STOCHASTIC MODELLING OF WIND LOADS IN A WELL BEHAVED WIND CLIMATE (NIGERIA AS A CASE STUDY)

BY

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DEDICATION

This work is dedicated to two sets of people.

First to my Lord Jesus Christ who crossed culture from Heaven to Earth to show the nations the Way to eternal life and to all His disciples who in following His example have had to also cross culture in order to proclaim the same tidings of great joy.

The second group include all His disciples yet "unborn" who are of the desert tribes and who by God's enabling power and Spirit I look forward to being instrumental in His hands to their "birth". They are those who through Christ's life in us and His ministry committed to us will be brought to worship Him in their own tongues and languages from the desert tribes. It was for the sake of this second group I came to Ahmadu Bello University for this higher degree. I patiently look forward to seeing your gathering together unto Him and in His Name.

To both groups: As I worked on this project, thoughts concerning you filled my heart.

Anyanwu, U. D.

June, 1996.

DECLARATION

I, Uchenna Daniel Anyanwu, do hereby declare that this thesis is my own work and, to the best of my knowledge, has not been previously submitted in any form by anybody for the award of any degree.

All works, opinions and ideas other than mine have been fully acknowledged.

Sign. Allched Date. June 21st, 1996

ANYANWU U. D.

CERTIFICATION

This thesis entitled **"Stochastic Modelling Of Wind Loads In A Well Behaved Wind Climate (Nigeria As A Case Syudy)"** by **Anyanwu, Uchenna Daniel** meets the regulations governing the award of the degree of Master Of Science, M. Sc. (Structural Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Wind loading estimation is one facet of the entire design process. Wind speed as a climatic process which is time-dependent requires proper assessment in order to predict its speed for specified return periods. This requires a good understanding of the wind process within the lower atmosphere (where the designer of civil engineering structures has interest) and then modelling it by applying stochastic methods. This is basically what this thesis addresses.

The wind speed data for twenty (20) synoptic meteorological stations in Nigeria were collected and analyzed using statistical and probability approaches. The means, variances and coefficients of variation for all the stations were computed. An empirical selection of a most probable stochastic model based on the understanding of the underlying physical phenomenon and literature is done.

The selected empirical and theoretical model turned out to be the extreme maximum value Type I Probability model (EV-I), also referred to as the Gumbel distribution Type I of the largest values. The model is tested using the acquired data. The parameters of the model are estimated using three methods of parameter estimation. These are then used in the statistical testing for the *goodness-of-fit*. The tests employed validate the selected model. The results of the predictions performed for twelve (12) return periods for all the stations are compared with those obtained by Soboyejo (1971) who worked on the distribution of extreme wind in Nigeria. The results from this present work are found to be more acceptable.

It is concluded that the use of design wind speed estimates higher than the more realistic estimates implies allocating scarce resources to areas having no necessary need, and therefore does not give the appropriate balance between safety and economy. The use of the

new wind speed estimates developed in this work is advocated and the need to undertake further research into the stochastic modelling of wind loads taking into consideration the subject of wind directionality is recommended.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL REMARKS

Structures are usually subjected to different types of loads. These can be broadly classified as follows (Melchers, 1987):

a) Loads due to "acts of God" such as wind loads, wave loads on off shore structures, snow loads and seismic loads.

b) Loads due to "acts of man" such as dead and super-imposed live loads.

Factors such as location of structure, intended use and expected lifetime of structure together determine the magnitude of these loads for any given structure. Methods of assessment and estimation of the magnitude of the different types of loads that may be acceptably considered as acting on a structure vary, depending on what type of load is being considered.

Wind or the natural movement of air of any velocity with respect to the earth's surface, exerts some degree of force on any object, body or obstacle standing on the path of its direction. Such objects, bodies or obstacles can be any structure; and for safety and functionality of such structure, it must be designed to withstand (in addition to other types of loads that will act on it), the action of the wind. In view of this therefore, the structural engineer has an appreciable interest on the subject of wind, its nature, measurement, variation with time, and how the knowledge of these among others can help him to properly assess or estimate what loading can be acceptably and reliably considered to act on a given structure which he must design both for safety and economy.

Wind is a climatic process which varies in any given location with time, and because it is a continuous time dependent process, it can be modelled stochastically. A stochastic process V(t) is a random function of time (t) such that for any point in time the value of V is a random variable (Melchers, 1987). It is an index set [V(t),;t ∈T] of random variables V(t), where all V(t) are defined within the sample space. It should be noted that in a stochastic process, both the variable V(t) and time (t) are variables (Thoft-Christensen and Baker, 1982). The set T to which t belongs is typically a time interval. It can be any kind of finite set, say the number of years, T which a specified structure will be expected to last, that is the lifetime of the structure.

