SIMULATION MODEL FOR PREDICTION OF STAND GROWTH AND YIELD OF *Tectona grandis* Linn F. IN AKINYELE LOCAL GOVERNMENT AREA, OYO STATE, NIGERIA

BY

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DEDICATION

This works is dedicated to Jesus, The great programmer, who despite my short comings has made all things beautiful for me and has made all things possible for me.

ABSTRACT

Effective management planning tools for forest require growth and yield functions that can produce detailed predictions of stand development. Models such as Gamma Distribution Function (GDF), Weibull, Beta, and similar functions have been used to predict growth and yield of forest stands. However, information on the use of GDF in forest management has not been fully documented. The development of a program using Java programming language for GDF to predict growth and yield of *Tectona grandis* was studied in Akinyele Local Government Area, Oyo State, Nigeria.

Stratified random sampling was used to select four different age classes of teak plantation namely; 11, 13, 22 and 59 years. Based on the size of each plantation, 7 and 8 temporary sample plots of 0.04 ha were selected from 11, 13, 22 and 59 year-old plantations respectively. Complete enumerations of trees (n = 433.) was done. Growth data sets collected include Diameter at Breast Height (DBH), total and merchantable heights. Basal Area (BA) and Volume were computed from measured variables. Data obtained were processed into tree level, stand level and size class. Parameters α and β for GDF were estimated from growth data. Based on the algorithm of GDF, α, β and n parameters, for the Java Program (JP) was written. Values obtained were fitted into the JP for growth and yield prediction. Linear and non- linear models were used to compare their predictive ability to the JP developed.

At individual tree level using JP, the Observed and Predicted (O&P) values for height and BA ranged from 16.80-43.80 m, and 16.10-39.30 m; 2.49-4.51m^2, and 2.45-4.31m^2. Volume ranged from 2.09-10.54m^3 and 2.04-12.03m^3. Error rate varied from 0.00-9.00, -23.09-4.99 and -14.09-5.27 for height, BA and volume respectively. At stand level the O&P values for height, BA and volume from JP ranged from 17.10-28.30 and 17.90- 32.10 m; 2.55-3.69 m^2 and 2.58-3.69m^2; 2.25-3.69m^3 and 2.28-3.69 m^3 with error rate of -2.77-13.4; -0.10-5.65 and -0.10 -0.40 respectively. Size class level shape and scale parameter of GDF for diameter distribution ranged from 0.96-25.20 and 0.07-2.28 respectively. These values have better predictive power than non-linear and linear models which at individual tree level, O&P values for height and BA models of best fit ranged from 16.80-43.80m and 15.86-39.00 m; 2.49-4.51m^2 and 2.50-4.98m^2 . For volume, it ranged from 2.09-10.54m^3 and 2.02-12.05m^3 with error rate of -14.32-6.37. At stand level, O&P ranged from 17.10-28.30m and 17.95-32.18m for height; 2.55-3.69 and 2.59-3.72 m^2 for BA and 2.25-3.69 and 2.29-3.65m^3 for volume with error rate from -2.88-13.71; -4.58 -0.81 and -1.77-1.08 respectively. The R^2 values for height, BA and volume models of best fit were 0.9490, 0.8981 and 0.9800 with the equations given as $H= [1.3^{1.08} + (H^{1.08}{}_{dom\ -1.3}{}^{1.08})1\text{-}e^{-0.06dbh}/1\text{-}e^{-0.06*1.08}{}_{dom}]^{1/1.08}$, $1n(B) = \ln(0.32)+ 0.42(1/A)+ 0.77(\ln H)+1.82(\ln N)+1.89(H/A)$ and $V= 1.62+22.38*DBH$.

The predictive ability of gamma distribution function for height, basal area and volume for teak plantation from the developed Java program consistently performed better than other models and could therefore be used for prediction of growth and yield in forest stands.

Keywords: Gamma distribution function, Teak plantation, Growth and yield models, Forest management

Word count: 498

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CERTIFICATION

I certify that this work was carried out by Mrs. Nelly Ufuoma Ureigho of Department of Forest Resources Management, University of Ibadan, under my supervision

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CHAPTER ONE

1.0 INTRODUCTION

1.1 GENERAL

Forest growth modelling has been an intrinsic part of forest management and research for many years. Decision processes in forest management depend on reliable estimates of stand growth and yield models (Vanclay, 2003). Till date, forest resource managers face a number of challenges. One of the most critical challenges is the need to provide forest products for an increasing world population amidst shrinking natural resource base due to global change, desertification, environmental pollution and other stresses. With forests as dynamic biological systems that are continuously changing, to obtain relevant information for decision making, it is necessary to project these changes. Growth and yield studies as well as projection models are therefore among the important elements in forest management for continuing timber production (Yong, 1997). Models need to be continually updated to reflect current management practices.

Forest land managers often require information concerning the size-class distribution of a forest stand i.e. the tabulation of numbers of trees by diameter class. Size-class distribution information is important because it affects the type and timing of management strategies and treatments applied, as it influences the growth and potential, hence the current and future economic values of the forest stand. A number of methods have been proposed to model diameter distributions in forest stands. In cases where assumption can be made concerning the underlying diameter distribution of the stand, a probability distribution – based approach provides both a Computationally efficient and a numerically consistent means of predicting both forest yield and structure. The classical approaches of diameter distribution of the stand can be adequately characterized by a probability density function (pdf) say f (d, θ), where d is diameter and θ is a vector of distribution parameter.

Diameter distribution of trees in a specific stand is critical for research in growth and yield of stands (Burnham, 2002; Lu *et al*, 2003). They also serve as models of the forest structure, which play a vital role in sustainable forest management. The distribution of diameter is the most potent simple factor for depicting the properties of a stand of trees. Diameter is generally well correlated with other important variables including volume, value, and conversion cost and product specifications. The prediction of the diameter distribution of a stand is of great interest to forest managers, for the evaluation of forest resources and scheduling the future silvicultural treatment(s).

Simulation allows much more flexibility in modelling. Any phenomenon that can be represented by mathematical relationships of any form is tractable by simulation (Joseph and Keith, 1987). Simulation can be described as the process of developing a model of a real system and conducting experiments with the model. In a sense, optimality is still the goal, since by experimenting we hope to discover the best way of managing a system.

In essence, simulation allows us to bring the real world to the laboratory for intensive study. For this reason, simulation has become one of the most powerful and versatile tools for problem solving in forest management. Simulation of tree growth requires the development of a system of equations and methods that can generate initial stand and update tree size attributes as needed. Yield has recently been defined as "the amount of wood that may be harvested from a particular type of forest stand by species, site, stocking and management regime at various ages" (Helms, 1998). Prediction of individual tree dimensions in growth simulations must be accomplished through system of linked models. Examples of some simulators used in growth and yield modelling include SYMFOR, PTAEDA2, Stella ®, MYRLIN and a host of others too numerous to mention.

Gamma distribution function has the ability to fit various empirical distributions (Maltamo *et al*., 1995, 2000; Liu *et al*., 2002).It belongs to the family of continuous probability distributions. It has a scale parameter θ and a shape parameter k. If k is an integer, then the distribution represents an Erlang distribution i.e., the sum of k independent exponentially distributed random variables, each of which has a mean of θ (which is equivalent to a rate parameter of θ^{-1}). A random variable x that is gamma distributed with scale θ and shape k is denoted $x \approx \Gamma(k, \theta)$, or x ≈≈ Gamma (k, θ). Exponentially the gamma distribution is a two – parameter exponential family with natural parameters $k - 1$ and $-1/\theta$ and natural statistics x and ln (x).

Gamma distribution function is a general distribution covering many special cases including the chi – square distribution and exponential distribution. The gamma distribution has two parameters.

a. α = shape parameter

b. β = Scale parameter

It is commonly used positively in Skewed data such as movement data and electrical measurements. The gamma distribution function has three different types namely, 1 -, 2 - and 3 – parameter gamma distributions. If the continuous random variable x fits to the probability density function of

$$f(x) = \frac{1}{\Gamma(\alpha)} x^{\alpha-1} e^{-x}, \quad x \geq 0 \text{ ....equation (1)}$$

It is said that the variable x is 1 – parameter gamma distributed with the shape parameter α. In equation (1), Γ (α) the incomplete gamma function is given by

$$\Gamma(\alpha) = \int_0^\infty x^{\alpha-1} e^{-x} dx \text{ ....equation (2)}$$

The distribution function has a form of the simple exponential distribution in the case of α = 1. If x in equation (1) is replaced by x/β where β is the scale parameter, then the 2 – parameter gamma distribution is obtained as:

$$f(x) = \frac{1}{\beta\alpha\Gamma(\alpha)} x^{\alpha-1} e^{x/\beta}, \; x \geq 0 \text{ ....equation (3)}$$

Which returns to the 1 – parameter gamma distribution for β = 1. If x is replaced by $(x – \gamma)/\beta$, where γ is the location parameter, then the 3 – parameter gamma distribution is obtained as:

$$f(x) = \frac{1}{\beta\alpha\Gamma(\alpha)} (x-y)^{\alpha-1} e^{-(x-y)/\beta}, \; x>\gamma \text{ ....equation (4)}$$

Java programs run quickly and efficiently on any machine and on any operating system platform without modification as against most general purpose programming languages such as c++.The need to meet the rapidly growing demand for wood and wood products brought about a shift in emphasis from natural forest system to plantation system. Thus, plantations of exotic and indigenous species have been established. These plantations are generally more productive than the natural forests. For instance, results from permanent sample plots within plantations have shown that annual increment of timber volume above 40cm diameter at breast height (or diameter above buttress) range between 1.14m^3 ha^{-1} $year^{-1}$ and 8.30m^3 ha^{-1} $year^{-1}$ compared with annual increments of 2.00m^3 $ha^{-1}year^{-1}$ and 3.00m^3 ha^{-1} $year^{-1}$ for the natural stands (Abayomi, 1986).

One exotic species of prominent quality showing great potentials for good performances under plantation system is *Tectona grandis*. It has been recognized to grow under a wide variety of climate conditions. It is easily worked upon and has natural oil that makes it suitable for use in exposed locations, where it is durable even when not treated with oil or varnish.

1.2 STATEMENT OF PROBLEM

Although large hectares of plantation are being established annually, yet the plantation establishment efforts are still inadequate to replace the high forest (FAO, 1979). This is due to poor crop performance in some locations. However, the performance of a forest stand can only be properly monitored with available growth information. Unfortunately simulation of stand growth models for *Tectona grandis* are lacking in all the plantations under Akinyele Local Government Area, Oyo State even though these are vital tool for the management of the plantations (Joseph and Keith, 1987). The slow growth rate of the exploited forest and the possibility of timber shortage require a reappraisal of the national forest policy. The economic importance of teak which include high foreign exchange, its use in the manufacture of boats, decks and other articles where weather resistance is desired, for indoor floor and as veneer for indoor furnishing to mention but a few has greatly attracted private individuals towards investing much in forestry which has contributed greatly to forestry development. Since management prescription based on inadequate information and unreliable data usually lead to waste of forestry products, the need for adequate and reliable data on growth models and the simulation of *Tectona grandis* models cannot be over emphasized (Saksa *et al*. 1995). This therefore underpins the need for the development and simulation of growth models in Akinyele Local Government Area Teak Plantation as necessary step towards solving problem.

1.3 OBJECTIVES OF THE STUDY

The main objective of the study is to develop a computer – based model for simulating the growth and yield of *Tectona grandis* in Akinyele Local Government Area, Oyo State

Specific objectives of this work are highlighted below:

1. Estimate the parameters of gamma distribution function.
2. Develop a computer based program using Netbean IDE for the estimators of the parameter α and β.
3. Application of the computer program developed to predict growth and yield at individual and stand levels.
4. Assessment of the predictive abilities of some models.

1.4 JUSTIFICATION

Forestry competes with other sectors of the economy for factors of production such as capital, land and labour. If it is to continue to enjoy the allocation of these scarce resources, adequate information on our forest is a pre-requisite not only to aid management decision but also to show the productive capabilities of the forest. The construction and simulation of growth models, which forms a basis for evaluation of the forest is very important to meet this need. Forest management decision – making requires detailed information on stand growth and yield both for stands in current production and for stands that will exist in the future. For adequacy, many different types of information of varying degrees of details are needed in management of plantation system.

To date, much energy has been used to debate modelling alternatives while little effort has gone into integrating them for adequate decision making. There is however a shift from suggesting the use of any single type of model for forest management. Most recent system of models is designed more for flexibility in terms of options available than emphasizing any one specific approach (Prevosto *et al*., 2000, Gourlet-Fleury and Houllier, 2000). Emphasis is on developing a toolbox for application that promotes an ability to understand many things fully.

Estimating individual tree volume and site index and describing stand growth dynamics, simulation and succession over time requires accurate growth models (Botkin *et al*., 1972). Although volume and yield tables have been developed and used in Nigeria, their limitations have however necessitated the development and simulation of management models for forest plantations (Zhang *et al*., 1995). Since information required for the good management of plantation need to be qualitative, quantitative and be provided as quickly as possible, studies involving mathematical models and the simulation of such models are readily usable. Forest management decisions are predicted on information both about current and future resource condition (Avery and Burkhart, 1983). Inventories taken at one instant in time provide information on current volumes and related statistics. Forest is a dynamic biological system that are continuously changing, and it is necessary to project these changes to obtain relevant information for prudent decision making. Growth and yield models describe forest dynamics (i.e. the growth, mortality, reproduction and associated changes in the stand) over time and hence have been widely used in forest management because of their ability to update inventories, predict future yield and to explore management alternative and silvicultural options, thus providing information for decision making (Burkhart, 1990, Vanclay, 1994).

Different types of growth functions which include beta, weibull, negative exponential functions to mention but a few have been used extensively but not much work has been done using gamma distribution function. The choice of *Tectona grandis* for this study is justified by its unique importance. It is a timber used in the manufacture of doors, furniture, boat decks, transmission poles and other articles where weather resistance is desired. It is easily worked upon and has natural oil that makes it suitable for use in exposed locations where it is durable even when not treated with oil or varnish. Due to the great importance attached to teak, it is necessary to simulate the growth in order to predict into the future to ensure effective management and planning of the forest plantation. Phillip, (1995) described teaks as one of the world's most valuable timber and high interest is placed on the growth of this species.

1.5 SCOPE

The study was carried out on the teaplantation located at second gate in the University of Ibadan as well as a privately owned teak plantation. All the plantations are under Akinyele Local Government Area. The reason for this is because of the availability of *Tectona grandis* in these plantations, not much silvicultural activity has been done and the plantations are in good state. Four age series which include ages

59 was found in the plantation at second gate University of lbadan while ages 22, 13 and 11were located in the privately owned teak plantations. Data on tree growth were collected from these plantations using temporary sample plots of 20m x 20m (i.e. size of 0.04 ha).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 THE DEVELOPMENT OF GROWTH AND YIELD MODELS

The history of forest growth models is not simply characterized by the development of continuously improved models replacing former inferior ones. Instead, different model types with diverse objectives and concepts were developed simultaneously (Pretzsch, 2001). The objectives and structure of a model reflect the state of the respective research area at its time and document the contemporary approach of forest growth predictions. The growing trend in forest growth modeling has necessitated the development of different types of models to address various problems and issues in forestry (Mendoza and Vanclay, 2008).

Models for growth and yield prediction are usually developed for specific applications, for instance to provide estimate of future timber harvest and stand structures or offer inferences about possible future spaces composition (Mendoza and Vanclay, 2008). Many reviews of growth and yield models have been offered, most recently by Comas and Mateu, (2007), Gratzer *et al*., (2004), Hasenaer, (2006), Johnson *et al*., (2006), Parrott and Longe, (2004), Peng, (2000), Pinjur *et al*., (2006), Rennolls *et al*., (2007) Scheller and Mladenoff (2007), Sun *et al*., (2007)., these models were built on a long tradition of calibration of calibrating models against growth observation in existing stands. As with other aspect of models, there is no single optimal approach, the preferred method will depend on the nature of the data available and the purpose to which the model will be used (Mendoza and Vanclay, 2008).

Vanclay (2006) stated that increasing demand for better forest management has created new challenges for modelers to provide growth models with greater capabilities which are best able to deal with tree growth and competition in stands comprising many species and a wide range of tree sizes. However, Vanclay stated that new demands on forest management often require prediction outside this envelope of calibration data in (Beetson *et al*., 1992) and have led to renewed interest in hybrid models that draw on some elements of process models to offer greater generality. Most hybrids models for pure stands rely on the relationship between site index and the mean annual increment (Almeida *et al.*, 2004, Menserud, 2003). Complex stand structures may require nested models that combine the strength of stand level empirical models; processes- based models, as well as individual tree representing stand dynamics [Peng (2000) Rennols *et al.*, (2007) and Monserud (2003)]. Nevertheless, new technologies have been discovered to offer efficient ways to gather growth and yield data and have reduced the pressures impinging on forest growth modeling (Vanclay, 2003).

Today, a wide variety of yield equations have been developed for use in forest yield studies. The complexity of these equations varies from simplicity of a single regression equation to the detailed intricacy of equation systems that simulate the growth of individual tree in a stand. Irrespective of its detail, a model may be deterministic or stochastic. A deterministic growth model gives an estimate of the expected value (e.g. growth of a forest stand). On the other hand, a stochastic model attempts to illustrate the natural variation by providing different predictions, each with a specific probability of occurrence. Vanclay (1991) has demonstrated that deterministic growth models can be converted to stochastic models by adding normal varieties to the predictions. According to Vanclay (1994), although stochastic models can provide some useful information not available from deterministic models, most of the information needed by forest planners and managers can be provided more efficiently with deterministic models. It is however noteworthy that models development depends on the quantity and quality of data available for design, validation and operation.

Presumably models are constructed to make a difference, either to the understanding of tree growth or to the management of forests. In either case, models need to be adopted before they can make such a difference. This requires that models are available, accessible and appropriate for client needs. “User-friendly” code and consistent documentation are only part of the challenge of making models more accessible. They also need to be physically available. In theory, it should be easy to make models available freely via the internet, but this appears to be the exception rather that the rule. (Benz and Knorrenschild, 1997; Benz, 2001). In a related project (ECOBAS), Hoch *et al.*, (1998) have called for a common model inter change format, but it appears that very few modellers (<20) have risen to the challenge to participate in this initiative (Benz, 2001). The international Union of Forest Research Organizations is currently canvassing support for a model archive, and it will be interesting to observe support for this initiative and monitor any increase in uptake of models made available in this way.

Botkin's JABOWA Model (Botkin *et al.*, 1972) offers an interesting case study, as it has been particularly influential, inspiring many variants (Botkin, 1993) even though it, and its descendants, does not appear to have been used directly by forest managers. Most forest growth models are used primarily by their authors and a small group of technical experts, to explore growth patterns, devise optimal silviculture, and to forecast timber yields. That may well change, as the community demands a greater say in forest management. Modelers should respond to these pressures by developing user interfaces that encourage others to explore fully the practical implication of models and by devising ways to allow users to gain some understanding of the strengths and weaknesses of models.

It is believed that the most effective way of addressing yield calculation is through simulation models (Alder, 1991, Vanclay, 1993). Even for such models, growth and mortality data are indispensable as input variables to ensure accurate predictions of yield (Foli, 1993). Foli also evaluated the sustainability of the current yield formula in Ghana compared with an alternative iterative spreadsheet model suggested by Alder (1992) for calculating yield in tropical high forests.

Okojie (1995) has reviewed the methods of multi-variants analysis which have been tried for growth and yield modeling in Nigeria. They are either distance dependent models (primary unit – single tree parameters) or distance independent models (primary unit-stem parameters). Over the last two decades, a geographic information system (GIS) approach, combined with new data-processing techniques has promoted the development of an array of models that predict spatially explicit vegetation succession and forest cover changes. For example:

i. Simulating spatial processes of forest patch development (Perestrello de vasconcelos and Zeigler, 1993; Li, 1995; He and Mladeoff, 1999a)

ii. Linking models predicting forest land cover change with disturbance models (Turner and Dale, 1991; Baker, 1999; Entel and Hamilton, 1999; Mladenoff and He, 1999; Laterra and Solbrig, 2001; Miinier *et al.*, 2001);

iii. Applying models of forest succession to long term predictions (Bonan *et al*., 1990; Baker, 1995; Guisan and Zimmermann, 2000). Many forest succession models belong to the JABOWA family, which mechanically predict tree species composition and age structure from growth and mortality equations at the scale of individual trees or gaps (Kienast *et al*., 1998; Berger and Hildenbrandt, 2000).However, JABOWA-based models requires many fine-scale variables to parameterize rendering them impractical for use in large areas (Mailly *et al.*, 1999). Using JABOWA – based models at large scale requires much more computation (Urban *et al*., 1999). Thus, increasing model complexity and the number of parameters may not improve the accuracy of model predictions (Gruisan and Zimmermann, 2000).

As an alternative, probabilistic transition models can be used in simulations of large areas. Instead of mechanistic predictions of individual tree/gap behaviour, these models simulate a probability that a location will have a certain forest composition after a specific time interval. These models are simpler, require fewer parameters estimate, and are much more computationally efficient (Urban *et al*., 1999). However, they still require a lot of multi-temporal data for calibration (i.e. forest composition at different plots access different geographical locations.)

2.1.1 Growth Modelling

The processes of growth play an important role in various applied areas, such as biology, medicine, and forestry to mention but a few (Tsoularis, 2006).

Plant growth modelling has become a key research activity, particularly in the field of agriculture, forestry and environmental science. Due to the growth of computer resources and sharing experience between biologist, mathematicians and computer scientists, the development of plants growth models has progressed enormously during the last two decades. (Hu and Jaeger, 2003; Fourcaud and Zhang, 2008). These models are vitally important for forest management planning. Forecasting the growth and yield of individual stand is a prerequisite for planning the management of forest at any level. Therefore managers need to have an appreciation for the various modelling techniques and their limitations. Garcia, (1984); Pretzsch *et al*., (2008) gave an overview of models used in forest ecosystem management. These authors described the very first ecosystem models to be used which were maps in displaying the location of hunting grounds, forest and pastures.

However, new modelling techniques have evolved. These mathematical models permits estates of growth to be predicted and management strategies to be optimized by computer, like the accessible diagram –based modeling environment such as simile (Muetzelfeldt and Taylor, 2001). Most growth parameter estimation is done using linear or nonlinear regression. Monleon, (2003) made use of hierarchical linear model for tree height prediction. Rawat *et al*., (2002) made use of linear regression equation in inventorizing tree outside forest using several species to estimate the growing stock which is essential for sound management planning and policy formation. Also, Segura and Kenninen, (2005) made use of allometric models for tree volume and total above ground biomass in a tropical humid forest in Costa Rica.

Bada (1984) employed a modification of the generalized Chapman - Richard growth function based on Von Bertalanffy's growth model to examine growth data from a permanent sample plot of Usonigbe forest Reserve in Nigeria. The predictive basal area growth model is:

BA = (n/k) – c [exp(-{1-m} kt $^{(1/(t-m)}$)} (t = 1-7) …....................….equation (5)

Where n, k, c and m are growth coefficients, and t is the age of the stand in years (1……….7).

In addition Bada used the Markov model to assess tree population changes and future stand structures in the untreated natural forests. Osho (1988) applied matrix models to study the population dynamics of trees in Idanre Forest Reserve. He used the population growth matrix model to predict long-term growth of the untreated natural forests, of particular interest was the stand density and basal area growth. Bada (1984) used the value of dominant latent root to examine the stable state of distribution of the population in the untreated forests of Usonigbe. He observed that most members of a given size remained in the respective size class at some future date because of the slow growth rate. Osho (1988) developed a linear programming approach to determine the maximum sustainable yield in the forest of Idanre. He also developed a stochastic matrix model for simulating secondary succession in the untreated forest and was able to project the composition of the stand using the current species composition. Osho concluded that increased growth rate (30-40%) was required to reach a stable state in the forest. Ojo (1990) used the matrix modelling procedure to project the compositions in Oban, Omo, Owan and Sapoba Forest Reserves. He investigated the stable structure and obtained the stand table projection using matrix multiplication sequence.Height and diameter at breast height (dbh) is very important tree attributes in forest management (lge *et al*., 2013).Therefore measurements of tree heights and diameters are essential in forest assessment, modelling and management (lge *et al*.,2013). The potential of tree height- diameter equations should be evaluated and validated for their predictive capabilities across a range of tree diameter (lge *et al*., 2014). Ureigho (2013) stated that lnventory analysis of street trees is necessary for making plans leading to intelligent decision as to the management of street trees such as planting, thinning harvesting and utilization. Aigbe *et al*. (2014) used some equations to construct stock chart for density management regime.

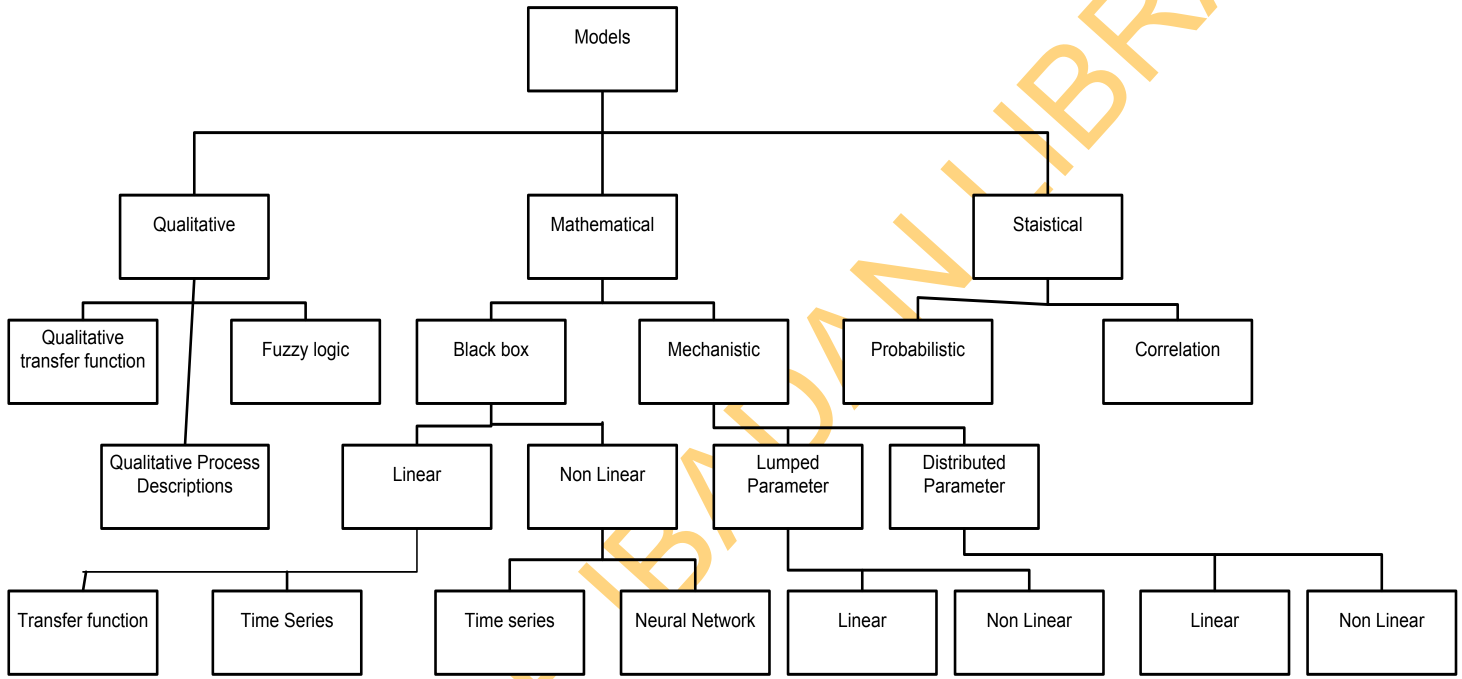

Figure 2.1. Classification of model types for process monitoring and control

Figure 2.1 shows the classification of model types for process monitoring and control. Based on the chart, the models used in this study fell into mathematical and statistical.

2.1.2 Diameter distribution in modelling

Diameter distribution is an effective method for describing stand properties because important variables such as volume, value, conversion cost and product specifications are dependent on tree diameter. A successful diameter- distribution model requires good prediction of its parameter. However, there is no strong rationale to prove one model better than another method. In even-aged stands various distribution functions such as negative exponential, Pearson, gamma, lognormal, beta, Weibull, Johnson, Gram-Charlier, have been used in describing the diameter distributions (Chen, 2004, Nord-Larsen and Cao, 2006 and Palahi *et al*., 2007).In practical applications it has the advantage that the same family of distribution functions can be used throughout the whole life of stands' development and the parameters of growth model are related to stand-level characteristics such as dominant height, basal area, site index and stand density. The approximation of empirical diameter (DBH) distributions with the help of selected theoretical distribution functions plays an important role in forest research and practice. Diameter distributions are used in many cases as parts of growth and yield models. They also serve as models of the forest structures, which play a vital role in sustainable forest management.

Diameter at breast height has a strong ability in predicting height (lge et al., 2014). Diameter distribution and the related statistical model can play an important role in some forest science topics including forestry and silvics. In some growth modelling, it is necessary to know the type of diameter distribution function and its parameters to identify the appropriate model (Mohammadalizadeh *et al*, 2009). Therefore, forest growth modelling has been an intrinsic part of forest management planning and research.

There have been numerous papers on the diameter at breast height (DBH) modelling published in the scientific forestry literature, starting from the paper by De Liocourt (1898), describing the use of exponential distribution for DBH distribution modelling in stands having a complex structure. There have also been results of various studies published during the last decade, which proves the importance of the topic. For example, Pretzsch (1995, 1997, and 2001) provided the methodology for the stand structure modelling based on data on mixed beech *Fagus Sylvatica* L. – larch *Larix decidua* Mill. Stands and described various options for modelling growth and structure of stands having various species composition. The author also assessed the influence of silvicultural treatments on forest stand structures including DBH distribution (Pretzsch, 1998). Examples of the most recent studies published in Poland include papers by Poznanski (1997), who described the relationships between the DBH distribution and the development phase of forests with a complex structure, and Zasada (2000), which searched for the best theoretical distribution for the DBH modelling in birch *Betula pendula* Roth stands.

For Shade –tolerant species such as fir Abies alba Mill and beech *Fagus Sylvatica* L. in central Europe, growth and yield models and models of the stand structure should be flexible enough to cover various stand structures, such as Unimodal distributions of one-storied (Zasada, 1995), more complex two-storied (Bernadzki and Zybura, 1989), band the most challenging multilayered and selection stands (Pretzsch, 2001). Publications on mixed *Abies Fagus* forest with a complex structure are much scarcer (Jaworski *et al*., 2000).

Historically, the very first theoretical distribution function used for DBH modelling in *Abies* stands with a complex structure was the exponential distribution. Subsequent functions used for the DBH distribution approximation in pure *Abies* and *Fagus* stands have included, among others, Weibull, beta and gamma distribution (Merganic and Sterba, 2006).

The diameters at breast height (DBH) models based on a single distribution function are in many cases not sufficient to provide a satisfactory fit to the data. In such situations a finite mixture of usually two distributions for all species together or for each species separately can be created, as described by (Zhang *et al*., 2001, Liu *et al*., 2002 and Zasada and Cieszewsk, 2005).

The diameter distribution information of a stand is as important as the information on total volume. But special techniques are involved in summarizing information on diameter distribution. Many probability densities other than the normal distribution are in use. These include the uniform distribution, the log-normal distribution, the gamma distribution, the beta distribution and the weibull distribution. The weibull distribution is flexible and characterizes different actual distributions simply by differences in its parameter values. Okojie (1981) employed the cumulative density function (cdf) of the 3-parameter weibull distribution to characterize stem-diameter distribution in some mixed plantations of indigenous Meliaceae in Sapoba. The cumulative density function of the weibull distribution used was of the form.

$F(x) = 1 - \exp(1-\{(x-a) / b\}^{c})$………………......................……..equation (6)

Where f(x) measures the area under the curve, x is the random variable, diameter and exp ( ) is the exponential function. The shape of the weibull distribution is dependent on the value of the parameter C while a and b represent the location and scale parameters respectively. The values of the weibull parameters have biological interpretations (Okojie, 1981). The relationships between the weibull parameters and stand attributes have been examined.

