



## Diameter growth and mortality assessment of river red gum (*eucalyptus camaldulensis* (dehnh) stands in Afaka forest reserve, Kaduna-Nigeria

B Abubakar<sup>1\*</sup>, SB Shamaki<sup>2</sup>, U Usman<sup>3</sup>, AG Bello<sup>4</sup>, A Dantani<sup>5</sup>, ZY Gada<sup>6</sup>, A Abubakar<sup>7</sup>

<sup>1-4, 6-7</sup> Department of Forestry and Environment, Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto Nigeria

<sup>5</sup> Department of Forestry and Wildlife Management, Faculty of Agriculture, Bayero University Kano, Kano, Nigeria

### Abstract

The research work was carried out in order to assess diameter growth and mortality of six classes of *Eucalyptus camaldulensis* stands in Afaka Forest Reserve, Kaduna, Nigeria. Stratified random sampling and proportional sample allocation were employed for the research. Live and dead trees were counted and recorded, diameter of the live and dead trees was measured using flexible tape, tree heights were measured with Hagar altimeter (in meter), planting spacing and age of each stand were determined. The result of the research revealed that, mortality was extremely high at the early stage of stand development with mortality rates of the lower Dbh and height classes recording 98.91% and 98.76% of the mortality rate respectively. Three Dbh classes (14-16, 17-19 and 20-22cm) and three height classes (21-25, 26-30 and above 30 m) recorded no mortality. The positive regression coefficients (16.737, 49.266 and 1.992) showed by Dbh, Height and age (as independent variables) indicated positive future mortality effects on the stands; as the trees ages and increases in size and height, the chances of mortality will increase. At the present age and sizes of the stands the fitted model shows no significant relationship between the current age, height and size of the stands, as such the notion held by the management of the plantation that Eucalyptus cannot grow for many years and in large sizes is not true. There is therefore, need for periodic re-measurement of the stands to evaluate future effect of the variables (Age, Dbh and height) on mortality.

**Keywords:** river, carried, diameter, growth, periodic, mortality

### Introduction

Growth refers to the increase in the dimensions of a tree in a forest stand over a given period of time, example volume growth in cubic meter per hectare per year. Yield refers to the final dimension of the tree growth at the end of a certain period, for instance volume in cubic meter per hectare per period [1]. Tree mortality is a critical ecological process that affects stand composition, structure and productivity. Tree mortality is the death of forest trees [2, 3, 4]. However, Plant death is a complex process, which is influenced by environment, age, e.t.c. In general, trees die when they cannot acquire or mobilize sufficient resources to recover from stress, heal injuries, or when they are killed by some external factors; local fire, wind, snow or insect attack, trees compete with each other and with other plants for the sunlight available on a site. When trees get over-topped and shaded by others, their access to sunlight is reduced or eliminated. As a result, the growth of overtopped trees slows or halts. Depending on the species, trees may eventually die after being overtopped [5]. *Eucalyptus camaldulensis* (Dehnh), (River red gum), is a tree of the genus Eucalyptus from Myrtaceae family, it is plantation specie in many parts of the world but is a native to Australia, where it is widespread [6]. *E. camaldulensis* is perennial tall tree reaching 30m in height although some authors recorded the tree to have reached 45m in height [7].

Mortality affect the productivity of the forest in different areas, moreover, unlike agriculture, forest has long rotation

period which make prediction intervention effects harder, hence the need for tools and models to assist forest managers in their decisions has become very apparent. Trees compete with neighboring vegetation for scarce resources such as light, water and nutrients. The availability of these resources needed by a tree to exist in a given site is called growing space. Competition for growing space between individual trees plays an important role in forest stand dynamics. Specifically, competition leads to a reduction in growth, reproduction and chances of survival of at least one of the competing individuals [8].