1.2 PRESENT PRACTICE IN NIGERIA

In Nigeria, approaches used to estimate wind loads vary depending on the individual designers and the approach they are familiar with. However, the Nigerian Standards Organization has regulations for wind load estimation for structures to be constructed in Nigeria and these regulations are stipulated in the Nigerian Code of Practice NCP1: Part 3 1972, Section 11: Wind Loading. The design wind velocities specified and tabulated in the code are based on highest wind gust velocities recorded by the Nigerian Meteorological Services (Nigerian Code of Practice NCP1: Part 3, 1972). Besides the deterministic approach to wind load estimation by this code regulation, it has been shown that the code underestimates the wind loads that may be considered acting on structures (Asante-Nimako, 1988).

Asante-Nimako (1988) also showed that the regulations of the NCP1: Part 3 as far as wind loading is concerned is not comprehensive and it estimates design wind velocities without considering such variabilities as height. Furthermore, adequate use and application of

statistical techniques and probability concepts which provide the most reliable methods or models of wind load estimation are not applied. All available appraisals of the NCP1: Part 3 Section 11 show that it is deficient and therefore requires the recalibration of wind load standards. Unfortunately, a few, yet impure modifications are presently being applied by engineers and designers in Nigeria through the use of topography factor S_1, terrain factor S_2 and statistical factor S_3 as recommended in the British Standards Institution Code of Practice CP3: Chapter V Part 2: Wind Loads.

Mayne and Cook (1980) have shown that the UK Code of Practice CP3: Chapter V Part 2: Wind Loads (1972) possesses some deficiencies in itself as a result of the mixing of deterministic and probabilistic methods. It can then be seen that this problem is worsened in the Nigerian context by the mixture of a standard which is deterministic and another which is a mixture of both deterministic and probabilistic methods. It can then be said with some degree of confidence that the present methods for estimating wind loads in Nigeria do not provide realistic and reliable assessment of the loading on structures.

1.3 TRENDS AND RECENT DEVELOPMENTS

Traditional static deterministic procedures have been widely used in several engineering designs. During the last three decades the application of statistical and probability rationale have been employed to describe loading problems. Basically, we know that the process of structural design involves the analysis of the loads that will be imposed on the structure during its lifetime and the assessment and proportioning of suitable structural members that will safely and satisfactorily support the loads within the minimum possible cost regime. Since loads imposed by nature or due to acts of God, such as wind load, are the most variable and usually difficult to limit, and have been said to account for the greater

percentage of world's structural failures (Taylor, 1971), it then follows that these loads should be realistically and reliably estimated in the process of design.

Deterministic approaches in the estimation of random loads has been found to be an unrealistic method. Hence, statistical and probability theories are now being used in description of such loads. For many years, this approach has been used in aircraft design and other fields, and presently a lot of researchers in several countries are developing interests in this method. The days of complete reliance on steady-state concepts are behind us in wind engineering studies and practice (Robertson and Flynn, 1980). However, the need to apply probabilistic techniques for wind load assessment which is becoming generally widespread in engineering designs and planning, has not yet been given adequate attention in Nigeria. Several building codes and standards that have been developed or that are being developed within the last two decades deal with the broad application of probabilistic concepts associated with the dynamic characteristics of the structure, the random and turbulent characteristics of wind as well as the dynamic component of structure response (Robertson and Flynn, 1980).

Furthermore, there has been a growing interest among civil engineering scholars in the field of structural safety and reliability analysis. The objective of structural reliability is to develop design criteria and verification procedures aimed at ensuring that structures built according to specification perform acceptably from the view point of safety and serviceability. This objective can be realized by making sure that the probability of failure P_f is equal to or less than some benchmark value referred to as target failure probability. Simply put, the measure of reliability of structure or member(s) of the same is the difference between unity and the probability of failure (that is $R; = ;1 - P_f$). (Simiu and Scanlan, 1986). R is the

reliability measure and it is the probability that the structure or its element(s) will survive when the load is applied.

Now in order to estimate the reliability, the probability of failure, P_f, must be known. In turn, to be able to do this, loads have to be described probabilistically among other things. In view of all these needs to use and apply probabilistic concepts, one can see why it is essential to contextualize the Nigerian wind load estimation techniques to follow the trends of growing wind engineering practice.

1.4 PROBLEMS AND RESEARCH AIM

In order to estimate wind loads on any particular structure in Nigeria, one may resort to any of the following three approaches:

(a) Use of the Nigerian Code of Practice without any reference to meteorological data

(b) Use of Isopleth maps for Nigeria, recommendations of the BSI Code of Practice CP3: Chapter V together with NCP1: Part 3, Section 11: Wind loads.