2.1.3 Growth and yield prediction models

Growth and yield prediction models are abstract or simplified representation of some aspect of reality used primarily to estimate the future growth and yield of forest stands. A stand growth model represents an abstract of the natural dynamics of a forest stand and changes in stand composition and structure (Vanclay, 1994). Several types of growth models exist with varying degrees of complexity depending on their end use and application. Dynamic growth model can be classified according to the level of detail in the description as follows.

2.1.3.1 Stand - level growth models

Stand – level growth models describe the state of the stand by a few variables representing a stand level aggregates such as basal area, mean diameter, volume per hectare, stem per hectare, average spacing, sometimes, parameters of diameter or height distributions are also used, although more also these are estimated as functions of the state variables. In most situations, this type of model is likely to be the most appropriate for management planning of forest plantations. Mendoza (2005) provided a more comprehensive review of recent development in decision making for forest management using stand-level growth models.

2.1.3.2 Distance – dependent individual tree model

These models use a much more detailed state of description. This includes the location (Co-ordinates) and diameter and sometimes height and crown dimensions of every tree in a sample plot. Chen *et al*., (2007) used distance dependent individual tree model on deciduous oak wood land in California. These models can be useful as research tools to study practices affecting tree spatial relationship. They may also provide insights into stand dynamics that could contribute to the development of better stand models.

2.1.3.3 Distance-independent individual tree growth models

These describe the state through individual tree data, but without specifying tree locations. This class of model should include only those based on a list of the actual tree in a sample plot with their dimension. These models also occupy an intermediate position between the stand-level and distance - dependent models in terms of stand description detail, computational cost and information requirement. An important feature of this model is that it is able to predict the growth and development of forest stands with any composition from pure even-aged to mixed-species uneven –aged structures. The basic modelling unit is the individual tree. The prognosis model is a set of computer programs that predict the growth and development of forest stands in North Idaho. Prognosis consists of four major sub models (1) diameter increment (2) height increment (3) crown ratio development and (4) mortality. Its growth equations are a function of tree size, vigour and dominance, not age (Teck *et al.*, 1996).

Distance independent single tree non-linear models were also developed for diameter increment in stands of indigenous Meliaceae (Okojie, 1981). These models were used to determine the expected number of stems in defined diameter classes in the stand at given future dates.

2.2 APPLICATION AND USE OF GROWTH MODELS IN FORESTRY

Several types of growth models exist with varying degree of complexity depending on their end use and application. It is impossible to validate any model or to determine absolutely that any model is the best representation of reality (Popper, 1963). The various growth models that have been used include:

2.2.1 Empirical growth models

Empirical forest growth models deals with the application of functions fitted to data without considering the physiological process involved in growth and morphogenesis, and predicting yield and quality of products (Zhang *et al*., 2008). Nevertheless, such models are usually calibrated for a particular species and well defined site conditions and therefore cannot be valid over a wide range of condition (Lacointe, 2000). Mendoza (2005) provides a more comprehensive review of recent development in decision making analysis for forest management at stand level using empirical growth model.

Advantages

1. It is used to describe growth rate as a regression function of variables such as site index, age, tree density and basal area.
2. They are used in describing the best relationship between the measured data and the growth determining variables using a specific mathematical function or curve.
3. They require only simple inputs and are easily constructed.
4. They are also easily incorporated into diversified management analyses and silvicultural treatments.
5. Greater efficiency and accuracy can be achieved in providing quantitative information for forest management.
6. They may be appropriate for predicting short term yield for time scales over which historical growth conditions are not expected to change significantly.

Disadvantages

1. They are not used to analyze the consequences of climatic changes or environmental stress (Kimmins, 1990; Shugart *et al*., 1992).
2. The flexibility of the model is intermediate.
3. It requires many field measurement plots
4. Environmental measured factors are based on site characteristics.
5. It has low to high complexity.

2.2.2 Process based growth models

The term "process-based growth model" was introduced to describe those models that considered the interaction between plant or tree functional processes and a biotic factor (Zhang *et al.*, 2008). This model usually focus on the description of Carbon(C) or nitrogen (N) balance and consider that plant development depends on a change of matter in different compartment, based on uptake (e.g. photosynthesis) and loss (e.g. senescence) either within an individual Carvalho *et al.*, (2006) and Gayler *et al.*, (2008) or a plantation (Gayler *et al.*, 2006, Pretzsch *et al.*, 2008). To model these interactions we need to take into account the physiological processes involved in growth e.g. water and nutrient uptake, photosynthesis and Carbon partitioning (Sterck and Schieving, 2007).Process models have reached critical mass in forestry only in the past 15 years (Dixon *et al.*, 1990).

Their common philosophy is to build a tool for scientific explanation rather than prediction. They attempt to explicitly represent causality between variables, thereby reaching toward generality. They set out to model one or more of the key growth processes and underlying causes of productivity: photosynthesis and respiration (carbon allocation), nutrient cycles, climate effects, moisture regime and water stress. From a system analysis point of view, these are the functional components of the biological system of interest. They are usually chosen at a hierarchical level that is one level below the level of the system (Makela *et al.*, 2000a). lsebrands *et al*. (1990) pointed out that, paradoxically, process modelers can increase their understanding of the overall system only if it possible to break into subsystems that are well understood. Because process models usually have a strong basis in physiological theory, lsebrands *et al*. (1990) contends that process models should have reasonable prediction accuracy outside the range of the original data.

Advantages

1. It is used to simulate the dependence of growth on a number of interesting processes, such as photosynthesis, respiration, decomposition and nutrient cycling.
2. They offer a frame for testing and generating alternative hypothesis and have the potential to help us accurately describe how these processes will interact under given environmental change (Landsberg and Gower, 1997).

3. They make use of eco-physiological principles in deriving model development and specification.
4. They are used for long-term forecasting applicability within changing environment.
5. It is used for long-term prediction time.

Disadvantages

1. It has low forest management on foresters and managers
2. It has low extension service
3. The complexity of the model is high
4. The model has low flexibility
5. It requires many model parameters
6. It requires more field data for complex calibration and validation procedures.

2.2.3 Functional - structural growth model

Several reviews exist describing functional-structural growth model. Lacointe, (2000) described the four major Carbon partitioning models, which are currently used in functional-structural growth models as:

1. Empirically determined allocation coefficients.
2. Models based on a description of growth patterns or relationships within the plants.
3. Transport-resistance models
4. Models based on source –sink relationship

Le Roux *et al*. (2001) reviewed twenty seven forest growth models that use the same main physiological processes involved in Carbon (C) metabolism. The concluding remarks of these authors with regard to functional-structural growth models were that Carbon (C) allocation and understanding of below growth process and nutrient assimilation was lacking in most models.

2.2.4 Physiological principles of predicting growth (3-PG)

Landsberg and Waring (1997) developed a simple process-based forest growth model called 3-PG (Physiological principle to predict growth) based on a number of established biological relationships and constrains. This model generates the number of growth parameters which are directly measurable. The 3-PG has demonstrated the potential to provide forest growth estimation and has been applied to wide range of forest species (Landsberg *et al*., 2003).For all too long, there has been a specious argument separating mechanistic modellers and traditional forest yield modellers: causal vs. empirical models. Korzukhin *et al*., (1996) challenged this fruitless view by demonstrating that neither pure process models nor pure empirical models exist. Rather, all models have elements of each, admittedly to different degrees. Recall that system modelling is hierarchical (O' Neill *et al*., 1986). At the hierarchical level of a given process, a mechanistic model might rightly be regarded as causal, with coefficient that can be derived from theory. But at higher- levels of organization (e.g., the tree, or stand), the theory is insufficient, and the higher-level generalization becomes empirical (Makela *et al*., 2000a). There will always be a parameter that cannot be determined from the definitions of process (e.g., canopy quantum efficiency in 3-PG), and that component must then include some bit of empiricism to be consistent.

2.2.5 Mechanistic Models.

lsebrands *et al.* (1990) and Host *et al*., (1990a) stated that ECOPHYS is a mechanistic whole-tree model that simulates the growth of clonal hybrid. *Populus* in its establishment yearly was originally designed as research tool in the genetic selection of *populous* clones. The individual leaf is the primary biological modelling unit, and the time step is one hour (Host and lsebrands, 1994). Hourly solar radiation, temperature and clonal genetic factors acting at the leaf level provide the major driving variables for growth. ECOPHYS successfully predict height growth and main stem leaf areas and biomass. One of the oldest successful paradigms in mechanistic modelling is the pipe model theory. Valentine (1990) has organized this theory into a system of differential equations in PIPESTEM. He uses the theory for the structural framework and dry-matter allocation rules needed for carbon-balance models of growth. The tree comprises leaves, feeder roots, active pipes, and disused pipes; the pipes represent all woody components of the tree: branches, bole, and support roots (Valentine, 1990). The model tree maintains a constant amount of leaf dry matter (carbon) per unit of cross - sectional area of active pipes. Although this model is based on the fundamental causes of productivity. It has been difficult for them to demonstrate accurate stand development. Several mechanistic models are difficult to validate, primarily because the physiological observations that could provide critical confirmation are so difficult to measure; the validation results for ECOPHYS are a counterexample. Hinckley *et al*., (1996) found that several important physiological processes are so poorly understood that an accurate physiological model is not yet possible.

2.2.6 Forest Yield models

This is the oldest and broadest class, dating from the first yield tables in the 18^{th}-19^{th} centuries. They were intended to predict an expected yield over the management regime. Foresters assumed that the management associated with such yields was sustainable. Now, modern computers have made individual tree modelling possible. A vast number of stand simulation models have been developed in the last 30 years (Ritchie, 1999). Yield models are also available for almost all ecosystems in the world where forest management is a sustainable practice. Most yield models share a common philosophy of site-specific prediction of yield over time. Site index (dominant height at an index age) is the standard measure of productivity; a measure used only by foresters. Yield models share several features. Almost all have site calibration, basic silviculture, can predict yield in terms of wood products, and often accommodate a variety of sample designs for different inventories (Robinson and Monserud, 2003).Few model natural regeneration, although all plantation models allow for the specification of initial density and various site preparations and treatments. Uncertainty is occasionally modelled (Wykoff *et al.*, 1982), but not often. The real advantage of forest yield models is their ability to make detailed predictions of tree and stand dynamics, particularly stem size distribution predictions that aggregate accurately to the stand level. A second is that tree mortality is often modelled in detail; incorporating both competitive effects at the individual tree level and stand level constraints. The fundamental disadvantage of forest yield models is that they are not linked to the underlying causes of productivity: the carbon and nutrient cycles, the moisture regime, and climate. For this reason, such models are often referred to as empirical, occasionally in a derogatory sense. Most traditional growth and yield models, which exclude soil processes and the role of ecosystem disturbance to determine ecosystem function, may be able to predict the continuity of timber harvest and the nature of future forest stands, but tell us little about the effects of timber harvesting on ecosystem structure and function (Peng, 2000). They also suffer from insensitivity to environmental change (e.g., climate change effects such as a rising temperature, increased CO_2 concentration, and altered precipitation regime). Because of this, they are environmentally static, and are limited to the range of environmental conditions represented in the underlying database used to build the model.

2.2.7 Ecological Gap Models.

There is a rich 30-year history of ecologists modeling population succession by the device of a gap in the forest that is formed when a large tree dies (Shugart, 1984). All of these models are genealogically related to the progenitor, JABOWA, and the first-born: FORET (Bugmann, 2001). Currently, over 50 variants exist. Their common philosophy is to test ecological population theory. This is very different goal from that of the foresters' yield models. Basically, the development of gap models has taken place independently of traditional forest yield model research, with almost no cross breeding (Sievanen *et al*., 2000).Gap models built by and for ecologist, have no typical forestry inputs or outputs. Uncertainty is not modelled, although the Zelig variants (Urban, 1993) simulate multiple gap replicates. Perhaps the most unusual attribute of gap models is that plot size (gap size) strongly influences the predicted population dynamics, and is therefore a growth parameter (shugart, 1984). In contrast, forest yield models are generally unaffected by change in plot size (Stage and Wykoff, 1998). Validation of gap models is a very difficult proposition, one that is usually not attempted. Gap models typically make prediction for 100-1000 years, well beyond the realm of the historic record. Recently, three reviews have critically examined the behavior of gap models. Lindner *et al*. (1997) examined the individual tree stem development of a second generation gap model, FORSKA (Prentice and Leemans, 1990). Using data from Bavaria, theirs was the first to use long term (1870-1990) forest observation records for the calibration and validation of a forest gap model (Lindner *et al*., 1997).Even with the greatly improved growth formulation in FORSKA, individual tree dimensions and simulated stand structures were "quite unrealistic" (Lindner *et al*., 1997). They uncovered two structural problems that affect all gap models. First, the invariant height-diameter relation produced quite unnatural stand development. The plot of height (H) vs. diameter (D) was a simple quadratic curve with no variation over time. In contrast, actual stand development is a series of changing height (H) curve with no variation over time, reflecting the differential response of individual trees to changes in stand density.Lindner *et al*. (1997) tested five height growth models, all of which performed better than the basic gap model. The second structural problem was the stochastic mortality function. Yaussey (2000) examined the generic gap model Zelig (Urban, 1993), and a forest yield model, NE-TWIGS (Hilt and Teck, 1989). They were compared using 30-year remeasured data in Kentucky. Yaussey (2000) also found that the stand and tree projection of the gap model to be "unrealistic". They recalibrated and adjusted the many parameters in Zelig in an attempt to improve performance, but none produced the proper number of trees to produce the right combination of biomass or volume. No combination of parameters could be found to improve the projections of Zelig to the level attained by NE-TWIGS (Yaussey, 2000).Hinckley *et al*. (1996) examined a broad suite of gap models regarding their ability to accurately model forest response to climate change. They uncovered several problems with the structural design First; JABOWA assumes that the realized niche of a species is identical to fundamental niche. The second problem is the failure of gap models to separate the effect of temperature on seedling establishment from the temperature effect on growth of established trees. Hinckley *et al*. (1996) considered this failure to be a potential "fatal flaw", especially for climate change modeling. Third, predictions of growth rate are not particularly reliable even in current climate conditions. They found that the equations used to predict the effect of changes in temperature, moisture, and nutrients on growth are basically arbitrary. This is especially a problem when temperature increases mortality rates on mature trees. Fourth, the parabolic model for the effect of temperature on growth ignores the repeatedly demonstrated fact that established trees can grow far outside their current range. Fifth, none of gap models is currently capable of making accurate predictions of the consequences of increased CO_2 concentration (Schwalm and Ek, 2001).

2.2.8 Hybrid models

In the past few years, some process modellers have seen the need to make their models amendable to normal forest management situations and problems (Makela *et al*., 2000a). One strategy is to merge the best features of a processed-based physiological model with an empirically based yield model. The result is called a Hybrid model, which is an attempt to build a forest management model that can indeed address the effect of a changing environment at a fundamental level. A hybrid model is thus a mixture of both causal and empirical elements at the same hierarchical level (Johnsen *et al*., 2001a). Makela *et al*., (2000a) finds that modelling the carbon balance of trees and forests based on photosynthetic production provides a workable framework for building management-oriented hybrid models. Furthermore, work will be accelerated if it can be demonstrated clearly that both empirical (yield) models can be improved through incorporation of mechanistic (causal) functions, and that process models can be improved by incorporating system-level empirical elements and constraints (Makela *et al*., 2000a).Progress will come when the modellers cooperate with and are responsive to the needs of forest managers. Overall, this remains largely a dream, but real progress is being made. The hybrid system uses empirical sub models for branch numbers, locations, and inclinations. An unusual strategy is the parallel development of empirical models for the same quality characteristics using MELA, the existing forest- yield planning simulator for Finland (Makela *et al*., 2000a). An additional noteworthy example of hybrid model is the hybridization or linkage of the forest yield model PTAEDA2 (Burkhart *et al*., 1987) with the process model MAESTRO (Wang and Jarvis, 1990) for Loblolly pine (Baldwin *et al*., 1993, 1998). One goal was to determine a more accurate estimate of stand carbon gain and allow investigation of potential future environmental scenarios (Johnsen *et al*., 2001). The strategy employed by Baldwin *et al*. (1993, 1998) was to 1) use the growth and yield model to grow a stand to a given age and describe the stand and structural characteristics of the constituent trees, 2) use the tree-structure descriptions and the process model to assess forest function at that age, 3) feedback the resulting information to the growth and yield model to adjust its prediction equations (e.g., crown characteristics like leaf area ,leaf density, crown biomass) and 4) repeat steps 1 to 3 until end of the rotation. Hybrid models hold the greatest promise, because they are predicted on the development of an operational model and useful products for the manager. Forest managers require a straightforward demonstration of model usefulness. The input data must be generally available or the model will not be used. Even if the input data are available, the output must relate to the needs of the manager.

We do not need managers to design our models, but we do need to listen to them to find out their needs and operating requirement.

2.3 APPLICATION OF FOREST SIMULATION MODELS

A number of forest simulation models are constructed for many reasons and for a variety of users. These users may apply forest simulation models for (1) Predicting tree volume (2) Optimizing appreciable silvicultural input for maximizing yield (3) Understand forest succession (4) Testing various hypothesis about tree structure and function.

During the last two decades, along with advanced mathematical statistics and rapidly developed computer technology, growth and yield modelling methodology and technology for even-aged stands have moved forward significantly, and many computer-based growth and yield such as FOREST (EK and Monserud, 1974), PROGNOSIS (stage 1973; Wykoff *et al.*, 1982) FREP (Hahn and Leary, 1979) and it successors STEM (Belcher *et al.*, 1982) and TWIGS (Miner *et al.*, 1988). Forest vegetation simulator (FVS) (Teck *et al.*, 1996) based on PROGNOSIS and uses STEM / TWIGS model architecture, and PROGNAUS have been developed and used in forest management (Monserud and Sterba, 1996, Sterba and Monserd, 1997).

2.3.1 Advantages and disadvantages of some existing simulators

Some advantages and disadvantages of simulators that have been used include:

2.3.1.1 MYRLIN (Method of Yield Regulation with Limited Information).

It is a set of tree software tool designed to assist the process of yield for a plantation.

Advantages

1. It is designed for processing partial and incomplete inventory data.
2. It is useful for first - order management planning applications, such as calculating future yields and annual allowable cut.
3. It is flexible as to the diameter limits employed.
4. It works on a flexible time step.

5. The model allows a percentage of trees above a minimum size class to be harvested.
6. It produces a stand table from inventory data using a series of linked spread sheets that include, tree measurement from sample plots and / or stock survey data.

Disadvantages

1. It is not sensitive to some dynamic aspects of stand behaviour.
2. Lower cutting diameter limits may reduce numbers of seed trees of species under heavy commercial pressure, the model does not account for this.
3. Heavy logging may induce more frequent fires, erosion, nutrient losses, and pioneer re-growth that impede valuable trees. Some important commercial species require disturbance in order to regenerate properly. This factor is not accounted for in the model.

2.3.1.2 PTAEDA2 Model

Daniel and Burkhart developed PTAEDA2 simulator in 1975. It was initially called PTAEDA. This simulator has undergone a myriad of changes over the years thus earning a new name PTAEDA2. It has been employed to generate an initial stand at age eight (Burkhart *et al*., 1987). Individual tree diameters are assigned from a two - parameter weibull distribution. Tree heights are computed as a function of tree DBH and then crown lengths are assigned based on tree DBH and height (Hilt, 1986).

1. It is used to grow a stand to a given age and describe the stand and structural characteristics of the constituent trees.
2. It uses the tree structure description and the process model to assess forest function at a given age.
3. It feedback the resulting information to the growth and yield model to adjust its prediction equations (crown characteristics like leaf area, leaf density, crown biomass).

2.3.1.3 JABOWA Model

It is used for simulating whole stand to individual tree and the objective extends from stand yield prediction to ecological process description. It is a distance independent model.

Advantage

They are predicted on producing an operational process model with useful products on yield for the manager.

Disadvantage

1. This assumes that the realized niche of a species is identified to its fundamental niche. This ignores the strong effect of inter specific completion limiting a species realized niche, to the point where the optimal growth can be at the southern limit rather than the centre of the distribution (Rehfeldt *et al.*, 1999).
2. Failure to separate the effect of temperature on seedling establishment from the temperature effect on growth of established trees (Hunkley *et al*,; 1996) considered this failure to be a potential "fatal flaw" especially for climate change modelling.
3. Predictions of growth rate are not particularly reliable even in current - climate conditions. The equations are used to predict the effect of changes in temperature, moisture and nutrients on growth, which are arbitrary. This is especially problem when temperature increases mortality rates on mature trees.
4. The parabolic model for the effect of temperature on growth ignores the repeatedly demonstrated fact that established trees can grow far outside their current range.
5. None of the gap models is currently capable of making accurate predictions of the consequences of increased CO_2 concentration. (Schwalm and EK, 2001).

2.3.1.4 SYMFOR Model (Sustainable and Field Management for Tropical Forest)

It is an individual tree growth model which can be used to formulate harvesting volume and growth capability for the subsequent cutting cycle using several alternative systems for sustainable timber yield regulation from production forest concession.

Advantages

1. It can be used to formulate harvesting volume and growth capability for subsequent cutting using several alternatives, systems for sustainable timber yield regulation from production forest concession.
2. It can be used to simulate alternative silvicultural practices and evaluate the management system (silvicultural system) from ecological point of view.
   Combination of the growth and yield model (for the concerned concession), the economic model and environmental frame work, can be used to produce general forest management activity / planning.
3. It can be used to simulate several alternative silvicultural practices to produce commercial timber volume in an initial harvest, and then to look at the subsequent regeneration of the stand in order to access when a second harvest will be viable.
4. It can be used to predict individual tree growth, the total yield from a stand of forest and the condition of the residual stand at specified intervals, so that an optimal cutting cycle can be evaluated.
5. It is a tool for simulating the effects of silvicuture in the growth, ecology and future yield of tropical forest.
6. It is used for the development and evaluation of management guidelines (policy).

Disadvantages

1. The nearly overwhelming data input requirement to run the model.
2. The location – specified nature of that input.

2.3.1.5 GEM FORM Model

It is a cohort and a stand Model, but can optimize harvest intensity on each stand to maximize annual allowable cut over multiple felling Cycles.

Advantages

1. Designed for processing partial and incomplete inventory data.

2. It is a stand model, but can optimize harvest intensity on each stand to maximize annual allowable cut over multiple felling cycles and project several strata simultaneously.
3. It has better forest inventory analysis features.
4. It is designed to incorporate stem quality and merchantability.
5. It is designed for situations, where only rudimentary or assumed growth data is available.
6. It is used to produce outputs for each felling cycle.

2.3.1.6 PROGNOSIS Model

It is a set of computer program that predict the growth and development of forest stands with any compositions from pure even aged to mixed species stands.

Advantages

1. It predicts the growth and development of forest stands with any composition
2. They do not require tree coordinates (tree spatial) information which are usually not available in forest inventory and permanent sample plots.
3. It does not require the complete enumeration of the plots to be prognosticated.
4. It is based on samples drawn through the stand.
5. It requires fewer amounts of data to run the model.

2.3.1.7 STELLA Model 31

Stella is a package of system Modelling Software developed by High performance systems incorporated (H.P.S Inc.). There are two versions of the modelling Software Stella® and iThink®. The software allows the modeler to develop and interface to facilitate the model's use and illustrate key features for the model user. The generic model building structures used within the Stella® environment make the modelling software adaptable to many fields (H.P.S Inc. 2000a).

Advantages

1. It is used to create model
2. It was designed as a model that could be flexible enough to simulate different harvesting systems.

3. It contains enough detail so that individual sections of the harvesting system can be analyzed.

Disadvantage

A detailed database including stand data time study or probability distributions for various functions are required.

2.3.2 Roles of forest growth models

Growth estimation of living trees and stand is needed by managers for many purposes including:

a. yield prediction
b. health monitoring
c. long term productivity monitoring
d. socio economic analysis of forest influences
e. marketing planning harvesting
f. Planning long term machinery requirements.

2.3.2.1 Yield Prediction

Yield prediction is an essential activity in forest management especially for the production of commercially important outputs such as fuel wood and sawn timber. Sometimes it is necessary to predict the future growth and structure even before the establishment of plantation or at the very early stages. The results of such estimations will be used for the planning purposes and necessary calculations such as expenses and profile etc. Mathematical models play vital role in predicting those values so that the effective planning can be done.

2.3.2.2 Health monitoring

Management of forest plantations is similar to that of long-term agricultural crops such as rubber. The growth of such plantations can be hindered by many factors. Main constraints can be fire, diseases and insect pest damages. Insect damages by skeletonises and defoliators are common in tea plantations in the early stages of establishment. Natural fire and insect damages may be seasonal or periodical and therefore the relevant models can be used to calculate the damage and thereby to understand the destruction with different intensities of the problem, Moreover, the history of damage and intensities can be modelled with the time or period to identify the specific critical time of the damage and hence the prevention methods can effectively be applied.

2.3.2.3 Long-term productivity monitoring

Typical forest management is a business which does not stop after completing one cycle. Therefore planning ahead and implementation of certain activities such as replanting for the second generation after the previous harvest, maintenance or to improve the quality of the site where the forest is grown are vital to maintain the similar or increased growth rates to that of the previous cycle. If the quality of the site decreases, steps should be taken to prevent it and to improve the quality in order to obtain a higher yield in the particular forest. For this reason, there should be a mechanism of identifying the change of site quality with the time even with a single cycle. In order to fulfil this requirement, modelling the site indicators with time has become a common practice. Mainly height indices are used as such indicators which are developed using a selected height (top height, dominant height, average height of dominants and co-dominants) and the age.

2.3.2.4 Socio economic analysis of forest inferences

Modelling is important when a particular forest is managed as a multi-purpose resource with the association of sustainable management. If the non-wood forest production such as fuel wood, medicinal plants and grazing are expected in a particular forest, the sustainable harvesting quota should be calculated using forest models in order to collect such products without over exploiting the resource. Since the multi-purpose management is even common with forest plantations, those particular models address the issue of “how much?” to be harvested within a particular area or within the entire forest for a defined time frame. Using the results, the appropriate allocation can be divided among the forest users.

2.3.2.5 Marketing

If forest products cannot be sold for a reasonable price, the profits cannot be obtained though the most intensive management practices are used. The price of the products is decided by the market demand. Therefore models generating "demand curves" are essential in forestry business aimed at profit earning. Those models will allow the forest managers or practitioners to identify the high demand periods, for example, summer in temperate countries where most of the outdoor furniture is purchased. Therefore the forest managers can couple the thinning and final harvests with the time when the demand is predicted as high in order to sell the products to a high price.

2.3.2.6 Planning the harvest

Forest harvesting must be planned due to many reasons. At the harvesting time, the managers should answer the questions of "how much to cut?", "where to cut?" and "when to cut?" for better planning. If clear cutting of the entire forest is not an objective, the amount harvested should be determined. This may depend on an exploitation size or a certain number/volume of trees. Only after deciding the amount of harvest, the manager can plan the required machinery, transport, labour and profits. The answer to the question "how to cut", i.e., felling techniques depends on the tree size and end product. If a specific area is to be harvested due to higher growth rates or poor growth rates, those areas will be identified by answering the question of "where to cut?" and the harvesting time is determined by " when to cut?" to eliminate the operations in undesirable periods. Usually harvesting operations are conducted in dry periods to increase the cost efficiency and to protect the site. The exploitable size is usually defined by a specific diameter which is always an easy measurement to be made. Therefore the tree growth models will allow the managers to project the current tree growth to the future and thereby to determine the number of trees to be harvested after a certain time. The method of felling will then be determined due to the projected tree size. Future growth differences will also be identified by projecting the current growth using models.

2.3.2.7 Planning long-term machinery requirement

Large-scale forest operations require planning of machinery, labour and cost. Those machineries may be hired from outsources or have to be purchased. Therefore it is essential to know the magnitude of forest operations before leasing or purchasing such high cost equipment because those should be capable of completing the task within a certain time. Whether one should model at tree level and aggregate for stand estimates or model an aggregate level depends on the scientific objectives. The use for which a growth model is intended, it is generally argued, should determine the resolution level at which one should operate.

2.4 PROBABILITY DISTRIBUTIONS IN MODELLING

2.4.1 Binomial Distribution

It is used in finite sampling problems where each observation is one of two possible outcomes ("success" or "failure"). The binomial distribution has two parameters;

a. n = the sample size

b. π = P ("success")

The binomial distribution is expressed as:

$$y_i \sim f(\pi, y_i) = \frac{N!}{y_i!\,(N - y_i)!}\,\pi^{y_i}(1 - \pi)^{N - y_i}$$

Or

$$y_i \sim f(\pi, y_i) = \binom{N}{y_i}\pi^{y_i}(1 - \pi)^{N - y_i}$$

Example: To assure quality of a product, a random sample of size 25 is drawn from a process. The number of defects (X) found in the sample is recorded. The random variable X follows a binomial distribution with n = 25 and π = P (product is defective).

2.4.2 Poisson Distribution

The Poisson distribution is used for modeling rates of occurrence. The Poisson distribution has one parameter:

a. λ = the rate (mean).

$$y_i \sim f(\lambda, y_i) = \frac{e^{-\lambda}\lambda y_i}{y_i!}$$

We have only one parameter to estimate: λ. θ = λ

Example: A process that creates fabric is monitored if the number of defects (X) per meter of fabric exceeds 5 then the process is stopped for diagnosis.

The random variable X follows a Poisson distribution with λ = number of defects per meter of fabric.

2.4.3 The Negative Binomial Distribution

It is used for modelling rates of occurrence. The negative binomial distribution has two parameters.

a. r = the total number of failures

b. π = P (success)

Example: A process that manufactures widgets is monitored. As each widget exists the process line, it is tested for defective versus non-defective. On the fifth defect, the process is stopped for re-adjustment. The random variable X follows a negative binomial distribution with r = 5 and π = P (widget is non-defective).

2.4.4 The Geometric Distribution

It is used for modelling rates of occurrence. The geometric distribution has one parameter.

a. π = P (“success”)

Example: Processes that manufacture widgets is monitored. As each widget exit the process line, it is tested for defective versus non defective. On the first defect, the process is stopped for re-adjustment. The random variable X follows a geometric distribution with π =ρ (widget is non-defective).

2.4.5 The T Distribution

It is used in many situations, some of which are listed below. The T distribution has one parameter.

a. γ = degrees of freedom

Common usage

i. Inference on a single normal mean, variance unknown

ii. Inference on the comparison of two normal means,

iii. Inference on individual regression parameters.

2.4.6 The Chi – Square Distribution

It is used in many situations, some of which are listed below. The chi-squared distribution has one parameter;

a. V = degrees of freedom

Common usage

i. Inference on a single normal variance

ii. Chi –squared Tests;

iii. Test for independence

iv. Homogeneity

v. Goodness of fit

2.4.7 The Gamma Distribution

It is a general distribution covering many special cases, including chi-squared distribution and exponential distribution. The gamma distribution has two parameters;

a. α = rate parameter

b. β = Scale parameter

A continuous random variable X has a gamma distribution when its probability density function is given as:

$$f(x) = \frac{A^{\beta} X^{\beta-1}}{\sigma(\beta)} \exp e^{-Ax} \quad \text{...} (7)$$

Common usage

i. Positively skewed data such as movement data and electrical measurement.

2.4.8 The Weibull Distribution

This is an example of exponential distribution derived by W – Weibull in 1939 for reliability studies and life testing experiments. It is very flexible and can generate curves with skewness varying from positive to negative (Okojie, 1981). It has gained popularity in biological studies, so it is reliable for characterising stem diameter distribution (Adegbehin, 1985). It exists in two types namely two and three parameter functions.

The probability density function of the two-parameter model for the Weibull random variable X is defined as:

$$f(x) = \left(\frac{c}{b}\right)\left(\frac{x}{b}\right) \exp \langle -\left(\frac{x}{b}\right)^{c} \rangle \quad X \geq 0,\ b > 0,\ c > 0 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

The cumulative density function of this two-Parameter Weibull model is given as:

$$f(x) = 1 - \exp \langle -\left(\frac{x}{b}\right)^{c} \rangle \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9)$$

Where b = scale parameter and c = shape parameter, X = random variable, (diameter), exp = exponential constant.