Lack of clear understanding of the growth and yield dynamics of the Eucalyptus stands in Afaka Forest Reserve is causing allot of managerial problems which invariably leads to poor management. The understanding of the management team of the Afaka plantation is that Eucalyptus stands do not have the potentials of growing into larger sizes over the years without mortality which is the more reason why they open up the area for exploitation within short periods of stands development. Management and or land use in Afaka forest reserve is however, one of the contributing factors causing death of the planted *E. camaldulensis* trees as some of the Eucalyptus stand had weeding done once a year while others, once every two years. Mortality is an important process in forest dynamics and succession, [8]. Forest models provide essential support for forest management, silviculture and harvest planning, wildlife management and landscape ecological

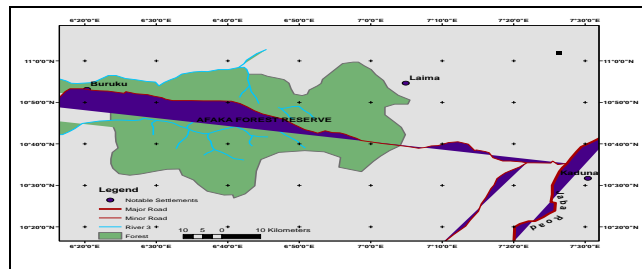
planning [9]. Afaka Forest Reserve was established to increase the productivity of the Savannah and arrest desertification in some part of the northern - guinea savannah of Nigeria [10]. Hence, evaluation of its condition is very vital. There are more than 500 species of eucalyptus, several of them were introduced to Nigeria but of all the species tried, only *Eucalyptus Camaldulensis*, *Eucalyptus Tertiary* and *Eucalyptus Saligana* are the most promising as plantation species in the Savannah area [11,12]. These species are widely used in Nigeria as shelterbelts, pulpwood and as house construction materials. Their use in agro-forestry for inter cropping is limited to the Savannah due to their tendency of inhibiting the growth of other trees in the vicinity. Other uses of *E. camaldulensis* include lumber production, plywood, veneer, solid and engineered flooring, fiberboard, wood cement composites, mine props, poles, firewood, charcoal, essential oils, honey, tannin and landscape mulch as well as for shade, windbreaks and phytoremediation. Eucalyptus oil is also used in very small quantities in food supplements especially sweets, cough drops and decongestants. It also has insect repellent properties and is an active ingredient in some commercial mosquito repellents [13]. Savannah zone of Nigeria have many Eucalyptus plantation as a result of afforestation programs being that the region is affected by many environment problems ranging from desertification, deforestation mining etc.

**Materials and Method**

**Study Area**

The study was conducted at Afaka Forest Reserve in Igabi Local Government Area, Kaduna State, Northern Guinea Savannah Zone of Nigeria, it occupies an area of 12,243.76 hectares [14]. It is within the latitude 10° 34' 24" N and 10° 96' 51" N and longitude 6° 23' 74" E and 6° 63' 73" E. The elevation varies across the forest region but it is generally a plain land with an average of 610m above mean sea level. The forest reserve has a tropical climate, which is characterized by two clearly distinct seasons of dry and wet seasons, the dry season lasts from October to early April, while the remaining months constitute the rainy season. The forest temperature is high throughout the year with mean minimum and maximum temperatures of 23° C and 34° C, respectively [14] (Adewuyi *et al.*, 2010). The mean annual rainfall is 1266.0mm based on annual rainfall record of 43 years (1969 – 2012) [15].

Afaka Forest Reserve was established in 1954 as an experimental plantation site, in order to increase the productivity of the Savannah and arrest desertification in some parts of Northern - Guinea Savannah of Nigeria [10]. The forest reserve provides a mixture of both man-made and natural vegetation. Some of the indigenous and exotic trees in the forest reserve include *Parkia biglobosa*, *Ceiba pentandra*, *Khaya senegalensis*, *Mangifera indica*, *Eucalyptus spp*, *Tectona grandis*, *Pinus caribea*, *Gmelina arborea* among others. The forest reserve is the main source of electricity pole for most part of the state in addition to providing wood for fuelwood and the construction industry [16].