(c) Use of Isopleth maps and recommendations of BSI CP3: Chapter V only. Reference is not made to NCP1: Part 3.

It has been shown that the magnitude of the wind loads that may be regarded as acting on a particular structure evaluated from the use of the above three approaches differ (Asante-Nimako, 1988). Besides, the first and the second approaches assume that uniform wind pressure over the whole projected vertical surface are in direction of wind. This is of course, not the practical representation of the real state because the effect of wind force on structures increases with height.

Apart from variation of wind velocity profile with height, the variation with ground roughness, location and the stochastic characteristics of wind must be taken into consideration in any method that should be used for an appropriate, acceptable and reliable assessment of wind loads. The lack of consideration of some of these variations together with the empirical mixture of deterministic and probabilistic approaches in evaluating loads characterized by randomness constitute a problem as well as presents a challenge for research.

Hence the aim of this work is to develop a stochastic model that can be used to evaluate reliable and acceptable wind loads that can be considered as suitable for design purposes for structures in a well behaved wind climate using Nigeria's meteorological data as a typical example. It will also serve as a demonstration of the procedures leading to the development of such a model which can be followed to arrive at suitable stochastic models in other well behaved wind climates. Probabilistic rationale and statistical approaches suitable for time dependent processes as wind will be employed since such rationale has already been recognized as appropriate and most suitable for use in reliability analysis and design loads estimation.

1.5 SCOPE AND LIMITATIONS

A simple classification of structures with respect to the degree of response or sensitivity to wind, fall into two classes namely: static and dynamic. The former are structures where dynamic response caused by wind loads is negligible and may not enter into the design consideration while the latter are those in which the stiffness and damping are such that movement will occur under wind excitation and therefore demands consideration of such a response in design. A broader classification however, has been given by Harris (1980).

Static structures comprise by far the most common structures covered by most wind loading codes and standards world-wide. Albeit, the development of design methods for dynamic and aero-elastic structures raises many problems and poses a lot of challenges, yet there exist many more data available for the development of wind loading models for static structures than for dynamic ones. In view of the fore-going , the scope of this work will be within the boundaries of static structures.

Limitations are expected from the quantity of meteorological data available for the statistical analysis. A 50-year return period is always specified for design of all permanent structures. The American National Standards Institute (ANSI) gives a recommendation of return periods for design of different structures. This is reproduced from Gould's and Abu-Sitta's work (1980) and shown in Table 1.1

Table 1.1 *Return Period For The Design Of Structures.*

	CONDITION OF STRUCTURE	R (YEARS)
A	Structures having no human occupants or negligible risk to human life.	25
B	All permanent structures except those presenting a high degree of sensitivity to wind and an unusually high degree of hazard to life and property in case of failure.	50
C	Exceptions to B.	100

Generally, the sample size used in modelling determines its suitability and the probability distribution most likely to be chosen as the model. Sample size is the number of years for which extreme wind data is available and collected. The Nigerian Meteorological Services started taking meteorological measurements in 1953 for some stations and as time went on some other stations were opened. 1953 to 1993 (inclusive) gives a sample size of

forty-one (41). The limited quantity of data, therefore, is envisaged as a limitation. However, a minimum sample size of twenty (20) has been suggested by Simiu and Scanlan (1986) while Fasanmi (1985) recommended a sample size of at least twenty-five (25).

1.6 METHODOLOGY OF STUDY

The modelling process follows a methodological sequence namely:

1. Review of relevant literature,
2. Acquisition of meteorological data and
3. Stochastic modelling.

Earlier work that has been done by researchers both in Nigeria and other countries on this subject are reviewed. Besides, a fundamental background of wind engineering is given. The procedure involved in acquiring the meteorological data for modelling and the rationale behind the choice of meteorological stations for which data is collected are discussed in a separate chapter.

The stochastic modelling which is the nucleus of this work involves the selection of the appropriate probability distribution and the estimation of the distribution parameters. Estimates of the means, variances, standard deviations and coefficients of variations for each meteorological station are evaluated. To facilitate data analysis, use is made of a computer statistical package.

CHAPTER TWO

FUNDAMENTALS OF WIND ENGINEERING

(REVIEW OF RELEVANT LITERATURE: PART I)

2.1 GENERAL REMARKS

A good wind load modelling evolves from a good knowledge of the wind structure. The wind structure can possess macro-, meso- or micro-meteorological characteristics. Micro-meteorological studies deal with details of wind flow within the earth's boundary layer and such studies are very valuable not only to the meteorologist in his understanding of the properties and behaviour of the earth's atmosphere, but much more to engineers and designers who apply the knowledge to solve several physical problems. In this chapter, a close review of basic micro-meteorological subjects very relevant to determination of appropriate wind loading for civil engineering structures is done. It is only the wind regime within the lower layer of the atmosphere (the *troposphere*), or to be more precise, within the earth's boundary that is of significant interest to the designer of civil engineering structures. Hence, the restriction of the review to micro-meteorological subjects of wind.