The cumulative distribution function for the 3 – parameter Weibull is also given by adding location parameter, a, as:

$$f(x) = 1 - \exp \left\{ -\left(\frac{(x-a)}{b}\right)^{c} \right\} \quad a \leq x \leq \alpha \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (10)$$

“a” is the location parameter which indicates the beginning of the point of distribution, “b” is the scale parameter which determines the peal of distribution (Kurtosis). “c” is the shape parameter, the value of which tells the skewness (shape) of the distribution. $c \leq 1$ is normally anticipated in natural forest where $b > 0$ (Rustagi 1978).

It is typically used in reliability modelling.

The weibull distribution has two parameters;

a. α = rate parameters

b. β = Scale parameters

For $\alpha = \beta = 1$, the weibull distribution is identical to the Exponential distribution.

Common usage

i. Time to failure modelling.

2.4.9 The Log - Normal Distribution

This distribution occurs when a random variable, X, has its logarithm showing a normal distribution. Its probability density function is expressed as:

$$f(x) = \frac{1}{2\pi^2}\ x^{-1} \exp - \ \frac{(\mathrm{Ln}\,X - \mu)^2}{2\beta^2} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (11)$$

Where X, β. 0 and Ln X = natural logarithm of X. The limitation of this type of model is that it can only generate left skewed curves in growth studies. Bliss and Reinker (1964) used it to describe diameter distribution in some even – aged stands.

It is useful when the raw data are highly skewed whereas the natural log of the data is normally distributed. The log – normal distribution has two parameters;

a. υ = location parameters

b. σ = Scale parameter.

Common usage

Positively skewed data such as movement data and electrical measurements.

2.4.10 The Beta Distribution

This is the distribution when a random variable X has a density function given by:

$$f(x) = \frac{\sigma(p+q)}{\sigma(p)\sigma(q)} - X^{p-1}(1-X)^{q-1} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (12)$$

Where: 0<X<1, p>0, q>0, p and q are beta constants to be estimated. The gamma and beta distribution functions have their density function highly flexible in shape and can therefore be adapted for growth studies.

It is a continuous distribution bounded between 0 and 1. The beta distribution has two parameters;

1. a = first shape parameter
2. b = Second scale parameter

When α = b = 1, the Beta distribution is identical to the uniform distribution on (0, 1).

Common usage

i. Modelling the probability of success for a binomial distribution.

2.4.11 The F Distribution

It is used in many situations, some of which are listed below. The F distribution has two parameters;

a. V1 = numerator degrees of freedom

b. V2 = denominator degrees of freedom.

Common usage

i. Inference of two or more normal variances

ii. ANOVA

iii. Regression.

2.5 GAMMA DISTRIBUTION FUNCTION

The generalized gamma distribution offers a flexible family and many of the important lifetime models are obtained as component models by setting its shape parameters to unity. The flexibility of the generalized gamma model, however, occurs at the cost of its increased complexity. It may offer a good fit to some sets of data. Numerous parametric models have been proposed for the analysis of lifetime data. Generalized gamma model is one such flexible family often advocated to model such data sets although the model has applications in several other fields too. The model was proposed by Stacy (1962) and later on independently given by Cohen (1969). The gamma distribution is a good fit for the sum of independent random variable.

The gamma distribution function can be given as:

$$fx(x) = \frac{x^{\alpha-1} e^{\frac{-x}{\beta}}}{\Gamma(\alpha)\beta^{\alpha}} \quad , \alpha > 0 \text{ and } \beta > 0$$

For $\alpha > 0$, $\beta > 0$ and $\Gamma\alpha = (\alpha\text{-}1)$. In other words, α must be a positive integer while the gamma function can be defined as definite integer for R(z)>0 (Euler's integral form)

Γ (z) = δ

So the gamma function reduces to the factorial for a positive integer argument. The generalized gamma family incorporates all the important life-testing distribution and this is perhaps the reason that the model has enough scope in lifetime data analyses. The exponential, Weibull and gamma models, which may be referred as the components models, are all quite important in the context of lifetime data and the inferences for these are available in bulk using both classical and Bayesian methodologies (Lawless, 1982; Upadhyay *et al.*, (2001) and Singpurwalla, 2006). Mendoza et al., (2013) applied gamma distribution to peak calling step (ie in recognition of signal) in chip – seq data analysis.

2.5.1 Gamma distribution function properties

For any positive n Γ (n +1) = nr (n) ....equation (13)

For a positive integer Γ (n + 1) = n! ....equation (14)

(For n = ½) Γ (1/2) = equation ....equation (15)

The gamma distribution represents the sum of exponentially distributed random variables. Both the shape and scale parameter can have non- integer values. Typically, the gamma distribution is defined in terms of a scale factor and a shape factor. When used to describe the sum of a series of exponentially distributed variables and the scale factor is the mean of the exponentially distribution variables, the shape factor represents the number of variables and the scale factor is the mean of the exponential distribution. This is apparent when the profile of an exponential distribution with mean set to one is compared to a gamma distribution with a shape factor of one and a mean of one.

Special cases of the gamma distribution include:

The gamma distribution is usually generalized by adding a scale parameter, thus, if z has the basic gamma distribution with shape parameter k, then for b> 0, x = bz has the gamma distribution with shape parameter k and scale parameter b, the reciprocal of the shape parameter is known as the rate parameter, particularly in the context of the Poisson process. The gamma distribution with parameters k = 1 and b is called the exponential distribution with scale parameter b (or rate parameter α = 1/b). More generally, when the shape parameter k is a positive integer, the gamma distribution is known as the Erlang distribution. The exponential distribution governs the time between arrivals in the Poisson model, while the Erlang distribution governs the actual arrival times. In ecology, Dennis and Patil (1984) used stochastic differential equations to arrive at a withed gamma distribution as the stationary probability density function (PDF) for a stochastic population model with predation effects.

Weibull can be transformed through change of variables techniques, to the standard gamma distribution. Such a transformation may be advantageous for simulation studies. For example, Gove (2000) used the Standard gamma to draw probability - weighted Samples to simulate the HPS tally distribution.

2.5.2 Exponential

When the shape parameter is set to one, and the scale parameter to the mean interval between events, the gamma distribution simplifies to the exponential. Oseni and Femi (2014) worked on fitting the statistical distribution for daily rainfall in lbadan, based on chi-square and Kolmogorov- Smirnov goodness of fit test and their results showed that exponential distribution is the best model followed by normal and poisson model that have the same estimated rainfall amount for describing the daily rainfall in lbadan metropolis.

2.5.3 Chi – Square

A Chi – squared distribution is a gamma distribution in which the shape parameter set to the degree of freedom divided by two and the scale parameter set two.

2.5.4 Erlang

The Erlang distribution is used to model the total interval associated with multiple Poisson events. The shape parameter represents the number of the events and the scale parameters, the average interval between events.

2.5.5 Application of Gamma Distribution Function

The application of gamma distribution function can be broadly put under two headings;

Applications based on intervals between events which are derived from the sum of one or more exponentially distributed variables. In this form, examples of its use include queuing models, the flow of its through manufacturing and distribution process and the load on web servers and the many and varied forms of telecom exchange.

Due to its moderately Skewed profile, it can be used as a model in a range of disciplines, including climatology where it is a workable model for rainfall and financial services where it has been used for modelling insurance claims and the size of loan defaults and as such has been used in probability of run and value at risk calculations.

A gamma distribution is also a general type of Statistical distribution that is related to the beta distribution and arises naturally in process for which the waiting times between Poisson distributed events are relevant. Gamma distributions have two free parameters, labelled α and θ.

Consider the distribution function D(x) of waiting times until the h[th] Poisson event given a Poisson distribution with a rate of change λ,

$D(x) = P(X \leq x)$………...equation (16)

$= 1 - P(X < x)$………...equation (17)

$$= 1 - \sum_{k=0}^{h-1} \frac{(\lambda x)^k e^{-\lambda x}}{k!}$$ ……..equation (18)

$$= 1 - e^{\lambda x} \sum_{k=0}^{h-1} \frac{(\lambda x)^k}{k!}$$ ……..equation (19)

$$= 1 - \frac{\alpha(h, x\lambda)}{\alpha(h)}$$ ……..equation (20)

For x E (0,∞), where α(x) is a complete gamma function, and Γ (α, x) an incomplete function with an integer, this distribution is a special case known as the Erlang distribution.

The corresponding probability function P(x) of waiting times until the n[th] Poisson event is then obtained by differentiating D(x),

P(x) = D(x):

$$= \lambda e^{-\lambda x} \sum_{k=0}^{h-1} \frac{(\lambda x)^k}{k!} - e^{\lambda x} \sum_{k=0}^{h-1} \frac{k(\lambda x)^{k-1} \lambda}{k!}$$ ….................................….equation (21)

$$= \lambda e^{-\lambda x} + \lambda e^{-\lambda x} \sum_{k=1}^{h-1} \frac{(\lambda x)^k}{k!} - e^{-\lambda x} \sum_{k=1}^{h-1} \frac{k(\lambda x)^{k-1} \lambda}{k!}$$ ………...................equation (22)

$$= \lambda e^{-\lambda x} - \lambda e^{-\lambda x} \sum_{k=1}^{h-1} \left[\frac{k(\lambda x)^{k-1}}{k!} - \frac{(\lambda x)^k}{k!} \right]$$ …..............................….equation (23)

$$= \lambda e^{-\lambda x} \left\{ 1 - \sum_{k=1}^{h-1} \left[\frac{(\lambda x)^{k-1}}{(k-1)!} - \frac{(\lambda x)^k}{k!} \right] \right\}$$……..................................equation (24)

$$= \lambda e^{-\lambda x} \left\{ 1 - \left[1 - \frac{(\lambda x)^{h-1}}{(h-1)!} \right] \right\}$$……...equation (25)

$$= \frac{\lambda(\lambda x)^{h-1}}{(h-1)!} e^{-\lambda x}$$ ……..equation (26)

Now let α = h (not necessarily an integer) and define $\theta = 1/\lambda$ to be the time between changes. Then the above equation can be written as

$$P(x) = \frac{x^{a-1} e^{-x/\Theta}}{\Gamma(\alpha)\,\Theta^{\alpha}} \text{..equation (27)}$$

For x E $(0,\infty)$. This is the probability Function for the gamma distribution and the corresponding distribution function.

$$D(x) = P(\alpha, x/\theta), \text{...equation (28)}$$

It is implemented mathematically as the function Gamma Distribution (alpha, theta).

The characteristics function describing the distribution is:

$$\phi(t) = fx\left\{\frac{x^{-x/\theta} x^{\alpha-1}}{\Gamma(\alpha)\,\theta^{\alpha}} \;\frac{1}{2}\left\{(1+\mathrm{Sgn}x)\right\}\right\}(t)\text{...........................equation (29)}$$

$$=1 - it\theta)^{\alpha}\text{...equation (30)}$$

Where fx (f) (t) is the Fourier transform with parameters a = b = 1, and the moment – generating function is

$$M(t) = \int_0^{\infty} \frac{e^{rx} x^{\alpha-1} e^{-x/\theta} dx}{\Gamma(a)\theta^{\alpha}} \text{..equation (31)}$$

$$= \int_0^{\infty} \frac{x^{\alpha-1} e^{-(1-\theta t)x/\theta} dx}{\Gamma(a)\theta^{\alpha}}$$

Giving moment about 0 of

$$\mu_{\Gamma}^{1} = \frac{\theta r(\alpha+\Gamma)}{\Gamma(\alpha)} \text{.. equation (32)}$$

The standard form of the gamma distribution is given by letting y = x/θ, so dy = dx/ θ and

$$P(y)\,dy = \frac{x^{\alpha-1} e^{-x/\theta}}{\Gamma(x)\theta^{\alpha}} dx \text{...equation (33)}$$

$$\frac{(\theta y)^{\alpha-1} e^{-y}}{\Gamma(\alpha)\theta^{a}} (\theta dy)\text{...equation (34)}$$

$$\frac{y^{a-1}e^{-y}}{\Gamma(\alpha)}dy \text{ ......equation (35)}$$

So the moments about 0 are:

$$\text{Vr} = \frac{1}{\Gamma(a)}\int_0^{\infty} e^{-x}x^{a-1+r}dx \text{ ......equation (36)}$$

$$= \frac{\Gamma(a+r)}{\Gamma(a)} \text{ ......equation (37)}$$

= (α) Γ Papoulis, 1984.

2.5.6 Characteristics of the Generalized Gamma distribution

The generalized gamma distribution includes other distributions as special cases based on the value of the parameters.

1. The Weibull distribution is a special case when

   λ= 1 and β =1/σ

   £ =1n (μ)

   In this case, the generalized distribution has the same behaviour as the weibull for σ>1, σ =1 and σ <1 (β<1, β=1 and β >1respectively).

i. The exponential distribution is a special case when λ = 1 and σ =1

ii. The Lognormal distribution is a special case when λ = 0

2. The gamma distribution is a special case when λ=σ

By allowing λ to take negative values, the generalized gamma distribution can be future extended to include additional distributions as special cases. The gamma is a skewed (nonsymmetric) distribution, most of the area under the density function is located near the origin, and the density function drops gradually. Some of the specific characteristics of the gamma distribution function are as follows:

1. For α > 1:

i. As t → 0, f (t) → 0

ii. f (t) increases from 0 to the mode value and decreases thereafter.

iii. .If α ≤ 2 then pdf has one inflection

iv. If α > 2 then pdf has two inflections.

2. For α = 1:

i.Gamma becomes the exponential distribution

ii.As $t \rightarrow 0, f(t) = \frac{1}{\alpha}$

iii. As $t \to \infty$, $f(t) \to 0$

iv. The pdf decreases monotonically and is convex.

2. For $0 < \alpha < 1$:

i. As $t \to 0$, $f(t) \to \infty$.

ii. As $t \to \infty$, $f(t) \to 0$. Alternatively, the gamma distribution can be parameterized in terms of a shape parameter $\alpha = k$ and an inverse scale parameter $\beta = 1/\theta$, called a rate parameter.

$$g(x;\alpha,\beta) = \frac{\beta^{\alpha}}{\Gamma(a)} x^{a-1} e^{\beta x} \text{ for } x > 0 \text{ ....equation (38)}$$

If α is a positive integer, then $\Gamma(\alpha) = (\alpha - 1)!$

Both parameterizations are common because either can be more convenient depending on the situation.

There are two methods used in parameter estimation namely: maximum likelihood estimation and moment generating function.

2.5.7 Methods of estimating parameters

Two methods for estimating parameters include Maximum Likelihood Estimation and Moment Generating Function

2.5.7.1 Maximum Likelihood Estimation

Maximum likelihood estimation is preferred method parameter estimation statistics and is an indispensable tool for much statistical modelling technique. The goal of modelling is to deduce the form of the underlying process by testing the viability of such models. Once a model is specified with its parameters, and data have been collected, one is in a position to evaluate its goodness of fit, that is, how well it fits the observed data. Goodness of fit is assessed by finding parameter values of a model that best fit the data, a procedure called parameter estimation. Maximum likelihood estimation is a standard approach to parameter estimation and inference in statistics. It has many optimal properties in estimation. Sufficiency (complete information about parameter of interest contained in its MLE estimator); consistency (true parameter value that generated the data samples); efficiency (Lowest possible variance of parameter estimates achieved asymptotically); and parameterization invariance (same MLE solution obtained independent of the parameterizations used.

The idea behind maximum likelihood parameter estimation is to determine the parameters that maximize the probability (likelihood) of the sample data. From a statistical point of view, the method of maximum likelihood is considered to be more robust (with some exceptions) and yield estimators with good statistical properties. In other words, MLE methods are versatile and apply to most models and to different types of data. In addition, they provide efficient methods for quantifying uncertainty through confidence bounds. Although the methodology for maximum likelihood estimation is simple, the implementation is mathematically intense. Using today's computer power, however, mathematical complexity is not big obstacle. Maximum likelihood estimation represents the backbone of statistical estimation (Usher and McClelland, 2001).

Advantages of Maximum Likelihood Estimation

1. It is the basis for deriving estimators or estimates of model parameter

2. Estimates of the precision (or repeatability). This is usually the conditional (on the model) sampling variance.

3. Profile likelihood intervals (asymmetric confidence interval)

4. A basis for testing hypotheses

(i) Tests between nested models (so-called likelihood ratio tests)

(ii) Goodness of fit tests for a given model.

5. Properties of maximum likelihood estimators

For "Large" samples ("asymptotically"), MLEs are optimal

(i) Maximum likelihood estimators are asymptotically normally distributed.

(ii) MLEs are asymptotically "minimum variance"

(iii) MLEs are asymptotically unbiased.

2.5.7.2 *Moment Generating Function*

If x ~ Ga (α,β) as defined in (39), the moment generating function can be derived as follows:

$$\mathrm{M_x}(t) = \mathrm{E}\left(\mathrm{e}^{tx}\right) = \int_0^{\infty} e^{tx} f(x)dx$$

$$= \int_0^{x} \frac{e^{tx} e^{-\frac{x}{\beta}} x^{\alpha-1} dx}{\beta^{\alpha}\Gamma\alpha}$$

Let $y = x\left(\frac{1}{\beta} - t\right)$

$$x \frac{y}{\left(\frac{1}{\beta} - t\right)} \quad \frac{dy}{dx} = \frac{1}{\beta} - t$$

$$dx = \frac{dy}{\left(\frac{1}{\beta} - t\right)}$$

$$= \frac{1}{\beta^{\alpha}\Gamma\alpha}\int_0^{\infty} e^{-y}\left[\frac{y}{\left(\frac{1}{\beta} - t\right)}\right]^{\alpha-1} \frac{dy}{\frac{1}{\beta} - t}$$

$$= \frac{1}{\beta^{\alpha}\Gamma\alpha\left(\frac{1}{\beta} - t\right)^{\alpha}}\int_0^{\infty} e^{-y} y^{\alpha-1} dy$$

Recall that $\Gamma(\alpha) = \int_0^{x} e^{-y} y^{\alpha-1} dy$

$$= \frac{\Gamma(\alpha)}{\beta^{\alpha}\Gamma\alpha}\left(\frac{1}{\beta - t}\right)^{\alpha}$$

$$M_x(t) = \frac{1}{(1-\beta t)^{\alpha}} = (1-\beta t)^{-\alpha} \quad \text{... (40)}$$

The first four moments about the origin can be obtained in order to find the mean, variance, skewness and kurtosis. These include:

$$M_x^{I}(t) = \alpha\beta(1-\beta t)^{-\alpha-1}$$

$$M_x^{II}(t) = \alpha\beta(-\alpha-1)(-\beta)(1-\beta t)^{-\alpha-2}$$

$$= \alpha\beta(\alpha\beta + \beta)\,(1 - \beta t)^{-\alpha-2}$$

$$M_x^{III}(t) = \alpha\beta(\alpha\beta + \beta)\,(-\alpha - 2)\,(-\beta)\,(1 - \beta t)^{-\alpha-3}$$

$$M_x^{IV}(t) = \alpha\beta(\alpha\beta + \beta)\ (-\alpha - 2)\,(-\beta)\,(-\alpha - 3)\,(-\beta)\,(1 - \beta t)^{-\alpha-4}$$

$$E(x) = M_x^{I}(0) = \alpha\beta$$

$$E(x^2) = M_x^{II}(0) = \alpha\beta(\alpha\beta + \beta)$$

$$E(x^3) = M_x^{III}(0) = \alpha\beta(\alpha\beta + \beta)(\alpha\beta + 2\beta)$$

$$E(x^4) = \alpha\beta(\alpha\beta + \beta)(\alpha\beta + 2\beta)(\alpha\beta + 3\beta)$$

The mean is $\alpha\beta$ and the variance, $v(x) = E(x^2) - [E(x)]^2$

$$= \alpha\beta(\alpha\beta+\beta) - (\alpha\beta)^2$$

$$= \alpha\beta^2$$

2.5.7.3 Moment Estimates of the Parameters of Gamma Distribution

Earlier, the mean and variance of the distribution have been obtained as $E(x) = \alpha\beta$ and $V(x) = \alpha\beta^2$,

In this section, an attempt is made to obtain the moment estimate of α and β, by this, we proceed as follow:

$E(x) = \bar{x} \quad \alpha\beta$………………………………………………………………… (41)

$V(x) = S^2 = \alpha\beta^2$………………………………………………………………… (42)

Solving these equations simultaneously we have

$$\hat{\beta} = \frac{S^2}{\bar{x}} \text{ and } \hat{\alpha} = \frac{\bar{x}}{\frac{S^2}{\bar{x}}} = \frac{\bar{x}^2}{S^2}$$

2.5.8 Java Programming

Java programming language is a high level language which requires translation before execution. It is defined by the Java language specification (JLs) and class files are defined by the Java virtual machine specification (JVMs). The Java code editor is the platform where the program codes are written and are debugged. The Java compiler reads source files written in the Java programming language, and compiles them into class files. The computer does not understand the code because they are written in English like statement, so the compiler translates the English like statement into a language that the computer understands. The language, the computer understand is 0 and 1 (bits or machine language).

Java uses a combination of compilation and interpretation. When Java source code file (the file that contains the Java instructions and is saved using the Java extension), it needs to be translated before a computer can understand the instructions, so the Java file is compiled. However, unlike other compiled languages, the Java compiler does not produce machine code designed specifically for a particular type of computer. Instead, it produces a new file containing bytecode, and this file has the class extension. Bytecode is like an idealized form of machine language, and the really special thing about byte code is that it is not machine dependent. Inother word, the bytecode produced by the Java compiler is not designed so that only one type of computer can read it; any computer (that has the Java interpreter installed) can read and understand bytecode.

The Java interpreter is sometimes referred to as the "Java virtual machine" (Java VM for short) and some books even refer to it as the "Java run-time system". The interpreter on the computer takes the Java bytecode in the class file, turns it into machine code which the computer can understand and then executes (or "runs") the code. The advantage of compilation and interpretation is that once Java file has been compiled, any computer with Java VM can interpret and run that file. So the code is a lot more portable.

Design approached in Java programming. There are two approaches:

1. **Top Chain Approach:**

This is also known as modularization. Which means breaking down major problems/tasks to sub-problems/tasks and implementing the sub-tasks using programming modules?

2. **Object- Oriented Programming:**

Using this approach, the entire software is seen as an object. The Software is created as object comprising of various objects and each object is protected from one another but there may be messaging among objects.

The interpreter interprets the program line by line so that if one line is having problem, it corrects it before moving to next line while the compiler gives compiled error after writing the program.

Java is good because it uses both compiler and interpreter.

2.5.9 Application of gamma distribution function in Java Program

The application of gamma distribution function was created using Java programming language. The reasons for Java selection according to James and Michael (1982) are summarized below

1. **Portability:** Java programs can be written on a platform and executed on other plat form. Platform here denotes operating system environment. For instance,

Java programs can be written in windows environment and be used on Linux operating system environment. Java has the concept of write anywhere and use anywhere. Java Programs can be ported to any machine regardless of the operating system and hardware architecture.

2. **Object -oriented:** Java is an object -oriented programming language. In this regard, programming is simplified by developing codes as object that can be reused as much time as possible. It also advocates modularization, in which programming can be written in modules. It is also powerful because it facilitates the definition of interfaces and makes it possible to provide reusable "software ICs".

3. **Efficiency:** Java programming language is very effective in solving mathematical problems because Java came with a lot of mathematical methods.

4. **Simple:** Java is used to build a system that could be programmed easily without a lot of esoteric training and which leveraged today's standard practice.

5. **Network- savvy:** Java has an extensive library of routines for coping easily with TCP/IP protocols like HTTP and FTP. This makes creating network connections much easier than in C or C++.

6. **Robust:** Java is intended for writing programs that must be reliable in a variety of ways. Java puts a lot of emphasis on early checking for possible problems, later dynamic (runtime) checking, and eliminating situations that are error prone.

7. **General-purpose:** Java can be used to develop any form of applications; ranging from mobile phone applications to the ones that run on servers. In addition, Java has capabilities for developing scientific, business and military applications, therefore is a language suitable for research.

8. **Rich Application Programming Interfaces (APIS):** Java has in-built APIS for solving mathematical and scientific problems without re-writing them.

2.6 *Tectona grandis* (TEAK)

2.6.1 ORIGIN OF *Tectona grandis* (TEAK)

Teak is the common name for the tropical hardwood tree species for *Tectona grandis* and its wood products. *Tectona grandis* is a native to south and south East Asia, mainly lndia, Indonesia, Malaysia, and Myanmar accounts for nearly one third of the world's total teak produced. The word teak comes from the Malayalam (in the Malabar region) word theka or tekka (Chambers, 1875).

2.6.2 Botany of *Tectona grandis*

Teak belongs to the Kingdom plantea, class magniopsida, order Lamiales, family verbenaceae, genus *Tectona* and species *Tectona grandis*, *Tectona* has three species namely grandis, hamitonians and Philippinesis (Bhat, 1998 and Herbison, 2007). The generic name comes from "tekka", the Malabar name from *T.grandis*. The specific name grandis is a Latin word which means large.

According to Pendey, (1998), teak is a large deciduous tree reaching up to 40m (131ft) tall with gray to greyish brown branchlets in height in favourable conditions. Leaves are ovate-elliptic to ovate, 15-45cm (5.9-17.7 ln) long by 8-23cm (3.3-9.1ln) wide, and are held on robust petioles that are 2-4cm (0.81-6ln) long. Leaf margins are entire. Fragrant white flowers are borne on 25-40cm (10-16 ln) long and 30cm (12 ln) wide panicles from June to August. The corolla tube is 2.5-3mm long with 2mm wide obtuse lobes. *T. grandis* sets fruits from September to December, fruits are globose and 1.2-1.8cm in diameter. Flowers are weakly protandrous in that the anthers precede the stigma maturity and the pollen is shed within a few hours of the flower opening (Bryndum and Hedegart, 1969).The flowers are primarily entomophilous (wind-pollinated). A 1996 study found that in its native range in Thailand, the major pollinators were species in the ceratina genus of bees (Bryndum and Hedegart, 1969). The crown opens with many small branches. The bole mostly buttressed and may be fluted up to 15cm long below the first branches. Pendey, (1998) further contributed by saying that the bark is brown, distinctly fibrous with shallow longitudinal fissures. The root system is superficial often no deeper than 50cm but roots may extend laterally up to 15cm from stem. Goh and Galiana (2000) say that the very large leaves are shed for 3-4Ib months during the latter half of the dry season leaving the branchless bare. The leaves are shiny above, hairy below, view network clear about 30x20cm but young leaves up to 1m long. Flowers are small about 8mm across, mauve to white in color and arranged in large flowering heads about 45cm long, found on the topmost branches in the unshaded part of the crown (Bolnal and monteuuis, 1997). The fruit is a drupe with 4(four) chambers, round, hard and woody, enclosed in an inflated –like shell, pale green at first then brown at maturity (Bekker *et al.*, 2004). Each fruit may contain 0-4 seeds. There are 1000-3500 fruits/kg.

2.6.3. Natural Habitat

T. grandis will survive and grow under a wide range of climatic and edaphic conditions. It grows best in a warm, moist, tropical climate with a significant difference between dry and wet seasons (Albrecht,1993).*T. grandis* is able to persist and dominate and naturally regenerate towards the climax phase of succession in most part of it natural range. It occurs naturally in various type of tropical deciduous forest (Albrecht, 1993).

In seasonal climate, *T.grandis* is deciduous, while trees grown in non- seasonal climate are semi-deciduous. It is often a dominate member of a mixed deciduous forest, where its main associates are *xylia* spp, *Afzelia* spp.*Tectona grandis* is found in a variety of habitats and climatic conditions from arid areas with only 500mm of rain per year to very moist forest with up to 5000mm of rain per year. Typically, though, the annual rainfall in areas where teak grows averages 1250-1650mm with a 3-5 month dry season (Kaosa-ard, 1981).

2.6.4 Propagation methods

Natural regeneration is particularly abundant in forests exposed to fires and often occurs in patches. Harvest can take place after natural abscission. In such a case, the stage of ripeness is obvious, but the seed collector is faced with the task of reaching the seed before predators remove it and also of minimizing the effort expended on harvesting poor quality or in viable seeds (Mbuya, 1994).

The best quality fruits are usually the last ones shed. Seeds collected from the forest floor are generally used to establish plantation. lt is recommended that seeds be collected from trees over 20 years old. Seed is often collected from selected stands. The general practice is to use fruits stored for a year after soaking them in water for 24 hours (Mbuya, 1994). A fruit that has lain dormant in the ground for 30 to 40 days has been known to germinate abundantly. Soaking the fruits for 48 hours in running water before sowing is the best treatment for hastening germination. Although, teaks demand strong light, it prefers slight shading during the seedling stage. Direct sowing into the field at the beginning of the rainy season is also practiced. Both grafting and budding method showed better results than branch cutting method. Tissue culture has been preferred for *T. grandis*; it is possible to produce 500 plants from a single bud of a mature tree or 3000 plants from a seedling in a year. Tissue culture plants possess better growth than seed-grown plants (Mbuya, 1994).

2.6.5 Tree management

For plantations, stumps are planted at a spacing of 2x2m. As the tree is deciduous, raising pure plantation is discouraged, rather, it is recommended to raise 80% of mixed indigenous species and the remaining 20% *T. grandis* (Hong, 1996). It is important to protect the forest from fire, each year's planting should be protected by a fire line 10m wide, which is cleared of all vegetation plantation and should also be protected from grazing animals, as the soil is often susceptible to erosion. Coppicing and weeding should also be practiced (Hong, 1996). *T. grandis* is a very strong light demander, and the optimum for its growth lies at 75-100% of full sunlight. Initial growth of the tree is rapid but after 15 to 20 years, growth slowdown. Thinning takes place 4 times at 5, 10, 18 and 28 years interval after planting (Hong, 1996).

2.6.6 Economic importance of teak

Teak has the following functional uses.

(a) Fuel: Teak wood has been used in the manufacture of charcoal and as fuel wood, but nowadays, it is usually considered too valuable for this purpose rather, pruning remnant and other rejects should be used instead.

(b) Timber: A rare combination of superior physical and mechanical properties makes *T. grandis* a paragon of timber, and there is likelihood of it being eclipsed by any other (Wood, 1992). The wood is a medium weight timber that is rather soft and has a characteristics appearance. The wood is excellent timber for bridge building and other construction in contact with water such as docks and flood gates in fresh water. In house building, teakwood is particularly suitable for interior and exterior joinery (windows, solid panel doors and framing) and is used for floors exposed to light to moderate pedestrian traffic (Wood, 1992). It is also used for cutting boards, indoor flooring and as a veneer for indoor furnishings. Teak, though easily worked upon, can cause severe blunting on edged tools because of the presence of silica in the wood. Teak's natural oils make it useful in exposed locations and make the timber termite and pest resistant. Teak is durable even when not treated with oil or varnish. Teakwood is suitable for the manufacture of decorative plywood. For export market teak wood is recommended, for ship decking and other constructional work in boat building (Wood, 1992).

Teak as a plant has gained recognition from centuries because of its many valuable qualities (Bhat, 1998). Teak is a wood which does not shrink, crack, offers resistance to termites, hard and durable. It is used in furniture making, wooden sculptures, door and coffins are considered virtually imperishable (Pendey, 1998).

Teak is preferred for construction of ship, building boats, bridges, railway sleepers, used as electricity poles and telephone poles because of its extreme resistance to decay and corrosive activity of water both on land and sea (Etukodo, 2000). Sasi, (2008) contributed by saying that the sapwood and heartwood which is white and green respectively emits fragrance. The leaves are used traditionally to cure illness like malaria, fever and tuberculosis. The natural oil extracted from young shoots is used to cure scabies, and the flowers are used for urinary complaints (Herbison, 2007). The leaves, young shoots and bark produces dye which gives colour to textile and colour to some food. To get this dye a mordant is needed. The leaves are also used for packing some local food products in the market (Etukodo, 2000).