**Fig 1:** Map of Afaka Forest Reserve

**Reconnaissance Survey**

A reconnaissance survey was carried out in an order to have visual view and be acquainted with the study area. With the aid of a GPS device, a ground survey of the Eucalyptus stands was carried out with a view to determining the area covered by each stand and also guide the number of plots allocated to each stand. The survey revealed that years 2005, 2006, 2007, 2011, 2012 and 2013 are 10.0, 19.4, 5.9, 21.6, 19.8, and 7.1ha, respectively.

**Sampling Procedure**

Stratified random sampling technique and proportional sample allocation were employed for the research;

1. The six stands (2005, 2006, 2007, 2011, 2012 and 2013 stand) were considered as strata.
2. The sampling plots of each stand were selected randomly through balloting for the measurement.
3. 30 sampling plots (20X20m) were set for the research to determine number of sampling plots for each stand using proportional sampling allocation technique. Thus;

$$n_i = \frac{(N_i)n}{N}$$

Equation 3

Where;  $n_i$ = No. of plots to be used for sampling on each stand proportionally,  $N_i$  = No. of plots within each stand,  $N$  = Total No. of all the plots in all the stand,  $n$  = No. of plots set for the research work

**Table 1:** No. of Sample Plots used per Stand

Stand	Hectares /Stand	Sampling plots (20X20m) within each stand	Sampling plots (20X20m) Proportionally selected
2005	10.0	250	3
2006	19.4	485	6
2007	5.9	147.5	2
2011	21.6	540	7
2012	19.8	495	7
2013	7.1	177.5	2
Total		2,095	

Source: Field survey, 2017

**Data Collection**

This involves the following;

1. Counting and recording the live and dead trees.
2. Measuring the Diameter of the live and dead trees at Dbh. Tree-trunk diameter was measured at breast height

(termed diameter at breast height or Dbh), defined as the diameter of the tree 1.3m above ground on the uphill side of the tree. However, flexible measuring tape was used to measure tree trunk circumference, which was divided with the value of pie (3.142) to determine the tree diameter (in cm).

3. Tree height, total tree height is the distance from ground level to the upper tip of the tree crown. Haga altimeter was used in taking the height measurement (in meter).
4. Inspection of planting spacing and age of each stand was conducted on all the sample plots.

**Data Analysis**

Data collected were organized and screened to ensure validity prior to model calibration. Field measurement values were further grouped into different diameter and height classes with a view to determine the size class with higher mortality at a certain age. Mortality was set as dependent variable, while, Basal Area, Dbh, spacing, and age as independent variables. SPSS Statistical Software Version 20 was used for analysis,

**Results**

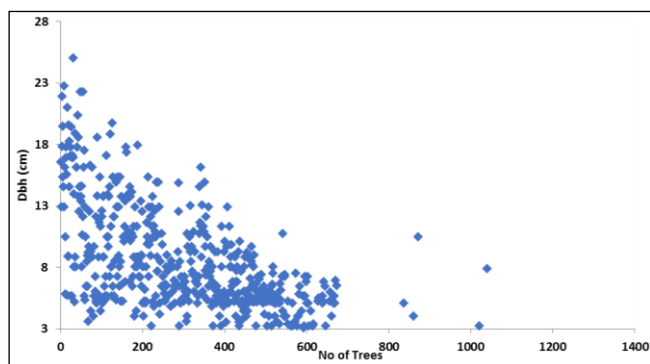
**Descriptive Statistics of the Independent Variables**

Table 2 presents the summary of descriptive statistics of the data set obtained on 1323 trees from 27 plots. The variables measured which were also included as the independent variables for model development include Dbh, Tree Height and Basal Area. Scattered plot of Diameter against the total number of trees in order to see diameter distribution pattern is presented as Figure 2 (the curve indicates positively skewed and around 700 trees has a distribution of all the dbh size recorded for the measurement).

