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Volumetric Mathematical Equations For Round Log Of Some Selected Species

Eguakun, Funmilayo Sarah., Okolo Ebere Chiamaka

Department of Forestry and Wildlife Management, Faculty of Agriculture. University of Port Harcourt
funmilayo.popo-ola@uniport.edu.ng

Abstract: Sawmills are major wood-based industries that participate in processing and efficient utilization of timbers. Sawmills constitute 93% of total number of wood-based industry. Accurate measurements are extremely important for the forest manager, harvesting and wood processing company as well as end users. This study was set out to develop mathematical prediction models for volume estimation of round logs using some log characteristics that affects log volume. Three (3) log species *Acer rubrum*, *Ficus elastica* and *Xylopia aethiopica* were selected for the study based on the frequency of sawing in the sawmill. Log characteristics like log length, top and bottom diameter, log taper, log ovality were measured and their mean estimated for thirty (30) sampled logs. The average length of log ranged from 3.02m to 3.48m which was used along with other log variables to estimate mean volumes ranging from 2.67m^3 to 5.67m^3. The result portrayed that there was positive correlation between length and volume in *Xylopia aethiopica* (0.94) and *Ficus elastica* (0.68) and also between volume and diameter in *Xylopia aethiopica* (0.96), *Ficus elastica* (0.97), *Acer rubrum* (0.99). There was a weak negative correlation between the volume and the taper (0.38) and between volume and ovality (0.34) in *Xylopia aethiopica*. Four mathematical functions namely linear, multiple, single logarithm and double logarithm were used to develop log volume prediction models for selected species. The best volume estimation model for *Xylopia aethiopica*, *Acer rubrum* and *Ficus elastica* are multiple model (R^2 = 0.97, SEE = 0.155), linear model (R^2 = 0.99, SEE = 0.295) and single logarithm (R^2 = 1, SEE = 0.068) respectively. However, the linear function was selected as the best for prediction in all the species. Development of specie-specific volume equations is essential to achieve higher levels of precision in estimation of logs which can bring about a rapid and effective process that avoids unnecessary felling of trees and minimizes cost. [Eguakun, F. S., Okolo E. C. **Volumetric Mathematical Equations For Round Log Of Some Selected Species,** *N Y Sci J* 2023;16(8):1-8]. ISSN 1554-0200 (print); ISSN 2375-723X (online). http://www.sciencepub.net/newyork. 01. doi:10.7537/marsnys160823.01.

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1. Introduction

Wood is a heterogeneous, hygroscopic, cellular and anisotropic material of biological origin. It is a hard fibrous tissue found in many plants (Okoye *et al*, 2014). Wood has been used and adopted by humans since the earliest recognition that they could make use of the materials they found around them. Wood has been used to meet varying array of human needs, in peace and in war, in farming and in industry, Logs are provided to other wood-based industries for construction, joinery, and furniture through primary industries called sawmills which plays important role in wood utilization (Babalola *et al*, 2018). Nigeria is one of the most populated countries in the world and it needs to keep up with the increasing technological growth hence; the need to satisfy man´s demand and man´s rapid evolution. Sawmilling activity is one of the ways to satisfy man’s demand.

Timber quality in addition to timber volume is one of the important parameters for fixing prices. For billing of timber individual log measurement is performed. Measurement such as diameter, length and volume are very important part of wood processing. Volume of wood is the quantification of an individual log, tree or group of trees in cubic value. Log volume estimation is the precise estimation of log volume through merchant log measurement that involves the quantification of individual log (Mushar *et. al*., 2020). Log volume is essential in designing a sustainable forest management plan and also has the potential in controlling the decision-making process related to the forest trade activities (Li *et al* 2015; Davis *et al* 2001). Volume of log can also be used as foundation for calculating the total gross vehicle weight for maximum individual load of log (Moskalik, 2022). Accuracy of round log volume estimation is of basic importance in planning and accounting for processes related to wood trade (Tadeusz, 2022). Due to increase in timber demand, other measurement methods are being used to represent the volume as accurate as possible (Pasztory *et al*, 2018).