The literative rewiew shows that several work has been done using various exponential distributions in growth and yield studies but Java program has not been applied for growth and yield prediction. It is clear that no single model is applicable and best best representation of reality. Hence there is need to apply the Java program using gamma distribution function algorithm to see it’s performance in growth and yield prediction.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 THE STUDY AREA

3.1.1 Location

The area is Akinyele Local Government Area. It is located approximately 7^0 23’30”N and $7^0$49’30”N as well as 3^0 54'30”E and $3^0$59’30”E. It is one of the eleven local governments that make up lbadan Metropolis. It headquarters are at Moniya. The local government was created in 1976 and it shares boundaries with Afijio Local Government to the north, Lagelu Local Government Area to the South. It occupies a land area of 464,892 square kilometres with a population density of 516 persons per square kilometre. Using 3.2% growth rate from 2006 census figures, the 2010 estimated population for the Local Government is 239,745.

3.1.2 Topography

The terrain is undulating in a West-East direction with well-drained soil; rock out crops exists at several locations. The Eastern slope is steeper than the Western side. The present rock is a basement complex of Precambrian era.

3.1.3 Geology and Soil

The soil is generally sandy loam, overlying clay with large stones and gravel in several places. Soil texture and depth are however poor generally.The soil in the upper layer is greyish brown with abundant ferrous concretions; the soil is generally shallow and well drained.

3.1.4 Climate

The mean annual rainfall is about 1220mm and the mean monthly temperature is 29.44^0C. There are two main seasons in the year consisting of a dry-season from October to March and rainy-season from April to September. The rainfall distribution shows two typical peaks in July and September. Humidity is relatively low during the dry months of the year. There are occasional strong winds during the onset of the rainy season in April-May. The two typical peaks of the rainfall distribution are depicted in table 3.1 below.

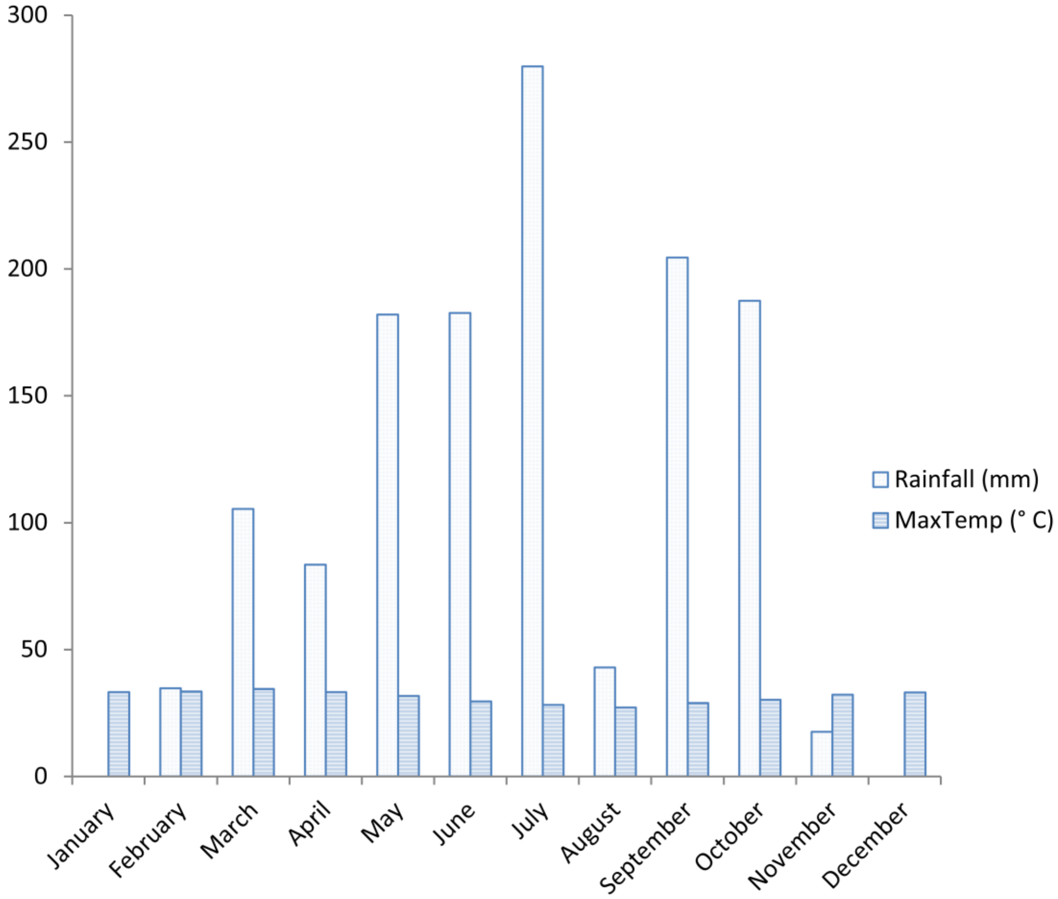

Figure 3.1. Rainful and temperature distribution of the study area

3.1.5 History of the plantation at second gate

The plantation was established in 1951 through 1953 for teaching and research purposes and to supply fuel wood and fencing poles to the University farm. The initial area of the plantation was 32.6ha. The plantation now occupies an area of 23hectares predominately of *Tectona grandis* Linn F. with sparse planting of *Cassia siasea* lam. The plantation consists of three compartment namely 1951, 1952 and 1953 compartments. Almost the whole of 1951 compartment and part of 1952 compartment have been deforested for other uses such as construction of the University press, the "5 Star Hotel and Power house".

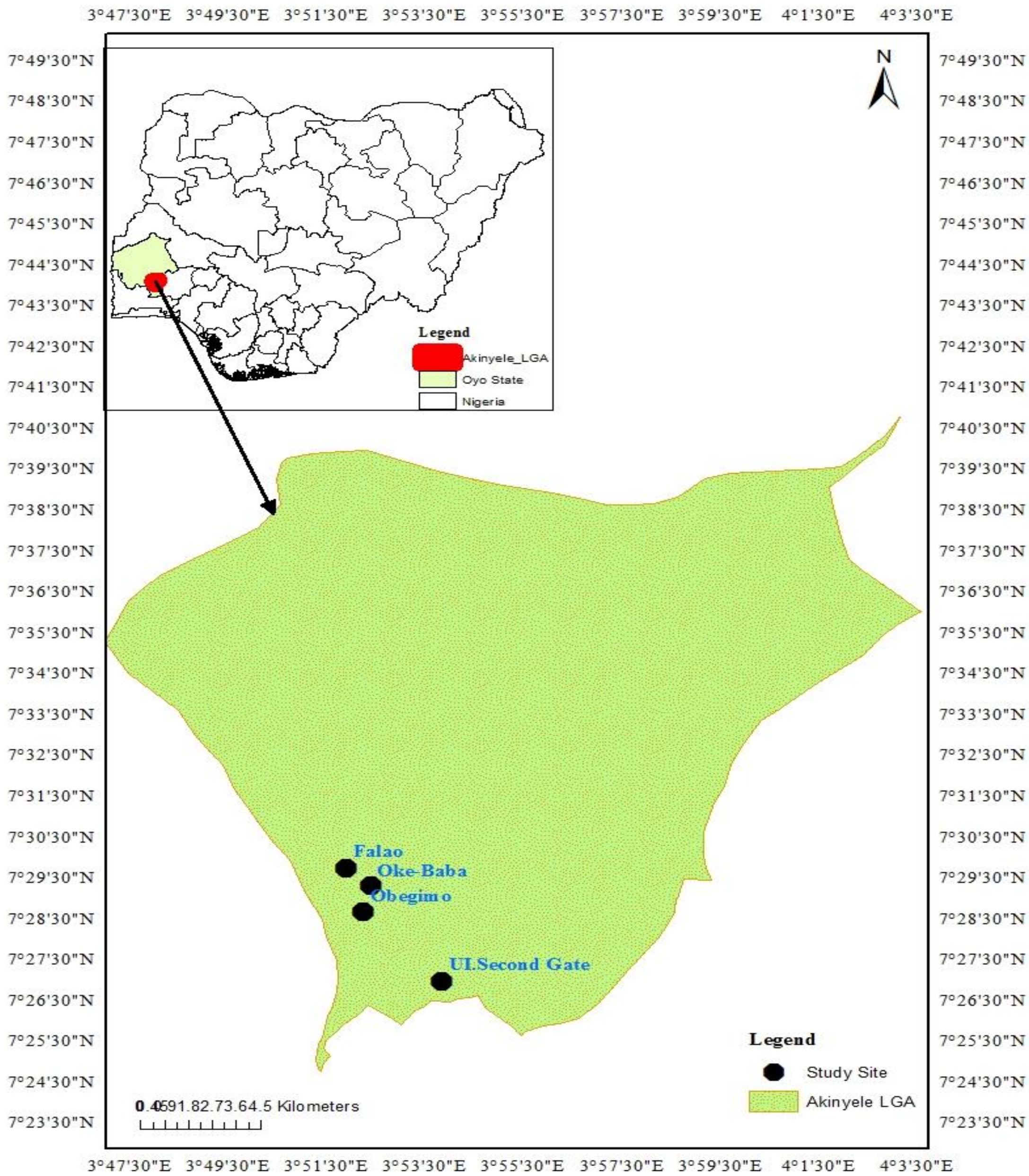

Figure 3.2. Map of Akinyele LGA Oyo state showing the study area

Figure 3.2 is the map of Akinyele local government area showing the study area.The longitude and latitude are also indicated in the map.

3.2 SAMPLING MATERIALS

The equipment/materials used for the collection of data include:

1. Prismatic compass
2. 50m distance tapes
3. Cutlass
4. Ranging poles
5. Spiegel relaskop
6. Diameter girth tape

3.3 DATA COLLECTION

3.3.1 Site Selection Procedure

Studies like Greaves and Hughes (1974) and Akindele (1990) have shown that the complete forest assessment of a country or region is seldom necessary or carried out.

According to them, pointers to this fact are:

a. Certain areas may be under a land use that precludes tree planting.

b. Some others may be unsuitable for forestation schemes to specific areas.

As a result, forest growth and yield assessments are usually restricted to existing stands. This study was therefore carried out in the Teak plantations where we have existing stands of *Tectona grandis* in the study area.

A reconnaissance survey of the Teak plantations in Akinyele Local Government Area was carried out. Visual assessment of the stands was made to determine their suitability for subsequent sampling and their present condition. The surveys showed that very little amount of silvicultural treatment has been done in the Teak stands. The planting density and survival of the teak stands were considered to be sufficiently uniform. The uniformity observes signifies that growth differences could be primarily attributed to site and age rather than crop treatment. Therefore, the stands (i.e. 1952, 1989, 1998 and 2000) were selected for this study. The stands selected are shown in the table below.

Table 3.1. *Tectona grandis* plantations selected for study in Akinyele Local Government, Oyo State

Year of planting	Location	Hectarage (Ha)
1952	U.I Second gate	2.5
1989	Falao	2.5
1998	Obegimo/Balogun	8.1
2000	Baba agba	4.1

Table 3.2. Distribution of Sample plots in the study area according to plantation ages

Plantation age (Years)	Plantation Size (Ha)	Number of Sample plots	Location
59	2.5	8	U.I Second gate
22	2.5	8	Falao
13	8.1	8	Obegimo/Balogun
11	4.1	7	Baba agba
Total		31	

3.3.2 Sampling Procedure

In forest inventory, sampling consists of making observations on portions of a population (the forest and its characteristics). This is done to obtain estimates that are representative of the parent population. According to Husch *et al.,* (1982), the essential problem in sampling is to obtain a sample that is a representative of population. If the sample is representative of the population, then useful statements can be made about the characteristics of the population on the basis of the characteristics observed in the sample observations.

Due to the fact that suitable permanent sample plots for the present study were not available in the *Tectona grandis* plantations, data were collected from temporary sample plots as done by Omiyale and Joyce (1982) and Akindele (1990).

Generally, the kind of sampling units used the number of sampling units to be employed and the manner of selecting as well as distributing them will determine the type of sampling design. In this study, a stratified random sampling method was used. The sampling units differ in terms of age constituting the strata. 8 sample plots were randomly selected from the teak plantations of ages 59, 13 and 22 while 7 sample plots were randomly selected from the teak plantation of age 11, as done by Greaves (1973) and Akindele (1990). Husch *et al.* (1982) pointed out that the specification for sampling design could be varied to yield the desired precision at a minimum cost. The random selection of sample plots done within each stand is to ensure the validity of the usual test of significance of the final equation (Weisberg, 1985). Each sample plot was 20m x 20m (i.e. 0.04ha) in size.Right from inception of sampling in forestry, a sample size of 0.04ha has always been used.When the sample plot is small, it create opportunity for more sample plots so that random could be made. In this study sample size of 0.04 ideal. The table above (table 3. 2) shows the distribution of sample plots in the study area according to plantation ages.

3.3.3 Estimation of gamma distribution function parameters

Gamma distribution is a generalization of the exponential distribution. It is a continuous form of distribution used in modeling life time analysis. A random variable x is a distributed gamma with parameters if and only if

$$f(x) = \frac{x^{\alpha-1} \ \lambda^{-\frac{x}{\beta}}}{\Gamma(\alpha)\beta^{\alpha}}, \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (39)$$

X > 0

α > 0

β > 0

The cumulative density function, CDF of the distribution in (39) can be obtained as follows:

$$f(X) = P(X \leq x) = \int_0^x \frac{t^{\alpha-1} \ e - \frac{t}{\beta} dt}{\Gamma \alpha \beta^{\alpha}}$$

$$f(x) = \frac{1}{\Gamma \alpha \beta^{\alpha}} \int_0^x t^{\alpha-1} e^{-} \frac{t}{\beta} dt$$

Let $y = \frac{t}{\beta}$ then $\frac{dy}{dt} = \frac{1}{\beta}$

dt = βdy and t = βy

$$= \frac{1}{\Gamma \alpha \beta^{\alpha}} \int_0^x (\beta y)^{\alpha-1} e^{-y} \beta dy$$

$$= \frac{1}{\Gamma \alpha \beta^{\alpha}} \int_0^x \beta^{\alpha-1} \ y^{\alpha-1} e^{-y} \beta dy$$

$$= \frac{1}{\Gamma \alpha} \int_0^x y^{\alpha-1} e^{-y} dy$$

$$f(x) = \frac{1}{\Gamma \alpha} \gamma \left(\alpha, \frac{t}{\beta} \right) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (40)$$

The values of α and β were estimated using maximum likelihood method as shown below.

3.3.4. Maximum Likelihood Estimation of Gamma Distribution function

The method of maximum likelihood estimate was used to obtain estimate of parameters for inferential purpose. We proceed as follows:

Given the distribution as defined in (39), the likelihood function can be obtained as:

$$L(x/\alpha, \beta) = \frac{e^{-\frac{\sum_{i=1}^{n} \Sigma^{n} x}{\beta}} \prod_{i=1}^{n} x^{\alpha-1}}{\Gamma \alpha^{n} \beta^{\alpha n}} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (41)$$

Introducing log to both side, we have

$$\text{In } L(x/\alpha, \beta) = \frac{-\sum_{i=1}^{n} x}{\beta} + 1n\prod_{i=1}^{n} x^{\alpha-1} \quad - \quad n \ 1n\,\Gamma\alpha - \alpha n\,1n\beta$$

$$= -\beta^{-1} - 1\sum_{i=1}^{n} x + (\alpha - 1)\sum_{i=1}^{n} Lnx - nLn\Gamma\alpha - \alpha nLn\beta \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (42)$$

Differentiating the above with respect to α we have

$$\frac{\partial \ln L|x|\alpha, \beta)}{\partial \beta} = \sum_{i=1}^{n} \ln x \ - \ n\,\frac{\Gamma^1 \alpha}{\Gamma \alpha} - n\ln\beta = 0$$

Since $\varphi(\alpha) = \dfrac{\Gamma^1(\alpha)}{\Gamma\alpha^1}$, we have

$$\sum_{i=1}^{n} Lnx = n\varphi(\alpha) + nLn\beta \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (43)$$

Differentiating again with respect to β, we have

$$\frac{\partial \ln L|x|\alpha, \beta)}{\partial \beta} = \frac{\sum_{i=1}^{n} x}{\beta^2} - \frac{\alpha n}{\beta} = 0$$

$$\frac{\sum_{i=1}^{n} x}{\beta} = \alpha n \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (44)$$

$$\alpha\beta = \frac{\sum_{i=1}^{n} x}{n} = \bar{x}$$

The α and β values cannot be obtained in closed form. Hence it has to be solved iteratively as obtained by maximum likelihood estimation in accordance with moments estimate equations (43) and (44). This can be achieved using an algorithm for generating gamma distribution function as proposed by Cheng (1977) as shown below.

3.3.4.1 ***Algorithm of gamma distribution function*** .The algorithm proposed by Chenge (1977) was adopted in writing the Java program as shown below.

1. Generate U1 and U2 as 11D U (0,1)
2. Let V = a1n [^{U1}/(1-U1)], Y = aexp(V)

   Z = U1^2*U2 and W = b + qv = Y

3. If W + d – Θz > 0, return X = Y otherwise, Proceed to step 4

4. If W> = 1n z, return X = Y, otherwise go back to step 1

Where a = ^{1}/Sqrt (2α - 1), b = α - In 4,

q = a + ^{1}/a, = 4.5 and d = 1 + In

Here X is the gamma distribution random variate

Function gamma (N, alpha, beta)

a = ^{1}/sqrt (2*alpha-1); % initialize the constants

b = alpha + (^{1}/a);

theta = 4.5

d = 1 + log (theta);

n = 1;

While (n < = N)

U1 = r and (1); % step 1 of the algorithm

U2 = r and (1);

V = a*log (^{U1}/U - U1); % Step 2 of the algorithm

Y = alpha*exp(v);

Z = (U1^2)*U2;

W = b + q* v-y;

If (w + d – theta*z>0) % step 3

ga (n) = beta*y

a = ^{1}/sqrt (2*alpha-1);

b = alpha – log (4);

q = alpha + (^{1}/a);

Theta = 4.5

d = 1 + log (theta);

n = n + 1

else

If [w>=log (z) % step 4

ga (n) = beta*y;

n = n +1

a = ^{1}/sqrt (2*alpha-1)

b = alpha – log (4)

q = alpha + (^{1}/a);

```
theta = 4.5;
d = 1 + log (theta);
(I, h) = hist (ga, 15* beta)
e = 1/N
S = [min (ga]: [max (ga] – min (ga)/15*beta-1): max (ga)];
bar (s, e, ‘r’); % plot the histogram of the generated varieties hold on;
g = 1
for K = 1: alpha – 1
g = g*k;
end
m = 1
for j = 0:0.1):max(ga)
P(m) = [1/(g*(beta ^alpha)] *[j^(alph-1)] *exp(-j/beta]*;
% the actual distribution
M = m + 1
end
j = 0:0.1: max(ga);
c = 1: m-1
plot(j,p(c)); % plot the original curve
P1(w) = (1/(g*(beta^alpha))*(h(w)^(alpha-1)*
exp(-h(w)/beta);
er(w) = e(w) – Pi(w); % Calculate the error between the two
```

3.3.5 Java Programming Language Used

For the development of the system, Java was used as the programming language. Java is an object-oriented application programming language developed by Sun Microsystems (now Oracle). Java is a very powerful general – purpose programming language. Java capability covers scientific, mathematical, engineering and business areas. This implies that Java can be used to develop scientific applications, with its applications covering virtually all areas.

Java programs run quickly and efficiently on any machine and on any operating system platform without modification as against most general – purpose programming languages such as C++.

3.3.5.1 Program design methodology

For the development of the system, the object-oriented design methodology was applied. Object-oriented design is a software engineering approach that models a system as a group of interacting objects. Such object represents some entity of interest in the system being modelled, and is characterized by its class, its state (data elements), and its behaviour. Various models can be created to show the static structure, dynamic behaviour, and run-time deployment of these collaborating objects.

An object-oriented system is composed of objects. The behaviour of the system results from the collaboration of those objects. Collaboration between objects involves those sending messages to each other. Sending a message differs from calling a function in that when a target object receives a message, it decides on its own what function to carry out to service that message. The same message may be implemented by many different functions; the one selected depends on the state of the target object. The implementation of "message sending" varies depending on the architecture of the system being modelled, and the location of the objects being communicated with (Grady, 2007).

3.3.5.2 Rationale for selecting the Java Language

The Following are the reasons for selecting object-oriented design as the methodology over other several available ones.

1. It simplified application development process by modelling software into objects with attributes and methods.
2. It also simplifies the process of software maintenance. With this approach to software development, the software can easily be maintained.
3. It reduces software development time via inheritances.
4. Errors can quickly be detected and corrected before the final deployment.
5. The methodology offers code security where the sources code is secured.
6. It is machine independent unlike other language.
7. It can be used to create user's friendly applications.

3.3.5.3 Development platform

The Java program for gamma distribution function was developed using NetBeans IDE (Integrated Development Environment). NetBeans IDE is a Java development environment for creating Java programs. The environment integrates the Java code editor, compiler and interpreter into one environment. Also the NetBeans IDE was installed on Windows 7. This implies that NetBeans IDE can execute on UNIX base operating system such as Linux, Solaris etc. Alpha is on both side of the gamma distribution function equation and cannot be solved explicitly, it has to be solved iteratively which led to the use of algorithm (James and Michael, 1982).

3.3.6 Measurement of tree variables

The following tree variables were measured in each sample plot

i. Diameter at breast height (Dbh) overbark of all trees (cm). This was measured at a standard position of 1.3meters (m) above the ground.
ii. Diameter over bark at the base, middle and top of all the trees (cm)
iii. Total height of all trees in each plot (m)
iv. Merchantable height of all trees in each plot (m)

The diameter girth tape was used to measure dbh (overbark) and diameter at the base of all trees within each plot. The Spiegel relaskop and 50m distance tape were used for the measurement of total height, merchantable height, diameter at the middle and top of all the trees within each plot.

3.4 DATA ANALYSIS

Based on the algorithm an attempt was made to build the program. The input variables include height, basal area and volume.

3.4.1 Computation of input variables

The input variables used in building the model include height, basal area and volume.

3.4.1.1 Dominant height (Hd) per plot

This was obtained by finding the mean of the height of the four largest trees per 0.04ha plot.

$$Hd = \frac{\hat{\sum}_{i=1} hi}{n} \quad \text{.......equation (49)}$$

Hd = dominant height in meters

hi = total height of ith dominant trees (i = ….4)

n = numbers of dominant trees in each plot

3.4.1.2 Basal area and volume estimation

The basal area for each tree in each plot was estimated using the formula

$$BA = \frac{\pi D^2}{4} \text{ ....equation (47)}$$

Where BA = Basal area (m^2), D = Diameter at breast height (m), π = 3.142 (a constant). In each plot, the total basal area and volume of all the trees were computed and used to estimate the basal area and volume per hectare. This was achieved by multiplying the plot basal area and volume by 25 (being the number of 0.04ha sample plots in a hectare). In addition to this, the annual tree basal area growth and stand basal area growth as well as annual stem volume per hectare were obtained by dividing individual tree basal area and basal area per hectare by the corresponding plot age respectively.

The stem volume of each tree was estimated using the Newton's formula as presented by Husch *et al.*, (1982).

$$V = {}^{h}/6\ (Ab + 4Am + At) \text{..................................equation (48)}$$

Where:

V = Stem Volume (m^3), h = merchantable height (m), Ab, Am and At are cross sectional areas at the base, middle and top of the tree respectively (m^2).

3.4.2 Model Development

Various variables were used in the growth models. Simple, non linear and multiple linear regression models were used for the models in order to evaluate their predictive abilities.

3.4.2.1 Height-Diameter models

The following height- diameter growth models were evaluated in the course of this study:

Table 3.3. Height-diameter functions evaluated based on fitting data

S/N	Model	Source
1.	$H = 1.3+e^{a+\frac{b}{dbh+1}}$ ....equation 49	Wykoff *et al.*, (1982)
2.	$H = 1.3+a(1-e^{bdbh^{c}})$ ....equation 50	Yang *et al.*, (1978)
3.	$H = 1.3+e^{(a+\frac{b}{dbh+c})}$ ....equation 51	Ratkowsky (1990)
		Generalized height-diameter functions
4.	$H = 1.3+e^{a+\frac{b}{dbh+1}}$ ....equation 52 $a = a_1 + a_2 \times BAL$ $b = a_3 + a_4 \times BAL + a_5 \times N + a_6 \times BA$	Temesgen and Gadow (2004)
5.	$H = 1.3+a(1-e^{bdbh^{c}})$ $a = a_1 + a_2 \times BAL + a_3 \times N + a_4 \times BA$ $b = a_5 + a_6 \times BAL$...............equation 53	Temesgen and Gadow (2004)
6.	$H = 1.3 + e^{(a+\frac{b}{dbh+c})}$............equation 54 $a = a_1 + a_2 \times BAL$ $b = a_3 + a_4 \times BAL + a_5 \times N + a_6 \times BA$	Ratkowsky (1990)
7.	$H = \left[1.3^b + \left(H_{dom}^b - 1.3^b\right)\frac{1-e^{-adbh}}{1-e^{-aD_{dom}}}\right]^{1/b}$ ....equation 55	Schnute (1981)

Where H = Height, Dbh = Diameter at breast height, BAL = Summarized basal area for all trees greater than the subject tree (m^2/ha), N = Number of trees per hectare (tree/ha), BA = Basal area, D_{dom} = Dominant diameter, H_{dom} = Dominant height,e = Naperian constant, a, a_1 ,a_2, a_3, a_4, a_5, a_6 = parameters in the equation.

3.4.2.2 Basal area and volume models

The following basal area and volume models were evaluated in the course of this study.

Table 3.4. Basal area models evaluated based on fitting data

S/N	Model
1.	$1n\ (B) = b_0 + b_1(^1/A) + b_2 1n(H_1) + b_3 1n(N) + b_4\ (^H1/A) + b_5(^N/A)$.. equation 56
2.	$1n\ (B) = 1n(b_0) + b_1(^1/A) + b_2(1nH_1) + b_3(1nN) + b_4\ (^H1/A)$ ……...equation 57
3.	$1n\ (B) = b_0 + b_1 1n(^H{}_1/A) + b_2 1n(N)$……………………………………..equation 58

Where B = Basal area, A = Ages of the different sampling unit constituting the strata, H = height of trees in meters, N = Number of trees per hectare (tree/ha), b_0, b_1, b_2, b_3, b_4, b_5 = parameters in the equation.

Table 3.5. Volume models evaluated based on fitting data

S/N	Model
1.	1n $V = C + a*d$ ………………………….............................equation 59
2.	$V = C + a*1n(d)$ ……………………………......................equation 60
3.	$V = C + a*d$……………………………............................equation 61
4.	$V = a + b*d^2*h$………………………….......................equation 62
5.	$V = a + b*d + C*d^2*h$……………………………..............equation 63

Where;

h = height of trees in meters

d = diameter at breast height (1.3m above ground)

a, b, C = Parameters in the equation

V = volume

3.4.3 Writing the Java program

The program was written using Java programming language in order to evaluate its predictive ability. The model was implemented in object-oriented manner. The source code is the file that contains the Java instructions used in writing the program. A brief description of the source code is shown below while the detail is described in the appendix.

3.4.4 Source code of Java program for gamma distribution function

```
/*
 * Gamma_DistributionView.java
 */

package gamma_distribution;
import org.jdesktop.application.Action;
import org.jdesktop.application.ResourceMap;
import org.jdesktop.application.SingleFrameApplication;
import org.jdesktop.application.FrameView;
import org.jdesktop.application.TaskMonitor;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.Timer;
import javax.swing.Icon;
import javax.swing.JDialog;
import javax.swing.JFrame;
 private void Gamma(int nval, float alpha, float beta) throws Exception{
        g=new double[nval];
        final double  theta=4.5;
        int n=0;
        double u1,u2,v,y,z,w;
        double a=1/Math.sqrt(2*alpha-1);
        double b=alpha-Math.log10(4);
        double q=alpha+(1/a);
        double d=1+Math.log10(theta);
                //g=new double[nval];
        for(int i=n;i<=nval-1;i++){
```

```
            u1=Math.random();
            u2=Math.random();
            v=a*Math.log10(u1/(1-u1));
            y=alpha*Math.exp(v);
            z=Math.pow(u1, 2)*u2;
            w=(b+q)*(v-y);
            if((w+d)-(theta*z)>=0){
              g[i]=beta*y;
               a=1/Math.sqrt(2*alpha-1);
               b=alpha-Math.log10(4);
               q=alpha+(1/a);
               d=1+Math.log10(theta);
               //n++;
            }else if(w<=Math.log10(z)){
              g[i]=beta*y;
               a=1/Math.sqrt(2*alpha-1);
               b=alpha-Math.log10(4);
               q=alpha+(1/a);
               d=1+Math.log10(theta);
               //n++;
            }else{
              // g[i]=3.5;
            }
            //n++;
        }
        //for(int i=1; i<nval-1; i++){
        //      g[i]=Math.random();
        //}
        result.setText("");
        for(int i=n; i<nval; i++){
               result.append(g[i]+"\n");
        }
            //result.append(nval+"");
    }
```

3.4.5 Model application

The Java program written was run on the system for predictive purpose. The results of the Java program written was displayed in the runtime mode and the output showed the results after inputting values for α and β to the desired number of iterations.

3.4.6 Model Comparison and Selection

Model evaluation and comparison are important aspects of model building. It is imperative that some examination of a model be made at all stages of model design, fitting and implementation. Selected models were evaluated quantitatively by examining the magnitude and distribution of residuals to detect any obvious patterns and systematic discrepancies and by testing precision to determine the accuracy of model predictions (Vanclay, 1994; Soares *et al.*, 1995, Mabvurira and Miina, 2002). On the other hands, after parameter estimates were obtained, the predictive abilities of the selected growth functions were evaluated using coefficient of determination (R^2) and mean square error (MSE) criteria, the asymptotic t-Statistics of the parameters and the asymptotic 95% confidence intervals. A thorough evaluation of model involves several steps, which include two major ones often called verification and validation. In forest growth modeling, the two steps usually denote qualitative and quantitative tests of model respectively.

3.4.6.1 Model verification

Model verification involves examination of the structure and properties of a model. As a matter of fact, model verification implicitly means comparing and evaluating candidate model. Model evaluation should be convincing enough to boost user's confidence.

According to Soares *et al.*, (1995), a thorough evaluation should include the following aspects:

a. Examine the model and its components for logical consistency and biological realism (Oder Wald and Hans, 1993)
b. Ascertain the statistical properties of the model in relation to data.
c. Characterize errors in terms of magnitude (i.e. Confidence intervals) residuals and contributions by each model component to total error.

d. Test, using statistical approaches for bias and precision of the model, goodness of fit and patterns in, and distribution of residuals (Mayer and Butler, 1993)

e. Identify model components with the greatest influence on predictions. These analyses need not be sequential. All relevant aspects should, however be examined in each model component and in the assembled model. The models developed in this study were evaluated using the following statistical test.

i. The mean square Error (MSE): this is a measure of the spread of the data and therefore an indication of the precision of the predicted response. MSE is expressed as;

MSE = $^{RSS}/_{n-p}$ …………..……equation (50)

ii. The coefficient of determination (R^2): This measures the proportion of variation in the dependent that has been accounted for by the relationship to the independent variables. R^2 is expressed as

$R^2 = 1 - {}^{RSS}/_{TSS}$………..…equation (51)

The coefficient of determination is always between 0 and 1, it can be expressed in percentage by multiplying its decimal fraction by 100 where;

P = number of parameters in the model (Including b_0)

n = number of observations

RSS = residual sum of square

TSS = corrected sum of square

In addition, the significance of each regressive coefficient in the model was tested using the t-test. The various regression options of the STATISTICA version 5.1 package used in this study provided the t-value for the regression coefficient of the independent variables in each equation.

The t-value was compared with the critical value of t at α = 0.05. Where t-calculated for the regression coefficient exceeded the critical value of t, at α = 0.05 level, the independent variable was considered significant and vice –versa. Thus it was possible to drop out any of the insignificant independent variables from the models and carry out further regressions based on only the significant independent variables.

Suitable models are those with large values of R^2 and least Mean Square error values (MSE).

3.4.6.2 Model Validation

It is imperative to subject the models that were verified suitable in the proceeding section to a process of validation. This is necessary before output obtained from them can be used for decision making with confidence. Validation involves the testing and comparing of model output with what is observed in the real world. This requires that the predictions of the model be compared with real world data that are independent of the data used in the construction of the models.