**Table 2:** Descriptive Statistics of the Independent Variables

	N	Range	Min	Max	Mean	SD	SE
Dbh (cm)	1323	25.051	0.00	25.051	3.5803	4.8128	0.13231
Height (m)	1323	34.40	0.00	34.40	4.85	6.721	0.185
Basal Area (m <sup>2</sup> )	1323	0.0493	0.00	0.0493	0.0028	0.0057	0.00016

Source: Field Survey, 2017. N= number of trees, SD = Standard Deviation, SE= Standard error



Source: Field Survey, 201

**Fig 2:** Dbh distribution in respect to No of tree

**Mortality Distribution by DBH and Height Classes**

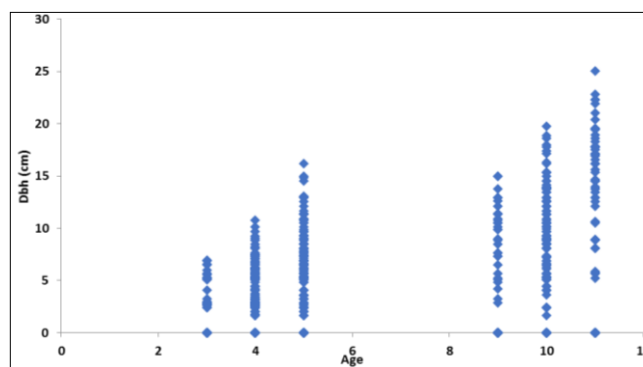
Table 3 shows mortality frequencies and percentages in respect to the Dbh and Height class distribution. Scattered plot of Dbh and Basal area against the tree mortality was fitted

(Fig: 3 and 4) to see the pattern of mortality across different size categories.

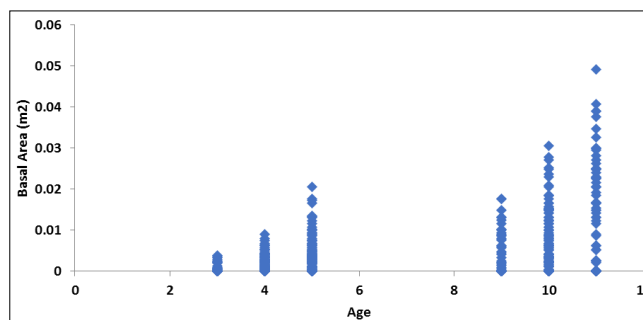
**Table 3:** Mortality Distribution by Dbh and Ht Classes

Dbh class (cm)	Mortality Frequency	Percentage (%)
< 5	638	98.91
5 – 7	2	0.31
8 – 10	3	0.47
11 – 13	1	0.16
14 – 16	0	0.00
17 – 19	0	0.00
20 – 22	0	0.00
23 and above	1	0.16
Height class (m)		
< 2	637	98.76
2 – 5	5	0.78
6 – 10	2	0.31
11 – 15	0	0.00
16 – 20	1	0.16
21 – 25	0	0.00
26 – 30	0	0.00
Above 30	0	0.00

Source: Field Survey, 2017 Note: Ht=Height, Dbh=Diameter



**Fig 3:** Relationship between Dbh and age



**Fig 4:** Relationship between basal area and age

**4.3.1 Logistics by DBH Class**

Diameter at breast height has effect on the growth of tree which in turn contribute to the overall growth dynamics of a tree at a given condition, that is the nature of how tree will grow at a given level of competition with other trees surrounding the environment or other vegetation which may result to the chances of the tree survival in that environment. The result of the analysis (Table 5) indicated that there was no significant (P>0.05) association between mortality and the current sizes of the trees for all the dbh classes. Dbh growth

differences at the current age of stands has not shown any effect on the mortality of the trees planted on the site considering the planting spacing of 3 X 3m. Hence the odds ratio for all the dbh classes are absolutely zero (0) indicating that none of the dbh size class is responsible for the mortality of the trees in the site at their current ages.