Information on log measurement is kept for record keeping or inventory purpose to know how much forest has been harvested and know how much has been lost by timber theft, fire and illegal logging. This is also important to establish forest management plans. In sustainable forest management, researches on accurate estimates of log volume have become very important in log/ timber trading (Davis *et al*, 2001). Knowledge of volume of wood is essential in forest management planning, inventories commercial harvest and conservation Report of Onefeli and Adesoye (2014), stated that sustainable forest and forest resources management requires reliable estimates of growing stock because such information guides forest managers in timber evaluation. Davis *et al*., (2001) emphasized that for accurate evaluations and for trading forest resources, volume estimation is crucial in sustainable forest management. Understanding the volume of wood in forests and the regions is fundamental for regional forest management planning, commercial harvest, and conservation.

Mathematical equations are valid tools for estimation and valuation of timber for decision-making and effective management strategies. Research has proven the use of mathematical equations in predicting tree/log variables as a function of other tree/log attributes (Avery & Burkhart, 2011; Chave *et al*., 2014). However, models developed by integrating theoretical information about the underlying relationships between dependent and independent variables are generally well specified and better reflects the fundamental biological and physical relationships shown by the system. These models can yield consistent results even when applied beyond the range of the data used to develop relationships between dependent and independent variables. The purpose of this study is to shed more light on developed mathematical equations for volume estimation of round log and its relationship with other log characteristics at Iloabuchi Sawmill, Rivers State.

2. Material and Methods

Study Site

The research was carried out at Iloabuchi sawmill (Latitude 4°78' 77" - 4°78' 89" N, Longitude 6° 98' 75" E). It is located in Rivers State, Nigeria, and is part of the Port Harcourt city local government area. Adedeji *et al* (2016) explained Port Harcourt to be located in the subequatorial zone, which is prone to frequent and extended rainfall. Almost the entire year, water transportation is the means suitable for logging in the area. The fluctuations in the weather conditions in Port Harcourt City are caused by the wet south-west breeze and northeast trade winds. Between February and November, the moist south-east air stream flows over the region, bringing rain, while the Northeast trade wind blows over Port-Harcourt from November to February, ushering in the dry season. The average annual temperature in Port Harcourt is 28°C, and relative humidity is high, with an average annual value of 85 percent. Port Harcourt soil gradually becomes alluvial soil.