Models validation requires that some data set are set aside (e.g. Akindele, 1990), or that new data are obtained for the tests. The most convincing test would use a set of data drawn from an independent population measured over a long period, but such data are rarely available. Growth modelers frequently are faced with the decision of having to partition a data set from a single population into two subsets. One is used for the model development and the other for testing the model. Where ample data exist, partitioning causes few problems. However, when data are scarce, there is a temptation to use all available data for development. This is done in an attempt to improve the model. Unfortunately, this diminishes the modeler's ability to demonstrate the quality of his model.

In forest growth models, fewer data are often used for validation (West, 1981 and Shifley, 1987 reserved a quarter of their data, Akindele, 1990 reserved one third of his data). The validation data set should contain sufficient replications to enable the natural variability to be expressed. In situations where the collection of new data is to be avoided, an alternative approach is to split the data into two sets. The first set being called the calibrating set and the second the validation set. The former is used to construct the models while the latter is used to test them (Snee, 1977, Reynolds *et al.*, 1988). According to Vanclay (1994), since growth models are used to forecast future forest conditions, one way to split data is on time, if the data cover very wide age range. In addition, it is important that the subset used for model validation should contain at least some data collected over very long periods. This could not be achieved in this study. Adesoye, (2002) used data from the oldest stand for validation set. Ureigho (2004) used 10% of the data for validation set while the rest of the data were used in calibrating the models. However in this study, 10% of data were set aside as the validation set, while the rest of the data were used in calibrating the models.

The selected equations were used to predict values for test plantations. The values were compared with the observed values (i.e. values from the validation set) and the differences were expressed as model bias. The paired t-test procedure was used to compare the predicted values with the observed values from the validation as done by Goulding (1979). For a valid model the comparison should indicate that the observed and the predicted are not significantly different at the level of significance of 0.05.

CHAPTER FOUR

4.0 RESULTS

4.1 RESULTS OF MODELS ANALYSIS

4.1.1 Summary of growth data

The summary of the growth data for *Tectona grandis* in Akinyele Local Government Area, Oyo State is shown in table 4.1 below. The ranges of the summary of the growth data indicate that *Tectona grandis* in this local government are doing well.

4.1.2 Results of α and β from maximum likelihood estimation

Maximum likelihood was used to estimate the values for α and β. The results are summarized in Tables (4.2-4.5)

Table 4.1. Summary of Growth data for *Tectona grandis* In Akinyele Local Government, Oyo State

Age (Years)	Number of Stems per Hectare (N)	Mean Diameter at Breast Height (cm)	Basal Area/Hectare m^2 /Ha	Volume/Hectare (m^3/Ha)	Volume/Stem (m^3)
57	500	32.39	1.52	11.28	0.12
22	510	20.38	1.35	0.98	0.08
13	600	18.33	0.98.	4.36.	0.02
11	605	18.05	0.82	2.82	0.07

Table 4.2. Estimates of α and β for dbh at individual tree level

	Plantation age 11				Plantation age 13				Plantation age 22				Plantation age 59			
PLOT NO.	**MEAN Dbh (cm)**	**Standard error**	**α**	**β**	**MEAN Dbh (cm)**	**Standard error**	**α**	**β**	**MEAN Dbh (cm)**	**Standard error**	**α**	**β**	**MEAN Dbh (cm)**	**Standard error**	**α**	**B**
1	17.99	1.45	1.70	1.06	21.82	1.02	4.56	0.48	20.82	1.92	11.70	0.18	32.96	1.25	4.61	0.71
2	18.26	1.02	3.52	0.52	19.51	0.75	6.64	0.29	17.76	1.12	25.20	0.07	33.45	2.14	2.26	1.36
3	17.61	1.08	2.39	0.73	15.08	1.46	0.96	0.15	24.86	2.07	14.48	0.17	31.26	1.29	4.89	0.64
4	17.11	0.09	2.75	0.62	18.85	1.33	1.80	0.10	17.75	5.27	1.13	1.56	37.60	1.66	3.63	1.03
5	18.70	0.79	3.96	0.47	18.76	1.08	2.72	0.69	21.44	5.68	1.42	1.27	30.91	1.87	2.26	1.39
6	18.15	0.68	4.97	0.36	17.22	0.94	2.74	0.63	19.46	3.15	3.82	0.51	38.76	1.88	2.25	1.51
7	18.52	1.12	2.25	0.82	19.08	0.79	5.84	0.33	18.13	2.35	5.95	0.30	38.74	1.45	3.05	1.30
8					16.34	0.58	6.61	0.25	23.07	3.00	5.91	0.39	38.72	2.50	1.70	2.28

Based on the results of table 4.2, it was observed that plantation age 13 had the lowest standard error while plantaion age 22 had the highest standard error.*Tectona grandis* distribution calculated by maximum likelihood method for plantation age 11, α coefficient assumed greater values from 1.70 to 4.97 while β coefficient assumed smaller values from 0.36 to 1.06 with a standard error which ranged from 0.68 to 1.45 For plantation age 13, α coefficient assumed greater values from 0.96 to 6.64 while β coefficient assumed smaller values from 0.10 to 1.56 with standard error which ranged from 0.58 to 1.46. For plantation age 22; α coefficient assumed greater values from 1.13 to 25.20 while β coefficient assumed smaller values from 0.07 to 1.56 with a standard error which ranged from 0.35 to 1.79. Also, for plantation age 59, α coefficient assumed greater values from 1.70 to 4.89 while β coefficients assumed smaller values from 0.64 to 2.28 with a standard error which ranged from 1.29 to 2.50 at individual tree level. The result shows that smaller values of β had smaller standard error values which imply that error is minimized with smaller β values. This is consistent with the findings of Podlaski (2008).

Table 4.3. Estimates of α and β for dbh, basal area and volume at stand level

Plant-ation Age (yrs)	Diameter α	Diameter β	Diameter Mean±SE	Basal Area α	Basal Area β	Basal Area Mean±SE	Volume α	Volume β	Volume Mean±SE
11	4.96	0.36	18.05±0.27	2.67	1.05	2.76±8.64	0.81	2.79	2.30±8.07
13	2.67	0.68	18.33±0.33	1.04	2.34	2.55±8.79	1.04	2.36	2.60±16.89
22	11.65	0.17	20.38±0.16	2.90	1.54	3.47±7.64	3.09	1.08	2.82±6.38
59	2.29	1.41	32.39±0.67	1.14	3.11	3.69±11.98	0.62	12.66	8.31±32.00

Standard Error (S.E) $=S/\sqrt{n}$

Where:

S= Standard deviation

n = Number of trees per plot

At stand level, the standard error for dbh, basal area and volume is lowest with plantation age 22 and highest with plantation age 59.

The α coefficient for dbh assumed greater values from 2.29 to 11.65 and β coefficients assumed smaller values from 0.17 to 1.41 with standard error which ranged from 0.16 to 1.67. Smaller values of β had smaller standard error which implies that error is minimized with smaller β values.

The coefficients o f α and β for basal are varies. When the α value assumed smaller values, β assumed greater value and vice versa. The α coefficient assumed values from 1.04 to 2.90 and β assumed values from 1.05 to 3.11 with standard error which ranged from 7.64 to 11.98. When α value assumed a smaller value and β greater value, the standard error was greater which implies that for error to be minimized the value of β coefficient should be smaller.

The α coefficient of volume assumed smaller values which ranged from 0.62 to 3.09 and β coefficients assumed greater values from 1.08 to 12.66 with standard error which ranged from 6.38 to 32.00. The smaller β values had smaller standard error which implies that error is minimized with smaller β value coefficients. At stand level, β had smaller values with corresponding smaller standard deviation which implies that error is minimized more at stand level than at individual tree level. The results of the table showed the difference in the standard error with plantation aged13 having the lowest and plantation aged 59 having highest standard error for diameter at breast height, basal area and volume respectively.

Table 4.4. Estimates of α and β for Basal area at individual tree level

PLOT NO.	Plantation age 11				Plantation age 13				Plantation age 22				Plantation age 59			
	Mean Basal Area(m^2)	Standard error	α	β	Mean Basal Area(m^2)	Standard error	α	β	Mean Basal Area(m^2)	Standard error	α	β	Mean Basal Area(m^2)	Standard error	α	β
1	2.88	39.70	0.56	5.01	2.98	19.56	2.32	1.28	3.43	20.43	2.81	1.21	3.08	19.44	1.67	1.84
2	2.57	40.87	0.44	5.84	2.85	48.16	0.35	8.14	3.37	26.91	0.39	2.14	3.44	36.46	0.89	3.85
3	2.60	27.67	0.80	3.23	3.27	29.98	1.08	3.01	3.08	30.76	1.11	2.76	3.00	33.98	0.65	4.61
4	2.69	19.83	1.42	1.89	2.98	15.93	2.61	1.23	3.30	14.09	4.58	0.72	4.51	39.23	0.94	4.77
5	2.49	23.03	0.83	2.98	2.62	17.90	1.95	1.34	3.71	15.09	6.07	0.61	4.27	45.81	0.72	5.89
6	2.74	16.08	2.08	1.32	1.75	26.39	0.36	4.77	3.33	20.58	2.01	1.65	3.84	24.83	1.84	2.08
7	3.13	8.86	10.44	0.30	1.96	29.09	0.45	4.31	3.65	29.70	1.52	2.41	4.26	55.15	0.54	7.84
8					2.49	14.10	2.41	1.03	3.93	17.18	4.75	0.82	3.10	20.66	1.87	2.04

Table 4.4 showed that plantation age 22 had the lowest standard error and plantation age 59 had the highest standard error. The values of α and β for basal area of *Tectona grandis* distribution was calculated using maximum likelihood method for plantation aged 11; α coefficient was found to have values within the range of 0.44 and 10.44. The β coefficient values ranged from 0.30 to 5.84 with standard error which ranged from 8.86 to 40.87. Greater values of β had larger standard error values and vice versa which implies that error value is minimized with smaller β values. For plantation year 13, α and β coefficient values varies. When α coefficient was small, the β coefficient was great and vice versa. The α coefficients assumed values from 0.35 to 2.61 and β coefficient assumed values from 1.03 to 8.14 with standard error which ranged from 14.10 to 48.16; For plantation aged 22, α coefficient assumed values from 0.39 to 6.07 and β coefficients assumed values from 0.61 to 2.76 with standard error values which ranged from 15.09 to 29.20. For plantation aged 59, α coefficient assumed smaller values from 0.54 to 1.87 and β assumed greater values from 1.84 to 7.84 with a standard error which ranged from 19.44 to 55.15.The smaller β values had smaller standard error which implies that error is minimized when the β values are smaller.

Table 4.5. Estimates of α and β for Volume at individual tree level

	Plantation age 11				Plantation age 13				Plantation age 22				Plantation age 59			
PLOT NO.	Mean Volume(m^3)	Standard error	α	β	Mean Volume(m^3)	Standard error	α	β	Mean Volume(m^3)	Standard error	α	β	Mean Volume(m^3)	Standard error	α	β
1	2.28	27.34	0.77	2.94	2.52	16.77	2.26	1.11	2.87	15.05	3.65	0.78	6.35	64.25	0.65	9.74
2	2.68	53.6	0.27	9.61	2.41	40.61	0.35	6.82	2.41	26.76	0.81	2.97	9.28	141.00	0.43	21.42
3	2.14	24.10	0.72	2.97	2.77	27.45	0.93	2.98	2.55	22.72	1.40	1.81	8.69	85.74	0.86	10.15
4	2.18	14.56	1.72	1.26	3.16	32.19	0.87	3.60	3.03	15.66	3.13	0.96	6.27	48.33	0.35	5.21
5	2.09	12.59	1.97	1.62	2.77	14.57	2.22	1.03	2.81	17.62	2.55	1.10	7.70	79.25	0.79	9.77
6	2.31	13.07	2.24	1.03	3.50	197.46	0.22	3.36	3.07	8.02	11.31	0.27	10.54	119.96	0.59	17.74
7	2.43	11.76	3.57	0.68	1.68	23.73	0.50	3.34	3.13	24.49	1.63	1.91	8.93	105.72	0.65	13.75
8					2.51	22.60	0.95	2.64	2.65	16.36	0.24	8.42	8.73	91.68	0.64	13.46

Based on table 4.5, plantation age 22 had the lowest standard error while plantation age 13 had the highest standard error. *Tectona grandis* distribution estimates of α and β for volume calculated by maximum likelihood method; for plantation age 11, α and β coefficients varies. When α assumed a smaller value, β assumed a greater value and vice versa. α assumed values from 0.27 to 3.57 and β assumed values from 0.68 to 9.61 with a standard error which ranged from 11.76 to 53.60. For plantation age 13, α assumed value from 0.22 to 2.26 and β assumed values from 1.03 to 6.82 with a standard error which ranged from 14.57 to 197.46. For plantation age 22; α coefficients assumed values from 0.24 to 11.31 and β assumed values from 0.27 to 8.42 with a standard error which ranged from 8.02 to 26.76. The smaller β values had smaller standard error which implies that error is minimized with smaller β values. For plantation age 59 α coefficient assumed smaller values from 0.35 to 0.85 and β coefficient assumed greater value from 5.21 to 21.42 with a standard error which ranged from 48.38 to 141.00. The smaller β values had smaller standard error which implies that error is minimized with smaller β value coefficients. Based on the result of table 4.4, plantation aged 13 had the highest standard error while plantation aged 22 had the lowest standard error.

The parameter estimates of α and β for gamma distribution function calculated by maximum likelihood method were accurate. The results agreed with those of Chang and Tang (1994a).

Maximum likelihood is the basis for deriving estimation for parameters of given data. The procedure yield estimates of parameters associated with a likelihood ratio test based on the two-parameter gamma distribution for investigating possible treatment-induced scale differences. It also shows rapidly converging iterative procedures for obtaining exact maximum likelihood estimates of the two parameter gamma distribution scale and shape parameters. The iterative procedures yield maximum likelihood parameter estimates having reasonable specified degree of accuracy for any given shape parameter. This finding is consistent with Dempster *et al* (1977) that worked on maximum likelihood from incomplete data via the EM algorithm.

4.1.3 Listing of Java Program for growth and yield prediction

The Java program written is shown below:

```
Private void Gamma(int nval, float alpha, float beta) throws Exception{
        g=new double[nval];
        final double  theta=4.5;
        int n=0;
        double u1,u2,v,y,z,w;
        double a=1/Math.sqrt(2*alpha-1);
        double b=alpha-Math.log10(4);
        double q=alpha+(1/a);
        double d=1+Math.log10(theta);
                //g=new double[nval];
        for(int i=n;i<=nval-1;i++){
            u1=Math.random();
            u2=Math.random();
            v=a*Math.log10(u1/(1-u1));
            y=alpha*Math.exp(v);
            z=Math.pow(u1, 2)*u2;
            w=(b+q)*(v-y);
            if((w+d)-(theta*z)>=0){
               g[i]=beta*y;
                a=1/Math.sqrt(2*alpha-1);
                b=alpha-Math.log10(4);
                q=alpha+(1/a);
                d=1+Math.log10(theta);
                //n++;
            }else if(w<=Math.log10(z)){
               g[i]=beta*y;
                a=1/Math.sqrt(2*alpha-1);
                b=alpha-Math.log10(4);
                q=alpha+(1/a);
                d=1+Math.log10(theta);
                //n++;
```

```
        }else{
          // g[i]=3.5;

        }
        //n++;
    }
    //for(int i=1; i<nval-1; i++){
    //      g[i]=Math.random();
    //}
    result.setText("");
    for(int i=n; i<nval; i++){
          result.append(g[i]+"\n");
    }
        //result.append(nval+"");

}
```

4.1.4 Gamma Distribution Function Using Java Program

The results of the gamma distribution function using Java programming language when the values for α and β were fitted into the program written showed that the gamma distribution has a good predictive ability both at individual tree and stand levels as it was able to predict the height, basal area and volume of a tree at a given diameter at breast height since there was no significant difference between the observed and predicted values obtained.

The observed and predicted values of the height, basal area and volume from the Java program written are summarized in the Tables (4.6-4.11)

Table 4.6. Observed and predicted height at individual tree level

	Plantation age 11				Plantation age 13				Plantation age 22				Plantation age 59			
PLOT NO.	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %
1	19.00	18.40	17.50	4.78	22.80	21.60	22.40	-3.70	24.80	20.40	20.70	-1.47	34.70	31.00	32.90	-6.13
2	20.40	18.00	19.80	-10.1	21.00	19.50	18.90	3.08	21.60	17.60	17.30	1.70	34.20	31.50	31.50	0.00
3	20.00	16.80	17.40	-3.69	18.80	17.60	17.30	1.70	24.00	21.10	25.30	-19.9	32.40	30.50	32.00	-4.92
4	21.40	17.50	16.10	7.49	19.80	18.40	19.20	4.35	18.00	17.00	18.10	-6.47	43.00	33.70	38.90	-15.4
5	19.80	18.60	18.20	2.15	19.60	18.20	19.00	-4.40	19.60	18.20	17.00	6.59	37.20	28.70	29.60	-3.14
6	20.00	18.80	18.40	2.12	21.50	17.80	18.60	-4.49	20.00	18.50	19.40	-4.86	40.90	33.90	31.50	7.08
7	19.90	18.60	18.20	2.15	21.60	20.00	18.20	9.00	25.50	19.00	18.20	4.21	40.60	43.80	39.30	-7.88
8					18.80	16.40	16.70	5.98	18.80	18.00	22.60	-25.5	27.10	23.50	30.30	-28.9

The results of the Java program showed no significant differences between the observed and predicted values and the observed and predicted values were similar to a significant degree. The error rate in the predicted height was lower with larger trees which imply greater precision with larger trees. Table 4.6 showed that plantation age 13 had the lowest error rate while plantation age 22 had the highest error rate.

Table 4.7. Observed and predicted height at stand level

Plantation age	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %
11	18.05	17.10	17.90	-4.67
13	18.33	18.00	18.50	-2.77
22	20.38	18.50	19.90	-7.56
59	32.39	28.30	32.10	-13.40

The observed and predicted height values were not significantly different and error rate is reduced at stand level which indicates better precision.At stand level plantation age 13 had the lowest standard error while age 59 had the highest.

Table 4.8. Observed and Predicted Basal area at individual tree level

	Plantation age 11			Plantation age 13			Plantation age 22			Plantation age 59		
PLOT NO.	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^3)	Error rate %	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %
1	2.82	3.04	-7.70	2.98	2.83	4.84	3.43	3.34	2.55	3.08	3.19	-3.50
2	2.57	2.97	-15.45	2.85	3.28	15.27	3.37	3.84	-13.76	3.44	3.43	0.26
3	2.60	2.85	-9.59	3.27	3.49	-6.70	3.08	3.79	-23.09	3.00	3.36	12.14
4	2.69	2.81	-4.16	2.98	2.83	5.03	3.30	3.11	5.88	4.51	4.29	4.99
5	2.49	2.45	1.64	2.62	2.70	-3.19	3.71	3.67	1.13	4.27	4.31	-0.88
6	2.74	2.81	-2.42	1.75	1.55	11.03	3.33	3.18	4.33	3.84	3.81	0.93
7	3.13	3.18	-1.34	1.96	2.10	-7.02	3.65	3.70	-1.37	4.26	4.10	3.73
8				2.49	2.40	3.54	3.93	3.98	-1.43	3.10	3.54	-14.35

There is no significant difference in the observed and predicted basal area values. Trees with greater basal area having lower error rate which implies better precision.Based on table 4.8, plantation age 11 had the lowest error rate while age 13 had the highest error rate.

At stand level plantation age 59 had the lowest error rate while age 22 had the highest. Since the observed and predicted values of the basal area were not significantly different, it implies that the Java program has a good predictive ability. Trees with greater basal area had smaller error rate.

Table 4.9. Observed and predicted basal area at Stand level

Plantation age	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %
11	2.76	2.79	-1.04
13	2.55	2.58	-0.98
22	3.27	3.46	0.38
59	3.69	3.69	-0.10

Table 4.10. Observed and predicted volume at individual tree level

PLOT NO.	Plantation age			Plantation age			Plantation age			Plantation age		
	Observed Volume (m^3)	**Predicted Volume (m^3)**	**Error rate %**	**Observed Volume (m^3)**	**Predicted Volume (m^3)**	**Error rate %**	**Observed Volume (m^3)**	**Predicted Volume (m^3)**	**Error rate %**	**Observed Volume (m^3)**	**Predicted Volume (m^3)**	**Error rate %**
1	2.28	2.27	0.36	2.52	2.48	1.61	2.87	2.85	0.87	6.35	6.43	1.22
2	2.68	2.67	0.42	2.41	2.40	0.47	2.41	2.32	3.70	9.25	9.14	1.15
3	2.14	2.04	4.61	2.77	2.80	-0.92	2.55	2.55	0.03	8.69	8.70	-0.12
4	2.18	2.38	-0.09	3.16	3.32	-5.02	3.03	3.02	0.29	6.27	6.36	-1.43
5	2.09	2.17	-3.96	2.27	2.35	-3.36	2.81	2.70	3.94	7.71	7.70	1.40
6	2.31	2.31	-0.12	3.50	3.71	-6.02	3.07	3.08	-0.23	10.54	12.03	-14.09
7	2.43	2.41	1.05	1.68	1.75	-4.25	3.13	3.07	2.05	8.93	8.46	5.27
8				2.51	2.38	4.85	2.65	2.51	5.37	8.93	8.79	1.57

The observed and predicted volume values were not significantly different and the values were similar to a significant degree. The error rate in the predicted values was lower with greater precision in larger trees. Trees with larger diameters have a decisive effect on, for example, the formation of forest microclimate and creation of patches. Their presence frequently determines qualification of stands into a definite stage and phase of development. Plantation age 59 had the lowest error rate while age 22 had the highest.

The observed and predicted values were accurate to a significant degree. They were not significantly different. The error rate is lower at stand level than at individual tree level which implies better precision at stand level.Plantation age 59 had the lowest error rate while age 22 had the highest.

Error rate = $\left[\frac{O-E}{O}\right] X100$

O = Observed

E = Predicted

The observed and predicted diameter distributions are shown in table 4.13 below. There were over and under estimation in some of the plots

Table 4.11. Observed and predicted volume at stand level

Plantation age	Observed Volume (m^3)	Predicted Volume (m^3)	Error rate %
11	2.76	2.75	0.36
13	2.25	2.28	-1.12
22	3.47	3.46	0.38
59	3.69	3.69	-0.10

Table 4:12. Observed and Predicted Diameter Distribution (2000-1952) Using Gamma Distribution Function

Diameter	59		22		13		11	
Class	O	P	O	P	O	P	O	P
5 < 10	0	0	0	0	4	1	3	2
10 < 15	0	0	0	0	11	5	7	5
15 < 20	0	0	1	3	48	38	45	34
20 < 25	12	22	31	18	17	23	20	31
30 < 30	51	27	54	62	3	19	2	7
35 < 35	38	61	82	5	4	1	1	2
40 < 40	27	52	0	0	0	0	0	0
45 < 45	30	10	0	0	0	0	0	0
45 < 50	8	5	0	0	0	0	0	0
50 and above	7	1	0	0	0	0	0	0

O = Observed Values

P = predicted Value

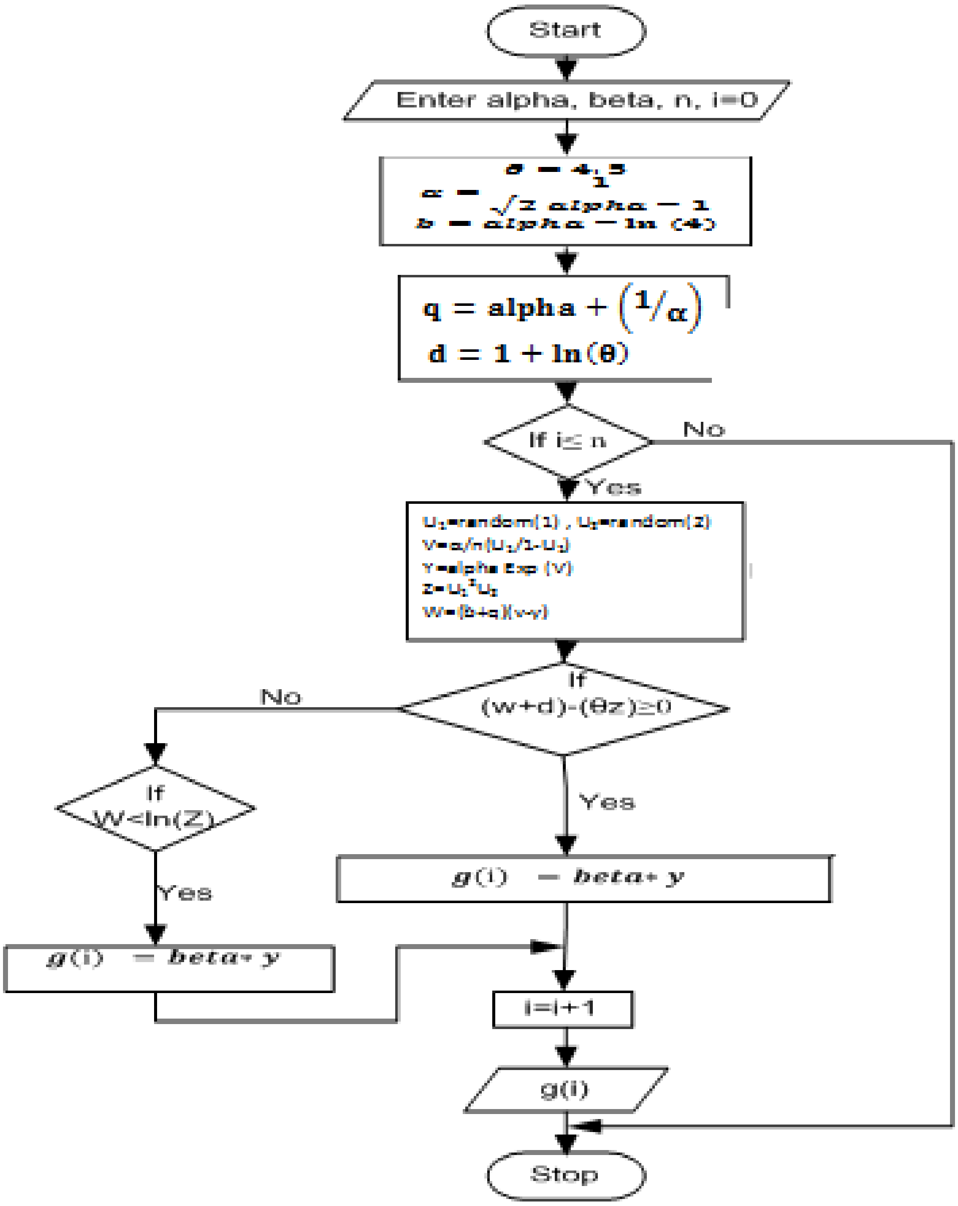

Figure 4.1. Flowchart of Java program based on algorithm of gamma distribution function

Source: Adopted from Chenge (1977)

Figure 4.1 shows the flow chart of the Java program which was written based on the algorithm of the gamma distribution function.

4.1.4.1 The Java program written based on the algorithm of gamma distribution function

The procedure involved in writing the Java program as depicted in figure 2 is summarized below.

1. Enter Beta, Alpha, n to the Java program
2. Initialize ϴ = 4.5

   Get the formula for a, b

   a = $\frac{1}{\sqrt{2alpha - 1}}$

   b = alpha – 1n (4)

3 Set the formular for q, d

   q = alpha + (^{1}/a)

   d = 1 + 1n (ϴ)

4. Determine the number of iteration: if i < n perform: Bq, BS to the end of the condition
5. If (w + d) – (ϴZ) ≥0

   Perform Pm

6. Else

   Perform m

7. n = n + 1, continuously add value to the n till it meets the number of iteration.
8. g(i) : Display the result
9. End of application

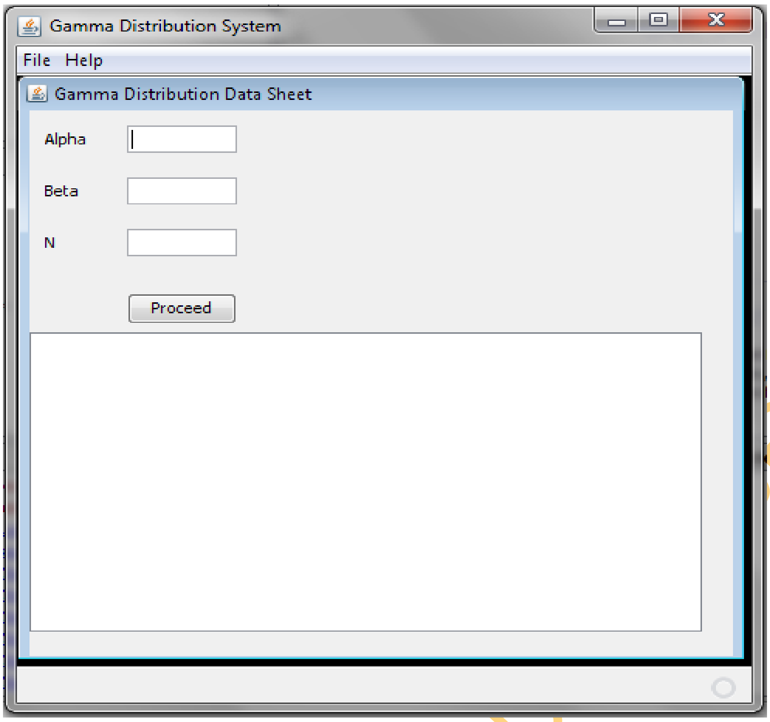

Figure 4.2. The user interface of the Java program

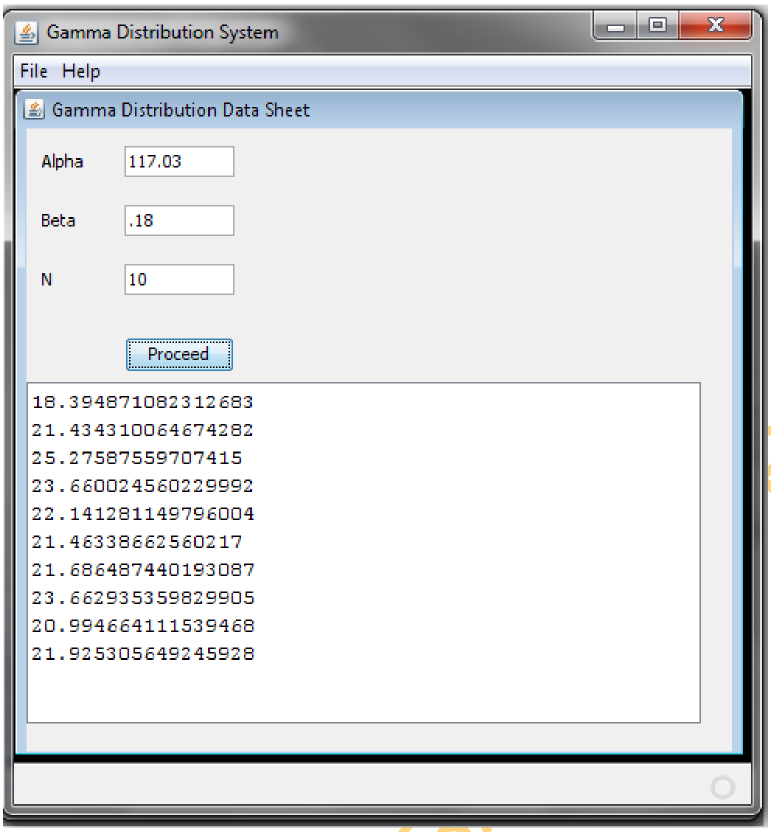

Figure 4.3. The output display after supplying data

Figures 4.2 and 4.3 show the interface of the Java program where three parameters (α, β and number of iterations) to be supplied by user, then the proceed button is clicked to generate output.The output display is shown in table 4.3 after supplying data. This is how the program was implemented.

The residual plot from the best height and diameter model which is the Schnute model indicated that tree height was well predicted across diameters as shown in figure 4.4.