**Table 5:** Logistic Regression by DBH Class

Dbh Class (cm)	Coefficient	OR	P – Values
Constant	1287.596	0.000	0.994
5 - 7	-3.089	0.000	1.000
8 - 10	-5.653	0.000	1.000
11 - 13	19.462	0.000	1.000
14 - 16	21.117	0.000	1.000
17 - 19	19.173	0.000	1.000
20 - 22	27.229	0.000	1.000
23 and above	26.184	0.000	1.000

**Source:** Field Survey, 2017

Note: OR=Odds ratio,

#### 4.3.2 Logistics by Height Class

Height is also an important variable that contribute to the overall behavior of a tree at a given condition, that is, nature of how the tree will grow at a given level of competition with the other trees surrounding the environment or other vegetation. The result of the analysis (Table 6) indicated that there was no significant ( $P>0.05$ ) association between mortality and height for all the height classes. Height growth differences at the current age of stands has not shown any effect on the mortality of the trees planted on the site considering the planting spacing of 3 X 3m. Hence the odds ratio for all the height classes are either zero (0) or close to zero (0) indicating that none of the height size class is responsible for the mortality of the trees in the site at their current ages.

**Table 6:** Logistic Regression by Height Classes

Ht Class (m)	Coefficient	OR	P – Value
Constant	1287.596	0.000	0.994
2 - 5	-1273.999	0.000	0.992
6 - 10	-1244.976	0.000	0.987
11 - 15	-1119.111	0.001	0.981
16 - 20	-928.620	0.000	0.983
21 - 25	-710.843	0.000	0.984
25 - 30	-484.677	0.000	0.986
31 and above	-217.165	0.000	0.993

**Source:** Field Survey, 2017

Note: OR=Odds ratio

## Discussion

### Descriptive Statistics of the Independent Variables

Summary statistics of the field data revealed that the data set is suitable for logistic regression analysis, with relatively low mean standard error of the independent variables (Dbh, H and Basal area) indicating low chances of making error in the prediction of what may cause the mortality from the Variables used for the prediction. Scattered plot (Fig. 2) described the distribution of dbh size to the number of trees in the research area and the curve indicates right skewed distribution (positive skewness). Hence, around 700 trees has a distribution of all

the dbh size recorded for analysis and in all the stands the planting spacing was 3X3m, this also is within the planting practices of Eucalyptus plantations as reported by <sup>[17]</sup> that adopted and used 3X3m spacing for *Eucalyptus spp.*

### Mortality Distribution by Dbh and Height Classes

The study on mortality frequencies in respect to the Dbh and Ht classes revealed that, mortality was extremely high as at the early stage of stand development of about 98.91 and 98.76% for Dbh and Ht classes, respectively. The study also revealed that three of the Dbh classes (14-16, 17-19 and 20-22cm) recorded no mortality so also that a 21-25, 26-30 as well as above 30m Ht classes. The result is in agreement with <sup>[18]</sup> whose investigation into the first nine years after planting of trees in New York City revealed that, mortality rates are markedly higher in the first few years, then reduces and stabilizes after the establishment phase. The scatter distribution of the independent variables (BA, Dbh and Height) in relation to the age of the stands showed clear mortality pattern to be more pronounced at the lower age categories. The scattered points are more concentrated towards the zero line of the graph in the lower age limits compared with the higher age limits. This is a clear indication of the slow growth dynamics of the Eucalyptus at the early stage with younger tree stands becoming more vulnerable to environmental conditions that can cause tree mortality. Once the trees are established under certain environmental conditions coupled with the genetic potentials of the species, the chances of mortality is very low until the stands reaches culmination level when they might have reached their full growth potentials. The result agrees with <sup>[19]</sup> who reported that, to provide other products from Eucalyptus such as sawn timber trees are allowed to exceed 10 years, they also added that for a healthy crop there is need for continuous monitoring of pests and diseases. Also, once trees reached 7-9 years, the total mortality difference between age classes becomes negligible <sup>[18]</sup>.

### 5.2 Mortality Distribution by DBH and Height Classes

The study on mortality frequencies in respect to the Dbh and Ht classes revealed that, mortality was extremely high as at the early stage of stand development of about 98.91 and 98.76% for Dbh and Ht classes, respectively. The study also revealed that three of the Dbh classes (14-16, 17-19 and 20-22cm) recorded no mortality so also that a 21-25, 26-30 as well as above 30m Ht classes. The result is in agreement with <sup>[18]</sup> whose investigation into the first nine years after planting of trees in New York City revealed that, mortality rates are markedly higher in the first few years, then reduces and stabilizes after the establishment phase.