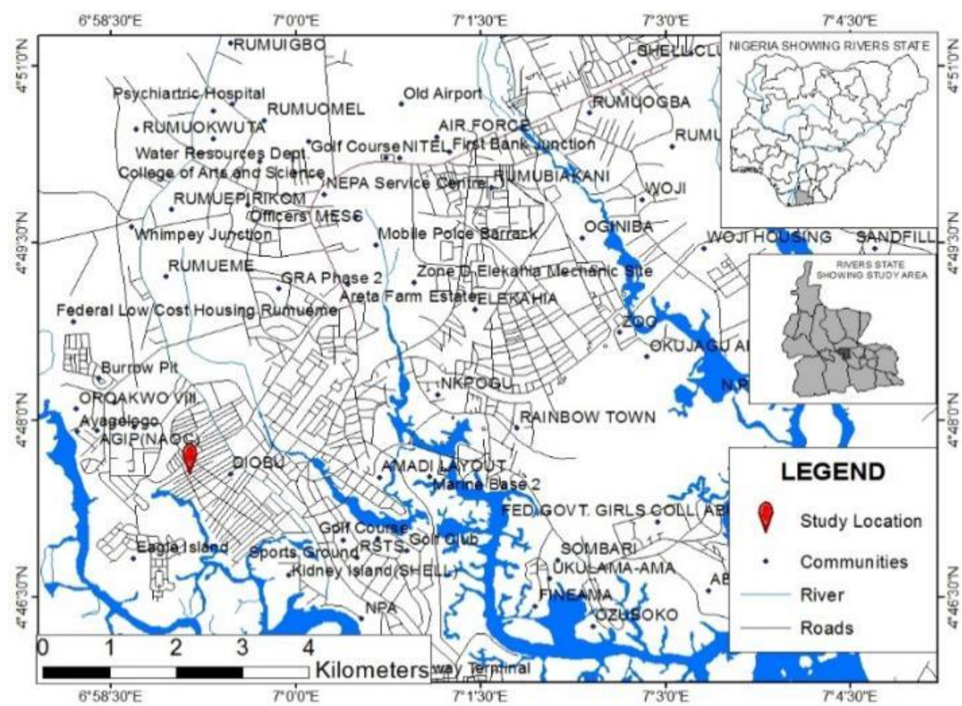


Fig 1: Map of Port Harcourt showing Iloabuchi Sawmill

Sampling Techniques

Reconnaissance survey was conducted to identify the most utilized and dominating wood species in the study area. Data was collected using a targeted sampling technique based on the frequency of sawing of the log specie. The most widely used species of timber in Iloabuchi sawmill River State, Nigeria, was surveyed. The study area was chosen since it was easily accessible for studying. Three (3) species of timber were purposely selected based on the abundance of the species in the sawmill. Among the selected log species, thirty (30) log samples were randomly selected for the study.

Data Collection

Data was collected on the following log characteristics of relevance on selected log samples. Distance measuring tape and tailor tape were used in measurement. The log characteristics measured and estimated includes:

- Diameter at both log ends
- Length
- Taper = $\frac{D-d}{L} * 100$……………….Eqn. 1
- Ovality = $\frac{dmax}{dmin} * 100$…………..Eqn. 2
- Volume = $\frac{Du+Db}{2g} * H$…………..Eqn.3

Development of prediction models

Log volume models developed and tested for this study were linear, multiple linear, semi logarithm and double logarithm functions. The models expressed log volume as a function of log characteristics.

Simple linear model,
$V = b_0 + b_1X$…………Eqn. 4

Multiple linear model,
$V = b_0 + b_1X_1 + b_2X_2$…………….Eqn. 5

Semi Logarithm model,
$V = b_0 + b_1 \ln X1$……………………Eqn. 6

Double Logarithm model,
$\ln V = b_0 + b_1 \ln X_1$………………...Eqn. 7

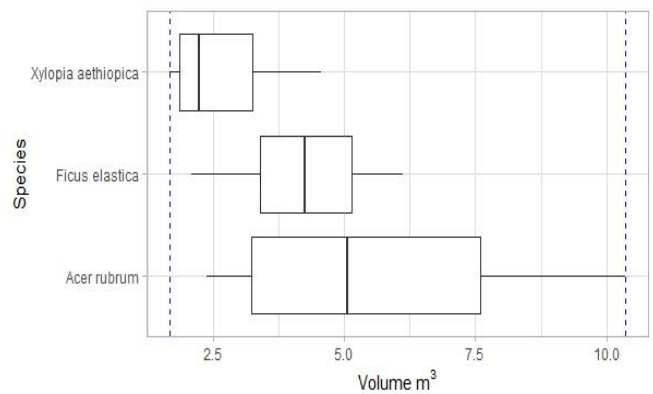
Where V= sawn timber volume
X= log characteristics and quality
b_0, b_1 = regression parameters
ln = Natural logarithm

Model evaluation

The model was developed with the aim of determining the most effective estimator of log volume. Only equations having all the parameters to be significant were selected. A model with high R^2 and low SEE was judged to have good fit. The following statistics were used to evaluate the developed models.

Coefficient of determination (R^2)
By this criterion, the closer the value of the coefficient of determination is to one (1.0) or 100%, the greater the total variation of the data explained by the equation, hence the better the model

$R^2 = 1 - (RSS/TSS)$…………………. Eqn. 8
Where R^2= Coefficient of determination; RSS = Residual



Sum of Square; TSS = Total Sum of Square

Standard Error of Estimate (SEE)
The SEE is also known as root mean square error which indicates the mean quadratic difference between observed and estimated values. Mehtätalo *et al*., (2006) stated that the lower the value, the better the estimate accuracy

SEE = $\sqrt{MSE}$ ………………….. Eqn. 9
Where SEE = Standard Error of Estimate; MSE =Mean Square Error

Significance of the overall regression equation (F-ratio)

Significance of regression coefficient.

Model validation.

One third of the data set was set aside to predict round log volume for selected species in Iloabuchi sawmill. Predicted values from the developed models and observed values were compared using T-test statistic. Models are considered good for prediction if there are no significant differences between the observed values and predicted values.

Statistical analysis.

Descriptive statistic was used to give a description of the volume and log characteristics relationship. Inferential statistics such as regression, correlation analysis and T-test was used in the study.

3. Results

General measured log characteristics.

