometallurgical method. Hence, this study aims to define the optimum leaching conditions for the extraction of copper and gangues reduction from Akiri hematite-dominated copper ore in sulpheric acid leaching with the aid of statistical optimization.

The interaction effects of leachant concentration, temperature of the reaction, and contact time on the dissolution process by applying response surface methodology with central composite design to optimized the variables was studied. Therefore, a design of experiment was applied to developed a statistical model in order to know the optimum dissolution conditions where copper recovery and iron reduction is highest to be obtained from the copper ore.

2.0 MATERIAL AND METHODS

2.1 Materials

Ore sample was obtained from Akiri copper mines in Akiri town, Awe local GovernmentArea of Nasarawa State, Nigeria. A representative sample from the bulk ore was crushed and ball milled and sieved with 250µm sieve to obtained 100% passing and the representative samples from the milled ore were used for both characterization and the leaching experiments. This particle size was used because it falls within the range of liberation sizes of the copper ore where copper particles are liberated.

2.2 Methods

The chemical and mineralogical characterizations were performed. These analyses of the test samples were conducted with aid of X-Ray Fluorescence (XRF) spectrometer, X-ray Diffractometer (XRD) methods, Atomic Absorption Spectroscopy(AAS) and Ore Micrograph respectively. Chemical analysis of the copper ore was done using a high-performance sequential wavelength dispersive XRF spectrometer, Shimadzu EDXRF-702HS operated at 40kV and 18mA. Mineralogical analysis was performed using a Shimadu XRS2400H diffractometer with Cu anode, $\lambda 1_{CU}$=1.541838[A^o]. The ore micrographs analysis was conducted with Leica optical microscope equipped with high level resolution digital camera for both reflected and transmitted light [3] at the department of Materials Science and Engineering of Obafemi Awolowo University, Ile-Ife, Osun State. Both XRD and XRF analyses were conducted at Afe Babalola University, Ado Ekiti, Ekiti State Nigeria. AAS was conducted at Central Science Laboratory of Obafemi Awolowo University, Ile-Ife, Osun State. These analyses were conducted to find the classification of individual minerals, the extent of association with each other and mode of occurrence.

The leaching reagent was prepared with analytic grade H_2SO_4 (Probus R.A ≥ 98% purity) and deionized water. The experiments were performed in 50ml conical flasks which were heated in electric oven under temperature control for different conditions to establish the best conditions for the leaching process. The leaching tests in bench scale were performed by using 3^3 factorial design experiments using the test parameters in the Table 1. A sample (5g) was prepared for each leaching test. The leachant was prepared in-predetermined concentrations stated in the Table 1. Then, based on 1:5g/ml solid-to-liquid ratio, 25ml of solution was poured into the conical flask. Then, sample of the ore was added into the flask and the content of the flask was mixed by stirring for 2 minutes. The mixture was heated at the set temperature for the required time.

After each experiment, solution was allowed cooled and then filtered into 250ml conical flask. Then residual collected, cleansed towards neutrality in-deionized water, air dried for 24hrs, oven dried at about 105^{o}C then weighed. The disparity in weight was noted for determining the fraction of the copper that had been dissolved. The solution of the experiment with the least weight was analyzed using AAS. The copper recovery into the copper loaded solution was estimated using the equation below:

$$Cu\ recovery = \frac{Cu\ leached\ per\ gram\ of\ copper\ ore}{Total\ Cu\ present\ per\ gram\ of\ raw\ copper\ ore}\ x\ 100\% \quad (1)$$

Copper leached = (xxmg/L*dilution factor*volume of the filtrate per gram of ore) [20].

The test was repeated on a magnetic stirrer hotplate and an agitated reactor to examine the effects of agitation rate on the leaching rate. This was performed in a 300ml reactor prepared with mechanical stirrer with a digital controller unit, thermostat and a timer. The reaction medium temperature was set as required. The contents in the reactor were heated initially with mild stirring at stage of heating and on reaching the set temperature, and then the stirring continued until the desired reaction time was reached. After the experiment, the content in the reactor was filtered immediately and the amount of copper and iron in the filtrate was determined by AAS.

Table1: Sulphuric acid LeachingTest parameters

		LEVELS		
Label	**Parameters**	**1**	**2**	**3**
A	Concentration(M)	0.5	1.0	1.5
B	Temperature(^{o}C)	50	70	90
C	Time(min)	30	60	90

2.3 Design of Experiment

Parameters used for copper dissolution from the Akiri hematite-dominated copper ore by H_2SO_4 leaching were evaluated with central composite design, a typical RSM design. RSM technique is appropriate to fits a quadratic surface and as well optimize the variables of the system with a least number of tests and to examine the synergy among the variables [21].

RSM is a statistical technique that is used for creating the empirical model, optimizing and improving process variables and find the synergy affecting variables [21]. The methodology involves designing experiments, creating models; and analyzing data in order to know the most significant input variables, and to examine the range of values that will yield the maximum possible outcome for the output variables [22].

2.4 Statistical Analysis and Model Fitting

Analysis of variance is a statistical tool for graphical analysis of information obtained from the experiment to explain the interaction among the parameters and the yields to calculate the statistical variables of the process. The analytical software was used on data from the experiments to plot the response surfaces, the regression analysis, and contour plot at the optimal conditions. Statistical weight was scanned with the F-

test, polynomial model fitting accuracy was evaluated with the R^2 coefficient and important model terms were estimated P-value (Probability value) with confidence interval of 95%.

3.0 RESULTS AND DISCUSSION

3.1 Characterization and Sulpheric acid Leaching Mechanism of the Copper Ore

Figure 1 shows the ore micrographs of the copper ore sample. From the result, three mineral phases can be recognized under plane polarized light, the phases are chalcopyrite (brassyellow), hematite (reddishbrown) and silica mineral (whitish). This confirmed that the mineral of interest copper is actually present in the Akiri copper ore sample. Nevertheless, the sample was subjected to further analysis for confirmation as follows.

The XRD pattern shows that the ore contains chalcopyrite ($CuFeS_2$)(-222) as the main copper mineral with 2.24% in composition,while covellite (CuS)(212), and cuprite (Cu_2O)(622) are the associated copper minerals with 1.76 and 1.29% respectively as shown in Figure 2. The XRD analysis also revealed the gangue minerals present in the ore namely; quartz (002), mica (011), plagioclase (022), K-Fieldspar (412), chlorite (222) and calcite (141). Calcite ($CaCO_3$) was present as a main acid consuming mineral. The XRD analysis indicated that the ore is made up of four major mineral groups that is sulphide, silicate, carbonates and oxide. This result is similar to the study reported by [23] that, Akiri copper ore contains chalcopyrite, siderite, azurite, quartz, hematite, goethite, pyrite and malachite from XRD analyses of different samples from the deposit, and interms of frequency of occurrence, $CuFeS_2$, $FeCO_3$ and SiO_2 are the most dominant minerals in the samples.

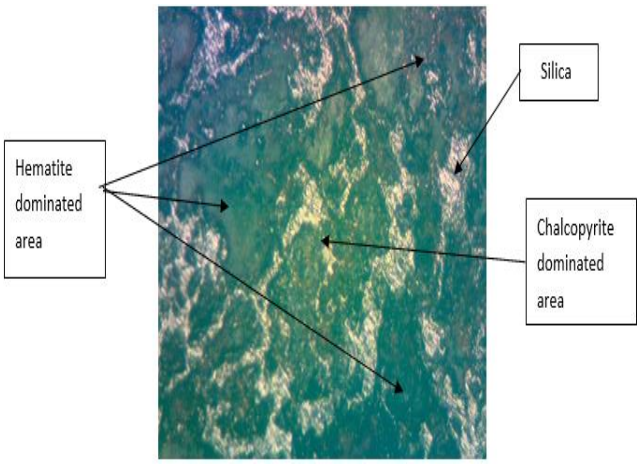

Figure 1: Micrograph of Head Sample under plane polarized light (x100)

The major oxides in the samples according to XRF analysis are hematite (Fe_2O_3), copper oxide (CuO) and quartz (Si_2O) as shown in Figure 3. The sulphur that is present means that the deposit is a sulphide ore deposit. A high content of Fe in combination with S and O is confirming that pyrite and hematite present. Deposits of chalcopyrite are mostly found with pyrite and hematite as major associated gangues. There are other trace elements,which constitute impurities in the ore Mn,Si,Ca,Ni etc. The AAS analysis result of the raw ore shows that, the ore contains 4.61% Cu and 22.48% Fe.

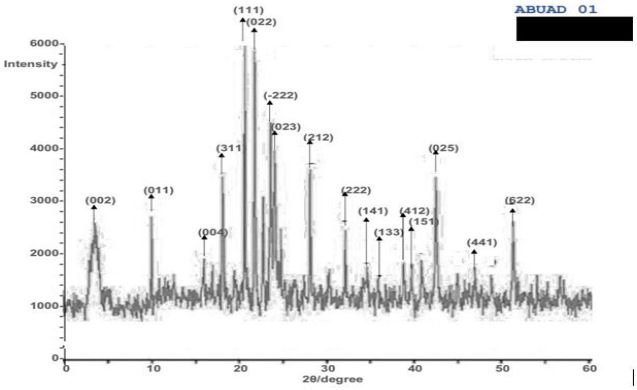

Figure 2: XRD pattern of the raw ore

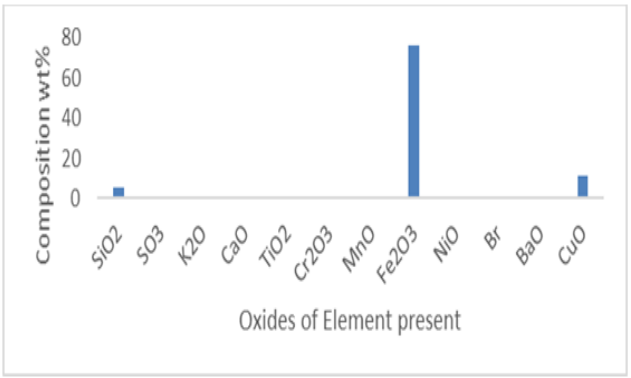

Figure 3: Chemical analysis of the Head Sample by XRF

The leaching behaviour of minerals is in response to temperature, concentration and contact time. The most used effective media with higher latent of extraction is sulpheric acid as compared with other substances that are used for leaching agents. The basis behind for greater degree of leaching may be as a result of the high attraction of hydrogen ion (H^+) towards the copper matrix minerals. Copper oxide ores contain Cu in the divalent state, for example, malachite, chrysocolla, tenorite and azurite and these are usually soluble in H_2SO_4 at 25°C [24]. Hence, when sulphuric acid is applied as leaching reagent to dissolve Cu from the copper ore, elements apart from

copper in the matrix of the ore as well leached along with the copper in the course of dissolution process. The impurities inside the filtrate need to be separated by solvent extraction before to the copper electro-winning step to raise the process current efficiency as well as the final product quality [25].

The reaction that always takes place during H_2SO_4 dissolution of chalcopyrite ore are as follows:

$$CuFeS_2 + Fe_2(SO_4)_3 \rightarrow CuSO_4 + 2FeSO_4 + FeS + S^0 \quad (2)$$

$$S^0 + H_2O + 1.5O_2 \rightarrow H_2SO_4 \quad (3)$$

$$2FeSO_4 + H_2SO_4 + 0.5O_2 \rightarrow Fe_2(SO_4)_2 + H_2O \quad (4)$$

The significant economic factor in the dissolution of oxidized ore of copper is the cost of the acid. Limestone and dolomite, which are carbonate rocks that are present in the ores, caused consumption of more acid. Hydrometallurgical method has become the most applied technique for treatment of tailings and low-grade ores because of the small fund as against that of high cost of pyrometallurgical method that demand serious environmental controls [26].

3.2 Model Development

A statistical ‘‘design-expert 6.0.6” software was used to examine the regression analysis of the data obtained from the experiments and to sketch the response surface plot. Statistical variables were calculated by applying analysis of variance. The sulpheric acid dissolution study, the needed scope of the experiment and parameters coded level are given in Tables 2 and 3, which shows the experimental design together with the outcomes from the tests.

As the yield suggested by the software, the quadratic model was not named. The final empirical model interms of a coded factor for copper extraction (weight loss, P%) is shown in Equation 5:

$$Wt.Loss = +21.84 + 2.14A + 1.18B + 5.00C + 0.76A^2 + 1.41B^2 + 3.73AC - 0.013BC \quad (5)$$

Where the + signify the synergistic effects whereas - signify the antagonistic effects.

Each model coefficients with lack of fit test and test for significance of the regression model were performed in order to fit a good model. Generally, the significant parameters were positioned based on the Model F-value or Probability value (P-value) with confidence level of 95%. As shown in Table 4, the analysis of variance for the data produced by Equation 5 for the copper recovery from the copper ore. The bigger F-value and the smaller ‘P’ value (Prob.>F), show more significant of the corresponding coefficient [27]. The F-value of the model is 22.50 implies that the model is significant. Also, the model coefficient terms are significant only when the values of‘‘Prob.>F” are > 0.05. In this work, A, C, C^2 and AC are the significant model terms.

Table 2: Experimental independent parameters and their coded levels for the central composite design

Independent variables	Symbol	Levels of coded variables		
		Low	Medium	High
		-1	0	+1
Temperature(°C)	A	50	70	90
Time (min)	B	30	60	90
Concentration(M)	C	0.5	1.0	1.5

Table 3: Experimental factors in actual unit and experimental responses

Std	Run	Block	Independent variables			Wt. LossP(%)
			A(degC)	B(Min)	C(M)	
6	1	1	90	30	1.50	37.82
2	2	1	90	30	0.50	19.42
5	3	1	50	30	1.50	24.68
13	4	1	70	60	0.50	21.20
11	5	1	70	30	1.00	22.40
9	6	1	50	60	1.00	21.98
14	7	1	70	60	1.50	28.37
12	8	1	70	90	1.00	23.72
10	9	1	90	60	1.00	22.84
3	10	1	50	90	0.50	24.38
1	11	1	50	30	0.50	21.62
4	12	1	90	90	0.50	21.96
8	13	1	90	90	1.50	39.10
16	14	1	70	60	1.00	21.50
15	15	1	70	60	1.00	22.94
7	16	1	50	90	1.50	27.82

Table 4: Analysis of variance (ANOVA) for response surface quadratic model for copper recovery in leaching of the crude copper ore

Source	Sum of Squares	Df	Mean Square	F value	Prob>F(value)	Remark

Model	495.40	9	55.04	22.50	0.0006	Significant
A	45.97	1	45.97	18.79	0.0049	Significant
B	13.97	1	13.97	5.71	0.0541	
C	249.90	1	249.90	102.13	<0.0001	Significant
A^2	1.53	1	1.53	0.63	0.4590	
B^2	5.26	1	5.26	2.15	0.1931	
C^2	25.94	1	25.94	10.60	0.0173	Significant
AB	0.21	1	0.21	0.086	0.7788	
AC	111.15	1	111.15	45.43	0.0005	Significant
BC	1.250E-003	1	1.250E-003	5.109E-004	0.9827	
Residual	14.68	6	2.45			
LackofFit	13.64	5	2.73	2.63	0.4354	Insignificant
PureError	1.04	1	1.04			
CorTotal	510.08	15				

The ‘‘Lack of fit F-value”of 2.63 means the Lack of Fit is significant comparative to the pure error. There is a 43.54% chance that a "Lack of Fit F-value" this large could take place due to noise. Non-significant lack of fit is good. Each parameter level was estimated based on initial swelling. The distance from the center to the axial points was ±1.6817 and it was estimated from $a=(2^k)^{0.25}$ where k denotes the number of parameters. Adequacy precision measured the signal to noise ratio, which contains both the average prediction error and predicted value at the design points. In this work, adequacy precision ratio is 15.735 and is good due to this ratio has been higher than 4. Therefore, the model developed can be applied to navigate the design space.

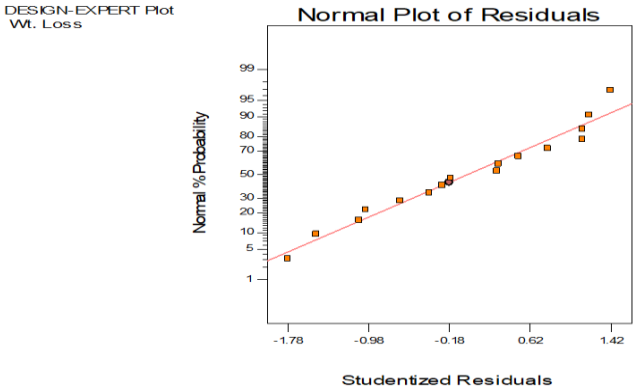

Figure 4: Studentized residuals and normal percentage probability plot for weight loss in leaching the copper ore

The adequateness of the built model was the primary step to examine the test data analysis. The studentized residual and normal probability plot was illustrated in Figure 4 for copper extraction % from the copper ore. From Figure 4, it can be seen that there was neither apparent problem nor response transformation with normality. Figure 5 illustrates the plot of internally studentized residual versus predicted copper extraction %. This shows that the entire values of the random scatter plot, the variance of original observation and the response is stable, and this was a sign that, transformation of response parameters was not needed. The actual and the predicted % for copper recovery was shown in Figure 6. 97% and 93% were the values for R^2 and adjusted R^2 (R_{adj}) found respectively.

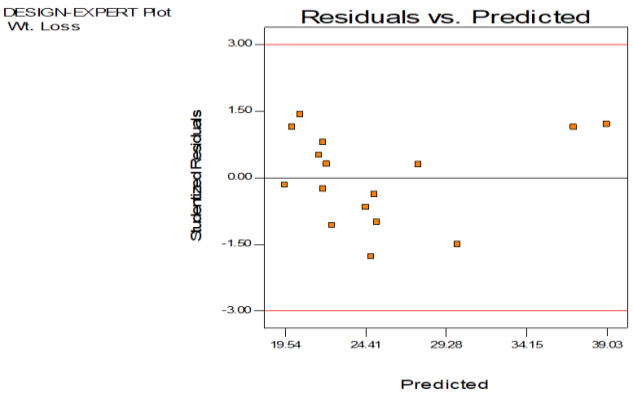

Figure 5: Predicted weight loss of the copper ore and studentized residuals plot

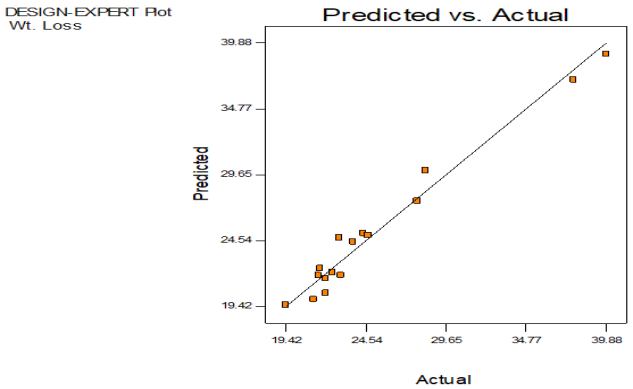

Figure 6: Actual and predicted plot of weight loss in leaching of the copper ore

R^2 value obtained explains upto what level good model can calculate the experimental data points and the value of the R_{adj} estimated the quantity of variation about mean spell out by the model. The value of predicted R^2 for Equation 5 was 0.7733, and relatively closes to the value of R^2. The data from the experiment for copper recovery % from the copper ore fitted well with the value predicted from the model as revealed. The model standard deviation is 1.56. The standard

deviation small value proves good model that gives close value between actual and predicted values for the responses. Table 6 illustrates the statistical parameters obtained from analysis of variance.

The pareto (Figure 7) was plotted using coefficients in Equation 5. Acid concentration (*C*) was major parameter that has impacts on the dissolution of copper from the ore. Since the coefficient for *C* in Equation 5 carries a + signs mean that the copper recovery increases as the concentration increases. Also, the most significant interaction term is AC. This means that the copper extraction is favourably influenced by combined variation in both temperature and concentration. From Equation 5 and Figure 7, increasing the entire variables can have positive effects on the extraction of copper.

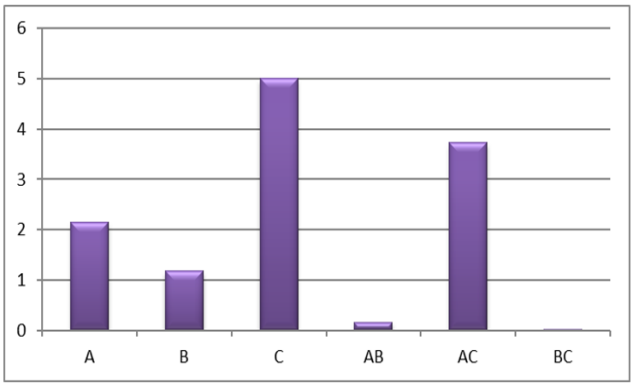

Figure 7: Pareto chart for copper extraction

Similarly, copper extraction is adversely affected by combined variation in both temperature and contact time, although these two parameters individually increase copper recovery, the term AB negative sign shows that more iron will be released as gangue as contact time is lengthen, depending on the temperature of the sample. Nevertheless, in the equation, the effect of BC terms interaction is minimal. The quadratic terms in the equation indicate the presence of curvatures. The + signs in Equation 5 shows that the quadratic curves for A^2, B^2 and C^2 are convex. This shows that copper extraction will be raising as the respective parameters are increased until maximum extraction is achieved.

Table 5: Staistical variables obtained from analysis of variance (ANOVA) for the models for weight loss percentage in leaching the crude ore

Insignificant factors excluded	Weight loss P(%)
Standarddeviation(S.D)	1.56
Mean	25.16
Coefficientofvariance(C.V)%	6.22
Adeqprecision	15.762
R^2	0.9712
AdjustedR^2	0.9280
PredictedR^2	0.7733
PRESS	115.63

Coefficients of the quadratic term's magnitude indicates the decent of the curvature. Hence, it from Table 5 and Equation 5 that C^2 is steeper than A^2 and B^2. The correlation coefficient of R^2 of 0.9712 value shows that only 2.88% of the entire variation could not be explained by the empirical model.

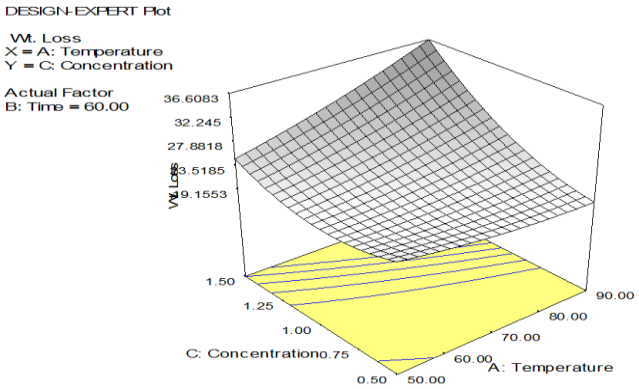

Figure 8: Combined effect of temperature and concentration on the copper recovery from of the copper ore

3.3 Combination Effect of Concentration, Temperature and Time on Copper Extraction

RSM was applied to examine the interaction and each factor effect of the 3-factor on copper extraction from the copper ore. According to analysis of variance, the results that were obtained, the effects of test factors on copper extraction, corresponding 3-D response surface plots were illustrated in Figures 8–10 and the response model was illustrated in Equation 5. The factors, temperature, time and concentration have significant effects on the copper extraction from the copper ore. By the application of RSM technique, it was discovered in Table 4 that the leaching factors affects the copper extraction (P) from the ore.

From Table 4, sulphuric acid concentration (C) was the factor that has major impact on the dissolution of copper from the copper ore compared to other factors, which may be as a result of the large F-value of 102.13 for sulphuric acid. Nevertheless, both temperature and contact time have less significant impacts for copper extraction from the ore. Though, the combined interaction between the parameters has no impacts on the copper extraction; only the concentration was discovered to be more effective on copper extraction. The dissolution concentration and temperature quadratic function demonstrated nearly alike impacts on the response, which was the small level significance in comparison to the quadratic function of time.

Response surface methodology was applied to examine the 3-D response plots that were produced from the impacts of the 3 parameters on copper extraction from the copper ore by sulphuric acid leaching. The ANOVA for a response surface quadratic model for copper extraction from the copper ore is shown in Table 5. According to RSM, the dissolution factors were involved more or less in increasing the efficacy of copper extraction (P).

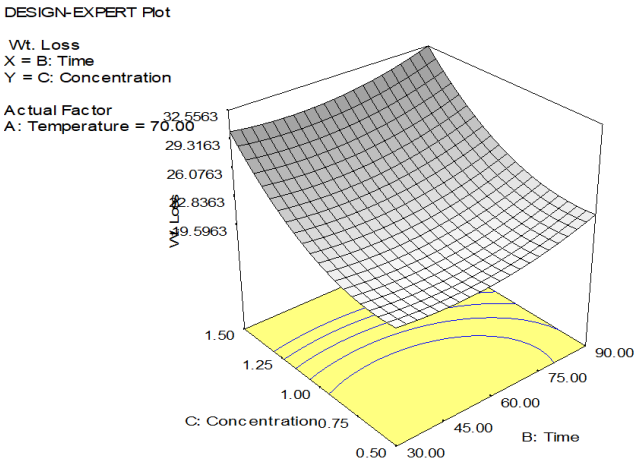

Figure 9: Interaction effect of time and concentration on the leaching of the copper ore

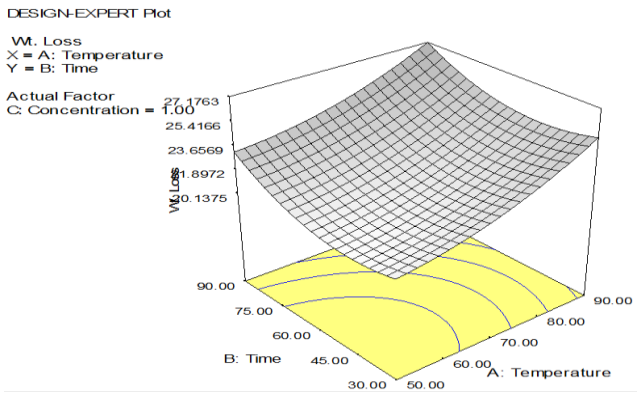

Figure 10: Interaction effect of time and temperature on the leaching of the copper ore

Figures 8 - 10 demonstrate the synergy among the factors in 3-D response surface plots. The scale values of the axis in the Figures 8-10 are real values. Figure 8 illustrates the interaction effect of temperature (A) and concentration (C) on copper extraction at constant contact time (60min). Copper dissolution increased due to the effects of concentration and temperature at constant contact time. The highest copper recovery of 92% was obtained. The synergy between the temperature and concentration was the most efficient factor for the copper extraction in the leaching process. Figure 8 and 10, showed that, the copper recovery increases with rise in temperature. Because, rise in temperature leads to the increase in reaction rate and as well as the reaction activation energy. When the leaching time is constant, the increase of leachant concentration from 0.5 to 1.5M and temperature rises from 50°C to studied range, this made the copper recovery to increase from 61 to 90.38%. The case for raised copper extraction discover from the analysis of variance table was the larger 'F'value of temperature and acid concentration, which showed the larger extent of dissolution effect [28]. The interaction effect of time (B) and concentration (C) on copper extraction from the copper ore at stable temperature (70°C) was illustrated in Figure 9. The copper recovery of 81.11% was obtained by the effect of time and concentration at constant temperature.