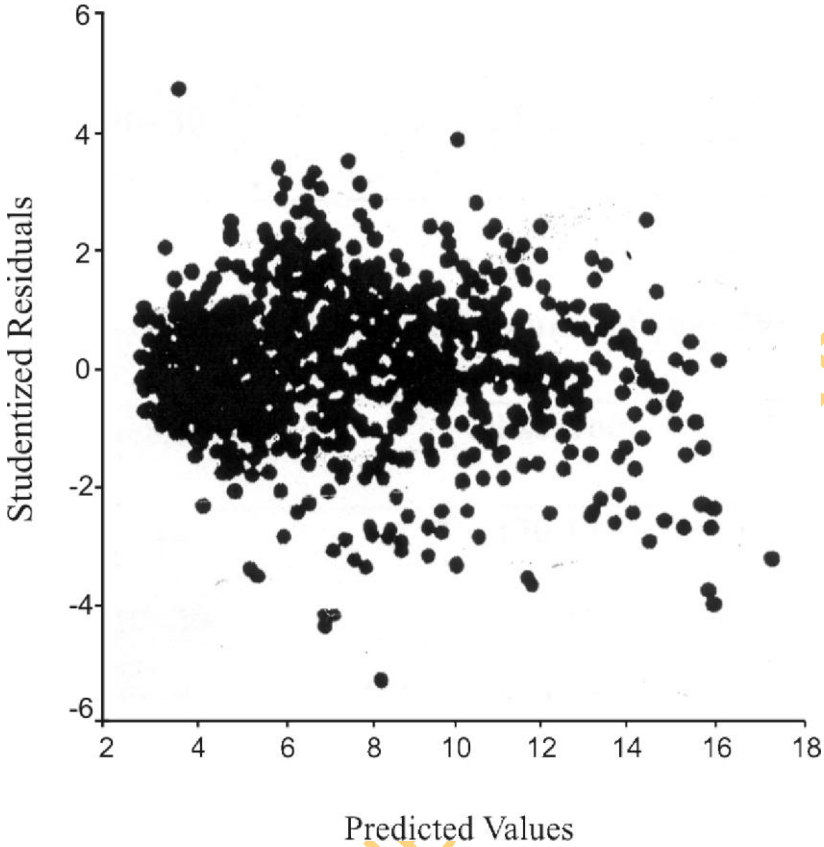

Figure 4.4 Residuals over predicted tree height for *Tectona grandis* using Schnute function.

The residual plot against the predicted height and diameter for model 7 clearly shows that the function appropriately fit the data Figure 4.4.

Figure 4.5 shows the scattered diagram of the best volume model from the regression analysis. The model clearly shows that volume is well distributed across diameter and the function appropriately fits the data.

The graph of diameter and age relationship shows that diameter was well distributed across the age as shown in Figure 4.6.

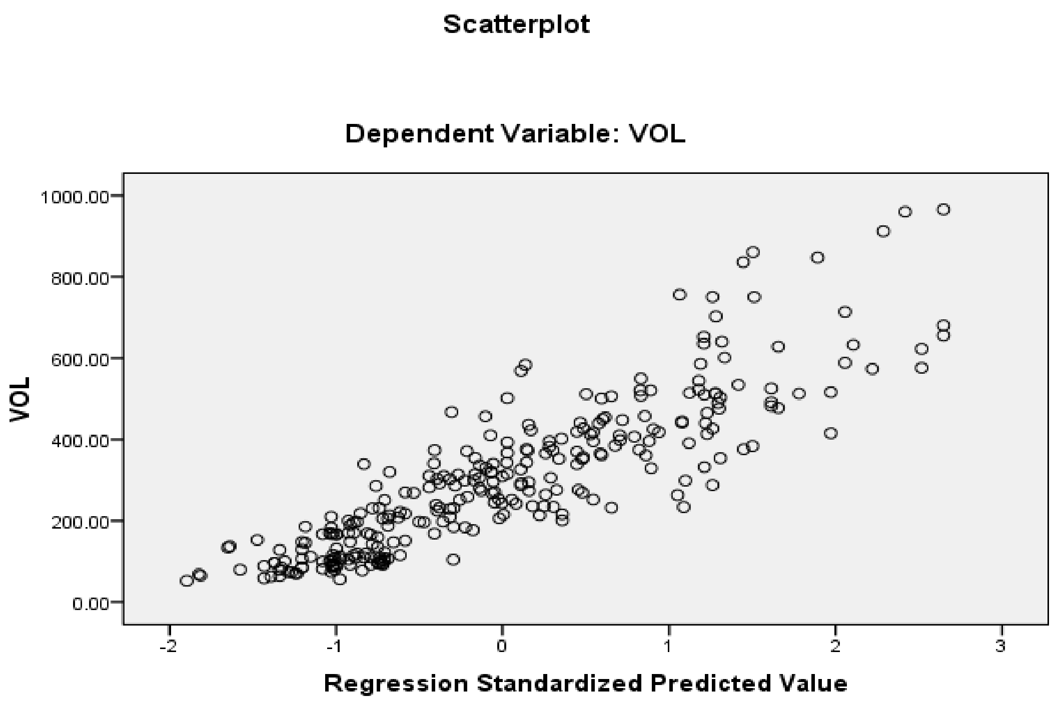

Figure 4.5. Plot of the volume using best model

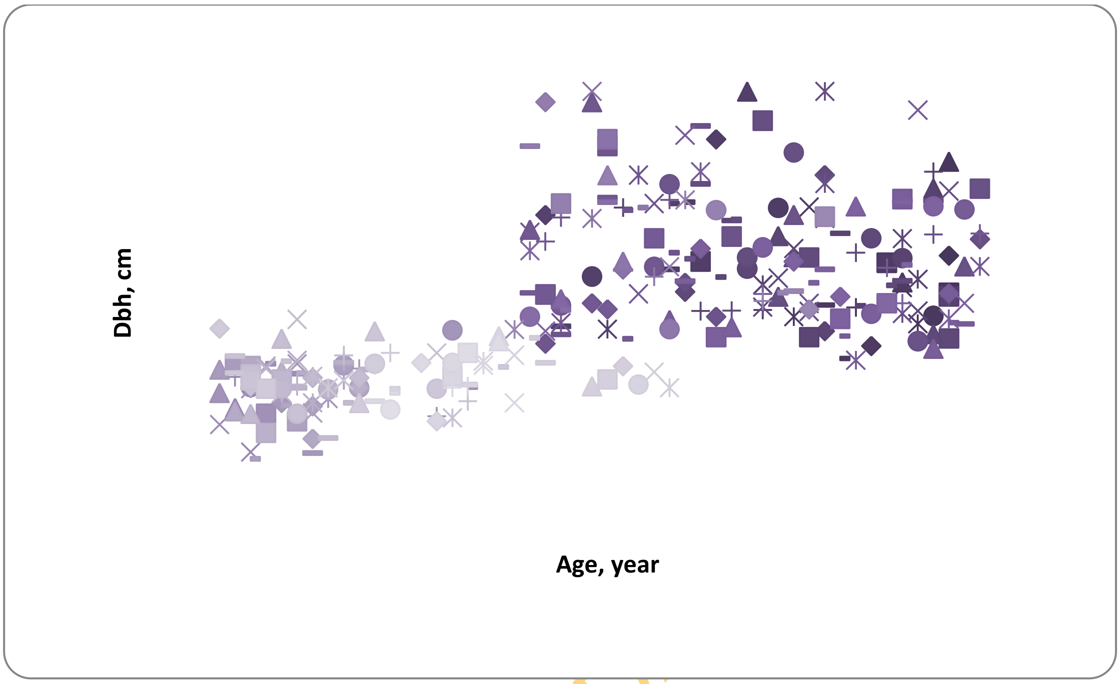

Figure 4.6. Diameter – age relationship

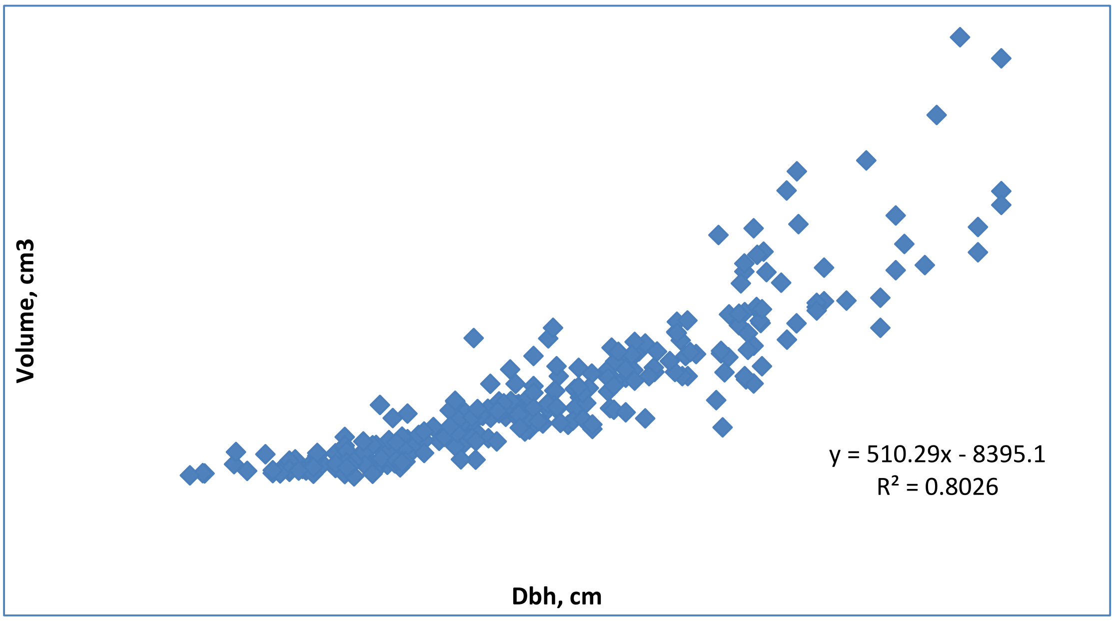

Figure 4.7. The Volume-Dbh relationship

``

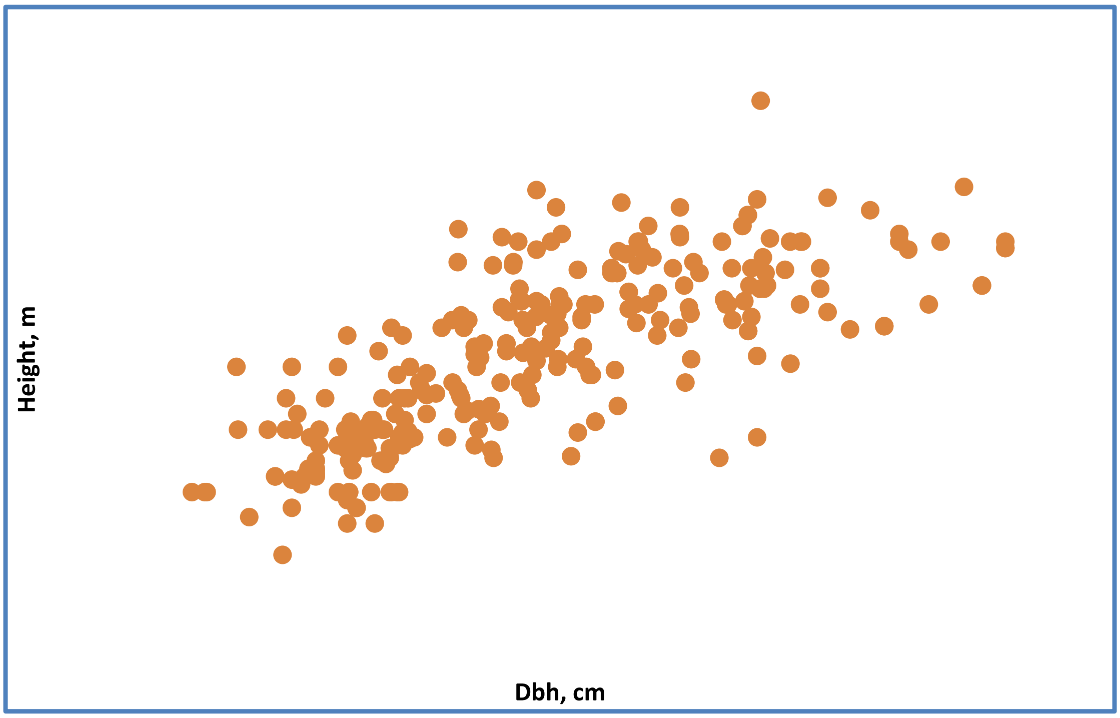

Figure 4.8 . Height-Dbh relationship

The volume and dbh relationship graph shows that the volume was well distributed across the diameter as shown in Figure 4.7.

Figure 4.8 shows that height were well distributed across diameter at breast height.

Figures (4.9 - 4.12) descrbe the observed differences between the size class diameter increment and these figures showed that ages 11 and 13 had more trees distributed in diameter class between 15 – 20, while ages 22 and 59 had more tree thats fell within the range of 20 to 25 this may be attributed to the fact that trees in the middle and top canopy tend to grow more vigorously than the lower storey ones. Perhaps, due to their vantage position in terms of access to light and soil nutrients..For plantation age 59, the graph is positively skewed.

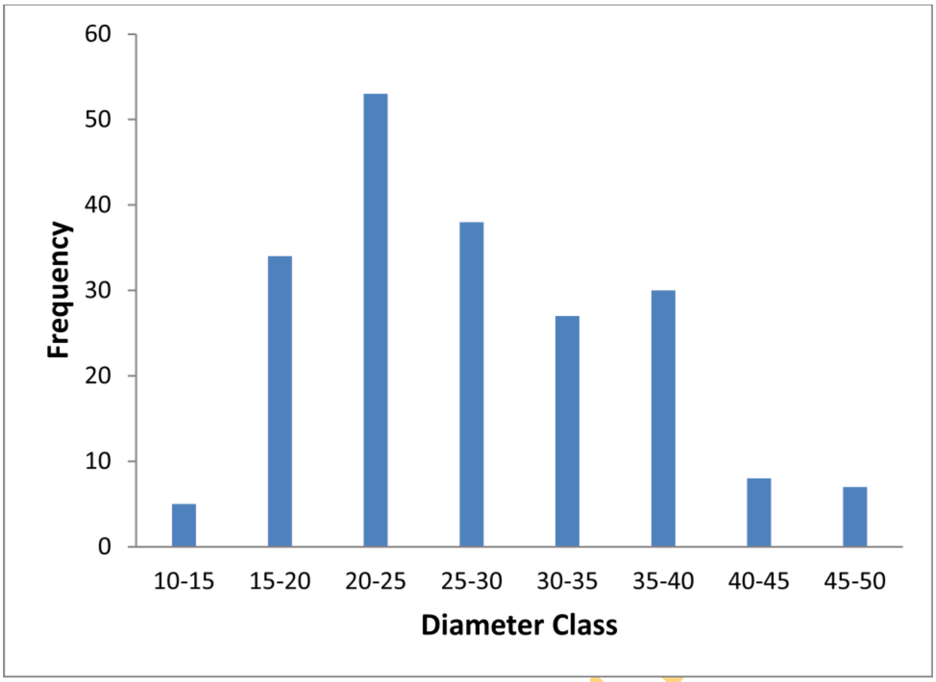

Figure 4.9. Diameter distribution for age 59 stand

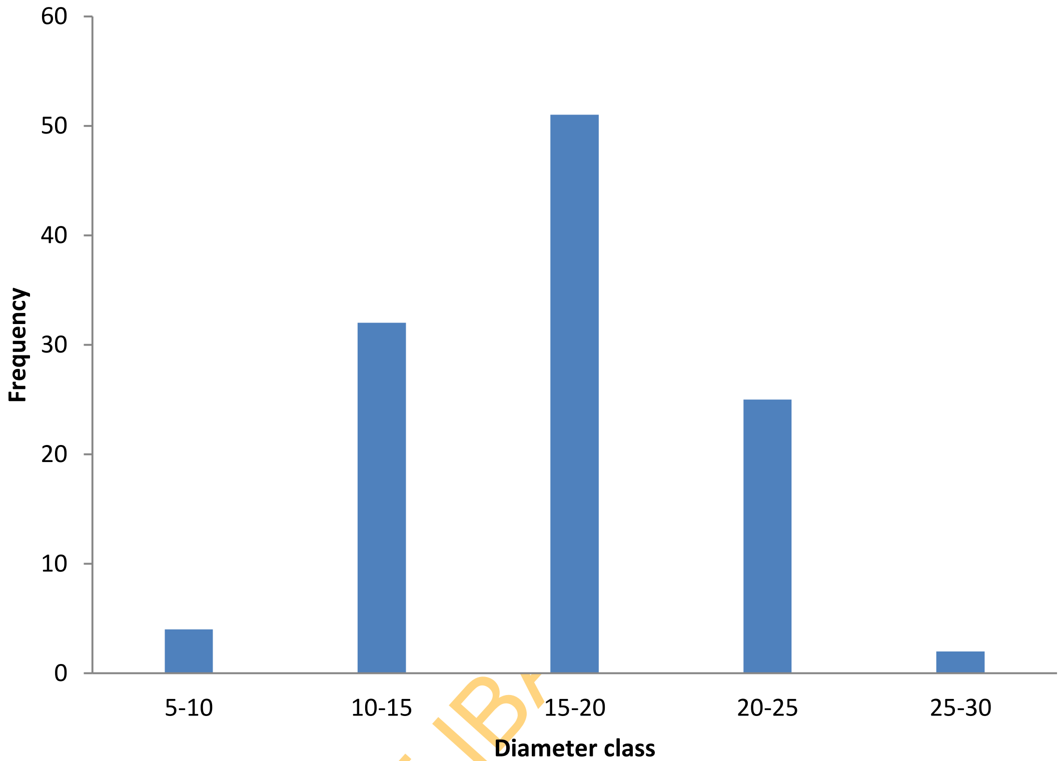

Figure 4.10. Diameter distribution for age 11 stand.

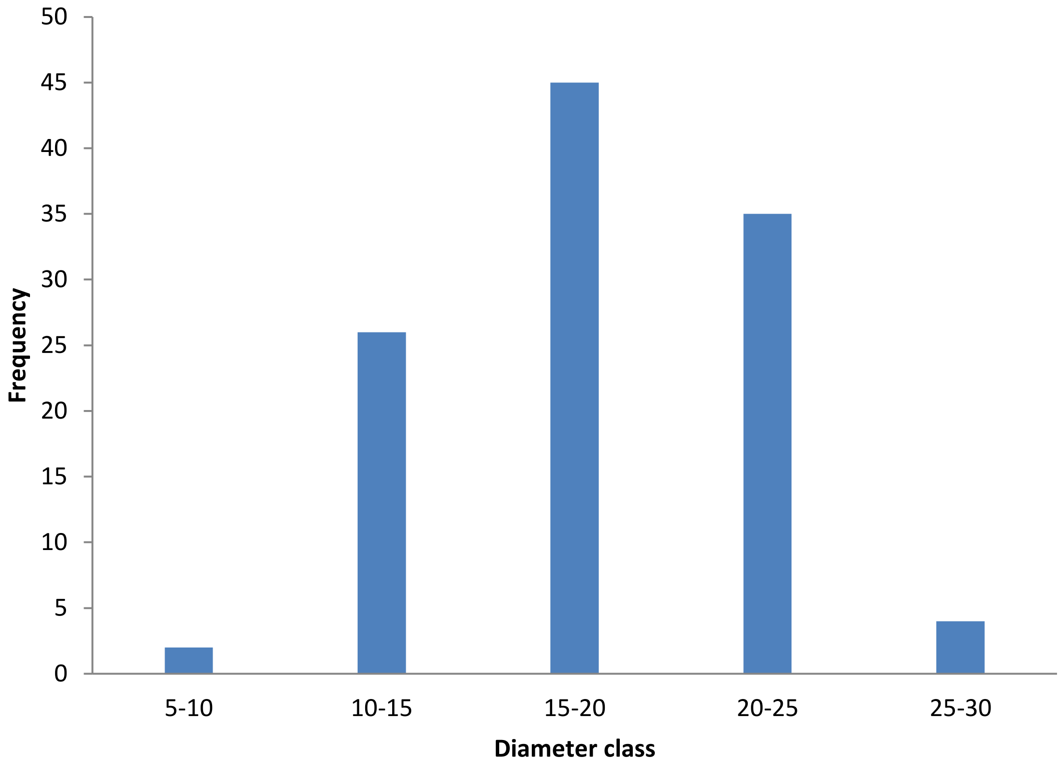

Figure 4.11. Diameter distribution for age 13 stand

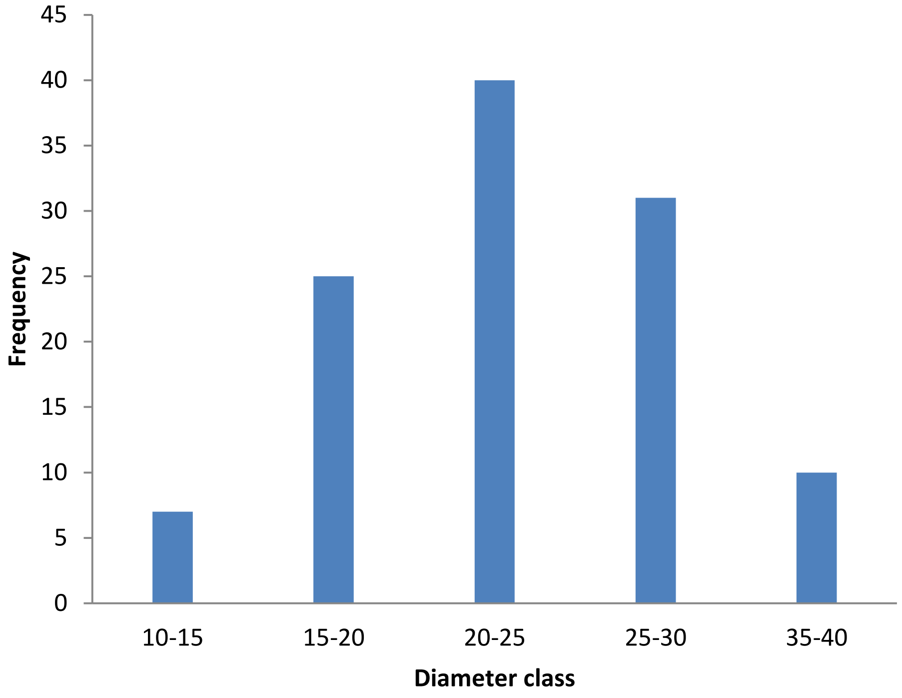

Figure 4.12. Diameter distributions for age 22 stand

The diameter distribution across the classes for ages 11, 13 and 22 skewed towards the right.This will help avoid unrealistic diameter distribution at older ages. Figures (4.13-4.16) show that there were under and over estimation in some diameter size classes in the graphs of predicted and observed diameter distribution of the gamma distribution function. The model prediction and true values were similar and the graphs show strong correlation which implies that the Java program performed well.

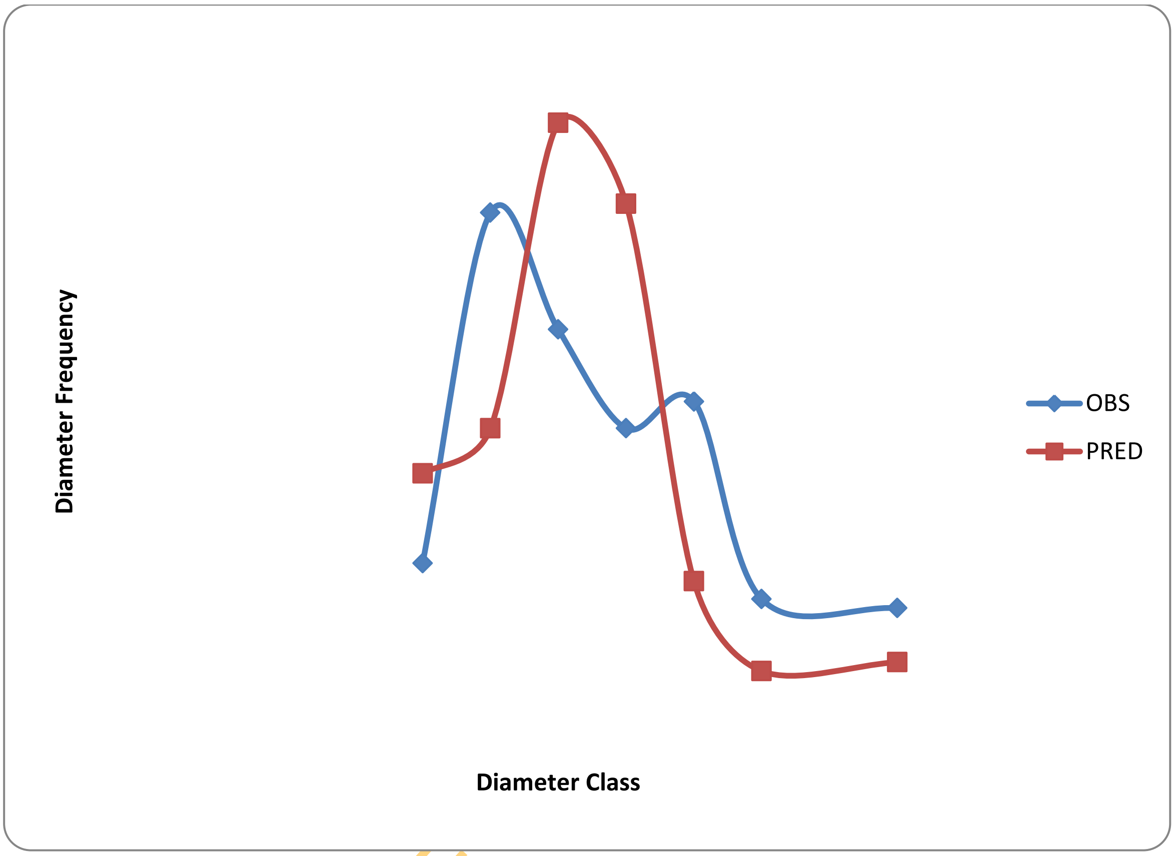

Figure 4.13. Predicted and Observed diameter distribution of gamma distribution for plantation age 59

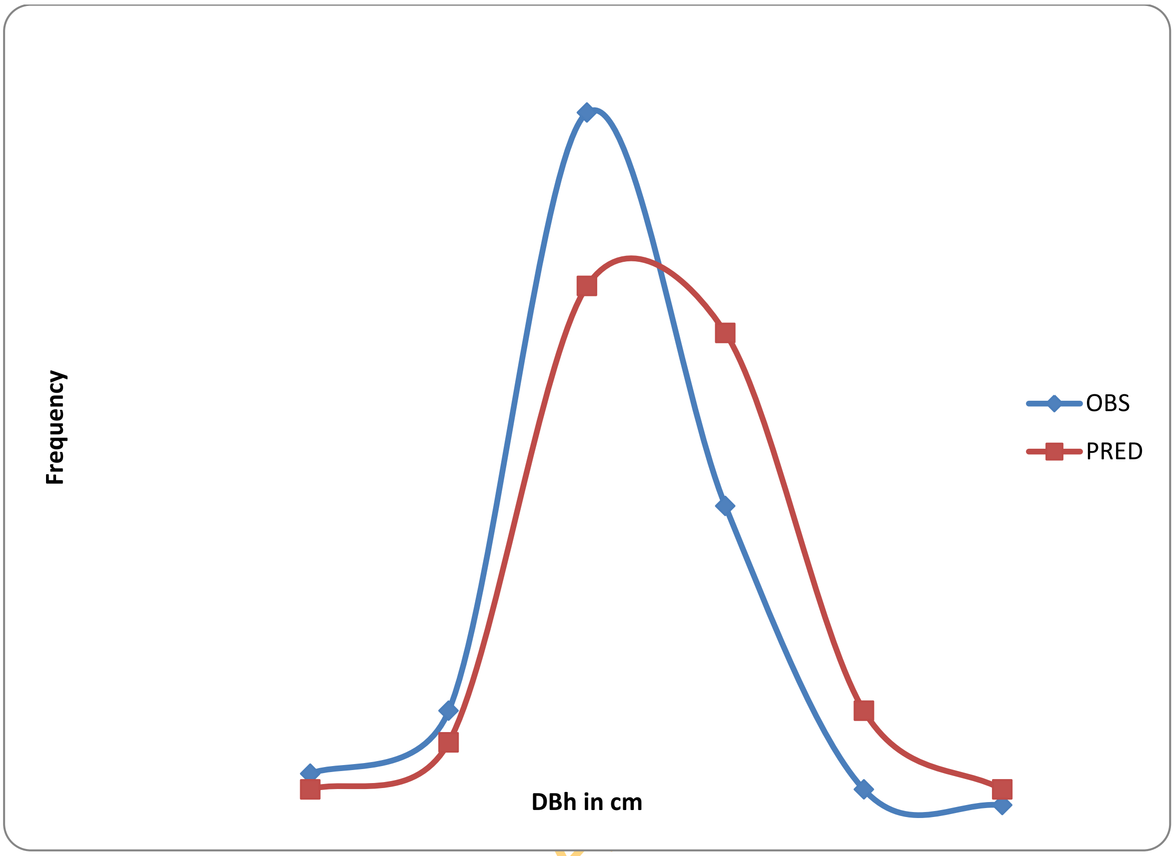

Figure 4.14. Predicted and Observed diameter distribution of gamma for plantation age 11

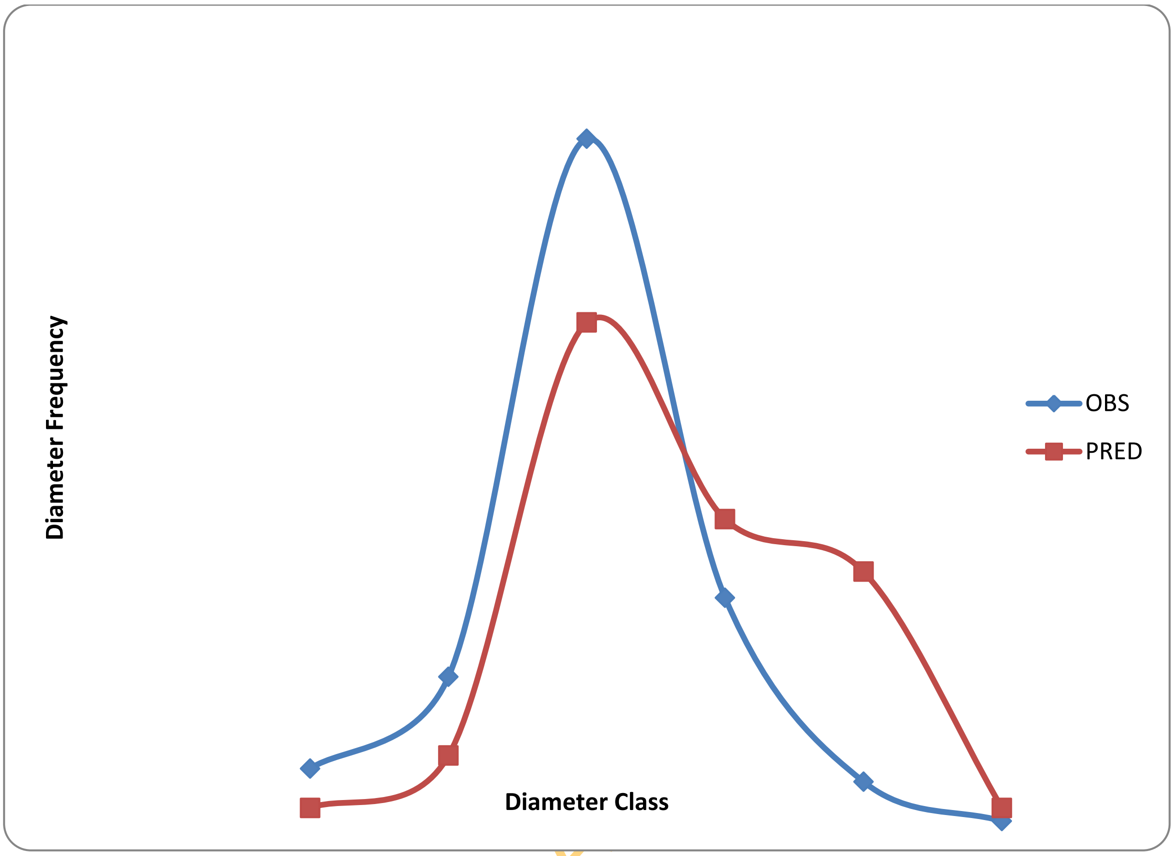

Figure 4.15. Predicted and Observed diameter distribution of gamma for plantation age 13

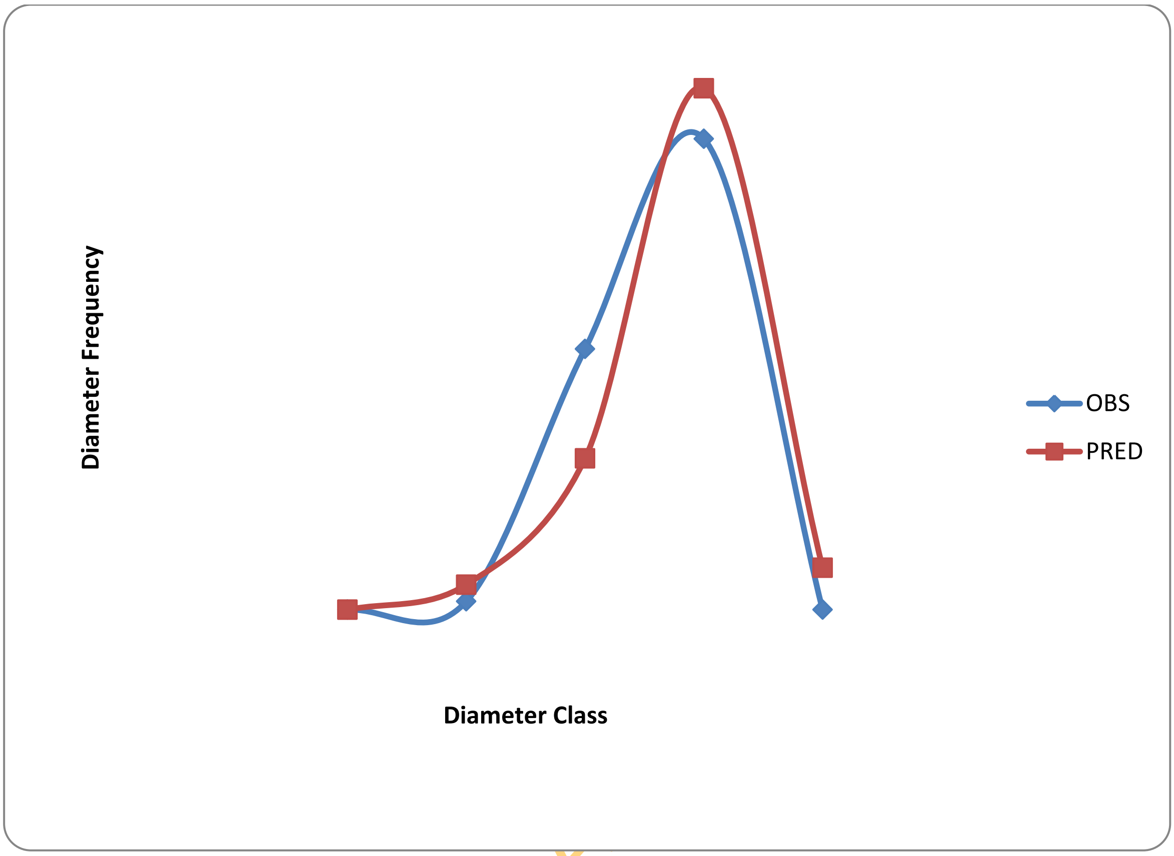

Figure 4.16. Predicted and observed diameter distribution of gamma for plantation age 22

4.1.5 Prediction equation for gamma distribution function

The gamma distribution function is given as

$$fx(x) = \frac{x^{\alpha-1} e^{\frac{-x}{\beta}}}{\Gamma(\alpha)\beta^{\alpha}} \quad , \alpha > 0 \text{ and } \beta > 0$$

The prediction equations for the gamma distribution parameters are presented as follows.