Log characteristics such as diameter, log volume, log taper, ovality and volume were measured and estimated for *Xylopia aethiopica*, *Acer rubrum* and *Ficus elastica*. The result reveals that average log length, volume and taper for the studied species ranges from 3.02m to 3.48m; 2.67 to 5.67 and 3.88 to 11.06 respectively (Table 1). *Acer rubrum* had the highest average length (1.39m) and volume (5.67m^3). In terms of ovality and taper *Xylopia aethiopica* had the highest average percentage of 142.57 and 11.06 respectively (table 1).

Species influence on volume.

Box plot was used to show the spread of the volume of the species. The result showed that *Acer rubrum* (5.67) has the highest average volume followed by *Xylopia aethiopica* (4.14) and lastly *Ficus elastica* (2.67) (fig 2). The volume ranged for *Acer rubrum, Xylopia aethiopica* and *Ficus elasticai* are presented on the box plot.

Fig. 2: Box plot of Round log volume

Relationship between Round Log Volume and other Log Characteristics

Correlation analysis was used to test the degree of association between volume and other log characteristics. For a model to have good fit, the R2 value must be high (> 0.50). There were mostly positive correlations between volume and log characteristics. The highest correlation coefficient value for the overall data set was obtained in the relationship between volume and diameter (0.99). Table 2 portrayed that there was significant positive relationship between length and volume in *Xylopia aethiopica* (0.94) and *Ficus elastica* (0.68). Also volume and diameter showed positive relationship in *Xylopia aethiopica* (0.96), *Ficus elastica* (0.97), *Acer rubrum* (0.99). The correlation analysis result shows that diameter is a strong variable that influences volume. Ovality had a strong positive correlation with taper (table 2).

Table 1: Descriptive Measures of Round Log Characteristics and Volumetry of Studied Species

Scientific name	Common name	Mean±SD				
		Diameter (m)	**Length (m)**	**Tapper (%)**	**Ovality (%)**	**Volume (m^3)**
Xylopia aethiopica	Uda	1.19±0.15	3.48±0.39	11.06±6.25	142.57±29.3 1	4.14±1.32
Acer rubrum	Oba Red	1.39±0.32	3.48±0.39	3.88±3.10	109.6±46.46	5.67±2.93
Ficus elastica	Bush Rubber	1.03±0.13	3.02±0.44	4.94±3.39	116.68±14.7 6	2.67±1.07
	Total	**1.20±0.26**	**3.32±0.45**	**6.62±5.39**	**122.96±23.5 5**	**4.16±2.26**

Table 2: Correlation Analysis between Round Log Volume and Log Characteristics

Species	Variables (Mean)	Length	Volume	Tapper	Ovality	Diameter
Xylopia aethiopica (Uda)	Length	1.00				
	Volume	0.94**	1.00			
	Tapper	-0.24	-0.38	1.00		
	Ovality	-0.18	-0.34	0.99**	1.00	
	Diameter	0.83**	0.96**	-0.50	-0.48	1.00
Acer rubrum (Oba Red)	Length	1.00				
	Volume	0.56	1.00			
	Tapper	0.17	0.76*	1.00		
	Ovality	0.17	0.67*	0.98**	1.00	
	Diameter	0.49	0.99**	0.76*	0.66*	1.00
Ficus elastica (Bush Rubber)	Length	1.00				

	Volume	0.78**	1.00			
	Tapper	0.74*	0.66*	1.00		
	Ovality	0.65*	0.39	0.94**	1.00	
	Diameter	0.65*	0.97**	0.50	0.19	1.00
All	Length	1.00				
	Volume	0.68**	1.00			
	Tapper	0.32	0.23	1.00		
	Ovality	0.29	0.06	0.95**	1.00	
	Diameter	0.63**	0.99**	0.16	-0.03	1.00

* Significant at $p < 0.05$; ** Significant at $p < 0.01$

Mathematical Equations for Round Log Volume of studied Species in Iloabuchi Sawmill

The prediction models of various mathematical functions were used based on measured and estimated variables. The linear, multiple, single log and double log models were tested in predicting log volume. The coefficient of determination, the F-ratio and the P-value was computed for each model for each species. These estimates were used as guide in selecting the best model. Model performance criteria and parameter estimates are presented in table 3. All the parameters used in fitting the models were significant. Using the mean diameter as an independent variable gave the best model. The selected models for each species are shown in table 3. Model performance criteria were based on a model with the highest R^2 value and least SEE value. The best volume estimation or prediction model for *Xylopia aethiopica*, *Acer rubrum* and *Ficus elastica* are multiple model (R^2 = 0.97, SEE = 0.155), linear model (R^2 = 0.99, SEE = 0.295) and single logarithm (R^2 = 1, SEE = 0.068) respectively (table 3).