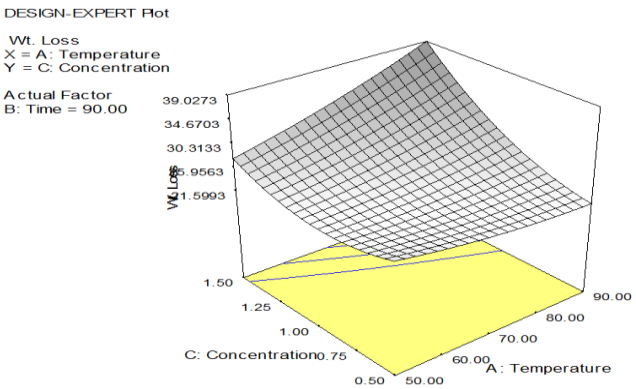

Figure 11: Optimum region on the concentration and temperature for maximization of copper recovery from the copper ore

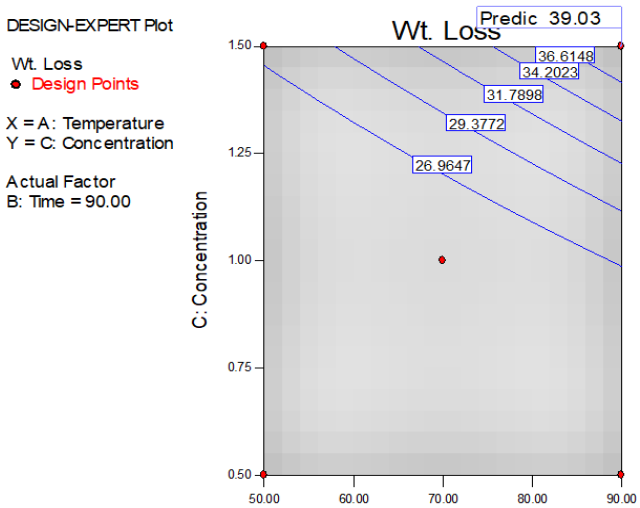

Figure 12: Contour plot of temperature and concentration on the leaching of the copper ore at optimum conditions

Also, the interaction effect of contact time (B) and temperature (A) on copper extraction at 1M concentration and the related 3-D response surface were showed in Figure 10. The results show that, temperature and contact time has fewer effects on

copper extraction from the copper ore because of the small value of F statistics. Copper recovery of 75.03% was obtained by the effect of temperature and contact time at 1M concentration.

3.4 Response Surface Modelling Optimization

To estimate the leaching optimum conditions where the highest copper recovery can be obtained from the copper ore is the most important aspect of this work. The leaching parameters optimization was examined in a numerical optimization technique. Figure 11 and 12 illustrate the response surface and contour plot at best leaching conditions for highest copper recovery respectively. Therefore, 1.5M acid concentration; 90°C temperature and 90min contact time were the optimum process conditions for the extraction of copper in the leaching of the copper ore. The experimental and predicted values obtained for the weight loss from the copper ore were 39.10% (92% copper recovery) and 39.03% (91.8% copper recovery) at the optimum leaching conditions, respectively. A contrast betwixt the predicted and experimental results shows <0.08% error. Therefore, the results show that the developed model can correctly predict the copper recovery. Optimization conditions information is illustrated in Table 6.

Table 6: Optimal processing conditions and model validation of percentage weight loss from numerical optimization

Parameters	TemperatureA(°C)	TimeB(Min)	ConcentrationC(M)	Weight LossP(%)	
				Predicted	Exptal
Optimum conditions	90.00	90.00	1.5	39.03	39.10

Table 7: Result of leaching crude ore with Stirring

Operation	%Cu	%Fe	R_{Cu}(%)	R_{Fe}(%)
Feed(-250μm)	4.68	11.33	***	***
LeachingwithoutStirring	6.64	2.31	92.00	57.30
LeachingwithStirring	7.84	5.47	83.51	24.07

3.5 Effects of Stirring Rate on the Extraction of Copper

To study the impact of rate of stirring on the extraction of copper, experiment was conducted using the optimum conditions (Acid concentration, 1.5M, Temperature, 90^{0}C and Contact time, 90minutes) and with optimum stirring rate of 400rpm [29]. In Table 7, the copper extraction efficiency increased with stirring rate. The copper grade increased from 6.64% Cu (leaching without stirring) to 7.84% Cu (leaching with stirring). But the copper recovery decreased from 92% (without stirring) to 83.51% (with stirring). The stirring action also affected the iron contents by increasing it from 2.31% to 5.47% Fe. It shows that, more iron was dissolved when the solution was stirred. According to hydrometallurgy kinetics principle ([30];[4]), reported that the rate of stirring has a strong impact on the leaching reaction efficiency (liquid-solid reaction) when the control step is fluid film diffusion, which can generally improve the dissolution efficiency greater than 40%. Although, the effect of stirring on the copper extraction efficiency is unnoticeable, shows that the rate-controlling step is not diffusion through the fluid film [31].

3.6 Validity of Shrinking Core Model (SCM) Test

The optimum leaching conditions found was applied to determine leaching kinetics of copper ore minerals. When liquid film diffusion (LFD) model controlled the leaching rate of the particle, then the integrated rate equation of this step is Equation 6 [31].

$$x = kt \quad (6)$$

When diffusion through a product layer (DLP) model controlled the leaching rate, the integrated rate equation of this step is Equation 7 [32].

$$1 - 3(1-x)^{\frac{2}{3}} + 2(1-x) = kt \quad (7)$$

The activation energies estimated for leaching of copper in sulphuric acid leachant according to LFD and DLP are 13.2 and 25.67kJ/mol^{-1}, respectively. The small values show that the dissolution rate is diffusion process controlled ([33];[34];[35]).

Hence, the activation energy value obtained in this work affirms that the leaching process is diffusion controlled through the product layer and liquid film controlled. Hence, the mathematical expression involving the factors in the experiment to represent the kinetics of the dissolution process can be written as follows:

$$x + 1 - 3(1-x)^{\frac{2}{3}} + 2(1-x) = 0.90944 \times e^{\frac{-25.67 \times 10^3}{8.314 \times T}} \times t \quad (8)$$

4.0 CONCLUSION

A simplistic single-step technique was used to activate sulpheric acid dissolution into hematite-dominated copper ore obtained from Akiri copper

mines. At optimized dissolution conditions, the level of copper extraction was maximized to obtain high grade copper by the reagent dissolution. The victorious activation of H_2SO_4 leaching on the copper ore shows that the copper can be beneficiated by hydrometallurgy to increase the copper grade from 4.68% to 6.64% at high copper recovery of 92% and reduced iron contents from 11.33% to 2.31%.

The maximal copper extraction from the copper ore at optimum dissolution conditions by using central composite design together with response surface methodology was examined. The optimization of variables and the regression analysis were estimated with the aid of design expert software to predicts the yield in the investigative regions. Regression analysis, statistical significance and response surface study was conducted using the values obtained from tests at factor working conditions. The dissolution test parameters were correlated to the responses by the model developed. Response surfaces were derived based on the models. The acid concentration used was the most significant effect on copper extraction from the copper ore to produce nearly pure copper metal with reduced iron and other gangues minerals. The dissolution system optimization was done and values obtained from experiments conducted for the copper extraction and obtained values predicted by the models were nearly closer. The optimal working conditions for maximizing the copper extraction were got at 90^{o}C temperature, 1.5M concentration and 90min contact time. Then, 0.08% was obtained as the absolute error. The acid wastes resulting from the leaching processes was treated by adding proper proportion of caustic soda and soda ash to ensure safe and clean environment.

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COMPARATIVE ANALYSIS OF ABRASIVE WEAR BETWEEN ALUMINIUM ALLOY AND MILD STEEL IN A PIN-ON-DISC TRIBOLOGICAL TEST

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Abstract

A comparative analysis of the abrasive wear of aluminium alloy and mild steel on the pin-on-disc wear test machine has been successfully carried out. An investigation on the effects of wear, stress and strain on the aluminium alloy and the mild steel was conducted. The wear test carried out determined the difference between rate of wear of the aluminium alloy and the mild steel. The input parameters applied in determining the wear rate were time of wear, sliding distance, track diameter of the disc and mass difference before and after the experiment. The finite element analysis developed the stress and elastic strain distribution obtained on the application of 2 kg load (20 N) on the aluminium alloy and mild steel specimen. The equivalent (Von Mises) stress distribution in mild steel had a maximum stress value of 0.023625 Mpa and minimum stress of 1.444×10^{-5} Mpa while that of the aluminium alloy yielded a maximum and minimum stress of 0.0365 Mpa and 8.5×10^{-5} Mpa respectively. It was evident that the aluminium alloy recorded a higher magnitude of stress than the mild steel. This showed that the aluminium alloy being relatively light was more stressed than the mild steel. It was discovered that the rate of wear was higher in the aluminium alloy than in the mild steel.

1.0 INTRODUCTION

The tribological study is a branch of engineering that entails the rubbing off of material surfaces. The process which leads to loss of materials is known as wear. A lot of materials have been put to use wrongly, because most engineers have not come to terms with adverse effect offered by conditions like wear, fatigue and corrosion [1]. The alloys of ferrous and non ferrous metals as they are applied in the environment are susceptible to the destructive influence of these material conditions [15][16].

Many types of wear exist. They are abrasive, frictional wear, adhesion and cohesion wear and corrosion wear. The most common is the Abrasive wear which has to do with the loss of material due to a hard particle been forced against a solid surface. A good knowledge of surface engineering will keep us abreast with how to tackle the menace of wear [2]. Surface finishing and application of lubricants on material surfaces will go a long way in checking the ravaging effect of wear.

Tribological studies have been carried out using various tools for its analysis. Experimental and optimization investigations have been conducted using tools such as the Design of experiments,

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Taguchi Design, Signa to noise ratio, Artificial Neural Network, Response Surface Methodology which comprises of Box-Behnken Design and Central Composite design, Genetic Algorithm and Particle Swarm Algorithm[3]. In the recent past some attention has shifted to the dexterity of applying Finite element analysis in material optimization. This Finite element analysis has a concern in various aspects of engineering.

The finite element method is a computer numerical method that utilizes the act of discretizing solution domain of complex mathematical problems into minute elements and nodes. It is applicable in the formation of new product as well as product refinement [4]. Notably, it handles the identification of nonlinear behaviour of components assembling such as the interaction between specimen pin and circular disc. The wear machine could be tagged nonlinear in behavior because of the nature of the load, torsion, stiffness, deformation, contact and boundary conditions. It involves solving the contact problem between the known areas of the pin and disc with respect to unknown areas [5][19]. This makes the problem quite nonlinear.

Some works have been done using the Finite element method. In optimization of the wear parameters by [6] the Finite Element Method was used to optimize the operating levels involved in the surface roughness of an aluminium alloy. The parameters employed were feed rate, cutting time, cutting speed and material removal rate. The prediction of wear rate is dependent on a number of experimental factors. Some of the factors examined by [7][17] showed a nonlinear influence on the wear rate of an automobile aluminium alloy component. The developed regression equation predicted a wear rate of about 0.013 g/mm from an interaction of process factors such as material removal rate, sliding speed, wear time and variable load.

Also, the effect of sliding distance, variable load, time of wear and surface roughness on abrasive wear was experimented upon by [8][18]. The experiment was performed under a dry lubricated condition of 23^{o}C and 40% environmental temperature and relative humidity respectively. A preliminary result revealed that wear volume increases with increasing sliding distance, time of wear, applied load and surface roughness. Conversely, the result showed a decreasing abrasive wear rate with sliding distance, time of wear, applied load and surface roughness.

This study is geared towards comparing the abrasive wear behavior between aluminium alloy and mild steel in a pin-on-disc wear test machine using finite element analysis. The parameters investigated are effect of wear, equivalent stress and strain.

2.0 MATERIALS AND METHODS

The materials used in this work are Pin-on-disc wear test machine shown in Figure 2, a modelled aluminium alloy specimen is shown on Figure 1, variable weights, stop watch and steel alloy. The ANSYS Finite Element software was used to perform stress and elastic strain analysis of the specimen pin.

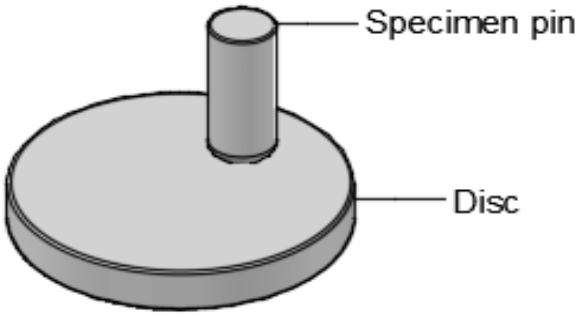

Figure 1: Specimen Pin on Disc

Figure 2: Pin on Disc Wear Test Machine

2.1 Method

The experiment was conducted by mounting the mild steel and aluminium alloy specimen pins whose length and diameter are 25 mm and 14 mm respectively on the lever arm placed directly on the circular disc. The circular disc was designed to be of diameter and thickness of 165 mm and 8 mm respectively as specified by ASTM-G99 standard code for wear experiment [9]. A weight of 2 kg was placed at the load holder to complete the contact action between the pin and the disc. The weight of the specimen pin was taken before and after each experiment. The disc rotated with a speed range of between 1000 and 1500 rpm in running the experiment. As the disc rotates in contact with the specimen pin there exists a detachment of material particles from the contact

surface of the pin. The pin on disc wear test machine has an in-built weighing balance that helps in recording the amount of the wear or lost material.

2.2 Determination of Wear Rate

The wear rate of the material was determined by using equation (1) obtained from [9]

$$W_r = \frac{M_i - M_f}{S_d} \quad (1)$$

Where; M_i is the initial mass of specimen in mg, M_f is the Final mass of specimen in mg, S_d is the sliding distance in mm, W_r is the Wear rate in mg/mm.

The sliding speed is the product of the angular speed in radians and the track radius. While the sliding distance in the wear experiment is the product of experimental time taken in seconds and the sliding speed. The wear test experiment was conducted between 3 minutes to 7 minutes with sliding speed of between 1100 rpm to 1500 rpm and track diameter of between 50 to 90 mm yielded various sliding distances and wear rates shown in Tables 3 and 4 for aluminium alloy and mild steel specimens respectively.

3.0 RESULTS AND DISCUSSION

3.1 Spectrographic Results

The results obtained from the experimentation conducted in determining the chemical composition and wear rate of the aluminium alloy specimen is shown on Tables 1 and 3. While that of the mild steel specimen is shown on Tables 2 and 4.

Table 1: Chemical composition of Aluminium alloy (AA 6061)

Components	Al	Mg	Si	Fe	Cu	Zn	Ti	Cr	Mn
Percentage weight	96.10	1.30	0.85	0.60	0.45	0.20	0.18	0.20	0.12

Table 2: Chemical composition of Mild Steel

Components	Fe	C	Si	Mn	S	P
Percentage weight	91.60	3.75	4.00	0.35	0.025	0.05

3.2 Wear Test Result

The results obtained from the abrasive wear experimentation conducted on aluminium alloy and mild steel specimens on the Pin-on-Disc wear test machine are as shown on Tables 3 and 4. Upon maintaining the input parameters, it was obvious that the mass difference between the initial mass of the specimen before experimentation and the final mass after experimentation was higher in aluminium alloy than the mild steel. Consequently, the wear rate of the aluminium alloy is higher than that of the mild steel as shown in Tables 3 and 4. This shows that more material particles were lost in the application of aluminium alloy than mild steel, as also reported by [10].

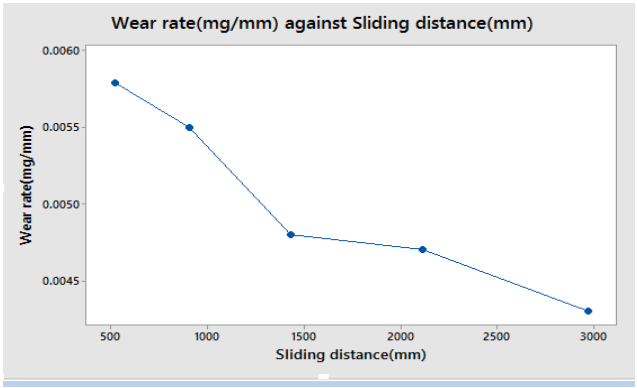

Figure 3: Scattered plot of Wear rate against sliding distance of aluminium alloy

Table 3: Wear test parameters for aluminium alloy specimen

S/N	Time, T(mins)	Speed (rpm)	Track diameter (mm)	Sliding distance, S_d (mm)	Initial mass of specimen,M_1 (mg)	Final mass of specimen, M_2 (mg)	Mass difference (mg)	Wear$(M_1M_2)/S_d$ (mg/mm)
1	3	1100	50	518.40	120	117	3	0.00579
2	4	1200	60	904.90	117	112	5	0.0055
3	5	1300	70	1430.00	112	105	7	0.0048
4	6	1400	80	2111.40	105	95	10	0.0047
5	7	1500	90	2969.20	95	82	13	0.0043

Table 4: Wear test parameters for the mild steel specimen

S/N	Time, T(mins)	Speed (rpm)	Track diameter(mm)	Sliding distance(mm)	Initial mass of specimen,M_1 (mg)	Final mass of specimen, M_2 (mg)	Mass difference (mg)	Wear$(M_1-M_2)/S_d$ (g/mm)
1	3	1100	50	518.40	135	133	2	0.00386
2	4	1200	60	904.90	133	130	3	0.00332
3	5	1300	70	1430.00	130	125	5	0.0035
4	6	1400	80	2111.40	125	118	7	0.00331
5	7	1500	90	2969.20	118	108	10	0.00336

Furthermore, scattered plots were developed to determine the relationship between wear rate and some of the input parameters. It was noticed that the wear rate decreases almost uniformly with an increase

in sliding distance as shown in Figure 3. Also, the same trend was seen in Figure 4 where the wear rate decreases with time of wear. These results and graphical trends were similar to that of [8].

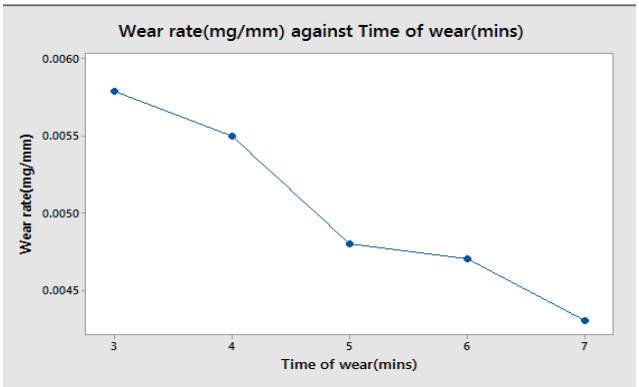

Figure 4: Scattered plot of Wear rate against time of wear of aluminium alloy

The scattered plot of the wear rate of the mild steel against sliding distance is shown in Figure 5. The graphical plot shows that the wear rate decreases with an increase in sliding distance initially and increases after sometime. Similarly, Figure 6 showed that the wear rate of the mild steel decreased with an increase in the time of wear.

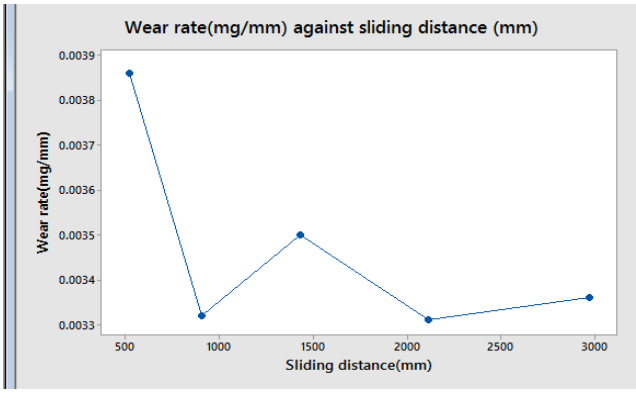

Figure 5: Scattered plot of Wear rate against sliding distance of mild steel

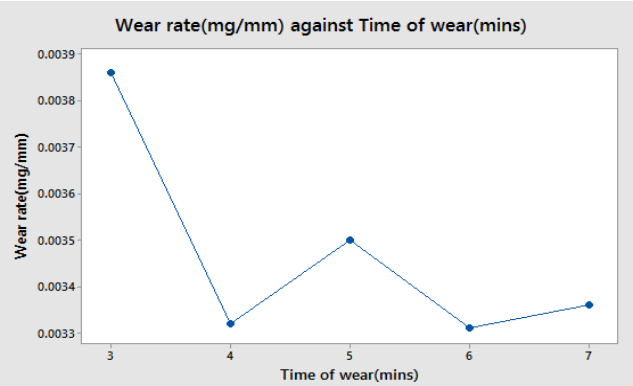

Figure 6: Scattered plot of Wear rate against sliding distance of mild steel

3.3 Finite Element Analysis

3.3.1 Finite element analysis of the aluminium alloy

The static structural tool of the Finite element ANSYS software was applied in this study. The modeled specimen pin was imported into the static structural Workbench environment. The aluminium alloy and mild steel specimens were analysed so as to obtain the stress and strain distribution using finite element ANSYS software [11][20]. A meshed structure of the aluminium alloy shown in Figure 7 comprised of nodes and elements of 3442 and 700 respectively. It was created with a smooth transition of 0.272 ratio having a growth rate of 1.2 and a maximum layer of 5.

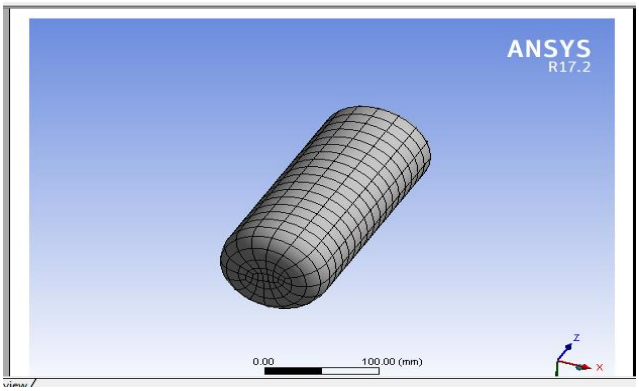

Figure 7: Meshed aluminium alloy specimen

The aluminium alloy examined for Equivalent (Von Mises) stress, had its graphical result shown in Figure 8. Its stress distribution showed that the maximum and minimum stress are 0.0365 Mpa and 0.000085 Mpa respectively. In carrying out the stress and elastic distribution a force of 20N was applied on the aluminium alloy. The elastic strain distribution obtained is shown in Figure 9. The distribution had maximum and minimum strain values of 1.82×10^{-7} and 8.166×10^{-10} respectively.

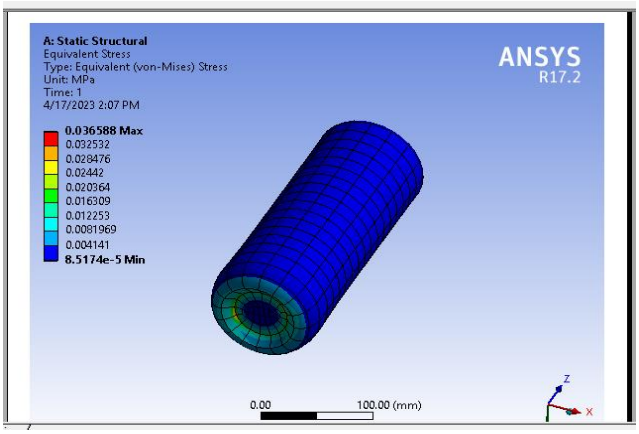

Figure 8: Von Mises stress distribution in Aluminium alloy

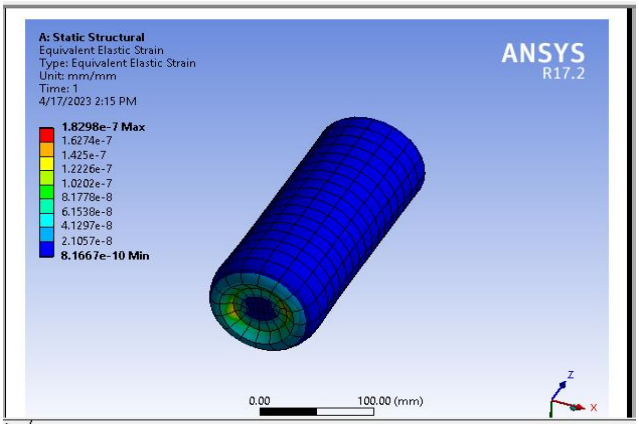

Figure 9: Elastic strain distribution in Aluminium alloy

3.3.2 Finite element analysis of the mild steel

The meshed mild steel specimen pin is shown in Figure 10. The meshing enabled the discretizing of the specimen for an effective and quick solution. The meshed structure had 700 elements and 3440 nodes as obtained in the aluminium alloy meshed structure.