Shape parameter (α)

$$ln \propto = b_0 + b_1 ln\overline{D^2} - b_2 lnS^2$$

$b_o = 1.002$, $b_1 = 1.021$, $b_2 = 1.023$

$R^2 = 0.980$, MSE = 0.0619

Scale parameter

$$ln\beta = b_0 + b_1 ln\, S^2 - b_2 ln\overline{D^2}$$

$b_o = -7.388$, $b_1 = 0.969$, $b_2 = 0.364$

$R^2 = 0.986$, MSE = 0.0513

Figures 4.17 and 4.21 show that there is a strong correlation between the observed and predicted values of the shape and scale prediction parameters equations of the gamma distribution function

Figures 4.18 and 4.20 show the plots of residual versus predicted values for both shape and scale parameters of the predictive equations of gamma distribution function. They show no systematic prediction problems.

Figures 4.19 and 4.22 show the diameter distribution of the shape and scale parameter of the prediction equations of gamma distribution function. It assumed a normal distribution.

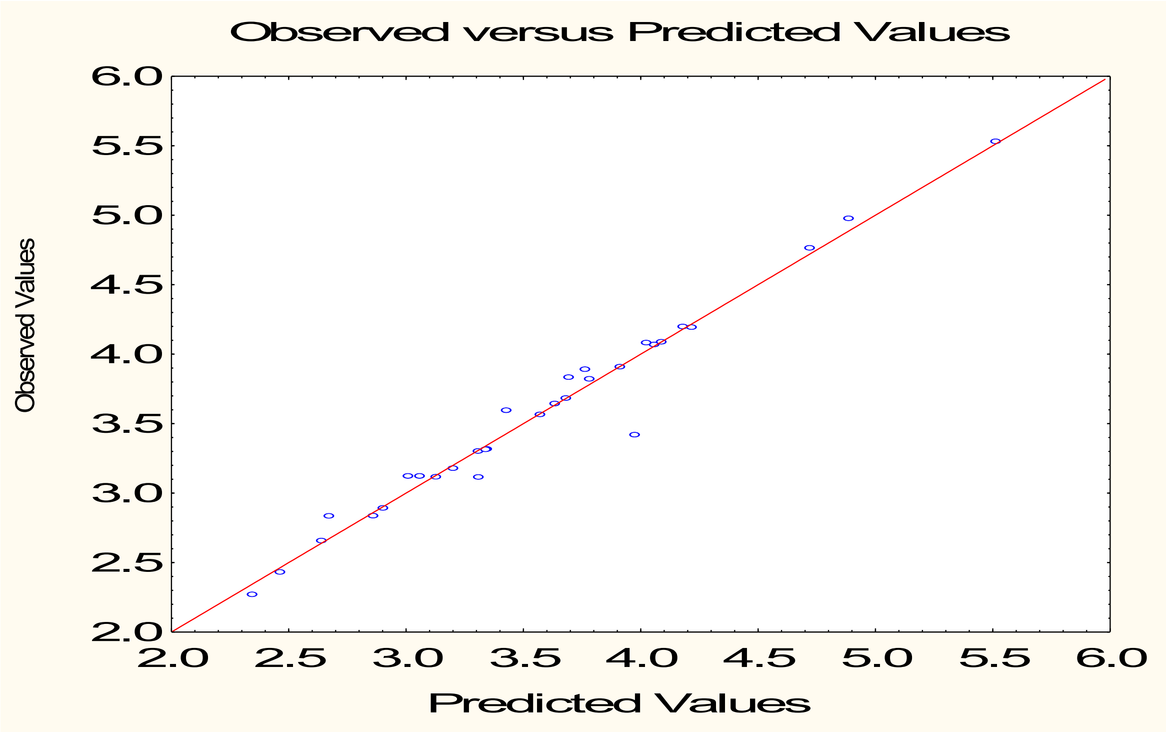

Figure 4.17. Predicted and observed values for shape prediction equation

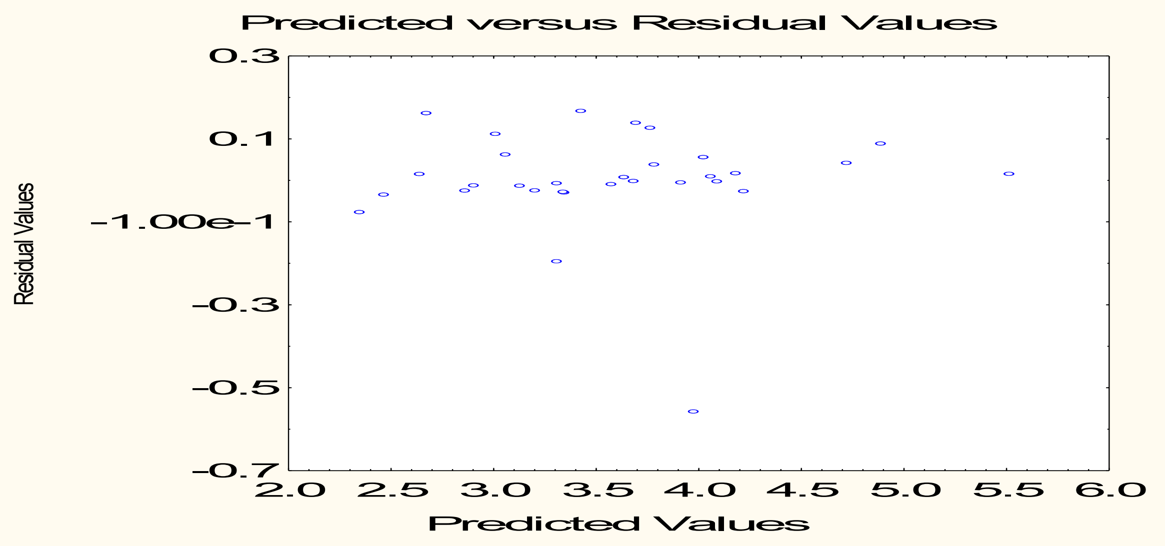

Figure 4.18. Plot of residual vs. Predicted values for gamma shape parameter prediction equation

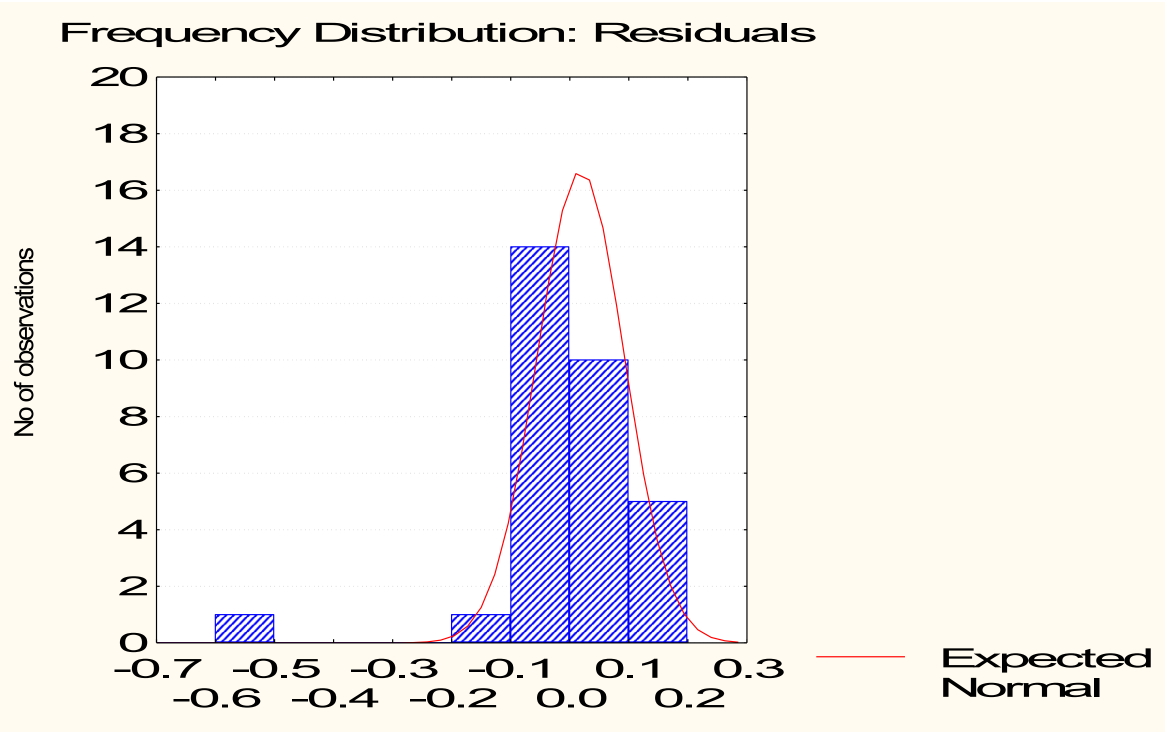

Figure 4.19. Diameter distribution of gamma shape parameter prediction equation

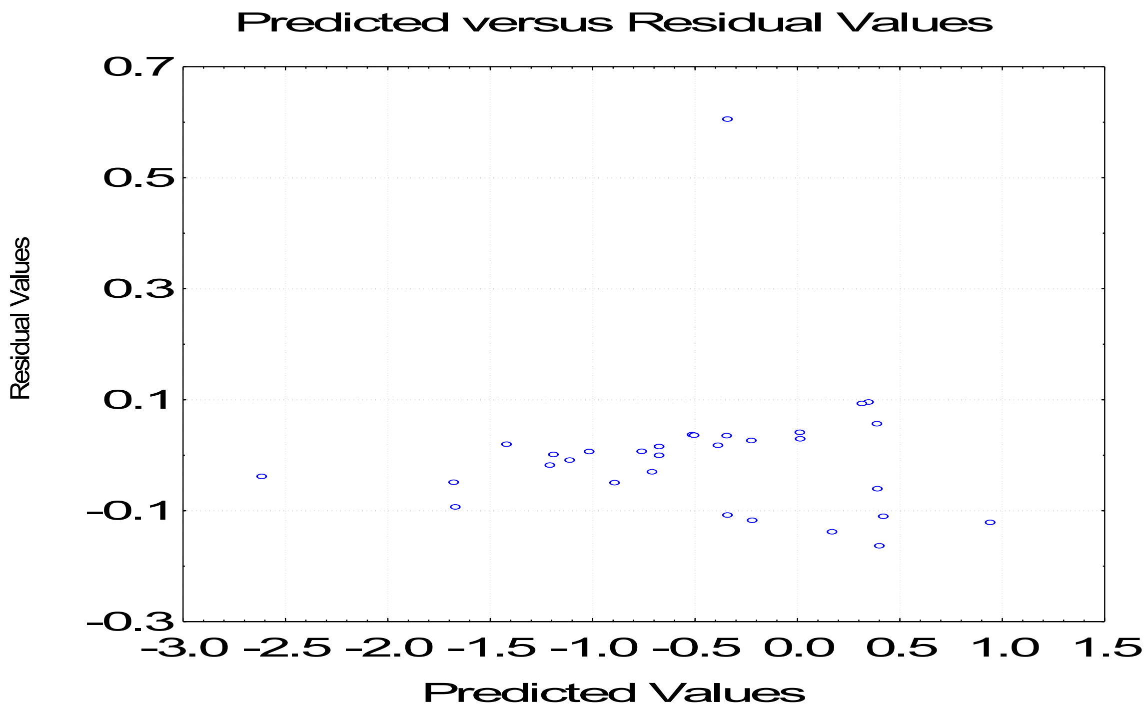

Figure 4.20. Plot of residual vs. Predicted values for gamma scale parameter prediction equation

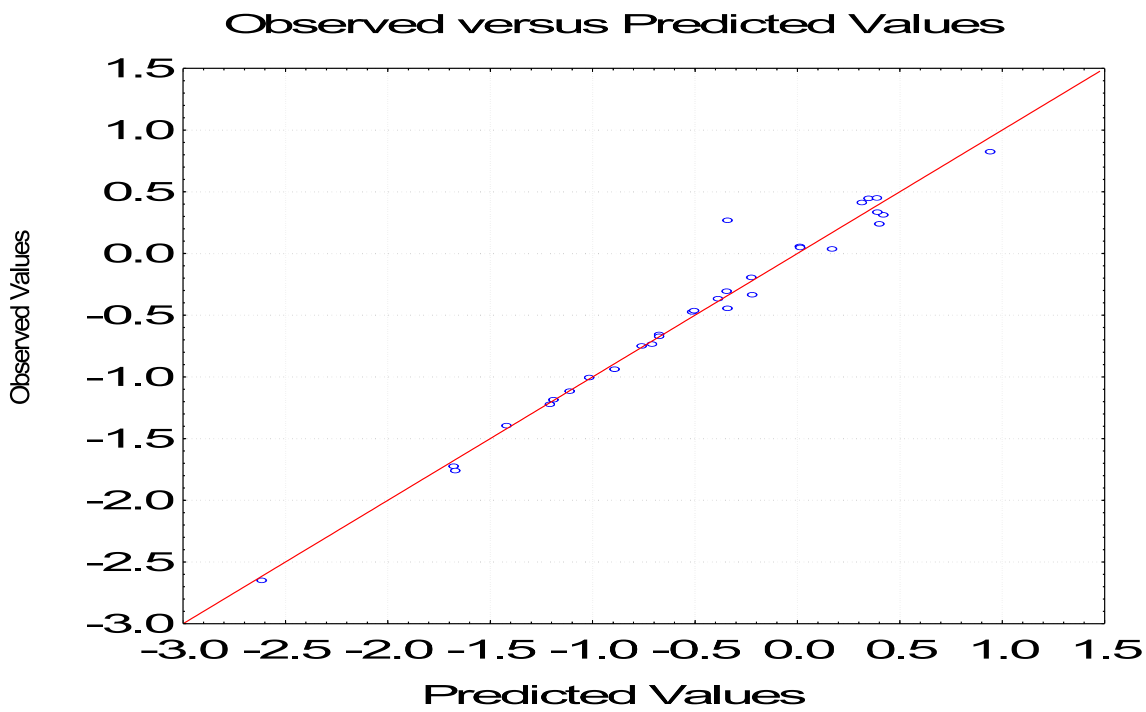

Figure 4.21. Predicted and observed values for scale prediction equation

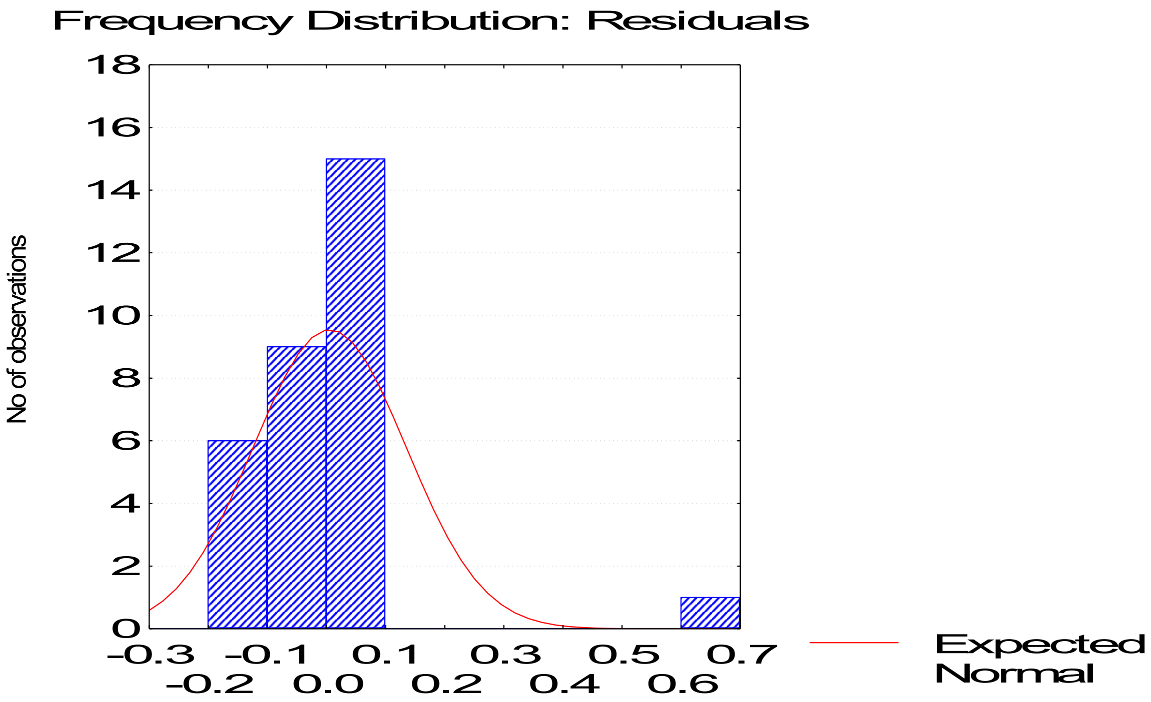

Figure 4.22. Diameter distribution for scale parameter prediction equation for gamma distribution function

The diameter distribution for the scale and shape parameter prediction equation for gamma distribution function assumed a normal distribution which agrees with Burkhart *et al.*, 2004, Emborg *et al.*,2000 and Podlaski, 2006).

4.1.5 General Growth Estimate

At tree – level, stem volume growth estimates ranged from $0.0025m^3$ to $0.1256m^3$/year, stem volume ranged from $0.1000m^3$ to $8.7842m^3$. At stand level, stem volume growth ranged from $0.80m^3$/ha/year to $38.85m^3$/ha/year while stem volume ranged from 2.82 to $564.29m^3$/ha. The basal area ranged from 2.49 to $4.51m^2$. At size class level, shape and scale parameters (of gamma distribution function) for the diameter distribution ranged from 0.96 to 25.20 and 0.07 to 2.28 respectively. The trend shown in these ranges correspond to the common trend similarly reported in tropical plantation studies (Abayomi,, 1986, Akindele, 1990 and Onyekwelu, 1995). These ranges indicate that *Tectona grandis* tree species in Akinyele Local Government Area teak plantatations are doing well.

4.1.6 Statistical evaluation of stands in the study area

The stand characteristics were captured from individual tree measurement in the stands. In additions, tree BAL index was calculated. Summary statistics, including mean, minimum, maximum and standard deviation of each of the individual and stand variables; basal area (BA), quadratic mean diameter (dq), mean height weighted by basal area (hq), number of trees (N) BAL index, dominant height (H_{dom}) and dominant diameter (D_{dom}) for both fitting and evaluation data set as shown in Table 4.15 below.

Table 4.13 Statistical evaluation of stands in the study area (Characteristics of the fitting and evaluation data set

	Fitting data set No of plots 25, No of trees: 357				Evaluation data set No of plots 6, No of trees: 76			
Variables	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
Dbh(cm)	21.60	54.11	37.86	9.52	21.90	48.11	35.01	9.59
D_{dom}	21.00	53.85	37.40	10.58	21.00	38.50	29.75	9.27
H_{dom}	16.70	29.50	20.50	4.85	20.80	26.50	20.50	4.60
h(cm)	16.20	30.00	23.40	5.44	17.40	11.80	22.30	6.38
dq(cm)	8.50	25.00	9.80	3.80	8.80	22.50	8.50	8.50
BA (m^2/ha)	9.50	60.80	18.88	12.88	11.80	120.60	13.80	12.22
N(trees/ha)	24.50	31.50	10.81	9.68	32.40	28.50	19.71	9.09
BAL(m^2/ha)	0.00	42.40	12.82	9.80	0.00	85.60	4.52	9.85

Regression analysis of the height and diameter growth models showed that significant differences were found among the predictive abilities of the equations as shown in table 4.14 below.

Table 4.14. Mean Square Error (MSE) and Coefficient of determination for height and diameter growth models

Model	MSE	R^2	Rank
$H = 1.3 + e^{a+\frac{b}{dbh+1}}$ ……........equation 49	1.511	0.790	6th
$H = 1.3 + a(1 - e^{bdbh^c})$ ……….equation 50	1.518	0.789	7th
$H = 1.3 + e^{(a+\frac{b}{dbh+c})}$ ....…..equation 51	1.510	0.791	5th
$H = 1.3 + e^{a+\frac{b}{dbh+1}}$ ….….........equation 52	1.419	0.816	3rd
$a = a_1 + a_2 \text{ x } BAL$			
$b = a_3 + a_4 \text{ x } BAL + a_5 \text{ x } N + a_6 \text{ x } BA$			
$H = 1.3 + a(1 - e^{bdbh^c})$	1.458	0.806	4th
$a = a_1 + a_2 \text{ x } BAL + a_3 \text{ x } N + a_4 \text{ x } BA$			
$b = a_5 + a_6 \text{ x } BAL$…...........…equation 53			
$H = 1.3 + e^{(a+\frac{b}{dbh+c})}$.............equation 54	1.418	0.817	2nd
$a = a_1 + a_2 \text{ x } BAL$			
$b = a_3 + a_4 \text{ x } BAL + a_5 \text{ x } N + a_6 \text{ x } BA$			
$H = \left[1.3^b + \left(H_{dom}^b - 1.3^b\right) \frac{1-e^{-adbh}}{1-e^{-aD_{dom}}}\right]^{1/b}$	1.226	0.949	1st
....equation 55			

Table 4.15. Summary statistics for parameter estimates of models 7 and 3

Parameters		Estimates	
		Model 7 schnute function (Generalized model)	Model 3 (Base model)
Fixed parameters	a	0.06712 (0.005)	2.75398 (0.280)
	b	1.08321 (0.065)	-8.55524(0.612)
	c		1.460867(0.338)
Model performance	Adjusted R^2	0.949	0.792
	MSE	1.225	1.510
	Bias (Ế)	0.088	0.001

a, b and c are variables

Table 4.15 shows the parameter estimates for model 7 and 3. In bracket is the characteristics of the fitting and evaluation data set.

Significant differences were found among the predictive abilities of the height-diameter equations. The MSE values ranged from 1.511, 1.518, 1.510, 1.419, 1.458, 1.418 and 1.226 for models 1 through 7 while the coefficient of determination values ranged from 0.790, 0.789, 0.791, 0.816, 0.806, 0.817 and 0.949. When height-diameter functions were fitted, differences were found among the estimated model parameters and the predictive ability of the height-diameter models. Among the three base models, model 3 had the lowest MSE value. Among the models tested with stand-level attributes, model 7 which was based on Schnute function recorded the lowest MSE value (Table 4.14).

Judging from the residual plots and the MSE values, model 7 generally performed better than the remaining models. The residual plot indicates that tree height was well predicted across diameters. The residuals plot against the predicted height and diameter for model 7 clearly show that the function appropriately fits the data (Figure 5). The parameters estimates obtained for models 3 and 7 widely showed significant t-statistics (Table 4.14). Models 3 and 7 have the flexibility to assume various shapes with different parameters values and produce satisfactory relationship under most circumstance. The relationship is biologically reasonable since unrealistic height prediction do not occur beyond the range of the empirical observations. The base model (model 3) and the basic generalized height-diameter model (model 7) were tested using student's paired t-test by an independent control data set (6 sample plots). The models presented in this study were considered to have an appropriate level (α = 0.05) of reliability

(t_{model3}= -2.012 and t_{model7}= 1.917 >P = 0.05).

The summary statistics of models 7 and 3 is shown in table 4.17 below. approximates standard error. lt also shows comparison of goodness of fit statistics and all estimated parameters were significantly different from zero (p< 0.005).

The regression analysis of the basal area models showed that significant differences were found in the predictive abilities of the models as shown in table 4.16 below

Table 4.16. Mean square error and coefficient of determination for basal area models

Models	R^2	MSE	b_0	b_1	b_2	b_3	b_4	b_5	Rank
$1n(B)=b_0+b_1(^1/A)+b_2 1n(H)+b_3 1n(N)+b_4(^H/A)+b_5(^N/A)$	0.7207	0.4788	10.9296	-2.0406	0.3690	5.8001	0.0834	-24.7831	3rd
$1n(B)=1n(b_0)+b_1(^1/A)+b_2(1nH)+b_3(1nN)+b_4(^H/A)$	0.8935	0.3247	0.3241	0.2204	0.4290	0.7754	-1.8266		1st
$1n(B) = b_0+b_1 1n(^H/A)+b_2(InN)$	0.7702	0.4805	0.4763	2.0823	-1.9419				2nd

Significant differences were found among the predictive abilities of the basal area growth equations. The mean square error ranged from 0.3247, 0.4788 and 0.4805 while the coefficient of determination values (R^2) ranged from 0.7207, 0.7702 and 0.8935.This shows that over 70% of the variation was accounted for by the independent variable in the models. Equation 60 had the highest R^2 and lowest MSE values.

The regression analysis showed that significant differences were found among the predictive abilities of the volume models as shown in table 4.17.

Significant differences were found among the predictive abilities of the volume equations. The mean square error (MSE) ranged from 0.0251, 0.0764, 0.0854, 0.0865 and 0.0954 while the coefficient of determination values ranged from 0.7706, 0.7090, 0.7903, 0.8410 and 0.8981. Equation 58 had the highest R^2 and lowest MSE values.

The observed and predicted values of height, basal area and volume of best fit are summarized in tables. 4.18 - 4.23 below.

The results of the height model of best fit showed no significant differences between the observed and predicted values and the observed and predicted values were similar to a significant degree. The error rate in the predicted height was lower with larger trees which imply greater precision with larger trees.The table shows that plantation age 22 had lowest error rate while age 11 had the highest.

Table 4.17. Mean square error and coefficient of determination for volume growth models

Models	**R^2**	**MSE**	**A**	**b**	**C**	**Rank**
$1n(V) = c + a*d$	0.8410	0.0868	0.9786		2.1606	2nd
$V = c + a*1n(d)$	0.7090	0.0954	20.6598		24.7086	5th
$V = c + a*d$	0.8981	0.0251	22.3818		1.6234	1st
$V = a + b*d^2h$	0.7706	0.0764	5.4018	30.46		4th
$V = a + b*d + c*d^2*h$	0.7903	0.0854	2.1840	17.365	3.9976	3rd

Table 4.18. Observed and predicted height model of best fit at individual tree level

	Plantation age 11				Plantation age 13				Plantation age 22				Plantation age 59			
PLOT NO.	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %
1	19.00	18.40	16.25	11.68	22.80	21.60	23.44	-8.51	24.80	20.40	20.76	-1.76	34.70	31.00	32.95	-6.29
2	20.40	18.00	17.45	3.05	21.00	19.50	19.75	-1.28	21.60	17.60	17.25	1.98	34.20	31.50	31.85	-1.11
3	20.00	16.80	15.86	5.59	18.80	17.60	18.55	-5.39	24.00	21.10	25.45	-20.6	32.40	30.50	32.45	-6.39
4	21.40	17.50	18.60	-6.28	19.80	18.40	20.00	-8.69	18.00	17.00	17.85	-5.00	43.00	33.70	38.95	-15.57
5	19.80	18.60	17.55	5.64	19.60	18.20	19.52	-7.25	19.60	18.20	16.85	7.42	37.20	28.70	29.68	-3.41
6	20.00	18.80	17.15	8.77	21.50	17.80	18.95	-6.46	20.00	18.50	19.65	-6.21	40.90	33.90	31.40	7.37
7	19.90	18.60	19.48	-4.73	21.60	20.00	18.00	10.00	25.50	19.00	18.00	5.26	40.60	43.80	39.00	10.95
8					18.80	16.40	16.98	-1.67	18.80	18.00	22.75	-26.38	27.10	23.50	30.85	-31.27

Table 4.19. Observed and predicted height model of best fit at stand level

Plantation age	Mean dbh (cm)	Observed height (m)	Predicted height (m)	Error rate %
11	18.05	17.10	17.95	-4.97
13	18.33	18.00	18.52	-2.88
22	20.38	18.50	19.95	-7.83
59	32.39	28.30	32.18	-13.71

The observed and predicted height values were not significantly different and error rate is reduced at stand level which indicates better precision.

There is no significant difference in the observed and predicted basal area values, trees with greater basal area having lower error rate which implies better precision.

Since the observed and predicted values of the basal area were not significantly different, it implies that the model of best fit had a good predictive ability. Trees with greater basal area had smaller error rate. Table 4.21 shows that plantation age 59 had the lowest error rate while age 22 had the highest.