Model Validation

The results of model validation are presented in Table 4. The result revealed that in some of the developed models (Linear, multiple, single log and double log) there were no significant differences between the observed and predicted log volume. Hence these models are good for prediction purposes. However, not all the selected models are good for prediction. From the selected models, all the linear models for the studied species are good for prediction.

Table 3: Selected Volume Equations Model for Studied Species

S/N	Function	Model	R^2	SEE	F-ratio	P-value
		***Xylopia aethiopica* (Uda)**				
1	Linear	V = -5.436 + 7.712*D	0.91	0.269	58.25	0.0006
2	Multiple	V = -2.943 + 6.006*D – 0.210*T	0.97	0.155	93.38	0.0004
3	Single log	V = -5.666 + 7.694**ln*H	0.90	0.274	56.08	0.0007
4	Double log	*ln*V = 0.801 + 2.844**ln*D	0.95	0.069	108.3	0.0001
		***Acer rubrum* (Oba Red)**				
5	Linear	V = -7.157 + 9.172*D	0.99	0.295	420.69	5.1e-06
6	Multiple	V = -7.554 + 9.103*D + 0.004*O	0.98	0.328	169.90	0.0001
7	Single log	V = 1.430 + 13.223**ln*D	0.98	0.351	294.10	1.2e-05
8	Double log	*ln*V = 0.915 + 2.307**ln*D	0.95	0.102	105.80	0.0001
		***Ficus elastica* (Bush Rubber)**				
9	Linear	V = -5.902 + 8.438*D	0.92	0.392	71.86	0.0004
10	Multiple	V = -7.180 + 8.192*D + 0.011*O	1.00	0.086	802.90	6.1e-06
11	Single log	V = 2.489 + 9.971**ln*D	0.92	0.389	73.00	0.0004
12	Double log	*ln*V = 0.925 + 2.646**ln*D	0.84	0.153	33.07	0.0022

V= Volume, D = Diameter, H = Height, O = Ovality

Table 4. Model Validation results

Species	Model Forms	MOV	MPV	P-Value	Remark
Xylopia aethiopica	Linear	3.25	2.83	0.018	NS
	Multiple	3.25	1.81	0.088	S
	Single log	3.25	3.58	0.396	S
	Double log	1.10	0.97	0.064	S
Acer rubrum	Linear	5.24	4.96	0.039	NS

	Multiple	5.24	4.88	0.040	NS
	Single log	5.24	4.54	0.150	S
	Double log	1.43	1.46	0.800	S
Ficus elastica	Linear	5.02	5.01	0.020	NS
	Multiple	5.02	5.06	0.340	S
	Single log	5.02	4.40	0.215	S
	Double log	1.61	1.46	0.172	S

4. Discussions

Log volume estimation has been a central research topic in forest science, because accurate estimates of log volume are essential in sustainable forest management and for trade in forest resources (Davis *et al*. 2001; Japheth *et al*., 2022). Despite the economic contribution of logs to development, logging in the forests has been complicated and as such led to the harvesting of most abundant tree species while others are abandoned or destroyed during harvesting process (Arowosoge, 2010). In the study area, species such as: *Mitragyna cilitate* (abura), *Brachystegia eurycoma* (achi*), Lophira alata* (ekki), *Ficus elastica* (bush rubber), *Ceiba pentandra (silkcotton/floater), Pterocarpus osun* (boko), *Milicia excelsa* (iroko), *Pterocapus erinaceus* (kosso), *Khaya ivorensis* (mahogany), *Mansonia altissima* (mansonia), *Acer rubrum* (oba red), *Symphonia globulifera* (okololo), *Nauclea diderrichii* (opepe), *Petadethra macrophylla* (ugba), *Xylopia aethiopica* (uda) and *Terminalia ivorensis* (black afara) were commonly sawn. *Xylopia aethiopica*, *Acer rubrum* and *Ficus elastic* were selected for the study based on their high frequency of sawing. This can be termed as a representative sample of logs in the sawmill. Pappoe *et al* (2010) stated that in tropical natural forests, it is impractical to represent every tree species for allometric model development due to the presence of hundreds of species per ha. However, priority is given to tree species which have high appearance frequency as carried out in the study.