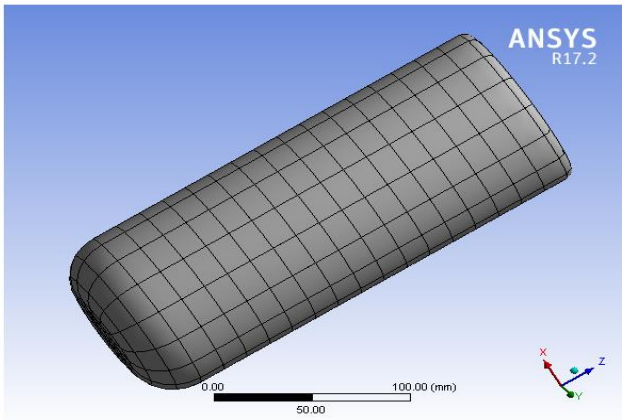

Figure 10: Meshed mild steel

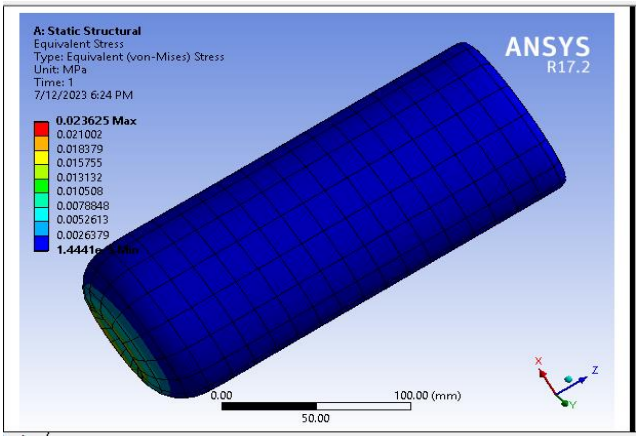

Figure 11: Von Mises stress distribution in Mild steel

The equivalent (Von Mises) stress distribution of the mild steel had a maximum stress of 0.023625 Mpa and minimum stress of 1.444×10^{-5} Mpa as shown in Figure 11. The maximum and minimum stresses obtained for the mild steel is known to be lower than that obtained for the aluminium alloy. This occurred because the aluminium alloy is lighter than the mild steel. Consequently, there was a higher distribution of stress in the aluminium alloy than in the mild steel.

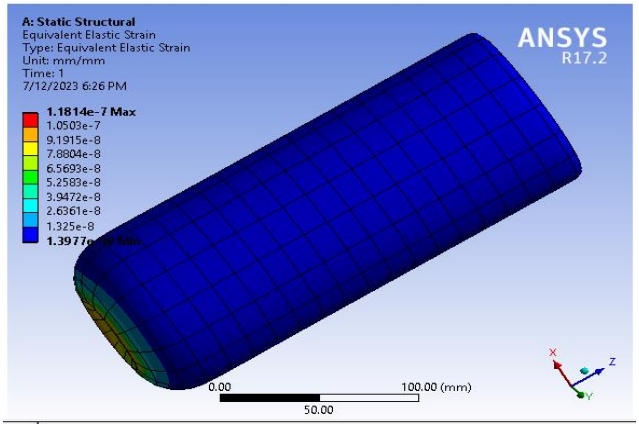

Figure 12: Elastic strain distribution in Mild steel

The elastic strain distribution is shown in Figure 12. The distribution had a maximum strain of 1.1814×10^{-7} and minimum strain of 1.3977×10^{-10}. Again, in comparison, it was noticed that the maximum and minimum strain values are lower than that obtained in aluminium alloy. This is also attributed to higher strength inherent in the mild steel as reported in [5] and [12].

4.0 CONCLUSION

A comparative analysis on the abrasive wear of aluminium alloy and mild steel on the pin-on-disc wear test machine has been successfully carried out. The wear rate of the aluminum alloy was noticed to have uniformly decreased with increase in sliding distance and time. While that of mild steel also decreased with increases in sliding distance and time of wear but not with the uniform trend obtained in alumimium alloy. The finite element analysis provided an opportunity of seeing the behavioural pattern of the stresses obtained on the application of 2 kg load (20 N) on the aluminium alloy and mild steel specimens. The equivalent (Von Mises) stress distribution in mild steel had a maximum stress of 0.023625 Mpa and minimum stress of 1.444×10^{-5} Mpa while that of the aluminium alloy had maximum and minimum stress of 0.0365 Mpa and 0.000085 Mpa respectively. This is a pointer that the lighter material aluminium alloy was more stressed than the mild steel. The study examined the effects of wear , stress and strain on the aluminium alloy and the mild steel. It was discovered that the rate of wear was higher in the

aluminium alloy than in the mild steel as shown in Figures 3 and 5. Similarly it was established that the aluminium alloy encountered a higher stress and strain than the mild steel [13] and [14]. That was occasioned by it's relatively lightness of weight of the aluminium alloy.

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A LINEAR MODEL-BASED SIMULATION TOOL FOR ESTIMATING NUMBER OF TRIALS NEEDED FOR UPPER LIMB STROKE RECOVERY IN A GIVEN REHABILITATION SESSION

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Abstract
Traditional methods for assessing upper-limb functional outcomes in stroke patients often fail to estimate the number of trials required to achieve performance stability of a chosen kinematic metric. Limited non-model-based studies have attempted to tackle this issue. To bridge this gap, this study utilized an iterative learning algorithm (ILA) in MATLAB, employing linear models to represent the muscle dynamics and forearm extension of impaired patients. The reference task space trajectory was set as a straight-line point-point trajectory within a range of 0 - 0.2828m. By using the root mean square error (RMSE) as a metric for evaluating kinematic accuracy, a maximum kinematic deviation error of 0.01m was imposed with respect to the trajectory by the (ILA). Results indicate that over 16 trials, performance stability was obtained with improvement in deviation error from 0.0168m in the first trial to 0.0060 at sixteen trials. The result obtained is in line with similar non-model studies and our findings inform the potential of ILAs with linear models for estimation of trial numbers required to attain performance stability of a selected kinematic metric (i.e., kinematic accuracy).

1.0 INTRODUCTION
Stroke is a neurological condition that arises from death of brain cells due to obstruction of proper flow of blood or injuries leading to blood spillage within the cerebrum [1-2]. Globally, stroke accounts for 11.6% of total deaths and 5.7% of total disability adjusted life years, thereby making it the second leading cause of death and disability respectively [3]. Recovery from stroke is highly time-dependent and often categorized into phases. The most significant improvement is known to happen between the hyperacute (<24h), acute (first 7 days) and beyond the early sub-acute (3-months). Beyond the sub-acute phase, recovery is reported to be at its limit leading to chronic deficit [4]. In most situations, the functional deficits developed by impaired patients is due to the huge financial burden (cost) on the patient, family, and society [5]. To further this claim, burden arises from direct and indirect cost associated with expensive health care systems and loss of downtime (i.e., productive time) [6].

Despite the cost, rehabilitation from stroke is seen as a cornerstone to restoration of brain tissue and networks via relearning and compensating for lost functional abilities [7]. It involves plastic re-organization of entire regions and brain pathways for

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the generation of commands to the same muscles that produced unique motor actions and patterns before the occurrence of stroke [8]. Clinician's prognoses are said to be an important factor in determining how timely an impaired patient starts or access rehabilitation and how much is paid. Currently, the widely utilized traditional scales (such as the modified Rankin Scale (mRS)) only provide a binary good or bad general outcome prediction that's not sufficiently detailed, helpful for patients and families [9].

Consequently, a new yardstick for evaluating adequacies of prediction tools was declared [9]. First, these tools should be capable of predicting future function rather than correlating current function. Second, usage should be at the start of recovery and rehabilitation so that predictions can inform rehabilitation sessions and discharge planning. Third, the tools need to make a forecast for a specified time point rather than the expected outcome at discharge. Lastly, the tools provide context and meaning for the individual patients being rehabilitated. In upper limb impairment, several studies have considered classification and identification of upper limb recovery. Additionally, these studies have employed prediction models for estimating upper limb function post stroke, but few have been transferred successfully from research to clinical practice due to lack of time, need for specific equipment and lack of adoption by therapists over their experience [10].

In a previous study, an algorithm called PREP was developed to predict potential for upper limb function [11]. Biomarkers obtained from specialized equipment' were combined with clinical scores measured with the action research arm test (ARAT) as predictors for the algorithm. The outcome of the study indicated a high positive predictive power for estimation of functional recovery post stroke. A graph probability curve tool for prediction of upper limb and ambulatory function six months post-stroke was developed [12]. Predictors employed were the national institute of health stroke scale (NIHSS) and age for estimating recovery. The outcome of the study showed that models combining the age and severity of stroke obtained using NIHSS predicted the ambulation and ability to perform functional tasks. In another study, a decision tree based PREP2 algorithm for upper limb function after stroke was created [13]. The study improved on earlier studies by applying clinical, neurophysiological, neuroimaging biomarkers of corticospinal integrity for prediction of motor function 3 months post stroke. The outcome of the study proved to be more accurate, efficient, and accessible than the preceding algorithm.

Another previous research applied machine learning for prediction of individual upper limb motor impairment after therapy in chronic stroke subject [14]. Predictors required by the machine learning algorithms were obtained using the Fugl-Meyer Assessment (FMA). The study concluded that elastic-net algorithm outperformed other algorithms in predicting recovery. Similarly, a computerized mixed-effect model was developed for patient-specific prediction in the upper limb area 6 months post stroke [15]. The predictors for the model were clinical (i.e., finger extension, shoulder abduction) and obtained using the ARAT. The outcome of the study indicated that only ARAT time course model performed as good as models with covariates when predicting upper limb function. A predictive algorithm using traditional logistic regression and random forest for early prediction of upper-limb function after 3-months post stroke was developed [16]. Predictors for respective models were extracted using ARAT. The outcome produced high classification accuracy when used to predict probable class (i.e., poor, limited, and good) of the subject. Additionally, several studies have developed simulation frameworks that combine models describing the non-linear dynamics of stroke subjects with robotics to estimate the level of functional recovery of impaired patients [17, 18, 19]. Rehabilitation robots are known to offer repetitive, goal-oriented, and highly intense tasks that invoke plastic changes and reduce burdens on therapists [20, 21]. However, owing to the time taken in identifying the mechanistic non-linear models used by these simulation frameworks, these works have found little adoption amongst therapists in traditional rehabilitation settings [22, 23].

Indeed, it can be stated that scholars have invested considerable effort in estimating the eventual functional outcome for individuals who have suffered from a stroke. Nevertheless, only a few studies up to date have explored the possibility of determining the specific number of trials needed to achieve performance stability. In a recent study, a non-model approach was utilized in determining the smallest number of trials required to attain a good performance stability of desired kinematic variables in a reach-and-drink task amongst non-disabled and stroke population [24]. The outcome of the study declared little trials were sufficient for attaining most functional outcomes in both groups within a given session except for outcomes that required more trials like reaching task, returning task, time to peak velocity, joint coordination, and movement smoothness. In another study, virtual reality simulat-

ion environment was used to estimate the number trials necessary to obtain stable kinematic variables during reaching movements in non-stroke subjects [25]. The outcome of the study showed that after five and three trials reaching stabilized in kids and adults respectively. Unlike previous works that relied on physical iterative experiments, this study utilizes iterative learning algorithms with linear models to estimate the number of trials required for achieving performance stability of a desired kinematic outcome. Notably, the goal is to show visible improvements from trial to trial on a planar surface within a single rehabilitation session. The study's significance lies in its ability to easily assess patients' performance stability for a selected kinematic outcome without subjecting vulnerable stroke subjects to tasks that yield limited benefits. Specifically, we utilize a single kinematic metric for determining performance stability of linear models representing an impaired subject tracking a given trajectory. This metric is referred to as kinematic accuracy (trajectory error) as given in [26].

2.0 MATERIALS AND METHODS

2.1 Models Employed

The models employed in this study is described from a top-bottom approach. First, a linear model that couples a forearm and robotic effect that approximates the effect of a physical therapist opposing a movement is discussed. Second, a linear muscle component of an established muscle model is presented. Third, a controller that ensures the resulting muscle activation is stable is considered.

2.1.1 Linear forearm model

In the present section, a linear approximate model is adopted because it offers a means to rapidly model a patient's forearm and desired opposing effects to movements. In healthy subjects, coordination of the arm results from the brain recruiting some muscle fibers to produce contractions necessary for movement [27]. As a result, a single input and single output (SISO), linear, time-invariant transfer function that gives a relationship between output forearm elbow joint movement and linear activated muscular contraction at the input is chosen. Furthermore, Equation (1) embeds an effect of a stroke patient interacting with a 5-link manipulator robot for upper limb stroke rehabilitation. (PULSR) [28].

$$T_{ar}(s) = \frac{\vartheta_f}{T_\beta} = \frac{1}{s\left((b_{a_3}+K_{M_2})s+K_{B_2}\right)} \quad (1)$$

where parameter b_{a_3} represents the triceps-brachii region of the forearm desired for rehabilitation, K_{M_2} and K_{B_2} parameters incorporate the virtual load and viscous friction to movement that a traditional therapist will present to an impaired patient during a rehabilitation session, ϑ_f denotes the resulting forearm movement due to muscle contraction T_β.

Furthermore, to accommodate differences in forearm length, weight, and other physical attributes of impaired patients' parameter b_{a_3} can be computed using the equation below.

$$b_{a_3} = m_f l_{f1}^2 + I_f + I_e\left(\frac{s_\gamma}{1-c_f^2 c_\gamma^2}\right)^2 \quad (2)$$

where $c_{(.)}$, $s_{(.)}$ denotes cosine and sine of orientation of elbow angles, m_f represents mass of forearm, l_{f_1} is the length of forearm from the olecranon joint to the forearm center of gravity, I_e explains the moment of the forearm, γ gives static angle of elevation of the arm on a 2D task surface and $\frac{s_\gamma}{1-c_f^2 c_\gamma^2}$ defines the region in the elbow where muscle is stimulated applied. Next section describes how T_β is modelled to yield necessary contraction that drives Equation (i).

2.1.2 Linear muscle model

There exist several methods such as the non-linear black box, light grey-box with physical insight approach and block-oriented approaches to capture dynamics of the muscle [29]. In the present work, a simplified block modelling approach given in Equation 3 is selected for its established dynamics in describing torque generated by the muscle as a function of stimulation delivered to the recruited muscle fibers, forearm movement dynamics and length. pulse-width, passive multiplicative effect of forearm length, active multiplicative effect of forearm displacement and velocity [30].

$$T_\beta = (H_{irc}(w_u) \times H_{lad}) \times F_{ma}(\dot{\vartheta}_f, \vartheta_f) + F_{mp}(l_f) \quad (3)$$

where $F_{ma}(\dot{\vartheta}_f)$ captures the active multiplicative effect of forearm displacement and its rate of change, $F_{mp}(l_f)$ denotes passive multiplicative effect of forearm length, H_{lad} represents linear activation dynamics and $H_{irc}(w_u)$ denotes the recruitment dynamics of the muscle based on applied stimuli w_u .

In accordance with [17, 31], the following equations approximated the inner blocks of Equation (3).

$$H_{irc} = f(u) = a_1.\frac{e^{a_2.w_u}-1}{e^{a_2.w_u}+a_3} \quad (4)$$

$$H_{lad} = \frac{{w_n}^2}{s^2+2s\zeta w_n+{w_n}^2} \quad (5)$$

$$F_{ma}(\dot{\vartheta}_f) = 0.54\tan^{-1}(5.69\dot{\vartheta}_f + 0.51) + 0.745 \quad (6)$$

$$F_{mp}(l_f) = e^{-\left(\frac{\bar{l}_f - 1}{\varepsilon}\right)^2} \quad (7)$$

where, a_1, a_2 and a_3 represents the static gain of the muscle contraction, $\dot{\vartheta}_f$ connotes the normalized rate of forearm displacement of the subject with respect to the maximum forearm displacement ability ($\frac{\vartheta_f}{\vartheta_{max}}$), $\bar{l}_f$ describes the normalized forearm length ($\frac{l_f}{l_{max}}$) and ε represents the shape-factor of force-length relationship. From [25], we approximate ζ to model damping factor and w_n oscillatory behavior of the muscle when excited.

With a focus on developing a linear simulation framework, the nonlinear torque elements contained in Equation (3) were linearized in the fashion below to leave the transfer function that describes only the activation or contraction dynamics of the muscle model in Equation (9) using Equation (8).

$$T_{\beta_{linearization}} = \left(\left(\left(\left(w_u + F_{mp}(l_f)\right)(H_{irc}{}^{-1}(H_{lad} \times H_{irc})\right)\right) \times F_{ma}{}^{-1}(\dot{\vartheta}_f, \vartheta_f)\right) \times F_{ma}(\dot{\vartheta}_f, \vartheta_f)\right) - F_{mp}(l_f) \quad (8)$$

$$T_\beta(s) = H_{lad} = \frac{T_\beta}{w_u} = \frac{{w_n}^2}{s^2 + 2s\zeta w_n + {w_n}^2} \quad (9)$$

2.1.3 Feedback controller

In an unimpaired patient with no stroke, joint coordination and movement requires relaying of fine-tuned, stable signals from the brain through the efferent pathways to the muscle [28]. Accordingly, it is deemed important to have a form of controller in the simulation framework that ensures transient response of the modelled unresponsive flaccid muscle of impaired subjects during a rehabilitative task to attain a steady state response rather than oscillatory response. Forthwith, an approximate form of a PD controller known as phase-lead compensator is selected to guarantee appropriate and stable physical characteristic during movement [32].

$$T_{pd}(s) = \frac{w_u}{e} = \frac{K_P}{1}\frac{\tau s + 1}{\varpi\tau s + 1} \quad (10)$$

where $\tau = \frac{K_D}{K_P}$, $0 < \varpi < 1$, and e is the feedback error between subject's movement error and the reference task given. The expression in (10) can be re-written as

$$T_{pd}(s) = \frac{w_u}{e} = \frac{(\frac{K_D}{K_P}s + 1)K_P}{\varpi\frac{K_D}{K_P}s + 1} \quad (11)$$

As $\varpi\frac{K_D}{K_P} \to 0$, the numerator approximates a typical PD controller. Next, an intelligent algorithm that estimates the number of trials that may be required by a subject to learn how to track a trajectory until a certain trajectory error is attained is discussed.

2.2 Feedforward Learning Algorithm

Iterative learning control (ILC) is a method that seeks to improve tracking accuracy of repetitive processes. The idea behind the technique is to use previous information from past operations to update the control input, in between iterations for better performance [33][34][35]. In the present study, ILC is formulated to estimate the number of trials required to attain certain level of tracking accuracy and to generate control efforts that causes the closed loop feedback system (i.e., the combination of the feedback controller, linear muscle model and subject's forearm) to have an improved performance at every trial within a given rehabilitation session.

2.2.1 Problem formulation

To begin with, a typical stroke rehabilitation is decomposed from an algorithmic perspective in this section. In rehabilitation scenarios, session starts with the clinicians assessing the physical impairment of the subject and using the relevant information obtained to define how long each session should be (i.e., number of repetitions per time unit/session) to avoid further injuries like ligament tears, capsule injuries and muscle fatigue [36, 37, 38, 39, 40]. For favorable outcomes, it is reported that a given session should last about 36 minutes to 1 hour per day [41]. In addition to this, recent consensus has established 15 trials as the least recommended number for functional task repetitions per session for both planar and 3D functional tasks [42]. Also, patient-specific tasks for each session must be developed to accommodate differences in physical attributes of patients and impairment stages [40]. Moreso, clinicians are occasionally tasked with setting the learning rate at which the subject should undertake the defined trajectory task [23, 39]. Accordingly, based on these real-life scenarios, these fundamental assumptions were established to formulate a proportional type of iterative learning algorithm for the linear simulation framework.

i. Definition of finite time interval for each trial for every given simulation/rehabilitation session.
ii. Availability or identification of system to be controlled. This refers to the closed loop feedback system. In this case is the linear models representing the stroke patients.
iii. Definition of the desired reference task plane trajectory to be tracked.
iv. Selection of a learning gain.

Likewise, fundamental ILC requirements that ensure the algorithm learns from repeating movement errors of an impaired subject were considered [43].

v. The bandwidth of the closed loop system must be known.
vi. Design of a Q-filter that removes ILC input signals that are above system's bandwidth at every iteration if noises exist in the feedforward input.
vii. The previous input signal applied by ILC must be stored in memory.
viii. The output displacement of the subject at every trial must be stored in memory.
ix. The error signal between the desired reference trajectory and the output displacement of the subject must be computed.

Consequently, a p-type linear-time invariant ILC structure is adopted in the present formulation [44]. It is indexed as a two-dimensional process over an iteration and fixed time domain [45].

$$U_{k+1}(t) = Q(U_k(t) + L_c e_k(t))$$
$$e_k(t) = Y_r(t) - Y_k(t) \quad (12)$$

where, t = trial period, k = iteration index, $U_k(t)$ is the ILC output over the present iteration index over t, $e_k(t)$ is the error at present iteration index over t, $Y_r(t)$ = reference trajectory over t , $Y_k(t)$ = subject forearm displacement over t, $U_{k+1}(t)$ = Next trial feedforward input over t, L_c = Proportional learning gain and Q = Filter.

2.2.2 Iterative learning algorithm (ILA) Development

The main objective or idea of the new algorithm is to estimate the number of trials k in the iteration domain that yields good forearm tracking performance under a given tracking error boundary $\bar{e}$ within a given rehabilitation period t. To start with,

i. Let $t_m = \frac{t}{t_s}$ be the length of vector space obtained from the ratio of trial time t and sample time t_s.
ii. Let the vector pair space of sample time and desired control variable be defined as
$\mathbb{R}^{t_m \times 2} = \{(\chi, t_s) | \chi, t_s \in \mathbb{R}\}$ (13)
where $U_k, U_{k+1}, e_k, Y_r, Y_k \in \chi$. Also let $Q, L_c \in \mathbb{R}$
iii. To obtain number of trials k which satisfies the objective, Equation (14) must be satisfied.
Find $k : \|Y_r(t) - Y_k(t)\| \leq \bar{e}$ (14)
$\bar{e}$ is the error threshold or boundary that must be met to predict k.
iv. With a defined desired reference trajectory $Y_r(t)$ and trial interval t, feedback controller parameters ϖ, K_D, K_p, muscle model parameters ζ, w_n, subject forearm parameter b_{a_3}, mechanical guide parameters K_{M_2}, K_{B_2}, given error threshold $\bar{e}$, sampling time t_s, learning gain L_c, and Q filter Compute
i. Create storage variables $Y_h, e_h, \in \mathbb{R}^{t_m \times 2}$
ii. Initialize $Y_h \leftarrow (\chi, t_s) | \chi = 0 \; \forall \; t_s$ and $e_h \leftarrow (\chi, t_s) | \chi = 0 \; \forall \; t_s$
iii. Set $k \leftarrow 0$
iv. Compute $G(H) \leftarrow T_{ar}(s).T_{\beta}(s).T_{pd}(s)$
v. Develop the closed loop feedback transfer function $T_c \leftarrow \frac{G(H)}{1+G(H)}$
vi. while ($e > \bar{e}$) do
vii. while ($t_s < t$)
viii. simulate (T_c, t_s, U_k, Y_r)
ix. store $Y_k \leftarrow [Y_h, t_s]$
x. store $e_k \leftarrow [e_h, t_s]$
xi. $k \leftarrow k + 1$
xii. compute U_{k+1} in Equation (12)
xiii. $U_k \leftarrow U_{k+1}$
xiv. return k

2.3 Implementation

In the section, an end-to-end straight line task plane trajectory was developed in MATLAB/SIMULINK environment for a typical reach-extend task for the linear forearm model discussed in the earlier sections. Anthropometric variables and muscle parameters describing an impaired stroke patient with upper-limb extremity were adapted from [31, 46]. Desired end-effector gains that incorporates a challenging task were manually selected as $K_D = 2$, $K_p = 9.98$, $\varpi = 0.05$ over statistically observed value range. Via Equations 15 - 20 and Table 1, the forearm joint angle movement is converted into the task plane trajectory for determination of performance stability of the model's kinematic movement with respect to the reference trajectory of 0 – 0.2828m. Thereafter, the algorithm generate signals for improving performance stability of the modelled subject until the kinematic movement error $e \leq \bar{e} = 0.01$m is satisfied over a trial period of 10 s.

$$r = \sqrt{{d_1}^2 + L^2} \quad (15)$$

where d_1 and L are horizontal (x) axis and vertical (y) axis respectively.

$$\phi = tan^{-1} \frac{d_1}{L} \quad (16)$$
$$Y_r(t) = [r, t_s] \quad (17)$$

With the output of $T_{ar}(s)$ been a joint variable ϑ_f and the designed trajectory paths mainly a resultant derived from cartesian plane components d_1 and L.

Thus, the forward kinematic relationship employed for mapping the joint space ϑ_f into cartesian space is

$$(\vartheta_f) = \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} L_u \cos(k(\vartheta_f)) + L_f \cos(k(\vartheta_f) + \vartheta_f) \\ L_u \sin(k(\vartheta_f)) + L_f \sin(k(\vartheta_f) + \vartheta_f) \end{bmatrix} \quad (18)$$

$$r_h = \sqrt{x^2 + y^2} \quad (19)$$

$$Y_h(t) = [r_h, t_s] \quad (20)$$

Table 1: Trajectory Path Parameters

Trajectory Parameter Description	Notation	Data
Minimum length of reach from glenohumeral joint base on the table	r_1	0.1m
Maximum Length of reach (MALOR) from glenohumeral joint base	r_2	0.3m
Task space trajectory orientation angle	ϕ	0.6109 rad
Horizontal distance from Subject's body	d_1	0.2 m
Subject specific workspace (Difference between MALOR and MILOR)	L	0.2 m

3.0 RESULTS AND DISCUSSION

3.1 Results

In this section simulation results of ILA with linear models representing impaired patients' muscle dynamics and forearm extension kinematic movement on a planar surface is reported. The root means square error (RMSE) metric was used for assessing the performance stability of the model tracking accuracy. As seen from Figure 1, the desired threshold that satisfies kinematic stability error $e \leq \bar{e} = 0.01$m was met under 2, 8 and 16 trial length for learning gains 0.9, 0.8, 0.2 and 0.1 respectively.