The scatter distribution of the independent variables (BA, Dbh and Height) in relation to the age of the stands showed clear mortality pattern to be more pronounced at the lower age categories. The scattered points are more concentrated towards the zero line of the graph in the lower age limits compared with the higher age limits. This is a clear indication of the slow growth dynamics of the Eucalyptus at the early stage with younger tree stands becoming more vulnerable to environmental conditions that can cause tree mortality. Once the trees are established under certain environmental

conditions coupled with the genetic potentials of the species, the chances of mortality are very low until the stands reaches culmination level when they might have reached their full growth potentials. The result agrees with <sup>[19]</sup> who reported that, to provide other products from Eucalyptus such as sawn timber trees are allowed to exceed 10 years, they also added that for a healthy crop there is need for continuous monitoring of pests and diseases. Also, once trees reached 7-9 years, the total mortality difference between age classes becomes negligible <sup>[18]</sup>.

### Logistics Regression

All the variables in the logistic regression model appeared to produce positive coefficients except the basal area which is an indication of possible future mortality with increasing age, sizes, height and competition. Even though, the current age and sizes of the plantation (all the stands) do not show any significant relationship with tree mortality, the odds ratio values were almost at zero level for all the independent variables and having the potential of moving higher with increasing age and sizes of the stands. The implication of these logistic values is that current ages and sizes of the six stands in the plantation were not significant enough to influence tree mortality, hence the non-significant relationship of the regression parameters.

At lower Dbh classes however, the regression coefficients recorded negative values which is an indication of the small size tree stands of becoming more vulnerable to environmental factors causing mortality with increasing heights. All the height classes appeared to have negative slope estimates of the regression line, thereby having a higher chance of mortality when the size of the tree is not increasing. Increasing tree height of the Eucalyptus stands should be concurrently with the diameter increase so as to have a positive tree basal area which will in turn give a better yield in terms of tree volume (total or merchantable). The result of the research conforms to the study conducted by <sup>[20]</sup> which revealed that, "unknown" was the largest single category recorded under causes of mortality.

### Conclusion and Recommendation

The result of the research revealed that, mortality was extremely high at the early stage of stand development; For Dbh and height which recorded 98.91 and 98.76% for Dbh class and Ht class respectively, while three Dbh classes (14-16, 17-19 and 20-22cm) recorded no mortality. It was also observed that, 21-25, 26-30 as well as above 30m classes of height had no mortality. The coefficient of Dbh, Ht and age values of the stands which were 16.737, 49.266 and 1.992 respectively, showed a positive implication to have future effect on mortality while the coefficient of basal area which is -5487.139 showed a negative implication to have future effect on mortality at the time of conducting the research. The following recommendations are made with respect to the findings from the study:

1. For effective and proper mortality prediction of the stands by age and size distributions, there is a need for establishing permanent sample plots (PSPs) to evaluate future effect and possibility of independent variables on mortality.

2. Management of Afaka Plantation is advised to allow the stands to grow beyond their current status.
3. Management of Afaka forest reserve should improve on their management practice for instance beating up operation and ensure thorough supervision for the survival of the planted trees of *E. camaldulensis*.