Li *et al* (2015) stated that sustainable forest management planning and decision-making on wood utilization can be influenced by accuracy of wood volume estimation. Volume estimates from various formulas do not give the exact same results because they have bias which is compared with the actual volume and creates discrepancy between the actual volume and predicted volume (Janak, 2012). Various documented literature on methods of estimating log volume have been seen stating that different log volume models yield equivalent estimates of log volume. If this assumption were true, then any model could be considered applicable and the need for accuracy of estimation would not be needed but this assumption has not been experimented using systematic methods (Li, *et al*., 2015). The average volume estimated ranged from 2.67m^3 to 5.67m^3. Findings of Şahin and Çomak (2022) observed that the average volume estimate of oriental spruce logs ranged from 2.76m^3 and 3.57m^3. Report of Robson *et al*., (2018) stated that lumber volume of studied species ranged between 1.63m^3 to 3.66m^3. The log volume of studied species was within the same range as other stated in literature.

Modeling wood quality attributes and its application in sawmill conversion simulation systems, has been acknowledged as an important method in order to link end users' product requirements with properties of the forest resource (Ikonen et al. 2003). This result supports the decision to use regression methods to construct models and estimate their parameters. Silva & Santana, (2014), stated the estimates of the parameters associated to each explanatory variable reflect elasticities, showing a proportional change in log volume for each percentage change in the respective variable. Inclusion of diameter as an independent variable in predicting log volume gave the best fit. This can be attributed to the fact that this attribute is needed in estimating log volume. Over 90% of variation in log volume was explained by diameter. Species specific models slightly improved the model fit compared to general models. The inclusion of log height improved some models as suggested by some authors (chave *et al* 2006, Silprandi *et al*., 2016) to guarantee biologically realistic models. This trend was also observed in the multiple linear models were inclusion of height variables improved the models.

The comparison between the developed log volume models and actual log volume for the studied species shows that the log volume of Xylopia *aethiopica* species was underestimated by the various predicted models. This pattern provides an insight into the actual volume difference between log species studied . This variation may be attributable to the log form differences such as log taper, ovality e.t.c. (Mugasha *et al*., 2013). Although some statistics such as R^2, SEE, significances of the model e.t.c. are commonly used in measuring overall predictive value of a model along with goodness of fit (Akindele and LeMay, 2006), there is a great need to test the predictive ability of the model because not all good models are good for prediction. Some researchers have also expressed volume models using different functions such as Fonton *et al*, (2002) reported the use of square of diameter, logarithm in volume estimation; Özçelik (2002) reported Centroid equation in red pine and cedar logs; Güney (2007) reported Huber and Smalian in red pine and cedar logs; Durkaya and Durkaya (2011) reported Smalian equation in cedar and black pine logs. Kozak's taper model has also been used in volume estimation (kozak, 2004). Robson (2018) found that logarithm, Schumacher and Hall model and linear model were selected as the best models for the studied species.

Linear models were selected as the best predictive model for the studied species. It can be seen that the selected equations adequately predict the volume for all species. Lower SEE indicates small tendency of under or overestimations in the generated predictions. The use of SEE as criteria for selecting models has show good measurements of the overall predictive value of the regression equations (Akindele & Lemay, 2006).

5. Conclusion

The prediction model using the three (3) species showed the effect of log characteristics on volume estimation of log in the study area. It showed that log variables such as diameter, ovality were in a strong positive relationship with log volume. From the findings in this study, development of specie-specific volume equations is essential to achieve higher levels of precision in estimation of log volume since the tree allometry was found to differ significantly between species. The selected log volume model can be applied since there is no significant difference in predicted log volume and observed log in the study area.

Corresponding Author:
Dr. Eguakun Funmilayo Sarah
Department of Forestry and Wild life Management
Faculty of Agriculture
University of Port Harcourt, Nigeria
Telephone: +2348038624661
E-mail: funmilayo.popo-ola@uniport.edu.ng

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