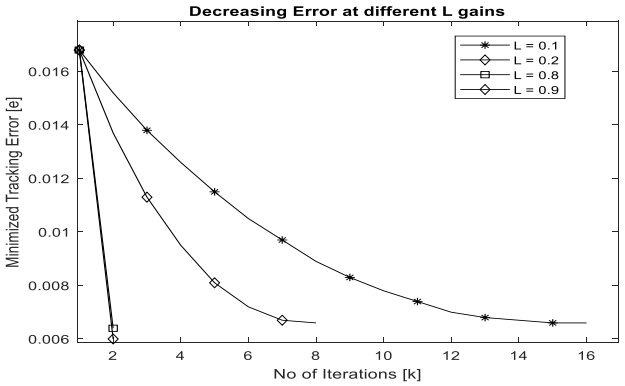

Figure 1: Plot of different kinematic stability error (e) at different learning gain (L) and trials (k)

Investigating further, Figure 2 shows the plot of kinematic movement of the subject's model around the given trajectory under an iterative learning gain of L = 0.1. Comparing the 1st and 16th trial of the simulation, the subject's model kinematic stability error e improved from a distance of 0.0168m to 0.0060m with respect to the trajectory. Furthermore, Figures 1 and 3 depict the impact of learning gain choice on kinematic stability performance. While it took the subject's computed model 16 trials to meet the desired error at L = 0.1, a step-by-step increase in learning gain depicts that a subject's computed model can be made to attain kinematic stability faster. Figure 3 confirms this claim by showing how the kinematic stability was attained under 2 iterations at L = 0.9.

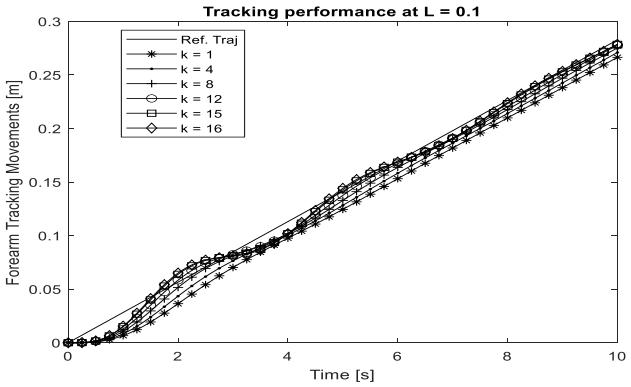

Figure 2: Plot of subject's model kinematic stability along reference trajectory at L = 0.1

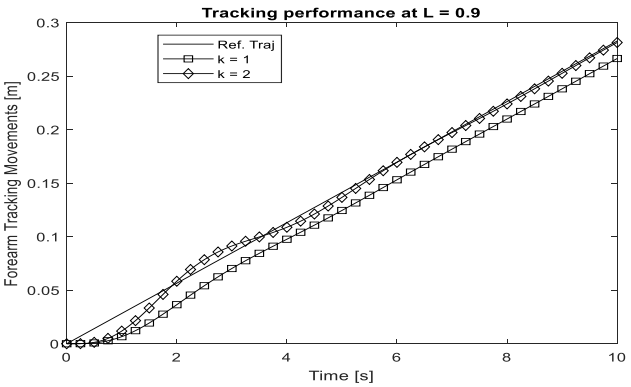

Figure 3: Plot of subject's model kinematic stability along reference trajectory at L = 0.9

3.2 Discussion

This study employed an iterative learning algorithm (ILA) to determine the optimal number of trials needed for achieving performance stability. Linear models represented impaired subjects, facilitating the investigation of kinematic movement on a planar surface. To assess kinematic stability, a predefined maximum deviation threshold ($\bar{e} = 0.01$m) was set, and simulation results showed that around 16 trials with a learning gain of L = 0.1 were required for attainment. Notably, the model's deviation error improves at every trial for instance, a noticeable improvement from 0.0168m to 0.0152m was observed between the 1st and 2nd trials, respectively. With $e > \bar{e}$, the simulation scheme continued until a good performance stability was attained at a constant error ($e < \bar{e}$) of 0.0066m at k = 16 trials. In comparison to other studies, ILA with linear model approach demonstrated progressive effectiveness in estimating the number of trials needed to achieve improved performance or meet the predefined maximum

deviation threshold. According to [42], authors recommended at least a minimum of 15 trials per task for assessment of performance on a 2D planar surface. In [47], an approximate number of 15 – 25 trials were utilized for reaching tasks in chronic stroke patients. In [24], authors reported that it took 2 – 3 trials to reach good performance stability of simpler kinematic measures in healthy and stroke subjects but more trials were needed to attain complex kinematic movements like reaching and returning task. As such, different studies reported that varying numbers of trials are required for kinematic stability based on task complexity and subject health status [25].

Another noteworthy outcome that deserves discussion is the influence of the learning gain (L) and the predefined kinematic error threshold ($\bar{e}$) in estimating the number of trials required to achieve kinematic stability. In a study without a specific kinematic error threshold, it was reported that a total of 47 trials before terminating movement due to non-improving kinematic stability in healthy individuals [48]. However, in the present work, by defining $\bar{e}$ the iterative learning algorithm (ILA) successfully simulated scenarios representing slow, medium, and fast recovery based on the choice of learning gain (L). Notably, when L was set to 0.9, the simulated model achieved the desired performance stability in only 2 trials, while L values of 0.2 and 0.8 required 8 and 2 trials, respectively. The careful selection of the learning gain proves to be critical, especially for models representing impaired subjects. For impaired patients nearing full recovery, it is advisable to use learning gains close to L = 1, while for severely impaired patients, learning gains between L = 0.001 and L = 0.1 may be more appropriate. This finding highlights the importance of tailoring the learning gain parameter to suit the specific needs and progress of the individual's undergoing rehabilitation or intervention.

Performance stability of selected kinematic metrics has been declared important for identification of deviations from typical patterns and evaluation of effectiveness of possible intervention [25]. This model-based study validates the combination of the ILA algorithm with linear models for estimating the number of trials needed to achieve kinematic accuracy under a strict deviation setpoint. The trial estimation results align with prior research in this field. Furthermore, it highlights the adaptability of the ILA learning gain subspace for different impaired subjects. Nevertheless, several caveats need consideration. Firstly, the linear forearm model only assesses a single kinematic variable (i.e., accuracy of elbow extension on a planar surface). Secondly, parameter values were sourced from existing studies, and validation with actual stroke subjects is essential. Thirdly, the efficacy of the scheme depends on cautious selection of ILA gains and accurate parameters for modeling impaired subjects.

4.0 CONCLUSION

Modeling and simulation can be an important first step at the start of recovery and rehabilitation. This claim is because it offers multiple benefits such as forecasting the number of trials that may be needed to attain kinematic stability rather than a precise functional outcome. The future of this work would investigate and validate ILA + linear model results with impaired subjects during pilot studies. Additionally, future work will focus on estimating the number of sessions that may be required to attain more selected kinematic skills along with likelihood prediction of subject recovery.

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USER PAIRING IMPACT ON THE PERFORMANCE OF HYBRID BEAMFORMING NOMA SYSTEM

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Abstract

This paper proposes a new user pairing technique for a power domain non-orthogonal multiple access (NOMA) deploying fully connected and sub-connected hybrid beamforming (HBF) structures for a typical urban microcell downlink of line-of-sight (LOS) and non-line-of-sight (NLOS) surroundings. NOMA system's configurations are set up for two (multiple input single output) users per cluster down-linking base station equipped with 128 antennas. HBF processing adopts phased zero forcing (P-ZF) for both fully connected (HBF-NOMA) structure (FCS) and sub-connected (HBF-NOMA) structure (SCS) precoders' optimization, and successive interference cancellation zero forcing (SIC-ZF) schemes to optimize the SCS-HBF-NOMA precoder exploiting dynamic power allocation. The new users' pairing exploits users' distance to the base station, namely near and far clusters different from the benchmark angle of arrival- based users' pairing. The proposed users' pairing and the precoding schemes' impact are investigated for finite-resolution HBF structures operating in LOS and NLOS surroundings. The execution under New York University (NYU) mmW channel model is explored for two users in a cluster with different angles of arrival. Results show that the users' pairing based on AoA performs better than the newly proposed users' pairing. However, the proposed users' pairing scheme performs better than their corresponding OMA counterparts, which still make them beneficial for multiple access technique and a scenario, where one of the far cluster users need to access the base station for high data rate service and vice versa. Finally, the modified Liang processing scheme for quantizing SCS-HBF-NOMA precoder is capable of mitigating the quantization error arising from the NLOS environment and the nature of sub-connected (HBF) structure under a low SNR regime.

1.0 INTRODUCTION

Hybrid beamforming (HBF) conjunct with non-orthogonal multiple access (NOMA) is a hybrid technology recently discovered to further allow high data rate in the order of GB per second in post 5G wireless communications. Specifically, the HBF evolved to address the hardware constraint attribute of digital beamforming in massive multiple-input-multiple- output (MIMO) systems, while the NOMA design was presented to further ameliorate the capacity of a conventional multiple users system by allowing more than one user pairing for the same resources of the base station [1]. More specifically, the HBF exploits the full connection or sub-connection of radio frequency chains (RFC) at the output of the

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digital precoder to the antenna connections at the output of the analog precoder. Detail of fully connected HBF and sub-connected HBF structure is referred to the [2].

Moreover, NOMA scheme involves the superposition of same cluster users' symbols before precoding at the base station and successive interference cancellation at each strong user before detection. Effective NOMA communications can be achieved by exploiting appropriate users grouping termed clustering. Hence, existing literature on HBF-NOMA had proposed several approaches for users' clustering, namely: users' clustering on the basis of weak users' channels correlation to the cluster head channels [3], and user's angle of arrival (AoA) [4]. Motivated by the single cluster HBF-NOMA scenario, where users are not on the same AoA, multiple cluster-based HBF-NOMA exploring users' clustering based on distance is expected to be practical for NOMA communications.

Additionally, HBF precoders can be quantized to further reduce the implementation cost and the power consumed by the analog precoder section of HBF. Therefore, extending our investigation to the finite resolution HBF-NOMA systems deploying the proposed users' clustering is crucial to readers. Therefore, this paper tends to study the user pairing (based on cluster distance) impact on the data rate Performance of HBFNOMA Users, considering both finite, and infinite resolution HBF precoders scenarios.

2.0 METHODOLOGY

For the purpose of benchmarking the proposed users' pairing scheme with that of the existing scheme formulated on the basis of AoA in [4], the system model is configured for multiuser-based multiple input single output (MISO) NOMA, where a base station at the center of an urban microcell downlinking the $M = 2$ (two) users per cluster and the total cluster's number is assumed for $N = 2$ to make the system analysis a simple one. Hence the transmit and receive antennas at the base station and users are set to $N_t = 128$ and $N_r = 1$, respectively. The rest system's configurations are similar to that in [4] with an exception to the users' clustering. Hence, users are clustered as near and far users as visualized in Figure 1. Furthermore, the near cluster contains users having different AoA but are nearer to the base station compared to the far cluster.

Notwithstanding, user $U_{n,m}$ indicates mth user in n cluster, where $m = [1,2]$ and $n = 1$ as well as $n = 2$ represent the near user and far user, respectively. Therefore, $U_{1,1}$ and $U_{1,2}$ denote the first user and second user in the near cluster, respectively, while $U_{2,1}$ and $U_{2,2}$ symbolize the first user and second user in the far cluster, respectively. Whereas Figure 1 of [4] have the cluster formulation on the basis of AoA rather than distance and named $U_{1,1}$ and $U_{1,2}$ as the first (near) user and second (far) user in the (10^o AoA) first cluster, respectively, as well as $U_{2,1}$, and $U_{2,2}$ are named as the first (near) user and second (far) user in the (20^o AoA) second cluster, respectively. Therefore, it can be inferred that the proposed new user pairing adopts the "near" and "far" distance-based clustering approach rather than the "first" and "second" AoA-based clustering approach in [4]. Common to the two clustering approaches to be studied here is that the users in each cluster can be classified into strong and weak users depending on their channel coefficients' magnitude. Usually, in each cluster, a user located at a nearer distance measured from the base station becomes a strong user, while the other one is regarded as a weak user.

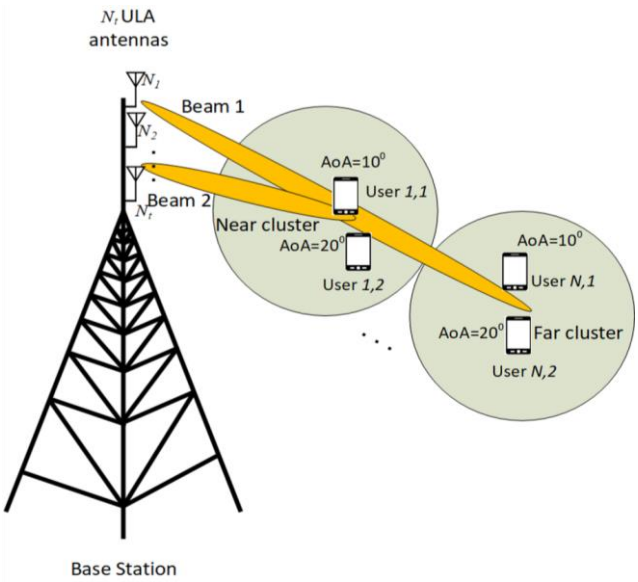


Figure 1: HBF-NOMA System deploying users clustering based on distance

Hence, the proposed user pairing based on the user's distance enables the feasibility of categorizing the user in the near and far clusters as either a strong or weak user. On the other hand, the user pairing based on AoA allows the near and far users in each cluster to be configured for strong and weak users, respectively. In this regard, the weak user in the AoA framework becomes a strong user in the proposed user's distance framework. The base station is equipped with the fully connected structure (FCS) and sub-connected structure (SCS) HBFs configured for MISO-HBF-NOMA framework in [4]. Hence, the hybrid

precoding method on the basis of phased zero forcing (P-ZF), and successive interference cancellation zero forcing (SIC-ZF) schemes are adopted to investigate the proposed user pairing approaches and that of AoA methods. Moreover, the dynamic power allocation method proposed in [2] is also adopted to optimize the power allocation coefficient deployed for NOMA scheme. Therefore, details of optimizing the HBF (using P-ZF and SIC-ZF processing) and dynamic power allocation factors are referred to [4] [2].

A. mmWave MISO Channel Modelling

Each MISO user's channel coefficient; a constituent of a multiuser HBF-NOMA channel is based on the NYU mmW channel model [5]. Hence, each user's channel coefficient $\mathrm{h}_{(n,m)}$ is modelled as

$$\mathrm{h}_{(n,m)} \in \mathbb{C}^{1\times N_t} = \sum_{v=1}^{V} \gamma_{(n,m,v)}\, e^{j\Phi_1} e^{-j\Phi_2}\, \mathrm{a}_t\left(\emptyset_{(n,m,v)}\right) \quad (1)$$

Where; Φ_1 and Φ_2 denote $\Phi_{(n,m,v)}$ and $2\pi f\tau_{(n,m,v)}$. respectively, and $\gamma(n,m,v)$, $\Phi(n,m,v)$, f, $\tau(n,m,v)$, and $\mathrm{a}_t(.)$ denote amplitude of the channel gain in the vth resolvable multipath component, the phase of the multipath component, carrier frequency, time delay and array steering function depending on the angle of departure (AOD), ϕ, at the Base station (BS), respectively.

NYUSIM software is configured for both LOS and NLOS scenarios adopting the data from Table 1 in [4] to generate DirPDPinfo.mat for the simulation of $\mathrm{h}_{(n,m)}$ exploiting NYU channel model. Users nearer to the base station are clustered together as a near cluster and ordered in subside sequence of their channel measured, namely, $|\mathrm{h}_{(n,1)}\mathrm{Fd}_n| > |\mathrm{h}_{(n,2)}\mathrm{Fd}_n|$ for two users per cluster, where F and d_n represent analog beamforming matrix and nth cluster users' digital precoding vector, respectively.

B. Performance Metrics

Before transmission, the users' symbols are superimposed to s_n at the BS using a dynamic power optimization scheme in [2], that is

$$s_n = \sum_{m=1}^{2} \sqrt{\alpha_{(n,m)} \times p_n \times s_{(n,m)}} \quad (2)$$

where $\alpha_{(n,m)}$, $s_{(n,m)}$, and p_n represent the power allocation factor, the transmitted symbol of a user $U_{(n,m)}$, and nth cluster power, respectively.

At the strong user, SIC has performed on the other weak user's symbols prior to the detection of its own symbol. Hence, a single-stage SIC processing is performed before the weak user finally detects its own symbols for two users per cluster scenario in this paper. This SIC is achievable on the account of the rate of strong users being higher than that of weak users.

Therefore, attainable rate of the user $U_{(n,m)}$ is prepared as:

$$R_{(n,m)} = \log_2(1 + y_{(n,m)}) \quad (3)$$

and $y_{(n,2)}$ of user $U_{(n,2)}$ for n = [1,2] is prepared as

$$\frac{\zeta_{(n,2)}|\mathrm{h}_{(n,2)}\mathrm{Fd}_n|^2}{\beta_{(n,2)}^{intra}+\beta_{(n,2)}^{inter}+1} \quad (4)$$

as well as $y_{(n,1)}$ of user $U_{(n,1)}$ for n = [1,2] is prepared as

$$\zeta_{(n,1)}|\mathrm{h}_{(n,1)}\mathrm{Fd}_n|^2 \quad (5)$$

where; $\zeta_{(n,m)} = \frac{p_n \times \alpha_{(n,m)}}{\sigma^2_{(n,m)}}$ denotes signal to noise(SNR) power for user $U_{(n,m)}$ and $\beta_{(n,2)}^{intra} = \zeta_{(n,1)}|\mathrm{h}_{(n,2)}\mathrm{Fd}_n|^2$ indicates the intra-cluster intercession at the $U_{(n,2)}$ after SIC refining at the strong user in the nth cluster.

Moreover, inter-cluster interference $\beta_{(n,2)}^{intra}$ represents $\sum_{l\neq n}^{2}\sum_{q=1}^{2}\zeta_{(l,q)}|h_{(n,2)}\mathrm{Fd}_l|^2$ at the $U_{(n,2)}$ in the nth cluster. Also, F, d, and $\sigma^2_{(n,m)}$ symbolize analog beamforming matrix, digital beamforming vector, and noise variance of additive white Gaussian noise arising through the user $U_{(n,m)}$ antenna, respectively. Hence, we formulate the sum rate execution of the mmW power-domain NOMA system as

$$R_s = \sum_{n=1}^{N}\sum_{m=1}^{M} R_{n,m} \quad (6)$$

C. Sum-rate Optimization Problem

The optimization problem for HBF-NOMA can be formulated as the escalation of sum rate in (6), subject to its associated constraints in (7), mathematically maximize R_s,

$$\begin{aligned} &\{\mathrm{F}, \mathrm{d}_n, \alpha_{(n,m)}\} \\ &\text{Subject to } \left|\mathrm{F}_{(i,j)}\right|^2 = \mathcal{M}_t^{-1}, \\ &\text{Blk.diag.}[\mathrm{f}_1, \mathrm{f}_2][\mathrm{d}_1, \mathrm{d}_2]\|^2{}_F = N, \\ &R_{n,m} > 0, \\ &\sum_{n-1}^{2}\sum_{m-1}^{2} p_{(n,m)} \leq P, \\ &p_{n,m} > 0, \end{aligned} \quad (7)$$

where M_t is the amount of antenna elements of each sub-assembly at the transmitter and blk. diag. denotes block diagonalization for SCS-HBF scenario, which can be replaced by N_t for the FCS-HBF case.

The problem of (7) has been addressed in literature deploying P-ZF-HBF and SIC-ZF designes for user pairing based on AoA. Hence, user pairing based on distance is proposed in this paper deploying the P-ZF,

and SIC-ZF (HBFNOMA) schemes under LOS, and NLOS downlink scenarios.

D. Hybrid Precoder Quantisation Using Modified Liang Procedure

The Analog precoder section of the hybrid precoder has elements differing in analog phases. whereas, the hands-on application of analog precoder is constrained to finite in bit resolution. An adequately quantized phase shifter is capable of consuming lower power on the ground that the power consumed by the phase shifter is commensurate to its bit resolution. In this regard, a hybrid beamformer under the hands-on framework of laboriously quantized phase shifters is investigated. In order to design an energy-efficient precoder. Therefore, the impact of our proposed users pairing based on users' distances on the performance of the FCSHBF-NOMA and SCS-HBF-NOMA deploying either P-ZF or SIC-ZF hybrid precoding scheme is investigated and compared to that of users pairing based on users' AoAs in both LOS and NLOS urban microcell links. Exploiting the Liang quantization algorithm proposed for HBF system in [6] and adopted for HBF-NOMA in [4], analog precoder and digital precoder parts of hybrid beamformer were quantized exploiting Equations (33) to (34) and (35) to (38) from [4], respectfully. Owing to the deployment of SCS-HBF at the base station, which may likely experience strange performance trends for finite resolution SCS-HBF-NOMA communication due to many reasons causing quantization errors, namely i.) users in different AoAs clustered together, ii.) Signal processing scheme deployed for optimization, and iii.) the low signal strength peculiarity of NLOS link.

Therefore, the Liang quantization procedure is modified at Equation (33) of [4] by introducing a mitigating parameter M to mitigate the quantization errors leading to the elimination of abnormal performance trends. Explicitly, the modified section of Liang finite resolution analog precoder **F** elements' phases using (33) of [4] is modified to

$$\hat{\phi}_m = \sqrt[8]{\mathcal{M}}\,\frac{2\pi\hat{e}}{B} \tag{8}$$

for b-bit resolution, where $B = 2^b$ and $\hat{e}$ is chosen according to

$$\hat{e} = arg \min_{e\in\{0,\dots B\}} \left|\phi_n(i) - \frac{2\pi e}{B}\right| \tag{9}$$

Notably, $i \in [1,\dots,N_l]$ and $i \in [1,\dots,M]$ for FCS and SCS analog precoders, respectively, and $\phi_n(i)$ is the analog phase of the nth vector's (ith) element of F precoder obtained from deploying phased and SIC schemes using (32) and (30) of [4], respectively. Details of the phased scheme for SCS analog precoder are referred to [7]. Hence, the digital precoder can be obtained by exploiting the ZF scheme defined as

$$\mathrm{D} = \bar{\mathrm{H}}_{(n,1)}\left(\bar{\mathrm{H}}_{(n,1)}\bar{\mathrm{H}}^{H}_{(n,1)}\right)^{-1}\bar{\beta} \tag{10}$$

Where β is the modified normalized factor to ensure total power constraint on the digital precoder matrix D $\in C^{N\times N}$ and the $\sqrt[8]{M}$ is employed to suppress any abnormal performance trend arising from SCS-HBF quantization in an NLOS environment deploying Liang procedure.

The composite hybrid channel comprising various strong users' hybrid channels for $n = [1,\dots N]$th clusters can be modeled as

$$\underline{H}_{(n,1)} = [\underline{h}_{(1,1)}F_T(\underline{h}_{(2,1)})F_T]_T \tag{11}$$

3.0 RESULTS AND DISCUSSION

Users in two clusters are simulated based on system model configurations. System parameters for both LOS and NLOS links are configured as in [1] and the rest configurations are the same as in Table 1 of [4] to obtain the output files 'DirPDPinfo.mat' and Basic Parameters. mat from the NYUSIM. For readers' convenience, the carrier frequency, RF bandwidth, barometric pressure, humidity, temperature, rain rate, foliage attenuation, and polarization are configured for NYUSIM are presented here as 28 [GHz], 800 [MHz], 1013.25 mbar, 50%, 20^oC, 0 [mm/h], 0.4, and co-polarization, respectively. The two output files are used to simulate the proposed mmW MISO-NOMA systems' channel coefficients. Users in the near and far clusters are ordered on the basis of the users' channel magnitude orders to classify users into either strong users or weak users. Link-level simulations of the proposed HBF-NOMA based on a dynamic power approach in [7] are implemented for M(= 2) users per cluster to benchmark the HBF-NOMA scenario based on the AoA users clustering scheme. Transmit and receive RF chains as well as the number of clusters is preset to 2, 1, and 2, respectively. For LOS and NLOS links, respectively. $d_{n,m}$ is set as shown in Table 1. With the deployment of the deterministic channel model, a single-run simulation is executed owing to the system structure for SNR values varying between $-10[dB]$ to $30[dB]$.

Table 1: NOMA Channel Parameters Exploited for NYUSIM

Parameters	LOS	NLOS
$d_{1,1}$ and $d_{1,2}$	16, 38 [m]	22, 25 [m]
$d_{2,1}$ and $d_{2,2}$	16, 38 [m]	22, 25 [m]
$\Phi_{(n.1)}$ and $\Phi_{(n.2)}$	10^o and 20^0	50^0 and 60^o
$\Phi_{(n.1)}$ and $\Phi_{(n.2)}$	10^o and 20^0	50^0 and 60^o
BS and users' height	35 and 1.65 [m]	35 and 1.65 [m]

Figure 2 manifests the attainable sum rates for various single stream SCS-HBF-NOMA schemes operated in LOS link. Under the P-ZF and dynamic power optimization schemes mentioned earlier, the new user pairing based on the Users' distances exhibits a higher performance than the OMA schemes for both fully connected and sub-connected HBF structures. On the other hand, the user pairing on the basis of users' AOAs manifests better performance than that of the proposed users' pairing based on distance. This result indicates that the user's AoA is crucial to the Phased scheme method of analog precoder's optimization. However, determining the AoA for each user can be computationally complex and prone to mean error in a practical system compared to the distance-based users' pairing approach, which can be easily obtained via the time of arrival localization's method [8] [9] [10], which is beyond the scope of this paper. Hence, a swap between the higher sum-rate execution and computational complexity depends on the mobile applications being run by the users. Furthermore, since the new users' pairing performs better than the OMA scheme, the new users' pairing can still be recommended for NOMA while sacrificing capacity to the complexity.