Table 4.20. Observed and Predicted Basal area of best fit at individual tree level

	Plantation age 11			Plantation age 13			Plantation age 22			Plantation age 59		
PLOT NO.	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^3)	Error rate %	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %
1	2.82	3.08	-9.21	2.98	2.79	6.37	3.43	3.32	3.20	3.08	3.20	-3.89
2	2.57	2.98	-15.95	2.85	3.30	-15.78	3.37	3.89	-15.43	3.44	3.41	0.87
3	2.60	2.87	-10.38	3.27	3.45	-5.50	3.08	3.80	-23.37	3.00	3.38	-1.26
4	2.69	2.89	-7.43	2.98	2.82	5.36	3.30	3.09	6.36	4.51	4.25	5.76
5	2.49	2.50	0.40	2.62	2.72	-3.81	3.71	3.65	1.61	4.27	4.33	-1.40
6	2.74	2.86	-4.37	1.75	1.53	12.57	3.33	3.15	5.40	3.84	3.78	1.56
7	3.13	3.20	-2.23	1.96	2.15	-9.69	3.65	3.73	-2.19	4.26	4.98	-16.90
8				2.49	2.42	2.81	3.93	4.00	-1.78	3.10	3.56	-14.83

Table 4.21. Observed and predicted basal area of best fit at Stand level

Plantation age	Observed Mean Basal Area (m^2)	Predicted Basal Area (m^2)	Error rate %
11	2.76	2.81	-1.81
13	2.55	2.59	-1.56
22	3.27	3.42	-4.58
59	3.69	3.72	-0.81

Table 4.22. Observed and predicted volume of best fit at individual tree level

PLOT NO.	Plantation age 11			Plantation age 13			Plantation age 22			Plantation age 59		
	Observed Volume (m^3)	**Predicted Volume (m^3)**	**Error rate %**	**Observed Volume (m^3)**	**Predicted Volume (m^3)**	**Error rate %**	**Observed Volume (m^3)**	**Predicted Volume (m^3)**	**Error rate %**	**Observed Volume (m^3)**	**Predicted Volume (m^3)**	**Error rate %**
1	2.28	2.25	1.31	2.52	2.45	2.77	2.87	2.83	1.39	6.35	6.45	-1.57
2	2.68	2.64	1.49	2.41	2.38	1.24	2.41	2.30	4.56	9.25	9.12	1.40
3	2.14	2.02	5.60	2.77	2.82	-1.80	2.55	2.56	-0.39	8.69	8.72	-0.34
4	2.18	2.39	-9.63	3.16	3.35	-6.01	3.03	3.00	0.99	6.27	6.39	-1.91
5	2.09	2.19	-4.78	2.27	2.33	-4.84	2.81	2.65	5.69	7.71	7.76	-0.64
6	2.31	2.28	1.29	3.50	3.73	-6.57	3.07	3.10	-0.97	10.54	12.05	-14.32
7	2.43	2.40	1.23	1.68	1.78	-5.95	3.13	3.05	2.55	8.93	8.49	4.92
8				2.51	2.35	6.37	2.65	2.50	5.66	8.93	8.75	2.01

The observed and predicted volume values were not significantly different and the values were similar to a significant degree. The error rate in the predicted values was lower with greater precision in larger trees. Trees with larger diameters have a decisive effect on, for example, the formation of forest microclimate and creation of patches. Their presence frequently determines qualification of stands into a definite stage and phase of development. Plantation age 59 had the smallest error rate while age 11 had the highest.

Table 4.23. Observed and predicted volume of best fit at stand level

Plantation age	Observed Volume (m^3)	Predicted Volume (m^3)	Error rate %
11	2.76	2.73	1.08
13	2.25	2.29	-1.77
22	3.47	3.44	0.86
59	3.69	3.65	1.08

The observed and predicted values were similar to a significant degree. They were not significantly different. The error rate is lower at stand level than at individual tree level which implies better precision at stand level.The error rate for age 11 and 59 were the same.

Error rate = $\left[\frac{O-E}{O}\right] X100$

O = Observed

E = Predicted

Comparing the results of the predictive ability of the Java program developed with the height, basal area and volume models of best fit, that of the Java program did better which implies that better precision could be obtained with the Java program.

CHAPTER FIVE

5.0 DISCUSSION

Effective forest management planning tools require growth and yield functions that can produce detailed predictions of stand development under different management schedules (Trasobares *et al*., 2004a and Trasobares and Pukkala, 2004). Hence in this study, considerable effort was directed towards obtaining prediction models for growth and yield. Camenson *et al* (1996) have stated that most systems of models are designed more for flexibility in terms of options available than emphasizing any one specific approach. Thus, in this study, emphasis is on developing a toolbox for learning in a systematic and comprehensive fashion.

The parameters for α and β from the gamma distribution function were estimated using the maximum likelihood estimator. Estimation of the parameters by maximum likelihood has been found to produce consistently better goodness-of-fit statistics compared to other methods (Usher and McClelland, 2001). The values of α and β were fitted into the Java program written based on the algorithm of the gamma distribution function. After fitting the values of α and β into the Java program, it was run in order to produce an output. There are several tools for studying model compatibility. An important and logically convincing idea to check model compatibility is based on predictive simulation, which suggests that a model is compatible if it provides the prediction in accordance with the patterns given in the observed data.

The result of the Java program written based on the algorithm of gamma distribution function showed that the gamma distribution function has a good predictive ability as it was able to predict the height, basal area and volume of a tree at a given diameter at breast height both at individual tree and at stand levels i.e. the observed and predicted values were not significantly different. This is in line with Liu *et al*., (2002) who stated that gamma distribution has the ability to fit various empirical distributions. When the predicted results from the model agree with the observed results, it is to be noted that the predictive distribution is referred to mean the distribution of the future data given the observed data may be obtained by averaging out the parameters involved in the process with respect to some of its appropriate distribution. This finding is consistent with Upadhyay *et al.*, (2001).Comparing the predictive ability of the Java program to the height, basal area and volume models of best fit that of the Java program did better.

The error rate at individual tree and stand levels show that better prediction can be achieved at stand level than at individual tree level. It also shows that the data fitted well in the gamma distribution function which implies that the gamma distribution function performed well in the developed Java program. This result agrees with study of Chen and Zhang (2009) on diameter distribution simulation of *Quercus mongolica* stands, using normal distribution, Weibull distribution, gamma distribution and lognormal. The result of their work further goes to show that gamma distribution simulates much better than others. This result also agrees with study carried out by Zheng and Zhou (2010) that carried out a study on the diameter distribution of trees in natural stands managed on polycyclic cutting system using different intensity, their result shows that the medium intensity has a wider range of diameter distribution using gamma distribution function. Their values of α ranged from 0.5460 - 22.2934 while β ranged from 0.1076 - 13.6204. Gamma distribution function was also found suitable when fitted to loblolly Pin Data (1964).

This findings is also consistent with Podlaski (2006) who carried out a study on silver fir (Abies alba Mill), European beach (*Fagus sylvatica L,*) in the forest of central Europe and noted that for this group of stands, that gamma distribution function fitted best. The result of study also agrees with Mohammedalizadeh *et al*. (2009) that investigated the tree diameter at breast height in uneven-aged stands and fitted a statistical distribution to them. This finding is consistent with Mendoza and Vanclay (2008) who stated that models for growth and yield are used for growth and yield prediction and to provide estimate of future timber harvest. The results of the study is in line with Alder (1992) and Vanclay (1993) who noted that it is believed that the most effective way of addressing yield calculation is through simulation model. The results of tests show that Gamma distribution is very appropriate in the determination of diameter distribution of trees. The developed Java program based on the algorithm of gamma distribution function was also able to predict the height, basal area and volume of trees which were not significantly different from the observed height, estimated basal area and volume in the study area. The gamma predictions were very close to the actual height, basal area and volume with greater precision for larger trees. When compared with matrix model, the same result was obtained. Matrix model and gamma distribution model's predictions were closer to the actual values than the predictions from the Weibull distribution model. The superiority of the matrix model and gamma distribution function can probably be associated with the diameter distribution and the growth of trees (Hansen and Nayland, 1987).

5.1 Height- diameter growth models

In the development of height- diameter growth models, non-linear model was found suitable for prediction purpose. A large number of both local and generalized height-diameter equations are available in forestry (Huang *et al.*, 2000; Gadow *et al.*, 2001 Soares and Tome, 2002; Lopéz Sanchéz *et al.*, 2003; Temesgen and Gadow, 2004). According to Lei and Parresol (2001), when selecting a functional form for the height-diameter relationship the following mathematical properties should be considered; (i) Monotonic ascent (ii) inflection point (iii) horizontal asymptote. The number of parameters and their biological interpretation (e.g., asymptote, maximum or minimum growth rate) and satisfactory predictions of the height-diameter relationships are also important features (Peng, 2001).

In Huang *et al.*, (1992), model 7 is a Weibull type function which was consistently the best among the 7 height- diameter functions they tested.

Flewelling and de Jang (1994) also used Ratkowsky (1990) model to estimate missing heights in the British Columbia permanent sample plot data sets.

In Temesgen and Gadow (2004), model 2 is the most suitable for predicting tree heights from a diameter-stand table. The chapman-Richards function has been extensively used in describing height-diameter relationship. Huang *et al.*, (1992) gave a cautionary note; however, stating that this function approaches the asymptote too quickly when there is a weak relationship between the dependent and independent variable. Accordingly, this model was not selected in this study. The height-diameter model developed in the present study was based on the Schnute (1981) function. According to Lei and Parresol (2001), the schnute function together with the Bertalanffy-Richards function (Bertalanffy, 1957, Richards, 1959) are probably the most flexible and versatile functions available for modeling height-diameter relationships. The Korf function (Mehtatalo, 2004, Lynch *et al.*, 2005) and the logistic function (Huang *et al.*, 1992) have also been widely used. One of the important advantage of the schnute function is that, it is easy to fit and quick to achieve convergence for any database (Lei and Parresol, 2001), even with small datasets (Castedo *et al.*, 2005). This was particularly true in a preliminary analysis of the database in which convergence in the parameter estimates for all the plots was not achieved using the functions of Bertalanffy-Richards and Korf.

The inclusion of relative position of a tree and stand variables into the base height-diameter function increased the accuracy of prediction. The fit statistics indicated that models 3 and 7 are most suitable for predicting tree heights from a diameter stand table. In summary, the suggested models improves the accuracy of height prediction that ensures compatibility among the various estimate in a growth and yield model and maintains projections within reasonable biological limits. The parameter estimates using models 3 and 7 will provide reasonable precision and therefore these models can be recommended for growth estimation to teak stands in Akinyele Local Government, Oyo state.

Figure 9 shows the scattered diagram of the relationship between height and Dbh which indicated that tree height was well predicted across diameters. Figure 7 also indicated that Dbh was well predicted across the age. Figures 11, 12, 13, and 14 shows the diameter distribution across the various ages. Age 57 has more of the diameter class between 45-50 while that of ages 11, 13, and 22 falls between 20-24.

5.2 Basal Area Growth Model

In the development of basal area growth model, multiple linear model was found suitable for prediction purpose. The basal area models were fitted to the data to select the best model. Model 57 had the best fit. This was based on the fact that equation 57 had the highest R^2 and lowest MSE values. The very high value found for the coefficient of determination and low values of mean square error indicate that the model fitted well to the datasets. The result of validation test indicates that the model is suitable for predictive purpose. This is consistent with report of previous workers such as Akindele (1990), Onyekwelu (1995), Pretzsch (2001) and Adesoye (2002). This finding also agrees with Wykoff (1990) who worked on basal area increments for individual conifers in Northern Rocky mountains. Individual tree models developed are useful aids for making sound silvicultural management decisions, which hitherto has been unpopular in Nigerian Forestry (Evans, 1992). The basal area model developed in this study is useful for predicting both current and future yield of *Tectona grandis* in Akinyele Local Government Area teak plantations. The validation result indicates that it can be used for prediction purpose, with confidence.

5.3 Volume Growth Models

In the development of volume models linear model was found suitable for prediction purpose. Data were fitted using STATISTICA version 5.1 package. Mean square error and the proportion of variation accounted for denoted as MSE and R^2 value respectively, were used as a measure of fit. A lower MSE and higher R^2 value suggested better fit. Five volume equations were fitted to data to select the best model. Equation 61 had the lowest MSE value and the highest R^2 value, thus equation 61 worked or gave the best fit. The very high value found for the coefficient of determination and low values of mean square error indicate that the model fitted well to the datasets. The model is biologically sound, as age increases variability increases. The results of the validation tests indicate that the model is suitable for prediction purpose. This finding agrees with Segura and Kannien, (2005) who made use of these allometric models to estimate stem volume and total above ground humid forest, individual tree in a tropical humid forest comprising different species in Costa Rica. The volume model has biological validity. Figure 8 shows that volume was well predicted across Dbh.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The program written for gamma distribution function was developed using Java programming language. This was done in NetBeans IDE (Integrated Development Environment) which is a Java development environment whereby the Java code editor, compiler and interpreter are integrated into one environment. The IDE was installed on Window 7. Likewise, NetBeans IDE can be executed on UNIX base operating system such as Linux, Solaris etc.The program ran without any difficulty. The gamma distribution function has a good predictive ability like the Weibull distribution though not widely used. The study shows that the gamma distribution function could perform very well like the Weibull distribution.

The iterative procedures provides simple techniques for determining exact maximum likelihood estimates of the two-parameter gamma distribution scale and shape parameters with any calculator having an iterative capability. It also provides convenient techniques based on the two-parameter gamma distribution for describing data and evaluating possible scale differences between two populations.

No model can accurately describe every biological phenomenon that foresters encounter in their practice. The testes (controlled) generalized height-diameter model allowed accurate results, making this approach highly effective and useful. The suggested approach allowed the natural variability in heights within diameter classes to be mimicked and therefore provided more realistic height prediction at stand level.

In forestry, models are very useful tools in understanding the interaction and dynamic process occurring in the forest and examining the different forest management strategies and their impacts.

This study was also able to identify models for volume and basal area which gave the best fit. Volume models were able to determine the relationship between diameters at breast height (dbh) and stem volume which implies that as diameter increases; there is a proportional increase in volume. The application of these models in the formulation of yield tables has been able to estimate the future growth and yield of *Tectona grandis* for efficient forest management and planning. The Java program was able to predict height, basal area and volume at a given diameter at breast height when alpha and beta were fitted into the Java program.

6.2 RECOMMENDATIONS

Growth modelers cannot guess, at the time of model construction, all the possible uses to which a growth model may be put. It is therefore important to make sure that the model behaves in a realistic way for a wide range of site and stand conditions, and extrapolates safely to conditions not included in the development data; To fulfil the potentials of assisting forest managers and policy makers by providing adequate information in a useful and flexible format, easy to use, well documented and readily available. The growth models of best fit used in this study is therefore recommended for yield prediction for use in the study area. The gamma distribution function written with the Java programming language is also recommended for use in the study area because of the good predictive ability. The Java program written based on the algorithm of the gamma distribution function could be applied in other study area.

Most permanent sample plot data (if not all) available in the country are so limited to very few growth variables (especially diameter at breast height measurement). This has imposed serious limitation to many vital aspects of growth and yield studies necessary for proper management of our forest estate. There is therefore an urgent need to shift from the format of data collection and it is therefore recommended that permanent sample plots be established which will enhance growth and yield studies. It is also recommended that the established plantation be properly managed to ease data collection during inventory.

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APPENDIX I: DATA SHEET

Page ……….......……… of……...…………....

Name of Plantation……..Date:……………………. (D/M/Y)

Plot Number……......................................…......

Stand age ……………….years Area of stand/ha…………………

Book keeper's name……………………….
species:……………………….............……..

Tree Number	Dbh (Cm)	Total Height cm	Merchantable Height cm	Diameter at the base cm	Diameter middle cm	Diameter at the top

APPENDIX 2: SOURCE CODE

```
/*
 * Gamma_DistributionView.java
 */
package gamma_distribution;
import org.jdesktop.application.Action;
import org.jdesktop.application.ResourceMap;
import org.jdesktop.application.SingleFrameApplication;
import org.jdesktop.application.FrameView;
import org.jdesktop.application.TaskMonitor;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.Timer;
import javax.swing.Icon;
import javax.swing.JDialog;
import javax.swing.JFrame;

/**
 * The application's main frame.
 */
public class Gamma_DistributionView extends FrameView {

public Gamma_DistributionView(SingleFrameApplication app) {
    super(app);
    initComponents();

    // status bar initialization - message timeout, idle icon and busy animation, etc
    ResourceMap resourceMap = getResourceMap();
    int messageTimeout = resourceMap.getInteger("StatusBar.messageTimeout");
    messageTimer = new Timer(messageTimeout, new ActionListener() {
        public void actionPerformed(ActionEvent e) {
            statusMessageLabel.setText("");
        }
```

```
        });
        messageTimer.setRepeats(false);
        int busyAnimationRate =
resourceMap.getInteger("StatusBar.busyAnimationRate");
        for (int i = 0; i < busyIcons.length; i++) {
            busyIcons[i] = resourceMap.getIcon("StatusBar.busyIcons[" + i + "]");
        }
        busyIconTimer = new Timer(busyAnimationRate, new ActionListener() {
            public void actionPerformed(ActionEvent e) {
                busyIconIndex = (busyIconIndex + 1) % busyIcons.length;
                statusAnimationLabel.setIcon(busyIcons[busyIconIndex]);
            }
        });
        idleIcon = resourceMap.getIcon("StatusBar.idleIcon");
        statusAnimationLabel.setIcon(idleIcon);
        progressBar.setVisible(false);

        // connecting action tasks to status bar via TaskMonitor
        TaskMonitor taskMonitor = new TaskMonitor(getApplication().getContext());
        taskMonitor.addPropertyChangeListener(new
java.beans.PropertyChangeListener() {
            public void propertyChange(java.beans.PropertyChangeEvent evt) {
                String propertyName = evt.getPropertyName();
                if ("started".equals(propertyName)) {
                    if (!busyIconTimer.isRunning()) {
                        statusAnimationLabel.setIcon(busyIcons[0]);
                        busyIconIndex = 0;
                        busyIconTimer.start();
                    }
                    progressBar.setVisible(true);
                    progressBar.setIndeterminate(true);
                } else if ("done".equals(propertyName)) {
                    busyIconTimer.stop();
```

```
                statusAnimationLabel.setIcon(idleIcon);
                progressBar.setVisible(false);
                progressBar.setValue(0);
            } else if ("message".equals(propertyName)) {
                String text = (String)(evt.getNewValue());
                statusMessageLabel.setText((text == null) ? "" : text);
                messageTimer.restart();
            } else if ("progress".equals(propertyName)) {
                int value = (Integer)(evt.getNewValue());
                progressBar.setVisible(true);
                progressBar.setIndeterminate(false);
                progressBar.setValue(value);
            }
        }
    });
}

@Action
public void showAboutBox() {
    if (aboutBox == null) {
        JFrame mainFrame =
Gamma_DistributionApp.getApplication().getMainFrame();
        aboutBox = new Gamma_DistributionAboutBox(mainFrame);
        aboutBox.setLocationRelativeTo(mainFrame);
    }
    Gamma_DistributionApp.getApplication().show(aboutBox);
}
/** This method is called from within the constructor to
 * initialize the form.
 * WARNING: Do NOT modify this code. The content of this method is
 * always regenerated by the Form Editor.
 */
@SuppressWarnings("unchecked")
```

```
// <editor-fold defaultstate="collapsed" desc="Generated Code">
private void initComponents() {

    mainPanel = new javax.swing.JPanel();
    jDesktopPane1 = new javax.swing.JDesktopPane();
    jInternalFrame1 = new javax.swing.JInternalFrame();
    jPanel1 = new javax.swing.JPanel();
    jLabel1 = new javax.swing.JLabel();
    alpha = new javax.swing.JTextField();
    jLabel2 = new javax.swing.JLabel();
    beta = new javax.swing.JTextField();
    jLabel3 = new javax.swing.JLabel();
    N = new javax.swing.JTextField();
    proceed = new javax.swing.JButton();
    jScrollPane1 = new javax.swing.JScrollPane();
    result = new javax.swing.JTextArea();
    menuBar = new javax.swing.JMenuBar();
    javax.swing.JMenu fileMenu = new javax.swing.JMenu();
    javax.swing.JMenuItem exitMenuItem = new javax.swing.JMenuItem();
    javax.swing.JMenu helpMenu = new javax.swing.JMenu();
    javax.swing.JMenuItem aboutMenuItem = new javax.swing.JMenuItem();
    statusPanel = new javax.swing.JPanel();
    javax.swing.JSeparator statusPanelSeparator = new javax.swing.JSeparator();
    statusMessageLabel = new javax.swing.JLabel();
    statusAnimationLabel = new javax.swing.JLabel();
    progressBar = new javax.swing.JProgressBar();

    mainPanel.setName("mainPanel"); // NOI18N

    jDesktopPane1.setName("jDesktopPane1"); // NOI18N
```

```
        org.jdesktop.application.ResourceMap resourceMap =
org.jdesktop.application.Application.getInstance(gamma_distribution.Gamma_Distrib
utionApp.class).getContext().getResourceMap(Gamma_DistributionView.class);
        jInternalFrame1.setTitle(resourceMap.getString("jInternalFrame1.title")); //
NOI18N
        jInternalFrame1.setName("jInternalFrame1"); // NOI18N
        jInternalFrame1.setVisible(true);

        jPanel1.setName("jPanel1"); // NOI18N
        jPanel1.setLayout(null);

        jLabel1.setText(resourceMap.getString("jLabel1.text")); // NOI18N
        jLabel1.setName("jLabel1"); // NOI18N

        alpha.setText(resourceMap.getString("alpha.text")); // NOI18N
        alpha.setName("alpha"); // NOI18N

        jLabel2.setText(resourceMap.getString("jLabel2.text")); // NOI18N
        jLabel2.setName("jLabel2"); // NOI18N

        beta.setText(resourceMap.getString("beta.text")); // NOI18N
        beta.setName("beta"); // NOI18N

        jLabel3.setText(resourceMap.getString("jLabel3.text")); // NOI18N
        jLabel3.setName("jLabel3"); // NOI18N

        N.setText(resourceMap.getString("N.text")); // NOI18N
        N.setName("N"); // NOI18N

        proceed.setText(resourceMap.getString("proceed.text")); // NOI18N
        proceed.setName("proceed"); // NOI18N
        proceed.addActionListener(new java.awt.event.ActionListener() {
            public void actionPerformed(java.awt.event.ActionEvent evt) {
```

```
                proceedActionPerformed(evt);
            }
        });

        jScrollPane1.setName("jScrollPane1"); // NOI18N

        result.setColumns(20);
        result.setRows(5);
        result.setName("result"); // NOI18N
        jScrollPane1.setViewportView(result);

        javax.swing.GroupLayout jInternalFrame1Layout = new
javax.swing.GroupLayout(jInternalFrame1.getContentPane());
        jInternalFrame1.getContentPane().setLayout(jInternalFrame1Layout);
        jInternalFrame1Layout.setHorizontalGroup(

jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LE
ADING)
            .addGroup(jInternalFrame1Layout.createSequentialGroup()
                .addContainerGap()

.addGroup(jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Ali
gnment.LEADING)
                    .addComponent(jPanel1,
javax.swing.GroupLayout.Alignment.TRAILING,
javax.swing.GroupLayout.DEFAULT_SIZE, 434, Short.MAX_VALUE)
                    .addGroup(jInternalFrame1Layout.createSequentialGroup()

.addGroup(jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Ali
gnment.LEADING)
                            .addComponent(jLabel1)
                            .addComponent(jLabel2)
                            .addComponent(jLabel3))
```

```
                    .addGap(26, 26, 26)

.addGroup(jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Ali
gnment.LEADING, false)
                        .addComponent(N)
                        .addComponent(beta)
                        .addComponent(alpha, javax.swing.GroupLayout.DEFAULT_SIZE,
59, Short.MAX_VALUE)
                        .addComponent(proceed))))
                .addContainerGap())
            .addGroup(jInternalFrame1Layout.createSequentialGroup()
                .addComponent(jScrollPane1, javax.swing.GroupLayout.DEFAULT_SIZE,
434, Short.MAX_VALUE)
                .addGap(20, 20, 20))
        );
        jInternalFrame1Layout.setVerticalGroup(

jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LE
ADING)
            .addGroup(javax.swing.GroupLayout.Alignment.TRAILING,
jInternalFrame1Layout.createSequentialGroup()
                .addContainerGap()

.addGroup(jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Ali
gnment.BASELINE)
                    .addComponent(jLabel1)
                    .addComponent(alpha, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
                .addGap(18, 18, 18)

.addGroup(jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Ali
gnment.BASELINE)
```

```
                    .addComponent(jLabel2)
                    .addComponent(beta, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
                .addGap(18, 18, 18)

.addGroup(jInternalFrame1Layout.createParallelGroup(javax.swing.GroupLayout.Ali
gnment.BASELINE)
                    .addComponent(jLabel3)
                    .addComponent(N, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
                .addGap(27, 27, 27)
                .addComponent(proceed)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)
                .addComponent(jScrollPane1, javax.swing.GroupLayout.DEFAULT_SIZE,
220, Short.MAX_VALUE)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)
                .addComponent(jPanel1, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE)
                .addContainerGap())
        );

        jInternalFrame1.setBounds(0, 0, 470, 430);
        jDesktopPane1.add(jInternalFrame1,
javax.swing.JLayeredPane.DEFAULT_LAYER);

        javax.swing.GroupLayout mainPanelLayout = new
javax.swing.GroupLayout(mainPanel);
        mainPanel.setLayout(mainPanelLayout);
```

```
        mainPanelLayout.setHorizontalGroup(

mainPanelLayout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
            .addComponent(jDesktopPane1, javax.swing.GroupLayout.DEFAULT_SIZE,
570, Short.MAX_VALUE)
        );
        mainPanelLayout.setVerticalGroup(

mainPanelLayout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
            .addComponent(jDesktopPane1, javax.swing.GroupLayout.DEFAULT_SIZE,
441, Short.MAX_VALUE)
        );

        menuBar.setName("menuBar"); // NOI18N

        fileMenu.setText(resourceMap.getString("fileMenu.text")); // NOI18N
        fileMenu.setName("fileMenu"); // NOI18N

        javax.swing.ActionMap actionMap =
org.jdesktop.application.Application.getInstance(gamma_distribution.Gamma_Distrib
utionApp.class).getContext().getActionMap(Gamma_DistributionView.class, this);
        exitMenuItem.setAction(actionMap.get("quit")); // NOI18N
        exitMenuItem.setName("exitMenuItem"); // NOI18N
        fileMenu.add(exitMenuItem);

        menuBar.add(fileMenu);

        helpMenu.setText(resourceMap.getString("helpMenu.text")); // NOI18N
        helpMenu.setName("helpMenu"); // NOI18N

        aboutMenuItem.setAction(actionMap.get("showAboutBox")); // NOI18N
```

```
        aboutMenuItem.setName("aboutMenuItem"); // NOI18N
        helpMenu.add(aboutMenuItem);

        menuBar.add(helpMenu);

        statusPanel.setName("statusPanel"); // NOI18N

        statusPanelSeparator.setName("statusPanelSeparator"); // NOI18N

        statusMessageLabel.setName("statusMessageLabel"); // NOI18N


statusAnimationLabel.setHorizontalAlignment(javax.swing.SwingConstants.LEFT);
        statusAnimationLabel.setName("statusAnimationLabel"); // NOI18N

        progressBar.setName("progressBar"); // NOI18N

        javax.swing.GroupLayout statusPanelLayout = new
javax.swing.GroupLayout(statusPanel);
        statusPanel.setLayout(statusPanelLayout);
        statusPanelLayout.setHorizontalGroup(

statusPanelLayout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADI
NG)
            .addComponent(statusPanelSeparator,
javax.swing.GroupLayout.DEFAULT_SIZE, 570, Short.MAX_VALUE)
            .addGroup(statusPanelLayout.createSequentialGroup()
                .addContainerGap()
                .addComponent(statusMessageLabel)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED, 400,
Short.MAX_VALUE)
```

```
            .addComponent(progressBar,
javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)
            .addComponent(statusAnimationLabel)
            .addContainerGap())
      );
      statusPanelLayout.setVerticalGroup(

statusPanelLayout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADI
NG)
         .addGroup(statusPanelLayout.createSequentialGroup()
            .addComponent(statusPanelSeparator,
javax.swing.GroupLayout.PREFERRED_SIZE, 2,
javax.swing.GroupLayout.PREFERRED_SIZE)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED,
javax.swing.GroupLayout.DEFAULT_SIZE, Short.MAX_VALUE)

.addGroup(statusPanelLayout.createParallelGroup(javax.swing.GroupLayout.Alignme
nt.BASELINE)
               .addComponent(statusMessageLabel)
               .addComponent(statusAnimationLabel)
               .addComponent(progressBar,
javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
            .addGap(3, 3, 3))
      );

      setComponent(mainPanel);
```

```
    setMenuBar(menuBar);
    setStatusBar(statusPanel);
}// </editor-fold>

private void proceedActionPerformed(java.awt.event.ActionEvent evt) {
    //getting parameters
    try{
        float aph=Float.parseFloat(alpha.getText());
        float bet=Float.parseFloat(beta.getText());
        int n=Integer.parseInt(N.getText());

        Gamma(n,aph,bet);

    }catch(Exception e){
        result.setText(e.toString());
    }

}
private void Gamma(int nval, float alpha, float beta) throws Exception{
    g=new double[nval];
    final double  theta=4.5;
    int n=0;
    double u1,u2,v,y,z,w;
    double a=1/Math.sqrt(2*alpha-1);
    double b=alpha-Math.log10(4);
    double q=alpha+(1/a);
    double d=1+Math.log10(theta);
            //g=new double[nval];
    for(int i=n;i<=nval-1;i++){
        u1=Math.random();
        u2=Math.random();
        v=a*Math.log10(u1/(1-u1));
        y=alpha*Math.exp(v);
```

```
        z=Math.pow(u1, 2)*u2;
        w=(b+q)*(v-y);
        if((w+d)-(theta*z)>=0){
          g[i]=beta*y;
           a=1/Math.sqrt(2*alpha-1);
           b=alpha-Math.log10(4);
           q=alpha+(1/a);
           d=1+Math.log10(theta);
           //n++;
        }else if(w<=Math.log10(z)){
          g[i]=beta*y;
           a=1/Math.sqrt(2*alpha-1);
           b=alpha-Math.log10(4);
           q=alpha+(1/a);
           d=1+Math.log10(theta);
           //n++;
        }else{
          // g[i]=3.5;

        }
        //n++;
    }
    //for(int i=1; i<nval-1; i++){
    //       g[i]=Math.random();
    //}
    result.setText("");
    for(int i=n; i<nval; i++){
           result.append(g[i]+"\n");
    }
        //result.append(nval+"");

}
// Variables declaration - do not modify
```

```
    private javax.swing.JTextField N;
    private javax.swing.JTextField alpha;
    private javax.swing.JTextField beta;
    private javax.swing.JDesktopPane jDesktopPane1;
    private javax.swing.JInternalFrame jInternalFrame1;
    private javax.swing.JLabel jLabel1;
    private javax.swing.JLabel jLabel2;
    private javax.swing.JLabel jLabel3;
    private javax.swing.JPanel jPanel1;
    private javax.swing.JScrollPane jScrollPane1;
    private javax.swing.JPanel mainPanel;
    private javax.swing.JMenuBar menuBar;
    private javax.swing.JButton proceed;
    private javax.swing.JProgressBar progressBar;
    private javax.swing.JTextArea result;
    private javax.swing.JLabel statusAnimationLabel;
    private javax.swing.JLabel statusMessageLabel;
    private javax.swing.JPanel statusPanel;
    // End of variables declaration
    private final Timer messageTimer;
    private final Timer busyIconTimer;
    private final Icon idleIcon;
    private final Icon[] busyIcons = new Icon[15];
    private int busyIconIndex = 0;
    private double g[];
    private JDialog aboutBox;
}
```

APPENDIX 3: CONTRIBUTIONS TO KNOWLEDGE

The study has contributed to knowledge in the following ways:

1. An automated system was developed using Java programming language to predict growth and yield based on the gamma distribution function.
2. The study established that gamma distribution function is flexible and has good predictive ability on height, basal area and volume.
3. The study has provided useful information on attributes of *Tectona grandis* which can be obtained for the development of management practices. These attributes are height, basal area and volume of the tree.
4. The Java program was able to give better prediction of height, basal area and volume than height, basal area and volume growth and yield models,