### References

1. Pretzsch H. Forest Dynamics, Growth and Yield: From Measurement to Model, Springer-Verlag, Berlin, Germany, 2008, 670pp. ISBN: 978-3-540-88306-7 e-ISBN: 978-3-540-88307-4 DOI: 10.1007/978-3-540-88307-4
2. Mencuccini M, Martinez-Vilalta J, Vanderklein D, Hamid HA, Korakaki E, Lee S. *et al.* Size-mediated ageing reduces vigour in trees. *Ecology Letters*. 2005; 8:1183-1190.
3. Lutz JA, Halpern CB. Tree mortality during early forest development: A long-term study of rates, causes, and consequences. *Ecological Monographs*. 2006; 76:257-275.
4. Van Mantgem PJ, Stephenson NL. Apparent climatically induced increase of tree mortality rates in a temperate forest. *Ecology Letters*. 2007; 10:909-916.
5. Kocher SD, Harris R. Forest stewardship series 5 tree growth and competition ANR Publication 8235, California, 2007, pp10.
6. Mehani M, Ladjel S. Anti-microbial effect of essential oil of the plant *Eucalyptus camaldulensis* on some pathogenic bacteria. *IPCBE*. 2011; 24:212-216.
7. Brooker MIH, Conner JR, Slee AV, Duffy A. Eucalyptus of Australia: In Lima, L.M., Babachani B., Boldaji S.A.H. and Boldaji R.M. (2013). Essential oil composition and anti-bacterial activities of *Eucalyptus camaldulensis* Dehn. *International Journal of Medicine*. 2002; 3(2):214-219.
8. Kimmins JP. Forest ecology: A foundation for sustainable forest management and environmental ethics in forestry. 3rd ed. Prentice Hall. Upper Saddle River NJ, USA, 2004.
9. Messier C, Fortin MJ, Schmiegelow F, Doyon F, Cumming SG, Kimmins JP. *et al.* Modeling tools to assess the sustainability of forest management scenarios. Chapter 14. In: Burton, P.J., C. Messier, D.W. Smith, and W.L. Adamowicz (Eds.) Towards Sustainable Management of the Boreal Forest. NRC research press, Ottawa, Ontario, Canada, 2003, pp. 531-580.
10. Nwadiolor IJ. An Assessment of Spatio-temporal Variabilities of Deforestation for Sustainable Forestry Development: A Case Study of Afaka Forest Reserve International Conference on Spatial Information for Sustainable Development, Nairobi, Kenya, 2001, pp12.
11. Brian TS, Ikhlas AK. Comparison of Extraction Methods for Marker Compounds in the Essential Oils of Lemongrass and Eucalyptus Leaves"; GC, J Agric. Food Chemicals, 2002.
12. Kemp PH. Trials of Exotic Tree Species in the Savannah Regions of Nigeria: Aims, Procedure and Summary of Results"; Paper No.4, Savannah Trees Research Station, Ibadan, 1970.
13. Adewuyi TO, Olofin EA, Falola JA. Analysis of land

- degradation in the Peri-urban Area of Kaduna Metropolis, Nigeria. Kaduna State University Journal of Social Sciences. 2010; 2(2):181-201.
14. Reid RC, Poling BE. Properties and Uses of Some Liquids and Gases"; 4<sup>th</sup> edition; McGraw- Hill, 2005.
  15. NIMET. Rainfall data for Kaduna, Nigeria (1969-2003), Nigerian Meteorological Agency, 2012.
  16. Renato VOC, Carlos PBS, Helio GL, Agostinho L, Gilciano SN, Fabrina BM. *et al.* Individual Growth Model for *Eucalyptus* Stands in Brazil Using Artificial Neural Network. Hindawi Publishing Corporation ISRN Forestry Article ID 196832, 2013, 12 pages <http://dx.doi.org/10.1155/2013/196832>
  17. Lu JWT, Svendsen ES, Campbell LK, Greenfeld J, Braden J, King KL. *et al.* Biological social and urban design factors affecting young street tree mortality in New York City. *Cities and the Environment*. 2010; 3(1):1-15.
  18. Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S. Agroforestry Database: a tree reference and selection guide version 4.0, 2009. (<http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp>)
  19. Yahaya U, Abdullahi UY, Dangmwan DS, Namadi MM. Bioethanol production from *Eucalyptus camaldulensis* wood waste using *Bacillus subtilis* and *Escherichia coli* isolated from soil in Afaka Forest Reserve, Kaduna State. *Nigerian International Journal of Sustainable and Green Energy*. 2015; 4(2):40-46.
  20. Kenneth JB. Long-term patterns of Douglas-fir and western hemlock mortality in the western cascade mountains of Washington and Oregon. A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy University of Washington. 2001.