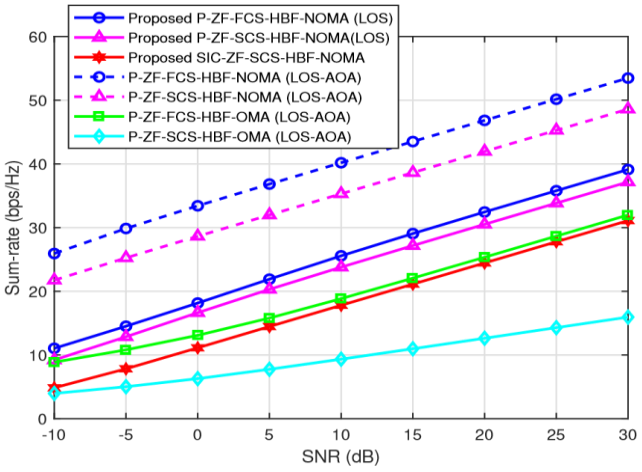
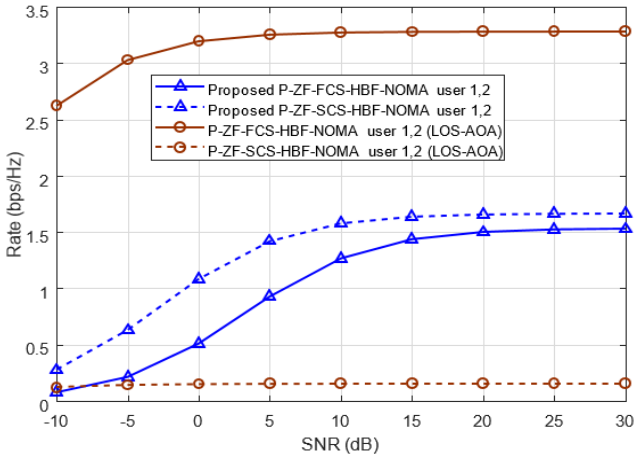
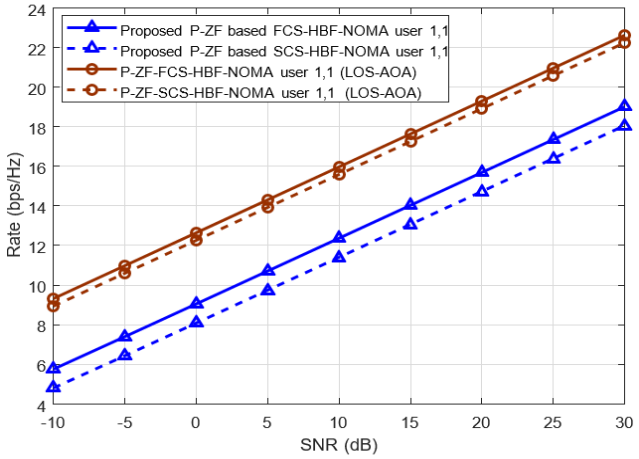


Figure 2: Sum-rate performance of the proposed NOMA scheme on the basis of distance-based user's pairing in LOS link, N_t = 128 and N_r = 1 for N = 2 clusters and M = 2 per cluster.

For the purpose of revealing the inherent benefit of the new users' pairing approach, the data-rate performance for various users deploying the P-ZF scheme for HBF-NOMA communication in LOS link is evaluated, namely, weak and strong users in both near and far clusters in Figures 3 and 4, respectively. Specifically, Figure 3(a) reveals that the data rate of the weak user $U_{(1,2)}$ in the near cluster deploying the FCS-HBF-NOMA and SCS-HBF-NOMA with proposed users pairing in the near cluster manifest better performances than SCS-HBF-NOMA with the AoA based users pairing and performs lower than the FCS-HBF-NOMA with the AoA based users pairing. The inference from Figure 3(a) is that the proposed scheme allows the user $U_{(1,2)}$ to yield high-performance improvement and to be far from the outage as the SNR increases. Furthermore, the proposed user pairing employed for the SCS-HBF-NOMA exhibits a higher performance than in the FCS-HBF-NOMA arising from the wider beams produced by the sub-connected HBF structure that mitigates against the effects of channel misalignment from pairing two users having different AoAs in the same cluster. This can further boost the higher energy efficiency of the SCS-HBF-NOMA system than its FCS-HBFNOMA counterpart. On the other hand, Figure 3(b) reveals that the performance trends of the strong user $U_{(1,1)}$ in the near cluster for FCS-HBFNOMA and SCS-HBF-NOMA communication exploiting the proposed users paring is consistent with that of AoA as the SNR increases but performs lower than that of the AoA counterparts at all SNRs.



(3a) Weak user in near cluster $U_{(1,2)}$

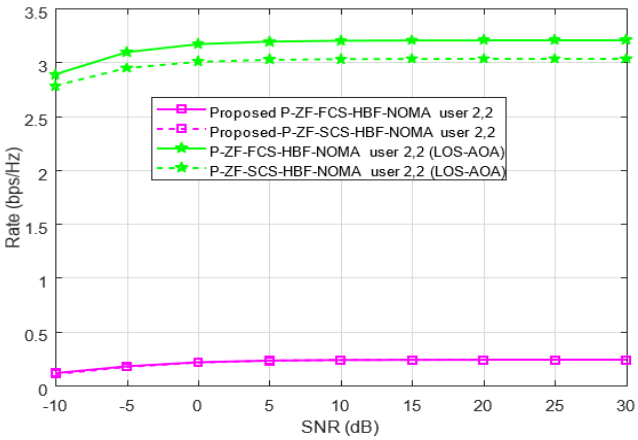


(3b) Strong user in near cluster $U_{(1,1)}$

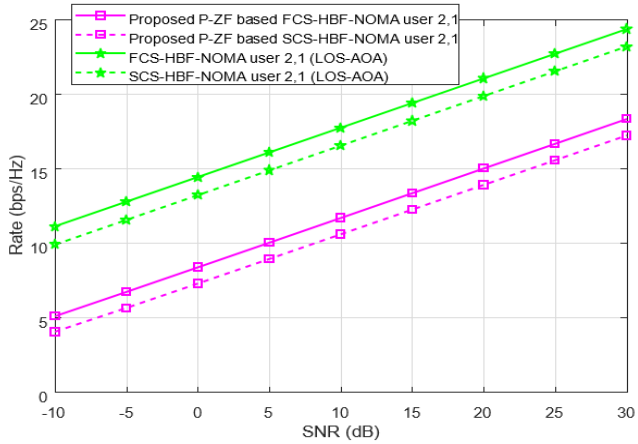
Figure 3: Achievable Data-Rates of the users in the near cluster for the proposed NOMA schemes comparing with those of the user pairing based on

AoA counterparts operated in LOS urban microcell environment.

Figure 4(a) illustrates the data Rates for the weak user $U_{(2,2)}$ in the far cluster for the proposed user's pairing deployed for P-ZF based HBF-NOMA system operated in LOS environment to benchmark with that of PZF based HBF-NOMA system employing user pairing based on AoA. Owing to the weak signal strength at the far cluster, the proposed users clustering approach suffers data rate loss compared to that of the AoA-based users pairing. On the other hand, Figure 4(b) shows that the proposed new users pairing performs lower than its AoA counterpart for strong NOMAuser equipped with fully connected and sub-connected (HBF) structures. For the sake of revealing the impact of the new user pairing on the sum-rate performance of the finite resolution HBF-NOMA system in LOS link, performance simulations are carried out for both (FCS and SCS) HBF structures deploying the P-ZF scheme, and results obtained are presented in Figure 5.



(4a) Weak user in far cluster $U_{(2,2)}$

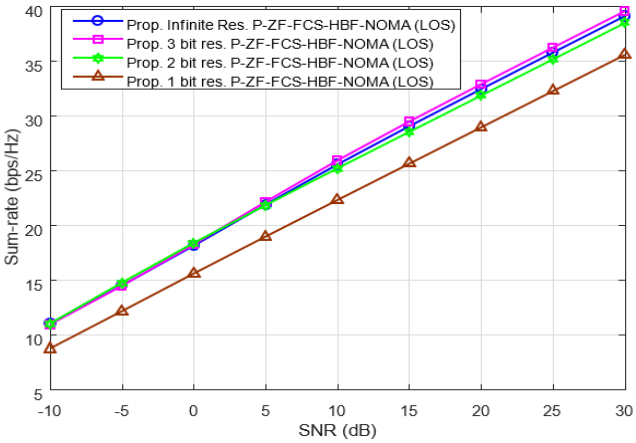


(4b) Strong user in far cluster $U_{(2,1)}$

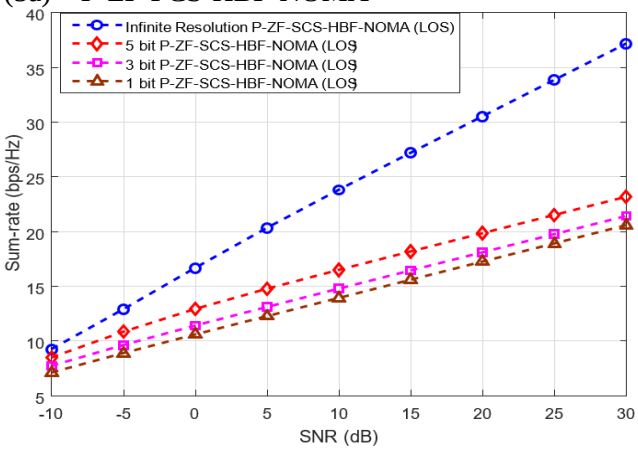
Figure 4: Achievable Data-Rates of the users in the far cluster for the proposed NOMA schemes comparing with those of the user pairing based on AoA counterparts operated in LOS urban microcell environment.

Specifically, Figure 5(a) manifests that the 2-bit resolution of FCS-HBF-NOMA optimized the sum-rate performance to that of the infinite resolution counterpart. Furthermore, extending the quantization bits value to 3 for finite resolution HBF-NOMA results in asymptotic performance to that of the optimal infinite resolution counterpart, which validates 2-bit resolution as the optimal resolution for the Proposed scheme. The lowest performance achievable for the 1-bit quantized FCS-HBF-NOMA arises from the highest quantization error associated with the lowest-bit resolution system.

More specifically, Figure 5(b) reveals that the SCS-HBFNOMA deploying P-ZF scheme and the proposed NOMA users pairing achieves peak performance at 3-bit resolution. This reveals the proposed users' pairing worse impact on the finite resolution SCS-HBF-NOMA deploying Liang quantization algorithm compared to that of users' pairing based on AoA exhibited in Figure 5 of [4].



(5a) P-ZF-FCS-HBF-NOMA

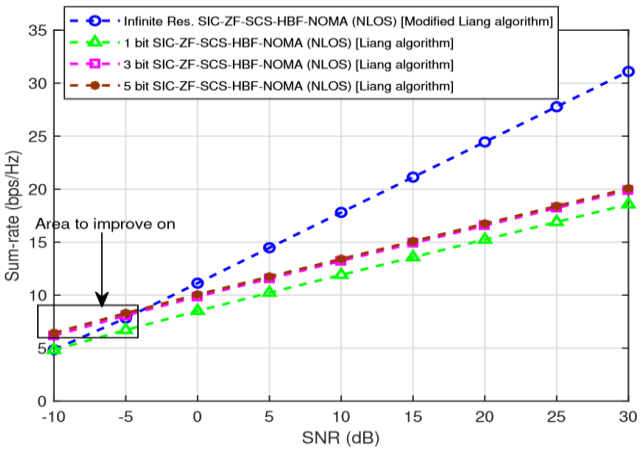


(5b) P-ZF-SCS-HBF-NOMA

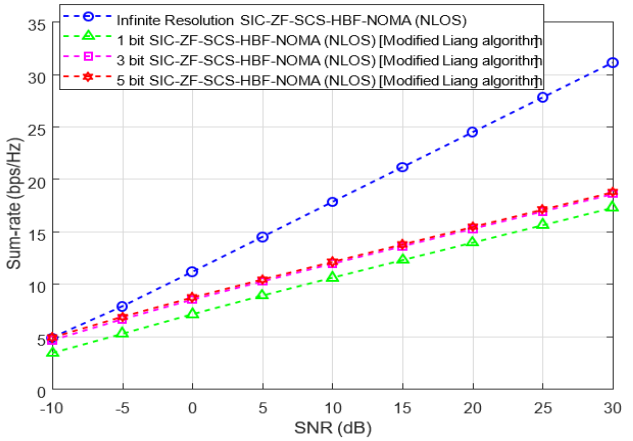
Figure 5: Achievable Sum-rates of the proposed finite resolution HBF-NOMA schemes benchmarking

the infinite resolution NOMA counterpart in LOS urban microcell environment. Notably, 'res.' and 'prop.' on the legend represent 'resolution' and 'proposed', respectively.

Hence a better algorithm that is capable of achieving an asymptotic performance for 2 or 3-bit resolution SCS-HBF-NOMA as that of the FCS counterpart in LOS link is recommended for future work. In order to reveal the frail performance of SCS-HBF-NOMA exploiting the proposed users' pairing is not peculiar to only the P-ZF scheme in LOS link but also to the existing SIC-ZF scheme in NLOS link [4]. Hence, the simulation is performed for the SIC-ZF-based SCS-HBF-NOMA adopted from [4] and the achievable sum-rate in NLOS link is presented in Figure 6. Specifically, Figure 6(a) presents the simulation results for 1-bit to 3-bit resolution of SCS-HBF-NOMA benchmarking that of optimal infinite resolution SCS-HBF-NOMA, whereby the 2-bit and 3-bit resolution optimized the SCS-HBF-NOMA to the peak sum-rate and the wider margin still exist between the finite and infinite resolution SCS-HBF-NOMA as in Figure 5(b).



(6a) Liang Algorithm.



(6b) Modified Liang Algorithm.

Figure 6: Achievable Sum-rates of the proposed finite resolution SIC-ZF based SCS-HBF-NOMA schemes operated in an NLOS urban microcell environment deploying the modified Liang quantization algorithm to address the performance abnormality at the Low SNR region.

More specifically, at the low SNR rages from -10 to -2.5 [dB], the finite resolution SCS-HBF-NOMA exploiting the proposed users' pairing for the SIC-ZF scheme achieves higher Performance than that of the infinite resolution counterpart in NLOS link.

This abnormal performance arose from the quantization error caused by both the nature of the users' (NLOS) environments and the structure of HBF equipped to users and base station, which is contrary to the quantization theory postulating that infinite resolution HBF-NOMA is an optimal system compared to the finite resolution counterpart. Hence, the modified Liang algorithm proposed to avoid this abnormal performance leads to the results in Figure 6(b). Explicitly, it is observed in Figure 6(b) that the postulated modify parameter $\sqrt[8]{M}$ is capable of eliminating the quantization error associated with the achievable sum rate corresponding to -10 to -2.5 [dB] SNRs. Therefore, an efficient quantization algorithm capable of closing the wider gap between the performance of the proposed user pairing deploying either P-ZF or SCS-ZF for finite resolution SCS-HBF-NOMA and the infinite resolution counterpart in both LOS and NLOS links is recommended for future study.

4.0 CONCLUSION

This paper has studied a new user pairing technique for a power domain non-orthogonal multiple access (NOMA) deploying fully connected and sub-connected hybrid beamforming (HBF) structures for a typical urban microcell downlink of line-of-sight (LOS) and non-line-of-sight (NLOS) environments. HBF-NOMA system was configured for two (multiple input single output) users per cluster down-linked to a base station equipped with 128 antennas. Aided by the dynamic power allocation scheme, HBF-NOMA optimization adopted phased zero forcing (P-ZF) for both fully connected structure (FCS) and sub-connected structure (SCS) in LOS link, and successive interference cancellation zero forcing (SIC-ZF) optimization scheme was adopted for the SCSHBF-NOMA in NLOS link. The new users' pairing approach exploited users' distance to the base station, namely:near and far clusters, unique to the benchmark angle of arrival-based users' pairing.

The proposed users' pairing and the precoding schemes' impact were investigated for finite-

resolution HBF-NOMA operating in LOS and NLOS environments. Results showed that the users' pairing based on AoA performed better than the newly proposed users' pairing. However, the proposed users' pairing scheme achieved better performance than their corresponding OMA counterparts, which validate its usefulness for multiple access technique and data rate (access) flexibility scenario, where one of the far cluster users need to access the base station for high data rate service and vice versa. Finally, the modified Liang processing scheme for quantizing SCS-HBF-NOMA precoder was revealed to mitigate against the quantization error arising from the NLOS environment and the nature of sub-connected (HBF) structure under a low SNR regime. Therefore, the results can serve as a clear guide during the design stage of a new radio NOMA for post-5G Systems.

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COVID-19 CRISIS ERA; ENGINEERING INTERVENTIONS IN SUB-SAHARAN AFRICA

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Abstract
Despite numerous notable contributions by Africans during the Corona Virus Disease (COVID-19) outbreak, little effort has been made to document these contributions in a comprehensive publication. Herein this work, an attempt was made to bring together African-based technological interventions proffered in Sub-Saharan Africa during this period. Across Africa generally, different engineering methods were used to develop several contrivances such as ventilators as well as deploying Artificial Intelligence to facilitate contact-free human-human and human-object interactions. Broadly, these approaches center on two key areas which are efforts to mitigate the spread of the infectious disease, and management of the infected, which are the focus of this present work. Indeed, a comprehensive report of these efforts is essential to appraise the contributions of the home-based researchers and to create an archive for future research and decision making across the African continent, thus necessitating the need for this systematic appraisal.

1.0 INTRODUCTION
The sudden outbreak of SARS-COV-2 virus has proven again beyond reasonable doubts that "necessity is the mother of invention." The COVID-19 outbreak, which stared the whole world in the face, took away loved ones unplanned, imposing serious socio-economic and health implications [1-3, 9]. This global crisis revealed current weaknesses in the Sub-Saharan African (SSA) region's health, connectivity and communications infrastructure, in addition to disadvantage of excessive dependence on importation of manufactured goods. Due to restriction ofmovement, traditional fields such as electrical, mechanical, civil, chemical engineering and others that rely on work by on-site teams were negatively impacted [1]. On the other hand, disciplines including AI, robotics, ICT, computer engineering, medical and biomedical engineering witnessed unprecedented growth being at the fore of supporting efforts towards mitigating the effects of the crisis and will continue to gain grounds in the era of the "new normal" [1]. These numerous challenges thus forced the necessity of several innovations in Africa which are aimed at curbing the spread of the pandemic as well as to aid its management. It is believed that many more innovations are still underway to completely flatten the curve of the infection [4]. While looking forward to these, it is imperative to showcase the several notable pandemic-inspired inventions by African

Engineers developed towards tackling the crisis that deserve worldwide attention and acknowledgement.

The significant outcomes of some of the technologies and engineering approaches to limit the severity of the COVID-19 pandemic across Africa have been published in some reputable journals. For instance, [5] provided a comprehensive overview of the utilization of addictive manufacturing for ventilator components in South Africa during the COVID-19. Also, [6] provided a rapid review on utility of telemedicine in sub-Saharan Africa during the COVID-19 pandemic, exploring the benefit and challenges. Furthermore, a comprehensive review was published by [7] to reveal the accuracy of utilizing big data analytics, artificial intelligence and nature-inspired computing models to detect COVID-19 infection and contact tracing in Africa. Also, a system review was done by [8] to explore the deployment of digital technology in Africa during the first wave of the COVID-19 pandemic. The authors attest that African countries employed technology and creative approaches to effectively handle patients, track cases, and communicate vital information in order to combat the transmission of the COVID-19 virus. While appraising the advancement in robot and drone applications to ease the negative effect of the COVID-19 pandemic in developed countries of the world, [9] noted that such technologies were not only adopted by researchers and scientist in Sub-Saharan Africa, but there were also attempts to develop them.

Several documented and undocumented efforts were made in line of engineering, technology and innovation across Africa, particularly Sub-Saharan Africa, and while the above-cited literature and many more have published a few of the innovations, none, to the best of the authors' knowledge, has provided an overview of the contribution of African home-based researchers and innovators to several core aspects of engineering and technology that were conceptualized, developed, implemented and deployed during the COVID-19 pandemic waves in Africa.

It is against this backdrop that the different interventions proffered, their outcomes and how they helped to shape SSA healthcare system were mapped out in this present work.

2.0 METHODOLOGY

This study was a mix of desk review of extant literature and inductive analysis of research and non-research innovative engineering activities across Sub-Saharan Africa during the COVID-19 pandemic. To achieve a comprehensive appraisal, published journals and articles available on the Internet on COVID-19 pandemic in Africa between 2019 and 2022 were considered since this was the period when the outbreak began and peaked. The initial search was limited to uploads on Google Scholar and ResearchGate. The second approach was to access pre-publication and not yet peer-reviewed publications from reliable sources such as University press, BBC documentary and random Internet search, which was then filtered by the authors for quality, and interest to the current article. Besides, the different materials were addressed by the co-authors based on their areas of teaching and research expertise and were finally addressed holistically by all authors before developing the entire article.

3.0 DISCUSSION

3.1 Engineering and Technological Interventions in Sub-Saharan Africa during COVID-19 Pandemic

3.1.1 Artificial intelligence and robotics

A. Artificial Intelligence

Throughout history, an effective epidemiologic approach towards safeguarding lives during any pandemic is to put in place measures that assure control and prevention of disease transmission. The COVID-19 was no exception, with many countries implementing physical distancing. AI was applied to COVID-19 in the areas of medical image acquisition, image segmentation and diagnosis, and the quick identification, classification, screening, and quantification of COVID-19 patients [10, 11]. However, tracking and predicting COVID-19 occurrences in affected regions like Africa has been challenging due to the lack of huge amounts of historical local data to train AI models [12]. Generally, lack of data is a big limitation to AI technologies [13]. This led to the development of AI forecasting models. The majority of the social media and noisy data used in the training of the forecasting models are in multiple data formats, lacks data standardization and interoperability, and missing values, which can be erroneous and unreliable [14]. This often times affects the performance and accuracy of the models.

In developed countries like Europe, COVID-19 outbreak forecasting helped in developing appropriate procedure in developing vaccine and therapy plans and to concentrate on areas that need more attention and implementing precautionary measures to stop the pandemic from spreading [15]. In Africa, it is noteworthy that some forecasting models were also developed using Artificial Intelligence. For instance, [16] used Ensemble Kalman Filter (EnKf) approach, a deep learning model for short forecasting of COVID-

19 pandemic using Cameroon as a case study. The authors sought to know the COVID-19 trend in Cameroon. The investigation was able to state the significance of efficient control measures in preventing the spread of the pandemic. Likewise, [17] proposed an online forecasting system of COVID-19 cases in Nigeria. In order to update the ensemble model's parameters, which in turn produced updated COVID-19 forecasts every 24 hours, data was streamed from the Nigeria Center for Disease Control (NCDC). This gave policymakers the push they needed to deploy containment strategies and/or evaluate containment interventions in order to stop the spread of COVID-19 in Nigeria. An artificial neural network (ANN) model was used in Seychelles between January 2020 and July 2021 to forecast COVID-19 confirmed cases [18].

There were other ways through which AI was employed by Africans in combating the pandemic, such as the effective control of physical distancing by implementing cashless, Internet-based transportation payment service in Ethiopia [19]. Also, [20] proposed an Artificial Intelligence-based technical framework to aid effective diagnosis and treatment of the COVID-19 and its associated comorbidities in resource-limited settings, focusing specifically on Sub-Saharan Africa. This AI-framework enables harnessing of diagnostic data from different point of care units using evaluations from radiological images, polymerase chain reaction and information provided by end-users so as to detect and manage COVID-19, thereby limiting the spread of the disease. Further work includes the proposed low-cost block chain and artificial intelligence-coupled self-testing system and tracking system for COVID-19 and other emerging infectious illnesses by [21]. The proposed technology, which is adaptable for use in communities with infectious diseases awakened the involvement of relevant stakeholders for the development and implementation of the technology. Furthermore, [22] developed a dynamical epidemic model for the estimation of vital epidemic parameters of COVID-19's early-stage transmission as well as to forecast the evolution of COVID-19 in Algeria.

According to UNESCO, radio is the most reliable and cost-effective way to acquire and share information throughout the majority of the developing world. On radio, people frequently provide first-hand accounts of situations that are not otherwise documented and express their personal opinions without being influenced by research questions or fear of judgment [23]. As a result, UN Global Pulse deployed a speech-to-text technology, an AI-based application to extract public radio content in real time using keywords related to COVID-19 for decision making in Uganda and Tunisia [24]. The analysis of the public radio discourse is of benefit in tackling COVID-19 through rapid identification of affected locations and intensity of possible outbreaks in the community. This also helps to support public health professionals to hasten investigation and respond faster to communities infected.

According to Euro News, Dr. Mustafa Hamdi and his students at the National Institute of Applied Sciences and Technology (INSAT) in Tunisia developed an online open access platform that aids in the detection of COVID-19 in the lungs of suspected patients in order to save time and have a diagnosis other than the standard test kit. The platform operates by comparing the x-rays of a COVID-19 patient with that of a person who is thought to be infected with the virus. The accuracy of the algorithm used was 92% [25].

In South Africa, a mobile and web application, EMGuidance which used AI technology was used by medical professionals for medicines and treatment [26]. Chatbots implemented using AI, HealthAlert Virtual assistant provided useful health information to people [26]. In Kenya, M-Pesa (a mobile application) was developed to make social distance easier with its mobile payment technology [27]. There was also development of an electronic pass to implement physical distancing between essential workers and travelers in Sierra Leone [28] and design and deployment of FAIR digital health infrastructure in Uganda, Ethiopia, Liberia, Nigeria, Kenya, Somalia, Tanzania, Zimbabwe, and Tunisia for COVID-19 reporting and genome research [29].

B. Robotics

In the aspect of robotics, students from Senegal Advanced School of Engineering in Dakar created a robot named Dr. Car—a car equipped with mechanical arms and a mounted camera [30]. Hospital workers may remotely engage with patients through Dr. Car, bring them food and medical supplies, monitor their temperature and take their blood pressure. Similarly in Rwanda, humanoid robots perform some medical staff tasks in COVID-19 isolation centers, such as taking body temperatures of patients in order to reduce human contact and transmission [31]. The creation and use of robots, the costs associated with provision of protective equipment for medical staff and the risk of spread of COVID-19 virus from patients to the front-line health workers were significantly reduced.

Another interesting application of AI and robotics during the pandemic was the use of drones. Drones equipped with a loudspeaker developed by a firm called Zipline were used in Rwanda and Ghana to convey pandemic prevention strategies as well as to monitor and manage containment and quarantine measures [32]. In the shortest time possible, drones deliver drugs, test samples, COVID-19 tests, and packages of blood to several hospitals or isolation centers since they do not require to use roads that are most likely in poor shape in the SSA countries. Sprayer drones developed in Botswana have the capability of disinfecting 3,000 cubic meters of air in 30 minutes in public places like hospitals, supermarkets, petrol stations, and isolation facilities [31]. Doctors and healthcare facilities were able to track shipments of PPE, vaccines, and blood after placing orders via an app [33]. Drone flight times range from 15 to 30 minutes, and they can be launched 5 to 7 minutes after an order is received. This innovation was slated for export to the United States (US).

While researchers worked independently from their countries, it is also important to mention that a collaboration between experts from 11 African countries (Botswana, Cameroon, Canada, Eswatini, Mozambique, Namibia, Nigeria, Rwanda, South Africa, Zambia and Zimbabwe) and researchers from York University implemented Big data and AI-based techniques in nine (9) African countries to provide data analysis strategies to aid informed public health decision making and COVID vaccination rollout approaches [25].

3.1.2 Medical and molecular engineering

The Africa Higher Education Center of Excellence for Genomics of Infectious Disease (ACEGID) located in Redeemer's University, Nigeria in collaboration with Center for Disease Control (CDC) is the first institution in Africa to successfully sequence Genomes for SARS-COV-2 [33]. Since 2020 after the outbreak of COVID-19, ACEGID has identified 55 variants of the virus including the B.1.1.7 (UK) variant [33]. As at 2021, ACEGID has tested more than 42,000 samples from Nigeria alone.

As measures to combat the spread of the SARS-COV-2, ACEGID has been helpful in training for CDC frontline health personnel in Polymerase Chain Reaction (PCR) diagnostic technique. Because of her laudable achievements towards mitigating the negative health implications of COVID-19 pandemic, ACEGID situated in Nigeria, Western Africa Region has been named by WHO as a specialized continental reference sequencing research laboratories for emerging pathogens, including the SARS-COV-2. In January 2021, [34] presented detailed phylogenetic analysis of genome sequenced in six SARS-CoV-2 positive samples from the first major infection wave in the Union of Comoros. Other researchers in this category include evaluation of reinfection with SARS-CoV-2 in Libya [35] and cross-sectional, nationally representative, age-stratified sero-survey study in Sierra Leone by [36].

3.1.3 Software, electrical and electronics applications

The software industry was not left out in the creation of countermeasures to combat the spread of corona virus. This is evident in the several software tools that were created to facilitate real time tracking and visualizations of the spread of the virus. For example, by using an online platform that is powered by an Unstructured Supplementary Service Data (USSD) protocol, Ghana citizens can self-report their corona virus symptoms and locations [31]. Ushahidi (which means 'testimony' in Swahili) is a mobile application developed in 2008 by a community of Kenya cyber activist. Ushahidi was developed initially to locate precisely on an interactive map any act of violence in the aftermath of a highly contentious election. In fact, this particular invention was the first 'crisis-mapping' application in the world and the first open-source software in Africa. Fast forward to mid-March 2020 (12 years later), Ushahidi became a worldwide tool used in fighting COVID-19. Italian humanitarian NGOs employed this Kenyan invention on a regular basis to report vulnerable and isolated people in northern Italy and Sardinia. This has helped elderly people in unstable situations gain access to medicine and food supplies during the lockdown. [27]. This same App gained relevance in other countries such as Nigeria, Peru and Japan during the pandemic. A similar App called Hackcovid App was developed by The Moroccan Federation of IT Technologies (APEBI) to digitize citizen solidarity to mitigate the social consequences of the COVID-19 virus [27].

One of the effective guidelines specified by the World Health Organization (WHO) to limit the spread of COVID-19 is by avoiding direct contact with the mouth, eyes and nose. However, these parts of the body are essential to humans and touching them is often by reflex action, for instance when itching. To address this, two students of Electrical and Electronics Engineering, Federal University of Technology, Owerri, Nigeria collaborated to develop a wrist contrivance which alerts the wearer when the hand on which it is worn is taken towards the face [41]. A

similar device called personal health monitoring device (PHMD) was designed by [42] in Nigeria which allows people to continuously monitor their health, thereby reducing the need to visit a hospital during the pandemic. The portable, mobile, low-cost and energy efficient device was equipped with capabilities to display electrocardiograph (ECG), to measure oxygen saturation (SpO_2) and pulse rate (beat per minute).

Although instrumental in addressing the outbreak, maintaining physical distancing could not completely prevent the spread of the disease due to its airborne nature. Surfaces such as clothing materials, bags, wrist watches, skin and others are medium through which the COVID-19 can be transferred. A scientific evaluation revealed different stabilities of the disease on skin (96hrs at 22° and 8hrs at 37°C), bank notes (8hrs at 22°C and 4hrs at 37°C) and clothing (96hrs at 4°C and 4hrs at 22°C) [43]. One of the technologies developed in this regard was disinfecting chamber equipped with pumps and piping that deliver alcohol-based sanitizers in form of fumes to the body of a person passing through it. Throughout Africa, different kinds of the disinfecting chambers were developed, which includes in Ghana [44] and DICovid Disinfectant Booth in Nigeria [45]. Other devices include; Police robots in Tunisia, automated hand sanitizers dispensers, Google assistant automatic home control device/switch, infrared-based thermometers [30, 46, 47].

3.1.4 Manufacturing: Mechanical tools and protective equipment

Mechanical tools such as the ventilator were crucial to the management of COVID-19 outbreak. At some point worldwide, there was a shortage of ventilators needed to savage the lives of infected patients [48, 49]. In fact, the United States Food and Drug Administration (FDA) listed ventilators as one of the essential tools inadequate in number for the management of the disease [50]. Innovators and experts in Africa also rose to the challenge of developing low-cost, effective and affordable ventilators in Ethiopia, Nigeria and Sierra Leone to bridge the gap created by the shortage [49, 51]. For instance in Kenya, engineers of the Kenyatta University situated in Nairobi successfully developed a prototype ventilator that costs just 10% of the cost that the ventilator machine will be imported [37]. In addition, engineers from different universities in SSA collaborated to develop a ventilator that will only take about one hour to install. Besides, the first ventilator made in Rwanda was successfully created by biomedical engineers from the Integrated Polytechnic Regional College Kigali (IPRC) [38]. Also, for the first time, the Jomo Kenyatta University of Agriculture and Technology (JKUAT) created a portable solar-powered ventilator during the peak of the COVID-19 season [33]. The importance of stepping in to manufacture ventilators locally is evident when considering the low numbers of ventilators available in SSA compared with the need estimates. As revealed by [39], South Africa had the lowest shortfall of about 40% while Nigeria had the highest percentage shortfall of about 98% in terms of needed ventilators at the peak of the pandemic [31].

Similarly at the peak of the outbreak, contrivances such as; face shields and nose masks were in considerable demand leading to innovators seeking alternative ways of producing them. 3D printing technology was deployed across Africa to achieve this. For instance, in places such as Cameroon, Egypt, Kenya and Gambia, affordable personal protective equipment was produced for frontline healthcare providers during the pandemic using 3D printing technique [37, 52]. This technique was also employed in additive manufacturing of motorcycle shields in Uganda [40] as well as ventilator masks adaptable for two to four patients' use in Kenya, thereby allowing the management of multiple COVID-19 patients simultaneously [53].

Other personal protective equipment made by African Engineers include: first, the self-sanitizing mask developed by Uganda engineers which is a mask with in-built sanitizer. Second, the medical oxygen station that enables hospitals to generate their own oxygen for a fraction of the cost of making use of a ventilator. This was an innovation by engineers of the National Advanced School of Engineering of Yaoundé. Third, a porch that has the ability of disinfecting people that enters public places was created at the National Advanced School of Engineering by a group of Cameroonian engineers. Fourth, in Uganda, engineers created an automatic disinfectant sprinkler system that were installed in public buses to mitigate against the spread of corona virus. As well, Kenya engineers were able to develop an automated solar powered hand-washing machine, taking advantage of the abundance of solar energy in their region [31].

Furthermore, one of the biggest challenges during the COVID-19 pandemic was managing paraplegic patients in isolation centers and home. In cases of emergency, they would often need a caregiver to move them from the conventional wheelchairs to a bed, which sometimes is time demanding. To overcome this challenge, authors of [37, 40] in Nigeria

developed a dual purpose, battery-powered wheelchair that is adaptable as a wheelchair as well as a bed, thereby eradicating the need to transfer paraplegic patients from isolation bed to wheelchair and vice-versa.

3.1.5 Educational tools

As with many other places in the world, the COVID-19 outbreak forced quite a number of SSA universities to carryout teaching activities and examinations online for the first time due to compulsory lockdown of schools. Numerous challenges accompanied this policy decision including the risks of students cheating and falsifying answers to examination questions. It was against this backdrop that engineers in African Institute of Informatics in Cameroon developed an application that can monitor students' computers during online exams including using a facial recognition system. At the time when the trial version of the application was released, more than twenty (20) cases of cheating were detected. Interestingly too, several tertiary institutions in Nigeria succeeded in their efforts to move education and training online during the COVID-19 global crisis. Some of these private universities include Babcock University (BU), Covenant University (CU), Elizade University (EU), and Afe Babalola University (ABUAD). BU and CU had their convocation ceremonies online during the crisis. In addition, with the funding from the Royal Academy of Engineering, the Nigerian Institution of Mechanical Engineers (NIMechE) moved all its activities to an online bootcamp. This enabled them create a virtual School of Engineering and Entrepreneurship called ENGentrepreneur [31]. Authors of [54] also confirmed that technology saved education in Lybia during the peak of the pandemic.

3.2 Summary of Significant Innovations by African-based Researchers during the COVID-19 Pandemic

Table 1 presents a summary of published creative inventions by Africans, reported by British Broadcasting Corporation (BBC), the Federal University of Technology (FUTA) news magazine and Scientific Africa [30].

Table 1: Significant Innovations by African-based Researchers during the COVID-19 Pandemic

S/N	Invention	Inventor	Country of Origin	Description of Invention
1.	PGuards	Tunisia Engineers [30]	Tunisia	Police surveillance robots used to enforce lockdown measures. Makes use of thermal-imaging cameras, light detection and ranging technology.
2.	Web based X-ray lung scanner	Engineers in Tunisia [30]	Tunisia	Detects signs of a possible COVID-19 infection. Recognizes the impact of COVID-19 on lungs. Adjudged 90% effective in reporting the probability of infection.
3.	Solar-powered hand washing basin	Richard Kwarteng and Jude Osei [30]	Ghana	On detection of hand by the sensor, it automatically releases soapy water followed by clean water for hand washing within a time frame of 25 seconds.
4.	Doctor car robot	Students from Dakar polytechnic [30]	Senegal	A multifunctional robot equipped with cameras and remotely controlled to deliver drugs and food as well as take the temperatures of quarantined patients in a bid to lower the risk of COVID-19 contamination from patients to caregivers.
5.	Respire-19 portable ventilator	Usman Dalhatu – a students of engineering [30]	Nigeria	The prototype automatic ventilator was built to tackle the shortfall in availability of ventilators in Nigeria during the COVID-19 pandemic.
6.	Nose masks	Notalie Raphil (founder of Robots Can Think) [30]	South Africa	Design and printing of 100 node masks per day with 3d printer during the heat of the pandemic.
7.	Wooden hand-washing machine	Stephen Wamukota – a 9-year-old school boy. Received a presidential award for this innovation [30]	Kenya	Mechanical draining of water from a bucket to was hands using foot pedal.
8.	Positive pressure ventilator prototype	Team of researchers at the Federal University of Technology Akure (FUTA) [55]	Nigeria	A portable Continuous Positive Airway Pressure (CPAP) non- invasive mechanical ventilator that has the ability of delivering constant and steady pressure. The device runs on DC and can be configured to be powered by solar energy.
9.	Dual purpose sanitizer	FUTA through Technology Park and Incubation Center (Tech-PIC) empowered 4 Faculty members and 2 students to develop the device [56]	Nigeria	The device makes use of a pedal mechanical system for dispensing soap, water and sanitizer. The device also makes use of sensors and other electronics components to detect hands and then dispenses soap, water and sanitizer. The total time programmed for hand washing is 25 seconds in accordance with WHO's recommendations.
10.	Dual-purpose wheel chair	Michael Kanisuru Adeyeri, Sesan Peter Ayodeji, and	Nigeria and South Africa	The inventors developed an ergonomically correct and safe dual-purpose wheel chair to be used by

	Abimbola Omotayo Orisawayi [40]	paraplegics in the under developed countries. This wheel chair powered by a battery and proposed to be used by the paraplegics in their homes, hospitals as well as rehabilitation centers is expected to ease sitting and lying positions of the patients which is desirable in reducing contacts of caregivers with infected paraplegics' patients. The system can switch between sitting mode and sleeping/relations modes and vice versa.

4.0 CONCLUSION

The sudden outbreak of the COVID-19 pandemic created a wide range of gaps that needed to be urgently filled, especially in area of health. This consequently necessitated the creation of many technological innovations across Sub-Saharan Africa. Many of these African-based innovations were instrumental in helping to curb the spread of the outbreak as well as the management of the recorded cases. The deployment of robots and AI significantly reduced human-human contact, consequently reducing the costs associated with provision of protective equipment for medical staff and the risk of spread of COVID-19 virus from patients to the front-line health workers. In the area of manufacturing, the scarcity of imported goods and essential equipment like the ventilator, face shield led to local manufacture of alternatives in Nigeria, Ghana, Rwanda, South Africa and many other African Countries.

In all, the various gaps created by the COVID-19 pandemic helped to push African innovators to put to good use their engineering and technological knowhow which ultimately helped to shape the health sector in Sub-Saharan Africa. As African nations bounce back from the negative impact of COVID-19, the African continent must be proactive by swinging straight into plans for possible future pandemic. It is hoped that the inspiration will be sustained post-pandemic to create more economically viable products and alternative devices, thus, reducing dependence on importation and improving healthcare delivery in Sub-Saharan Africa.

5.0 RECOMMENDATION

Although the initial intention was to carry out a survey across the entire African countries about the documented and on-going research and innovations that were employed during the COVID-19 pandemic, we could not achieve this because of the large scope. Hence, this review analysis is not a representative of the whole African continent. Consequently, an elaborate systemic review is recommended for future studies of this kind in order to inclusively applaud the intellectual efforts of home-based African researchers, policy makers and innovative individuals across the continent.

6.0 DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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DESIGN OF A CONCEPTUAL FRAMEWORK FOR CYBERSECURITY CULTURE AMONGST ONLINE BANKING USERS IN NIGERIA

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Abstract

This study aims to construct a comprehensive conceptual framework that elucidates the critical human factors influencing cybersecurity culture among online banking users in Nigeria. The research methodology is grounded in a meticulous examination of existing literature in the cybersecurity culture domain, serving as the foundation for this framework. The literature review reveals a conspicuous absence of academic research on cybersecurity culture within Nigeria and underscores the importance of comprehending its unique nuances. Key findings from the literature review highlight the prominence of "cybersecurity awareness," "cybersecurity policy," and "cybersecurity education" as influential factors. "Cybersecurity awareness" emerges as the most pivotal factor due to its recurrent emphasis and recognized centrality. "Cybersecurity policy" and "cybersecurity education" secure the second and third positions, respectively, due to their acknowledged significance in cultivating a security-conscious mindset among online banking users. Furthermore, the literature review exposes a research gap concerning the requisite "cybersecurity knowledge" that should permeate organizations and individuals to augment cybersecurity culture. Additionally, it reveals the underexplored influence of "social norms" and "interpersonal trust" in molding cybersecurity culture. This research accentuates the dearth of cybersecurity culture research within Nigeria and underscores the importance of understanding its unique facets. The proposed conceptual framework provides a valuable resource for designing tailored cybersecurity strategies and programs in Nigeria's online banking sector. It advocates for prioritizing cybersecurity awareness, education, and policy, empowering users with the knowledge and skills needed to safeguard themselves against cyber threats. The model also highlights the relevance of recognizing the role played by social dynamics, interpersonal trust, and social norms in shaping cybersecurity behaviours.

1.0 INTRODUCTION

In recent years, the growth of online banking has been remarkable, transforming the way individuals and businesses conduct financial transactions. Online banking has become a key player in the realm of business activities, offering unparalleled convenience, accessibility, and a wide range of services [1]. The banking industry has embraced this digital shift, adopting uninterruptible banking services to reduce operating costs and enhance customer experience [2]. Online banking in Nigeria has gained significant momentum, fuelled by the dramatic increase in e-commerce applications and the numerous benefits it offers, including fund transfers, checking account management, and bill payments [3].

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However, alongside the immense advantages of online banking, the banking sector in Nigeria faces persistent cybersecurity challenges. Despite substantial investments in securing data, networks, and cyber defines systems, the occurrence of cybersecurity breaches and vulnerabilities is on the rise [4]. The prominence of human factors in contributing to these cybersecurity risks cannot be overlooked. Human behaviour and actions often introduce inconsistencies and errors, posing substantial threats to information assets. Consequently, a comprehensive understanding of the human factors that influence cybersecurity culture is essential for effective risk mitigation [5].

Cybersecurity culture is the collective mindset, attitudes, and behaviours of individuals, organizations, and society as a whole towards ensuring and promoting the security of digital systems and information. It encompasses a shared understanding of the importance of cybersecurity, a commitment to implementing best practices and protocols, and a proactive approach to identifying and mitigating cyber risks. A strong cybersecurity culture fosters a security-conscious environment where cybersecurity is integrated into daily practices and where individuals are vigilant and proactive in protecting against cyber threats [6].

While the significance of human factors in shaping cybersecurity culture has been recognized, there remain notable gaps in the existing literature. Specifically, limited research has been conducted to identify and explore the specific human factors influencing cybersecurity culture among online banking users in Nigeria. The available literature primarily focuses on assessing the state of cybersecurity in Nigeria, with insufficient attention given to cybersecurity culture, standards, interpersonal trust, and social norms. As a result, there is a pressing need to bridge this gap and develop a comprehensive conceptual model that addresses the unique Nigerian context [7].

This study aims to fill the gaps by providing a well-grounded conceptual model that identifies and examines the key human factors influencing cybersecurity culture among online banking users in Nigeria. This research will contribute to the enhancement of cybersecurity practices, risk mitigation, and the overall cybersecurity culture in the Nigerian online banking sector. The systematic literature review will serve as the foundation for developing a robust conceptual model that encompasses the identified human factors and their interrelationships. By distilling and analysing the literature, this research aims to provide valuable insights into the specific human factors influencing cybersecurity culture. The model will shed light on the complexities and dynamics of these factors, facilitating a comprehensive understanding of their impact on cybersecurity behaviour among online banking users.

Also, it is crucial to highlight the limitations of previous milestone works in this field [8-9]. Although previous works have contributed significantly to the understanding of cybersecurity culture and behaviour, their focus on developed countries with distinct demographic, cultural, and infrastructural settings raise questions about the universality of their findings. Moreover, the limited research conducted in Nigeria primarily focused on assessing the state of cybersecurity, rather than delving into the realm of cybersecurity culture. Therefore, this study seeks to rectify these limitations and contribute novel insights specific to the Nigerian context.

By addressing the gaps in the existing literature, this research endeavours to provide a comprehensive understanding of the human factors that influence cybersecurity culture among online banking users in Nigeria. The findings will serve as a foundation for designing targeted interventions, policies, and educational programs to promote responsible cybersecurity practices and mitigate cyber threats. Ultimately, the aim is to foster a strong cybersecurity culture that safeguards the interests of online banking users, protects sensitive information, and ensures the sustainable growth of online banking in Nigeria.

2.0 METHODOLOGY

The methodology employed for developing the conceptual model involved a systematic review of previous cybersecurity frameworks and research papers relevant to cybersecurity culture. This process aimed to identify and analyze the key factors influencing cybersecurity culture. The gathered literature underwent a qualitative content analysis, whereby relevant documents were identified and classified. This approach allowed for a systematic examination of the variables and constructs proposed in previous research within the cybersecurity culture domain.

3.0 CONCEPTUAL MODEL DEVELOPMENT

The development of a robust cybersecurity culture model requires consideration of existing frameworks in the field. A thorough review of previous cybersecurity frameworks was conducted, leading to

the formulation of the current conceptual model for cybersecurity culture. The primary objective of this comprehensive evaluation was to provide a comprehensive summary and analysis of variables proposed in previous researches within the cybersecurity culture domain, thereby supporting the conceptual model of the present study. Extensive literature searches were conducted across prominent digital databases, including Emerald, AIS, Elsevier Science Direct, ACM, Springer, and Google Scholar, focusing on papers published between 2018 and 2022 and employing keywords such as "Cybersecurity Culture" and "human factors." Through qualitative content analysis, relevant documents were identified and classified. In total, 44 papers specifically addressed Cybersecurity Culture, with 28 papers (representing 64% of the total) aligning with the Cybersecurity Culture framework, in line with the study's objectives. The remaining papers covered a range of topics, including definitions of cybersecurity culture, distinctions between organizational culture and national culture in relation to cybersecurity culture, strategies for developing national and organizational cybersecurity culture, and the goals of cybersecurity culture development.

Table 1: The Summary of key Human Factors.

Research	Constructs
[11]	Knowledge, assumptions, norm and value, artifact.
[12]	Management commitment to information security, security policy and policy enforcement, security Awareness, security training and education, security risk assessment, security compliance, ethical conduct.
[13]	Security compliance, top management, security, communication, job satisfaction.
[14]	Security behaviour, security awareness, social norm, enforcement of information security policy.
[15]	Security policy, SETA program and Security monitority.
[16]	**Organizational level:** Assets, continuity, trust, operations, defense, security governance. **Individual level:** Awareness, attitude, behaviour, competency.
[17]	**Organizational culture model:** Cybersecurity culture has three layers: **Corporate Politics:** Cybersecurity policy, organizational structure, resources. **Management:** Implementation of cybersecurity policy, benchmarks, responsibilities, qualification, and training. **Individual:** Attitude, communication, and compliance.
[18]	Knowledge, education, awareness, risk management, monitoring, compliance, normative value.
[19]	**Top Management Security,** Security Policy, security education and Training, security awareness, **Security Ownership,** Security risk analysis and assessment, ethical conduct, security compliance.
[20]	Security awareness, security knowledge, top management security policy security education security compliance, trust, norms.
[21]	**Organizational level:** Policy and procedure, risk analysis, budget, benchmarking. **Group level:** Management, interpersonal trust. **Individual:** Awareness, ethical conduct.
[22]	**Managerial:** Policy and procedures, risk analysis, budget, response, **Behavioural:** Responsibility, integrity, trust, norm and value, orientation, motivation **Individual:** Training, education, awareness
[23]	**Top Management.** Information security policy, information security awareness and education, information security behaviour, information security acceptance
[24]	Management support, communication, cybersecurity knowledge, cybersecurity awareness cybersecurity guideline
[25]	External environmental factors, national culture (social norm), political and legal factors, economic factors, socio-cultural factors, technical and technological factors, management factors, management and governance, information security policies and procedure, cybersecurity risk management, security education training, awareness and communication, cybersecurity behaviour, knowldege of cybersecurity, cybersecurity compliance
[26]	Security knowledge, security policy, security awareness
[27]	Trust, social norm, cybersecurity compliance, cybersecurity knowledge, cybersecurity awareness, cybersecurity eduaction

Table 1 summarizes the list of previous cybersecurity culture research constructs for each study. The first column of the Table 1 represents various cybersecurity culture research frameworks. The second columns represent constructs and findings for each relative cybersecurity culture frameworks.

Eighteen studies were retrieved in Table 1. The process used to develop the conceptual model was to extract research in existing information security culture frameworks and models in order to develop an understanding of current information security culture phenomena. For each study, all the proposed constructs were extracted and counted in Table 2. The purpose for counting constructs for each study is to identify top constructs as potential candidates because it is simply impossible to examine every factor that could help conceptualize a security culture. Because of the scope limitation, the current paper will only consider the top constructs where there is strong agreement between academic researchers as to their importance for cybersecurity culture. Table 2 presents top key constructs for that influence cybersecurity culture among online banking users.

3.1 Scenario Design

In Table 1 above, the review of previous research and the adopted constructs from each study were analysed. The key constructs that influencing cybersecurity culture and led the development of conceptual model are summarized in Table 2. In the section that follows, we lay out the basic framework for modelling cybersecurity culture (see Figure. 1) and hypothesize about the link between cybersecurity cultures and influencing factors. Based on our review of the research, we selected the following top seven key variables as show below:

Table 2: Summary of the Key Constructs

Constructs	Number of cited	Ranking
Interpersonal trust	5	7
Social norms	7	4
Cybersecurity awareness	14	1
Cybersecurity education	9	3
Cybersecurity knowledge	7	4
Cybersecurity policy	11	2
Cybersecurity compliance	7	4

3.1.1 Justification for ranking of conceptual factors

To determine the ranking of key constructs that influence cybersecurity culture among online banking users, the proposed constructs from each study were counted and analyzed. The purpose of ranking was to identify the top constructs with strong consensus and importance among academic researchers. The ranking of key constructs was based on the frequency of their appearance in the reviewed literature and their recognized significance in influencing cybersecurity culture. The ranking of conceptual factors in the proposed cybersecurity culture framework was determined through a systematic and evidence-based approach. This ranking process aimed to identify the most influential factors based on their frequency in the reviewed literature and their recognized significance in shaping cybersecurity culture among online banking users in Nigeria.

Cybersecurity Awareness (Ranked 1): The top ranking of "cybersecurity awareness" is grounded in its consistent and prominent emphasis in the reviewed literature. Multiple studies and academic research papers consistently underscored the critical role of cybersecurity awareness in cultivating a security-conscious mindset among online banking users. It emerged as the most frequently cited and emphasized factor across the selected literature, signifying its central importance in influencing cybersecurity culture.

Cybersecurity Policy (Ranked 2): "Cybersecurity policy" secured the second position due to its recognized significance in guiding and enforcing cybersecurity practices. Numerous studies highlighted the importance of well-defined policies in setting the foundation for cybersecurity culture. It was consistently cited and emphasized in the literature as a pivotal factor in promoting security-conscious behavior.

Cybersecurity Education (Ranked 3): "Cybersecurity education" claimed the third rank based on its crucial role in equipping online banking users with the knowledge and skills needed to navigate the digital landscape securely. While slightly less frequent than awareness and policy, education was consistently recognized as a fundamental factor in enhancing cybersecurity culture.

The ranking reflects the prevalence and importance of each construct as evidenced by the reviewed literature. Notably, “cybersecurity awareness” emerged as the top-ranked factor due to its consistent emphasis and recognition in the field, highlighting its central role in shaping cybersecurity culture.

This approach ensures transparency and objectivity in the development of the conceptual model, as the ranking is grounded in a systematic review of existing research rather than subjective opinions.

3.2 Conceptual Model

The conceptual model human factors that influencing cybersecurity culture among online banking users in Nigeria.

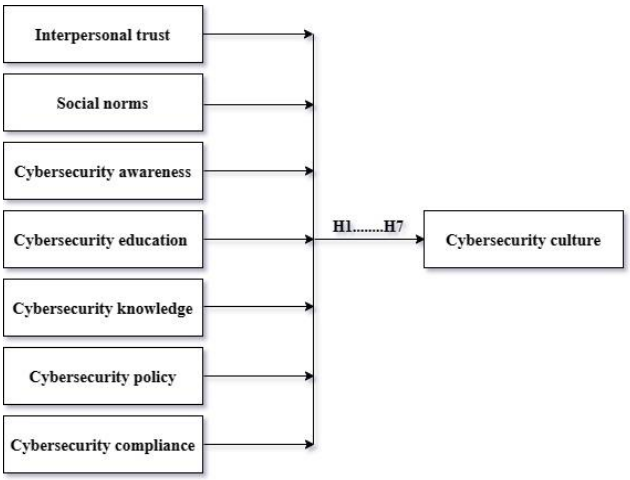

Figure 1: Conceptual Model

3.3 Hypotheses

Based on Figure 1, we can hypothesize the followings:

1- H1: Interpersonal trust significantly influences cybersecurity culture.

2- H2: Social norms significantly influence

cybersecurity culture
3- H3: Cybersecurity awareness significantly influence cybersecurity culture
4- H4: Cybersecurity education significantly influence cybersecurity culture
5- H5: Cybersecurity knowledge significantly influence cybersecurity culture
6- H6: Cybersecurity policy significantly influence cybersecurity culture.
7- H7: Cybersecurity compliance significantly influence cybersecurity culture.

4.0 DISCUSSION

The existing literature review provides and highlighted the key human factors that influence the Cybersecurity Culture among Nigerian internet banking customers. The significance and effectiveness of these human factors on Cybersecurity Culture are vary. From the Table 1 for the summary of previous research on cybersecurity culture the cybersecurity awareness, cybersecurity education and cybersecurity policy are the most construct proposed by the researchers. all of this clearly shows that cybersecurity awareness, education, and policy are the most important factors in identifying the value of cybersecurity, as they work to develop a strategic framework to educate users of the need to follow the cybersecurity policy to avoid any cybersecurity incidents and to enhance the security of users by minimizing the possible cyberthreat.

However, the culture of cybersecurity must be strengthened according to strategic plans and scientific methodology, in addition to educating everyone on the necessity and importance of awareness of the concept of cybersecurity culture and exchanging experiences in this regard. Furthermore, the literature review reveals that there is a lack of investigation into what is required of Cybersecurity knowledge that should be incorporated across the organization and individuals to improve Cybersecurity culture. Furthermore, the review also found that very few researchers have addressed the influence of social influence and interpersonal trust on cybersecurity culture. The review also suggested that having an effective cybersecurity culture may potentially contribute to positive cybersecurity behavior, there is a considerable research gap in recognizing each variable and assessing its influences on Cybersecurity culture among organization and individual.

In comparing the findings of this study with recent and related published reports, several commonalities and variations can be observed. Firstly, the importance of cybersecurity awareness, education, and policy as influential factors in cybersecurity culture is consistent across multiple studies. These factors are consistently recognized as essential for promoting a security-conscious mindset and behavior among online banking users in Nigeria.

However, it is worth noting that while cybersecurity awareness, education, and policy are widely acknowledged, the specific strategies and approaches for implementing them may differ among studies. Some reports emphasize the role of awareness campaigns and training programs, while others focus on the development and enforcement of robust cybersecurity policies. These variations highlight the need for tailored approaches that consider the unique context and characteristics of online banking users in Nigeria.

Another notable finding from this study, which aligns with some published reports, is the lack of comprehensive investigation into the required cybersecurity knowledge across organizations and individuals. While the importance of cybersecurity knowledge is acknowledged, there is a research gap in understanding the specific knowledge areas that should be prioritized and incorporated into cybersecurity culture initiatives.

Additionally, this study highlights the limited attention given to social influence and interpersonal trust as factors influencing cybersecurity culture. Similarly, some recent reports also identify this gap, emphasizing the need to explore the role of social dynamics and trust relationships in shaping individuals' cybersecurity behaviours and attitudes.

5.0 CONCLUSION

To conclude, this study provides valuable insights into the human factors influencing cybersecurity culture among online banking users in Nigeria. Through a comprehensive review of existing literature, several key findings have emerged, highlighting the significance of cybersecurity awareness, education, and policy in fostering a secure online banking environment. The findings emphasize the need for strategic initiatives to enhance cybersecurity culture in Nigeria. By prioritizing cybersecurity awareness campaigns, implementing comprehensive educational programs, and developing robust policies, financial institutions and relevant stakeholders can empower online banking users with the knowledge and skills needed to protect themselves against cyber threats. Furthermore, the study highlights the importance of recognizing and addressing the specific cybersecurity

knowledge requirements across organizations and individuals. Efforts should be made to identify and incorporate relevant knowledge areas into training programs and organizational practices, ensuring a comprehensive understanding of cybersecurity principles and practices. The study also emphasizes the role of social influence and interpersonal trust in shaping cybersecurity culture. Recognizing the impact of social dynamics on individual behaviours and attitudes, it is essential to foster a supportive and collaborative environment that encourages responsible cybersecurity practices.

Moving forward, it is recommended that further research be conducted to explore the identified research gaps and expand the understanding of cybersecurity culture in the Nigerian online banking context. This includes investigating the effectiveness of different awareness strategies, evaluating the impact of specific cybersecurity knowledge areas, and exploring the dynamics of social influence and trust in shaping cybersecurity behaviours. In conclusion, by implementing the insights gained from this study and adopting a proactive approach to cybersecurity culture, Nigeria's online banking sector can strengthen its resilience against cyber threats and create a safer digital environment for all users.

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AWARENESS OF CYBERCRIME AMONG ONLINE BANKING USERS IN NIGERIA

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Abstract

This study aimed to investigate the awareness of cybercrime among online banking users in Nigeria and provide quantitative data on various aspects related to cybersecurity awareness. A comprehensive survey was conducted among 283 online banking users in Nigeria to gather data. The data were analyzed to identify trends and patterns in cybersecurity awareness among Nigerian online banking users. The study revealed that 82.0% of the respondents were aware of cybercrime, indicating a high level of awareness among Nigerian online banking users. Social media (37.5%) and friends (16.0%) were identified as the primary sources of knowledge about cybercrime. The majority of respondents employed multi-factor authentication methods, such as login + password + biometric, to secure their online banking accounts. However, there was room for improvement in password preferences, as some respondents still used simple passwords. The most used features of online banking were transferring money between accounts (42.4%), checking account balances (26.5%), and paying bills (11.0%). This study contributes new insights to the existing body of knowledge by providing a comprehensive analysis of cybersecurity awareness among Nigerian online banking users. It emphasizes the evolving landscape of cybercrime awareness, the influence of digital platforms in disseminating information, and the importance of targeted awareness campaigns and improved security measures.

1.0 INTRODUCTION

The rapid advancement of technology and the increasing adoption of online banking services have brought significant convenience to individuals in Nigeria. Electronic banking, commonly known as E-banking, refers to the adoption of Information and Communication Technology in the banking sector. The integration of E-banking concepts, techniques, policies, and implementation strategies in banking services has become crucial for banks worldwide. It is not only a prerequisite for local and global competitiveness but also directly impacts management decisions, plans, and the range of products and services offered.

The implementation of an electronic-based cashless banking policy in Nigeria in June 2012, as emphasized by the Central Bank of Nigeria, brought numerous benefits to users. The introduction of E-banking in Nigeria aimed to achieve various objectives outlined by the central bank. One significant benefit for users is the curbing of negative consequences associated with the extensive use of physical cash in the economy. This includes reducing the high cost of

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producing, handling, and transporting money between banks and the public. Additionally, the cashless system targets issues like high subsidy and corruption [1].

However, alongside these benefits, there has been a parallel rise in cybercrime, posing a significant threat to online banking users. Cybercriminals may employ different techniques, such as phishing, malware attacks, identity theft, or social engineering, to gain unauthorized access to online banking accounts. They aim to exploit vulnerabilities in security systems, deceive users into revealing sensitive information like login credentials or personal data, or compromise the integrity of online banking platforms. These cybercrimes can result in severe consequences for individuals and institutions. Cybercriminals may gain unauthorized access to bank accounts, steal funds, conduct fraudulent transactions, or even engage in money laundering activities. Such activities can lead to financial losses for individuals, erosion of trust in online banking systems, and disruption of financial stability [2].

Despite extensive research in the area, there are still critical gaps that need to be addressed to enhance the awareness of cybercrime among online banking users. Recent studies have delved into the awareness levels of online banking users regarding cybercrime in Nigeria, shedding light on the evolving nature of this issue. Researchers have identified various types of cyber threats faced by users, such as phishing attacks, identity theft, and fraudulent transactions, highlighting the urgent need for improved cybersecurity measures and user education [3]. Financial institutions, regulatory bodies, and cybersecurity organizations have undertaken initiatives to mitigate these risks and promote awareness among users.

For instance, the paper of [4] explores the level of security and threats awareness among e-banking users in Palestine and identifies the main difficulties they face. The authors highlight the growth of internet services and the expansion of e-banking in Palestine, emphasizing the positive impact on service quality but also the increased opportunities for cybercrimes and security threats. Regarding the difficulties faced by e-banking users, the study highlights challenges related to remembering usernames and passwords, reliance on internet service, limited services, information security issues, and lack of help from bank employees. However, the study focuses on the situation in Palestine, but it would be beneficial to compare the findings with similar studies conducted in other regions or countries. This comparison would provide a broader perspective and allow for a better understanding of the unique challenges faced by e-banking users across different countries. Thus, the current study seeks to examine the level of awareness of cybersecurity and cybercrime in Nigeria.

Uchenna [5] analyzes the legal response in Nigeria to protect consumers from cybercrime in the banking and financial sector. The author finds that the current consumer protection regime under the Nigerian Cybercrimes Act is inadequate in safeguarding customers' personal information from unauthorized access and lacks a clear liability regime for unauthorized payment transactions. The paper suggests that Nigeria can learn from legal regimes in Europe and the United States to strengthen consumer protection under the Act. The article also identifies challenges hindering consumer protection in Nigeria's banking sector and proposes responses to address them. However, the paper was based on secondary data and did not examine the awareness of cybercrime among bank users and as well as their perception.

The study of [6] explores the relationship between e-banking and the increase in crime in Kaduna state. Although the study addresses an important topic, there are some gaps in the literature that need further investigation. One, the study briefly mentions new types of crimes that have emerged with the rise of e-banking, such as kidnap for ransom and ATM theft. However, it does not delve into these specific types of crimes in detail. Also, the study primarily focuses on the impact of e-banking on crime rates from a broad perspective. However, it overlooks the experiences and perceptions of individual users. Exploring user perspectives, attitudes, and behaviors related to e-banking and crime would provide valuable insights for developing targeted interventions and user-centric security measures.

However, a comprehensive analysis of the recent and relevant literature reveals significant research gaps that require further exploration. While previous studies have touched upon the general awareness of cybercrime, there is a dearth of quantitative analysis that measures the effectiveness of awareness campaigns and evaluates the actual levels of awareness among online banking users in Nigeria. This information gap hinders the development of targeted interventions and the assessment of the impact of awareness programs.

Moreover, although researchers have explored the initiatives undertaken by financial institutions and

regulatory bodies [Rufus Akintoye], there is limited focus on understanding the knowledge gaps and specific challenges faced by individual users. Obtaining a deeper understanding of users' perspectives, experiences, concerns, and perceptions regarding cybercrime awareness is crucial for tailoring effective educational programs and developing proactive defense strategies.

Therefore, this study aims to bridge these critical research gaps by conducting a comprehensive examination of the awareness of cybercrime among online banking users in Nigeria. By employing quantitative measures and considering the specific knowledge gaps related to different types of cyber threats, this research will provide valuable insights into the current state of cybercrime awareness. Furthermore, by incorporating the perspectives and experiences of individual users, this study will offer a holistic understanding of the awareness landscape, facilitating the identification of key areas for targeted interventions.

2.0 METHODOLOGY

The study employed a quantitative methodology to investigate cybercrime awareness among online banking users in Nigeria. It introduced a comprehensive research framework that combined quantitative analysis with a user-centric approach. This approach included a survey questionnaire to quantitatively measure cybercrime awareness levels among Nigerian online banking users and a comparative analysis of existing literature to identify research gaps. The questionnaire, organized into four sections, collected demographic information, assessed user-friendliness of online banking services, evaluated awareness of cybercrime, and explored security concerns.

Data collection utilized Google Forms and leveraged various social media platforms, resulting in 283 responses within six weeks. The collected data underwent analysis using SPSS software version 26.0, presenting findings through descriptive statistical analysis in the form of frequencies and percentages. This comprehensive approach aimed to provide a detailed understanding of cybercrime awareness while identifying areas for targeted interventions in enhancing cybersecurity awareness among Nigerian online banking users.

3.0 RESULTS AND DISCUSSION

3.1 Results

This section covers the statistical findings, analysis, and interpretation, which includes a descriptive analysis, frequency analysis of respondents' descriptive statistics, and lastly the discussion, conclusion, and recommendations.

Table 1: Respondent's Demographic Profile

Gender	**Frequency**	**Percent**
Male	206	72.8
Female	77	27.2
Age	**Frequency**	**Percent**
18 to 24	41	14.5
25 to 35	111	39.2
36 to 44	65	23.0
45 to 54	41	14.5
55 and above	25	8.8
Profession	**Frequency**	**Percent**
Working	161	56.9
Not working	122	43.1
Highest Education	**Frequency**	**Percent**
Postgraduate	38	13.4
Bachelor	82	29.0
Secondary and below	163	57.6
Where do you live	**Frequency**	**Percent**
City	150	53.0
Town	94	33.2
Village	39	13.8

The demographic profile of the respondents gathered from the questionnaire is shown in Table 1. Male respondents (72.8 percent) dominate female respondents (27.2 percent) from 283 respondents. Majority of the respondents were from group age of 25 - 35yrs old with (39.2 percent). Either majority of the respondents are working in public or private sector where they took almost more than half of the respondents with (56.9 percent). Besides that, majority of respondents were secondary school and below with (57.6 percent) followed by bachelor respondents with (29.0 percent) and postgraduate of (13.4 percent). In terms of geographical location, more than majority of the responders were from cities with (53.0 percent).

Table 2: Online Banking Users

Online banking users			
		Frequency	**Percent**
Valid	Yes	236	83.4
	No	47	16.6
	Total	283	100.0

From the Table 2 is for the respondent of online banking users where 236 respondents are using online banking with 83.4%. While the rest of 47 respondents with 16.6% are not using the online banking.

Table 3: Which features of Online Banking using

Which features of Online Banking you use

		Frequency	Percent
Valid	Pay the bill	31	11.0
	Check the account	75	26.5
	Transfer money between accounts	120	42.4
	Purchase and sale of foreign exchange	10	3.5
	Total	**236**	**83.4**
Missing	System	47	16.6
Total		**283**	**100.0**

Table 3 shows the responses of which feature of internet banking will you use. Transfer money between accounts took the highest percentage with 42.4% and 120 frequencies, followed by check the account with 26.5% and 75 frequency, then pay bill that took 11.0% with 31 frequency, and finally the purchase and sale of foreign exchange with 3.5% and 10 frequency.

Table 4: Aware of Cybercrime

Aware of Cybercrime			
		Frequency	**Percent**
Valid	Yes	232	82.0
	No	51	18.0
	Total	**283**	**100.0**

According to the respondent's feedback in Table 4 shows, 82.0% of the respondent indicated that they are aware of cybercrime. While the 18.0% of the respondents indicated that, they did not know about cybercrime.

Table 5: How do you know about Cybercrime?

How do you know about Cybercrime?			
		Frequency	**Percent**
Valid	Newspaper	39	13.7
	At School	42	14.8
	Social Media	106	37.5
	Friends	45	16.0
	Total	**232**	**82.0**
Missing	System	51	18.0
Total		**283**	**100.0**

Table 5 shows the respondents of how you know about cybercrime and in this question also allowed the respondents to selected more than one option. Social media took the highest percentages with 37.5%, follow by friends with 16.0%, then newspaper with 13.7 and finally at school with 14.8.

Table 6: Level of awareness of Cybercrime

Level of awareness of cybercrime			
		Frequency	**Percent**
Valid	Strongly aware	105	37.1
	Aware	81	28.6
	Un-decided	35	12.4
	Not aware	11	3.9
	Total	**232**	**82.0**

Table 6 describe how the respondents are described their level of awareness of cybercrime, where 37.1% are strongly aware of cybercrime, 28.6% are aware with 81 frequency, 12.4% respondents are un-decided about it, and the 3.9% are not aware. From the analysis, we realized that most of the respondents are aware about the cybercrime.

Table 7: Security Authentication

Which security authentication do you provided with when accessing an Online Banking website?			
		Frequency	**Percent**
Valid	Login + password	60	21.2
	Login+ password + biometric	81	28.6
	Login + password + token device	52	18.3
	Login + password + mobile (SMS) verification code	43	15.2
	Total	**236**	**83.4**
Missing	System	47	12.4
Total		**283**	**100.0**

In this Table 7 shows, the respondents of which security authentication do you provided with when accessing an online banking website and the question lowed to choose more than one option. Where 28.6% and 81 frequency choose login+password+biometric, follow by login+password with 21.2% and 60 frequency, then login+ password+token device with 18.3% and 52 frequency, the lowest is login+password+mobile (SMS) verification with 15.2% and 43 frequency.

Table 8: Changing of Password

How often would you prefer to change your online banking password?			
		Frequency	**Percent**
Valid	Every month	59	20.8
	Every 3 months	69	24.4
	Every 6 months	35	12.4
	Once a year	32	11.3
	I am not sure	25	8.8
	Never	16	5.6
	Total	**236**	**83.4**
Missing	System	47	11.0
Total		**283**	**100.0**

The Table 8 shows how the respondents change their online banking password for security. The highest percentage goes to every 3 months with 24.4%, followed by every month with 20.8%, followed every 6 months with 12.4%, then once a year and never have

11.3%, followed by not sure with 8.8%, then the lowest is Never with 5.6%.

Table 9: Password prefer to secure Online Banking

Password prefer to secure online banking			
		Frequency	Percent
Valid	Numbers	27	9.5
	Lower case alphabets (e.g., abc)	38	13.4
	Upper case alphabets (e.g., ABC)	19	6.7
	Special characters (e.g. @#%&*)	34	12.0
	Mixed of numbers and lower-case alphabets	74	26.1
	Mixed of numbers and upper-case alphabets	25	8.8
	Mixed of numbers and special characters	19	6.7
	Total	**236**	**83.4**
Missing	System	47	16.6
Total		**283**	**100.0**

Table 9 shows the type of password used by users to secure their online banking. Where 26.1% mixed of numbers and lower-case alphabets, 13.4% lower case alphabets, 13.4% numbers, 12.0% special characters, 8.8% mixed of numbers and upper-case alphabets, 6.7% mixed of numbers and special characters, respectively.

Table 10: Changing of Online Banking Password

How often would you prefer to change your online banking password?			
		Frequency	**Percent**
Valid	Every month	59	20.8
	Every 3 months	69	24.4
	Every 6 months	35	12.4
	Once a year	32	11.3
	I am not sure	25	8.8
	Never	16	5.6
	Total	**236**	**83.4**
Missing	System	47	11.0
Total		**283**	**100.0**

The table 10 shows how the respondents change their online banking password for security. The highest percentage goes to every 3 months with 24.4%, followed by every month with 20.8%, followed every 6 months with 12.4%, then once a year and never have 11.3%, followed by not sure with 8.8%, then the lowest is Never with 5.6%.

3.2 Discussion

Online banking has become an important tool and is radically transforming the banking industry around the world. Online banking is as the result of competition and technological innovation. Banks market their products to wholesale and retail online banking users through an electric delivery system. Those systems stayed largely ignored by the online banking users despite all their attempts and probably under-used as well. The biggest downside in Nigeria 's banking scenario was probably the lack of awareness of online banking users about the issue of cybercrime and the lack of desire to embrace improvements among the customers, which could contribute to it often touching the lowest possible standard of banking complexity. Hence, an attempt made to analyze and achieve the research objective. Based on the data from the current study on awareness of cybercrime among online banking users in Nigeria, several key findings emerge.

While the initial data analysis offered a comprehensive overview of respondents' awareness levels of cybercrime, the study acknowledges the need to delve deeper into the data to explore potential relationships between awareness and key demographic variables, namely age, education level, and gender. This aims to determine if the sample is representative of the broader Nigerian online banking user population concerning awareness of cybercrime. To assess the relationships between awareness of cybercrime and demographic variables (age, education level, and gender), correlation analysis was conducted. Pearson's correlation coefficient (r) was employed to examine the strength and direction of associations between these variables. The correlation analysis allows for a nuanced understanding of whether and to what extent these demographic factors are correlated with varying levels of awareness.

An analysis of variance (ANOVA) was conducted to investigate the relationship between age and awareness of cybercrime among respondents. Respondents were categorized into distinct age groups (18 to 24, 25 to 35, 36 to 44, 45 to 54, and 55 and above) to determine statistically significant differences in awareness levels among these groups. The ANOVA results provide insights into whether age influences cybercrime awareness.

To assess the relationship between education level and awareness of cybercrime, a chi-square test of independence was performed. This test examines whether there is a significant association between awareness levels and educational attainment, categorized into three levels: Postgraduate, Bachelor, and Secondary and below. The chi-square test helps understand if there are notable disparities in awareness among individuals with varying levels of education. Gender can be a critical factor in shaping awareness

of cybercrime. A chi-square test of independence was conducted to determine if there is a statistically significant association between gender (Male or Female) and awareness levels. This analysis discerns whether gender plays a role in cybercrime awareness among respondents.

In terms of online banking usage, a large percentage of respondents (83.4%) reported using online banking services. The most frequently utilized feature of online banking was transferring money between accounts (42.4%), followed by checking the account (26.5%) and paying bills (11.0%). These features represent the core functionalities of online banking and highlight the practical aspects that users find most beneficial. This agrees with the findings of Omodunbi et al., [21] that 96.8% of the respondents surveyed reported owning a mobile phone and having access to the internet, which are prerequisites for using online banking platforms. Additionally, findings from the study are in tandem with [22] who found that cyber security preparedness measures have a significant effect on the use of electronic banking channels and by extension financial innovation products. The study shows agreement with the work of [23] which found out that an increase in risk management was found to correspond to an increase in financial innovation, as did an increase in bank monitoring. The adjusted R2 value indicates that the variables in the study explain 44.7% of the changes in financial innovation, with the remaining 55.3% being influenced by external factors.

There is overall consistency regarding online banking adoption, awareness of cybercrime, security authentication measures, password preferences, and frequency of changing passwords among Nigerian online banking users. The findings suggest that online banking has gained significant traction in Nigeria, with a high percentage of users utilizing online banking services. The novelty of the current study lies in its comprehensive examination of various factors related to cybercrime awareness among online banking users. By analyzing the demographic profiles, usage patterns, and sources of knowledge about cybercrime, the study provides a holistic understanding of the subject matter. This approach distinguishes it from previous reports that may have focused on specific aspects or lacked a comprehensive analysis.

3.2.1 Practical implications of the findings

The practical implications of these findings are manifold and extend to multiple stakeholders. Policymakers can utilize this information to formulate evidence-based policies aimed at bolstering cybersecurity awareness in the online banking sector. Tailored educational programs can be designed to address the specific needs of different age groups and educational backgrounds. Financial institutions can leverage these insights to enhance their security protocols and user education efforts, ultimately contributing to a safer online banking environment. Moreover, educational institutions can incorporate cybersecurity awareness into their curricula to equip future generations with the knowledge and skills needed to protect themselves in the digital realm.

4.0 CONCLUSION

In conclusion, this study reveals a noteworthy level of cybercrime awareness (82.0%) among Nigerian online banking users. The primary sources of awareness include social media, friends, newspapers, and school. Respondents commonly employ multi-factor authentication methods to secure their online banking accounts. However, there is room for improvement in password preferences. These findings highlight the evolving landscape of cybercrime awareness and the significance of digital platforms and interpersonal networks in disseminating information about cyber threats among online banking users in Nigeria.

4.1 Limitations

The study primarily relies on self-reported data, which introduces the possibility of response biases. While respondents' answers provide valuable insights, their accuracy and completeness may vary based on individual perceptions and experiences. Also, the study's sample is limited to online banking users, potentially leading to a bias in the findings. Excluding non-users of online banking services means that the research does not capture the perspectives and awareness levels of this specific demographic. Furthermore, the study does not delve into an in-depth exploration of the specific cybersecurity measures implemented by financial institutions. A more comprehensive analysis of these security protocols could have offered a deeper understanding of the overall security landscape in online banking. Regardless of the limitations, the study was able to achieve its objectives.

5.0 RECOMMENDATIONS

Based on the findings of the study, the following are recommended. Given the high level of cybercrime awareness among online banking users in Nigeria, it is essential to further enhance cybersecurity education initiatives. Financial institutions, government agencies, and educational institutions should collaborate to develop comprehensive cybersecurity

awareness programs targeting users of online banking services. Also, while many users employ multi-factor authentication methods, there is still room for improvement in password practices.

Since social media was identified as a primary source of cybercrime knowledge, leveraging these platforms for awareness campaigns can be highly effective. Financial institutions should continue to invest in advanced security measures to protect online banking users. This includes regularly updating security protocols, implementing robust encryption, and monitoring for suspicious activities. Additionally, offering users a variety of secure authentication options can enhance account security. The study found that a significant percentage of users were uncertain about the ideal frequency for password changes or reported never changing their passwords. Clear guidelines and reminders can help users maintain better password hygiene.

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AN EXPLORATORY INVESTIGATION INTO THE STATUS OF WATER, SANITATION AND HYGIENE (WASH) OF SCHOOLS IN ENUGU STATE, NIGERIA

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Abstract

The status of water, sanitation and hygiene (WASH) facilities was investigated in sixty schools in seven local government areas of Enugu State, Nigeria. A total of sixty schools comprising of twenty-four (24) private schools, twenty (20) government schools and Sixteen (16) mission schools were investigated in this study. Using questionnaire and on-the-spot assessment, WASH facilities in the selected schools were subjected to in-depth scrutiny. The highest number of schools that do not have a water source within the school premises are government schools (10), followed by private schools (7) and then mission schools (2). About seventy-one percent (71%) of the schools investigated rely on self-help water supply sources such as water vendors, rainwater harvesting and private boreholes. Fifty-seven (57) or 95% of the sixty (60) schools of all the schools have toilet facilities ranging from improved pit latrine (10%), flush toilet (31.7%) and pour flush toilet (53.3%). With respect to toilet cleaning, 33%, 17% and 50% of private, government and mission school clean their toilets every day. Fifty-five percent (55%) of all schools always provide handwashing facilities while 13.3% never provide handwashing facilities. Based on school category, the distribution of schools that provide handwashing facilities are as follows: private schools – 54.2%, government schools – 40% and mission schools – 75%. There was a significant correlation (r = 0.85) between availability of toilet facilities and provision of handwashing facilities. There was also a significant correlation (r = 0.555) between the provision of handwashing facilities and the provision of soap.

1.0 INTRODUCTION

Water, sanitation and hygiene (WASH) have remained one of the foremost issues of concern in developing countries. The paucity of basic sanitation and personal hygiene facilities both in private homes and public places has imposed an inestimable toll on the health of the most vulnerable members of the society. Infants and school children who spend most of their time in the school premises are usually exposed to environmental conditions that exceed are far less than ideal or desirable. WASH facilities are central to both the transmission and mitigation of routine as well as rare contagious diseases [1]. It has been reported that diarrheal diseases are responsible for one in nine child deaths 88% of which can be attributed to inadequate sanitation, unsafe water and insufficient hygiene facilities [2]. School-aged children are at high risk for water, sanitation, and hygiene (WASH)–related morbidities, including soil transmitted helminths and trachoma [3]. The endemic annual outbreak of diarrheal diseases among children can be traced to the intermingling of infected and health children at school

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as well as transmission occasioned by the use of common WASH facilities that do not meet minimum standards. Though women and children are usually saddled with the burden of water and sanitation-related chores in the generality of sub-Saharan African communities, they have been reported to be the most vulnerable and susceptible to the outfalls of poor WASH services [4]. The spike in gastrointestinal and respiratory diseases responsible for half of all child deaths have been linked to poor WASH practices [5].

Shortage of water supply, inadequacy of toilets and general low level of sanitation in schools have been reported in many parts of the world [6]. Even in the most advanced countries, WASH in schools generally lags that of homes and offices. This situation exposes school children to several health risks and routes of infection. Impaired cognitive learning and poor learning performance are long-term outcomes of the negative effects of infections such as diarrhea, worm infestations, and dehydrations which are largely attributed to poor water, sanitation, and hygiene conditions both at homes and in schools [7]. Furthermore, inadequate WASH conditions have been reported to reduce educational outcomes in children by contributing to absenteeism and impaired cognitive abilities [8]. Absenteeism results from time spent at hospitals for consultations and treatments as well as convalescence time at home. Studies have shown that implementation of WASH programmes in schools result in significant reduction in absenteeism [9, 10].

In essence, WASH in schools is a pathway to healthier schools and healthier, better performing children [11]. Overall, the implementation of the WASH in schools has been found to be effective, though poor planning and coordination, inadequate funding, and low technical capacity were identified as barriers to achieve the intended objectives [12]. The educational system in Nigeria has been bedevilled with poor funding which has in turn caused progressive decline in the quality of education and infrastructural decay. Critical facilities such as classroom windows, chairs, school library, science laboratories, art studios and many others have gradually disappeared from government owned schools. This decay has also resulted in the dilapidation of basic WASH facilities which are critical to the wellbeing of school children.

2.0 METHODOLOGY

Seven Local Government Areas were selected for the study namely, Nsukka, Igbo-Eze South, Igbo-Eze North, Udenu, Enugu North, Enugu South, and Enugu East. The schools were selected by dividing the state into three cadres with respect to development namely; Urban, Semi-urban, and Rural areas and further chosen from different local governments within the state. Data collection was achieved using a combination of survey questionnaire and personal observation. The survey questionnaire was structured to elicit comprehensive data on the problems of WASH, and WASH facilities in schools across the seven local government areas of focus. A total of sixty schools were investigated under the following broad categories: private (24), government (twenty) and mission (16). For each school visited, while questionnaire was being administered, interviews and personal observation of the current state of WASH in the schools were simultaneously undertaken.

The observatory aspect of the study paid attention to the availability of hand-washing facilities, provision of potable water, functionality of the existing latrines, presence of anal cleaning agent in the toilets, drainage channels, and method of solid waste disposal and facilities etc. However, the contradictions of answers given by teachers and students during the questions were noted. Further confirmatory evidence was collected by means of pictorial representation of the true situation of events in those schools.

During the field analysis and data collection participation was made voluntary. None of the students and teachers was coerced to fill out the questionnaire. The respondents particularly school children, were allowed to ask questions at points of confusion and were given ample opportunity to completely understand the question before answering. Teachers and school principals were assured that none of the results deducted from the school analysis would be published or handed over to any governmental agency or rival school. The schools were assessed according to JMP and WHO standards, based on the comfort of the student, teachers and the environment.

3.0 RESULTS AND DISCUSSION

3.1 Water Sources and Supply in Schools

An analysis of the results obtained showed that nineteen (32%) of all schools surveyed do not have a water source in the school premises. The highest number of schools (10) that do not have a water source within the school premises are government schools, followed by private schools (7) and then mission schools (2). Only one school (government owned) has piped water within the premises. The mission schools and private schools mostly resort to self-water for water supply. Fifty percent (50%) of private schools rely on water trucks to supply water to them routinely, while twenty one percent (21%) of them have boreholes within the school premises. This way, constant supply

of water can be guaranteed subject to availability of constant power for pumping. Studies have reported a high rate of dependence on self-help water supply in many developing countries owing to the collapse of municipal water supply schemes [13, 14]. This reality that exists in the larger society is clearly propagated back to the schools. In order to ameliorate the degree of water stress faced by school children and students and also ameliorate the well-established repercussion of water scarcity, some school managements have resorted to rainwater harvesting in order to provide water for the staff and pupils.

Figure 1 shows that 3 government schools and 1 mission school rely on harvested rainwater as their main source of water supply. Even though this measure will go a long way in resolving some of the water-related problems associated with water scarcity, it has some adverse potential health implications for the children when consumed without treatment. The rainwater harvesting system shown in Figure 2b as captured in one of the schools is clearly not competent to serve as a potable water sources. A cursory examination shows that the tank is rusted and the top is open thus making it susceptible to invasion of contaminants. The overhead tank unit shown in Figure 2b is more reliable in terms of supplying potable water supply because it is a closed system that makes very little or no room for ingress of contaminants. If it is connected to a borehole, then the entire process from abstraction to point-of-use delivery is safeguarded against contamination. In a further attempt to cushion the water stress faced by school children, it is common for children to go to school with their personal water flasks which are usually kept on the floor at the back of the classrooms. These water bottles also present some degrees of health risk as a result of the poor hygienic habits of the children. Constant supply of water to school children is critical for the overall wellbeing of the children. Adequate water supply is a basic precursor to improved sanitation, personal hygiene and health of the school child. It has been reported that dehydration can adversely affect psychological factors that in turn affect cognitive performance such as attention, concentration, short term memory, mood and perceived efforts [15, 16]. [3] reported an association between dehydration and cognitive test scores among primary school children in Zambia. [17] reported that rehydration by water supplementation improved the overall cognitive ability and psychological state of college students in Cangzhou, China.

Table 1 further shows that only 18% of all schools surveyed have constant water supply, forty-eight percent (48%) have water sometimes and thirty-five percent (35%) do not have water at all. It is important to note that the availability of water source or infrastructure within the school premises does not usually guarantee availability of water. This partly explains why some schools might have a water source and yet suffer from lack of water supply. Despite the presence of borehole in some of the schools, reasons why constant water supply cannot be guaranteed include: pump failure, power failure, unavailability of operator, well collapse amongst others.

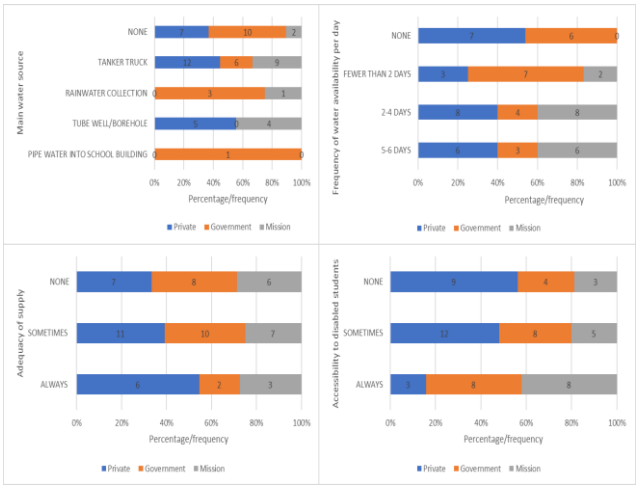

Figure 1: Status of water supply in schools

Figure 2: (a) Rain as water sources in a government school; (b) Overhead tank supply at a mission school

3.2 Provision of Sanitary Facilities in Schools

Results obtained show that 57 (95%) of all the schools investigated in this study have toilet facilities ranging from improved pit latrine (10%), flush toilet (31.7%) and pour flush toilet (53.3%). The improved pit latrine represents a retrofitting of pit latrines in order to improve on sanitary services. This type of toilet was found only in government owned and mission schools with a count of three in each. It is also important to note that most of the mission schools operate a hybrid management that is based on joint participation by the government and churches. Hence, it is expected that there may be some similarities in management

determined aspects of WASH. To further buttress the place of management and administration in determination on WASH status of schools, [18] reported that schools with male heads in Ethiopia were 7% less likely to have basic hygiene services than those with female directors

Two of the schools that do not have toilet facilities are in rural areas while the other one is located in the urban area. Though a very high proportion of the schools surveyed have toilet facilities, further investigation shows that these toilet facilities are grossly inadequate and poorly maintained. The most common type of toilet facilities irrespective of school management is the pour flush toilet type with the following distribution: private (62.5%), government (45%) and mission (50%). The use of flush and pour-flush toilets requires a fairly constant water supply which remains a fundamental problem in many developing countries. Further analysis of the data obtained reveals a worrisome contradiction in the sanitary condition of the schools. Only 26 % of the secondary schools have water supply up to five days a week, yet 80 % of these schools use flush and pour-flush toilets. Obviously, the water supply falls short of the requirement for keeping these toilets in good sanitary condition. Irregular water supply usually results in a situation where toilets are not flushed even after repeated use by several students, thereby increasing the risk of infection and other health complications. Abundant water supply is a pre-requisite for ensuring public health. The above points are clearly buttressed by Figure 3 showing the squalid and dirty state of some of the school toilets.

Figure 3: Sanitation facilities found in schools

Table 1: Sanitary conditions across various categories of schools

SANITARY STATUS	TYPE OF SCHOOL					
	Private		Government		Mission	
	Count	Percentage	Count	Percentage	Count	Percentage
TYPE OF TOILET						
Pit Latrine	0	0%	0	0.0%	0	0.0%
Improved Pit Latrine	0	0%	3	15.0%	3	18.8%
Flush Toilet	9	37.5%	5	25.0%	5	31.2%
Pour Flush	15	62.5%	9	45.0%	8	50.0%
Compost Toilet	0	0%	0	0.0%	0	0.0%
None	0	0%	3	15.0%	0	0.0%
FREQUENCY OF TOILET CLEANING						
5-6 Days Per Week	8	33%	3	15.0%	8	50.0%
2-4 Days Per Week	12	50%	11	70.0%	8	50.0%
Fewer Than 2 Days Per Week	4	17%	3	15.0%	0	0.0%
None	0	0%	0	0.0%	0	0.0%
NUMBER OF STUDENTS PER DROPHOLE						
< 25	6	25%	0	0.0%	2	12.5%
26-40	13	54%	5	25.0%	9	56.2%
41-50	3	13%	9	45.0%	3	18.8%
50 and above	2	8%	6	30.0%	2	12.5%
GENDER-SEGREGATED TOILETS						
All	15	63%	12	60.0%	16	100.0%
Some	5	21%	5	25.0%	0	0.0%
None	4	17%	3	15.0%	0	0.0%

All the private schools have either the flush or the pour flush toilet types which is an indication of better management and more detailed attention to children's welfare. The private schools tend to provide better learning and sanitary facilities which makes then the more desirable choice for parents who can afford the usually comparatively more exorbitant fees charged by private school operators. Since private school operators are constantly in competition with one another, they seem to be constantly under pressure to render improved services in order to retain their students and even attract new ones. In a similar study, [19] reported a significantly higher knowledge of basic WASH among students of private school than in public schools in Ibadan. However, this does not necessarily mean that the sanitary levels found in these schools meet relevant

standards. This reality is clearly portrayed in the frequency of toilet cleaning as shown in Table 1 which shows that only 33% of the private schools clean their toilets every day and 17% clean them fewer than two days per week.

The mission schools appear more committed to cleaning their toilet facilities as 50% of them clean their toilets everyday while the remaining 50% clean them two to four times per week. The worst performing are government schools where only 15% of the schools surveyed clean their toilets every day, while 70% clean on two to four times per day and the remaining 15% clean fewer than two days per week. There is clearly a lapse in the area of toilet cleaning in the schools surveyed. This can be attributed to shortage of manpower to undertake such menial and demanding task. Besides, it is a low paid job which only a few persons are willing to take in the interim. The squalid state of these toilets (Figure 4) forces the children to hold themselves until they get home before defecating. Those who cannot bear the unending wait are compelled to use the toilet as they are or even resort to open defecation in bushes and farmlands around the school premises. When people are compelled to use dirty toilets due to certain circumstances, there is usually the tendency to mess it up further. Some children might even defecate on the flour if no one is around or climb the toilet seats to prevent their buttocks from being in contact with the contaminated facilities.

Figure 4: Dilapidated sanitary facilities

Figure 4 shows the general condition of toilets in schools investigated. It would appear that, among other factors, poor maintenance, sheer neglect and poor health education are responsible for the abysmal state of hygiene in these schools. It is not uncommon to find toilets with missing doors, windows and roofs, dirty walls and soiled floors, surrounded by overgrown bushes especially in public schools. All these are indications of poor sanitary conditions at schools which can have a lifetime effect on the health and psychology of the students. [20] reported a high incidence of gastrointestinal infections among primary school children as a result of poor hygiene.

Another critical aspect to consider about toilet facilities is the number of drop holes per pupil. Table 1 shows that 41.7% of the schools have toilets to students' ratio of more than 1 drop hole per 40 students while the remaining have a ratio of equal to or less than 1 drop hole per 40 students. On category basis, 79% of private schools, 25% of government schools and 68.7% of mission schools have toilets with a drop hole to student ratio of 1:40. The percentage of schools by category with students to drop hole ratio greater than 40 is as follows: private (21%), government (75%) and mission (31.3%). The gravity of the situation is more clearly expressed by looking at the global space of the schools and taking a ratio of number of students to number of toilets. Based on this approach, the average number of students per drop hole is 137 for elementary schools and 366 for secondary schools. Obviously, this is an indication of various degrees of violation of standard guidelines of toilet cubicle to student ratio of 1:50 for boys, and 1:40 for girls. None of the school provided male urinals [12]

Gender-segregation of private activities run very deep in the African culture. Hence, the delineation of boys' and girls' toilets is a very important component of sanitation management and administration in the schools investigated. Table 1 shows that 43 (71.7%) of the schools have strictly gender-segregated toilets with 100% of all mission schools having gender-segregated toilets. Only 7 (11.7%) of all the schools irrespective of ownership or management have gender-neutral toilets. Each of the gender-segregated toilet compartment serves an average of 159 boys and 194 girls in elementary schools. These results bear very strong similarities to the findings of [18] who reported that 86.7% of investigated in the Bishoftu Town of Ethiopia had gender-segregated toilet facilities.

3.3 Exploring Hygiene Levels in Schools

Further assessment of the general sanitary condition of the schools reveals serious lapses that require immediate attention. For instance, not all schools provide handwashing facilities for their students. Table 2 shows that 55% of all schools always provide handwashing facilities while 13.3% never provide handwashing facilities. Based on school category, the distribution of schools that provide handwashing facilities are as follows: private schools – 54.2%, government schools – 40% and mission schools – 75%.

This shows that mission schools are more hygiene conscious than the other two categories of schools, followed by private schools. Closely related to provision of handwashing facilities is the provision of soap for handwashing. The distribution is also similar to that of handwashing facilities with mission schools having the highest percentage of 43.7% as compared to 37.5% for private schools and 20% for government schools. 86.7% of both elementary and secondary schools provide handwashing facilities. The importance of the provision of handwashing facilities in schools cannot be overemphasized because school children are usually exposed to a wide range of contaminants either by contact with various inert surfaces or other children.

Basically, children are mandatorily expected to wash their hands before eating and after using the toilet. However, this expectation is not usually met due to the absence of the requisite facilities, unavailability of water or lack of basic WASH knowledge among the children. In another study that considered only private and government schools, [19] observed that variables that significantly predicted hand hygiene practice were availability of water in school toilets, comfortability of using school sanitary facilities, availability of toilet cleaners, and practice of open defecation at home. The just exited COVID-19 pandemic played a vital role in properly situating hand-washing as a key defence mechanism against contagious diseases. As countries struggled with the pandemic, hand-washing facilities began to appear in places where hitherto, they were never thought of. It is recommended that hand-washing be observed even after interacting with asymptomatic persons [21]. Hand-washing also helps in curtailing the rate of propagation and transmission of childhood diseases. [22] reported that strategic handwashing interventions for children can significantly improve their health status. More specifically, children who wash their hands regularly four times a day are likely to suffer 24% fewer sick days due to respiratory illnesses and 51% fewer sick days due to gastrointestinal illnesses [5]. It is important to note that [23] reported that hand-washing is most frequently practiced (92.2% of surveyed households) after using the toilet, while the degree of practice for other activities such as before cooking and before cooking recorded lower frequencies in Ovia Northeast LGA of Edo State, Nigeria.

In terms of provision of information on menstrual hygiene, mission schools again outpaced the other schools with the highest in-category percentage of 56.3% as compared to 33% and 35% respectively for private and government schools. The same also applies to personal hygiene education with all the mission schools surveyed always providing personal hygiene instruction to their students but only 54.2% and 35% of private and government schools respectively providing personal hygiene education to their students. The foregoing reveals a deeper level of commitment of mission schools to environmental sanitation and personal hygiene of their students. This may not be unconnected with the moral inclination of administrating church with the underlying concept of *"cleanliness is next to godliness"*. Besides, mission churches seem to have a major departure from private schools in the sense that they are usually not profit-driven which makes them to go the extra mile to provide services the students might not ordinarily be able to afford. Private schools are different in this regard because certain services can only be provided as long as management can afford it within their target margin of profit. Besides, mission school seem to have a more disciplined management and administration which is largely absent in many government owned schools where motivations is abysmally low due to low remuneration. Hence, it appears that while other factors as already identified contribute to the WASH status of schools investigated in this study, availability of finance also plays a critical factor. [18] found a strong association between having a budget line specifically for WASH services and provision of basic WASH facilities. There is no doubt that the consistently low allocation of funds to education in Nigeria is largely responsible for poor staffing and infrastructural decay especially at the primary and secondary school levels.

Table 2: Hygiene status of schools investigated

HYGIENE STATUS	TYPE OF SCHOOL					
	Private		Government		Mission	
	Count	Percentage	Count	Percentage	Count	Percentage
AVAILABILITY OF HANDWASHING FACILITY						
Always	13	54.2%	8	40.0%	12	75.0%
Sometimes	8	33.3%	7	35.0%	4	25.0%
Never	3	12.5%	5	25.0%	0	0.0%
PROVISION OF SOAP FOR HANDWASHING						
Always	9	37.5%	4	20.0%	7	43.7%
Sometimes	11	45.8%	12	60.0%	6	37.5%
Never	4	16.7%	4	20.0%	3	18.8%
INFORMATION ON MENSTRUAL HYGIENE						

Always	8	33.3%	7	35.0%	9	56.3%
Sometimes	9	37.5%	8	40.0%	2	12.5%
Never	7	29.2%	5	25.0%	5	31.2%
PERSONAL HYGIENE EDUCATION						
Always	13	54.2%	7	35.0%	16	100.0%
Sometimes	11	45.8%	10	50.0%	0	0.0%
Never	0	0.0%	3	15.0%	0	0.0%
SOLID WASTE DISPOSAL						
Thrown on Garbage Dump within or Near School Ground	11	45.8%	8	40.0%	9	56.3%
Buried within or Near School Ground	7	29.2%	9	45.0%	4	25.0%
Collected and Taken away by a Waste Disposal Service	6	25.0%	3	15.0%	3	18.7%
HOW OFTEN IS SOLID WASTE DISPOSED OFF						
Once a Day	13	54.2%	4	20.0%	9	56.3%
Between Once a Day and Once a Week	8	33.3%	10	50.0%	7	43.7%
Less frequently than Once a Week	3	12.5%	6	30.0%	0	0.0%

Table 3: Spearman's rho non-parametric correlation

	Availability of toilet facilities	Provision of handwashing facilities	Provision of soap	Frequency of water availability
Availability of toilet facilities	1.000			
Provision of handwashing facilities	.850	1.000		
Provision of soap	.471	.555	1.000	
Frequency of water availability	-.575	-.407	-.104	1.000

Non-parametric correlation coefficients showed that there is a good correlation (r = 0.85) between availability of toilet facilities and provision of handwashing facilities (Table 3). Hence, most schools that have toilet facilities also provide handwashing facilities. This suggests that provision of toilet facilities for students puts on the school authorities the sense of responsibility to also provide handwashing facilities, thereby promoting hygiene among students. Moreover, most water closet toilet units come with wash hand basins. There was also a significant correlation (r = 0.555) between provision of handwashing facilities and provision of soap. The complete sequence of handwashing practice includes availability of water sources, provision of handwashing facility and availability of soap. In fact, most schools usually demand that students submit packets of soap and tissue paper at the commencement of every term possibly with the view to encourage handwashing. It would make no sense to ask children to submit soap if handwashing facilities were not provided. Besides, it is the students and not the school management that provides the soap for handwashing.

The good correlations among the WASH components shown in Table 3 is an indication of the interwoven and interdependent nature of these components. Hence, non-availability of one is likely to translate into the non-availability of another. Data generated during field study also shows that open defecation is still practiced in some schools. Inadequate numbers of latrines, limited accessibility and lack of maintenance by school management have been documented as factors that predisposes pupils to defecation on open grounds and nearby bushes [24]. This practice will continue in schools until decent toilet facilities are provided. None of the schools (Nursery and Primary) visited had a WASH club as at the time of this study. Out of the Secondary schools surveyed none of the schools has ever benefitted in any WASH-related activity/programme.

4.0 CONCLUSION

This study has clearly revealed that water, sanitation and hygiene (WASH) in elementary and secondary schools leave much to be desired and therefore calls for urgent intervention. Bivariate analysis revealed that access to water was rarely available despite the abundance of WASH infrastructures which may pose a threat to the health of schoolchildren and teachers as they both share synergetic relationship for a productive learning. WASH infrastructures are poorly maintained, and infinitesimal health education exist. However, introducing inclusive health education and practise and a more sustainable source of water supply, with support from governmental and non-governmental organisations may reduce to a bearable minimum the lack of WASH practise saturating schools in Nsukka, Nigeria and improve their wellbeing and future.

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