The review includes a short recap of the historical background and emergence of this branch of engineering - Wind Engineering. The principles governing the occurrence of wind, an overview of global circulation, a brief classification of wind and the variation of mean wind speed with height and surface roughness are discussed in this chapter. These will give

an overview of the basics of Wind Engineering as well as provide the fundamental knowledge and understanding of the wind structure.

2.2 HISTORICAL BACKGROUND

Wind has been defined since the sixth (6th) century as air motion within the earth's atmosphere. The sun is recognized as the basic source of wind's energy. Winds are caused primarily by differences of temperature between various points of equal elevation in the atmosphere (Davenport, 1965; Melaragno, 1982; Simiu and Scanlan, 1986).

Man's exploration into the nature and structure of wind began with mythology and continued with the emergence of the physical sciences - especially meteorology and atmospheric physics. However, a real understanding did not emerge until the eighteenth (18th) century. Edmud Halley, an English astronomer in 1680 recognized that solar heating of the atmosphere over the equator was the energy source for tropical winds. Scientific contributions to the knowledge of wind within the *troposphere* has been made by several people including Hardley; Guspard Gustav de Coriolis (1792-1843), a French mathematical physicist; William Ferrell (1817-1891); Ekman, Prandtl of Germany, Taylor and Sir O. G. Sutton of England (Melarangro, 1982). The history of wind study and loads resulting from wind action has followed a sporadic pattern of both experimental, empirical and analytical approaches over a period of four centuries (Sachs, 1978). For example, Isaac Newton postulated an empirical relationship between wind force and its velocity which he gave as:

$$\textit{Wind Force} \approx CV^2 \qquad \text{.....(2.1)}$$

where V is the wind velocity and C the coefficient of proportionality (also referred to as shape factor).

Furthermore, structural failures caused by the action of wind such as the Tay Bridge and Tacoma Narrows Bridge disasters in 1879 and 1940 respectively triggered off more precise studies, investigations and experiments into wind loading of structures. Demand for wind speed data for statistical analysis increased. Wind tunnel investigations and experiments evolved from which the statistics of extremes became useful and was applied for estimation of wind speed. As wind speed data increased world-wide, the statistics of extremes found wide application in wind speed estimation and spectral analysis.

The present emphasis since the last two decades has been on the use of wind tunnel investigations to model atmospheric turbulence and the investigation of the dynamic response of structures to wind action. Besides, studies are continuing on the modelling of extreme winds in extra-ordinary wind climates; that is, climates that are hurricane- and or tornado-prone. Probabilistic, though rigorous, methods of taking the effect of wind direction into consideration in design is also receiving attention of study in wind engineering by scholars and researchers.

Perhaps it may be conveniently concluded that Wind Engineering became recognized as a branch of engineering following the emergence of International Conferences On Wind Effects On Buildings And Structures. The first of such conferences was held at the National Physical Laboratory Teddington, Middlesex, England between 26th and 28th, June, 1963. Subsequent international conferences on Wind Engineering have followed, thereby, providing an international platform for deliberation and exchange of knowledge and research findings in this field.

2.3 THE OCCURRENCE OF WIND

It has already been indicated that the sun is the primary source of energy for wind. Kraght (1976), noted that wind occurs as a result of thermal convection due to the heat of the sun. Temperature in the earth's atmosphere differs from place to place depending on the position of the place relative to the sun. This thermal differences cause imbalance in the atmosphere. So wind is a necessary circulation of the atmosphere to bring about an equilibrium of the imbalance. This implies that any movement of the air in one direction must be offset or balanced by a return current elsewhere. Hence, it is the variable heating of the earth's surface by the sun and the subsequent thermal currents initiated by such solar heating that are the fundamental causes of the motion of air (wind) within the *troposphere*.

A simplified model to illustrate atmospheric circulation was proposed by Humphreys (1929,1940,1964). Sir Sutton (1960) of England also gave an idealized square circuit to illustrate the basic weather pattern in both vertical and horizontal planes. Both are based on the physics of atmospheric thermodynamics. An improved graphical representation of these models is shown in Fig. 2.1 as taken from Kraght (1976).

Houghton and Carruthers (1976) gave a description of the simplified global atmospheric circulation. The earth's axis of rotation being inclined to the plane of its orbit around the sun, the average annual intensity of solar radiation and consequently atmospheric temperature becomes higher in the regions around and closer to the equatorial belt than those regions farther away from it (that is, the temperate and polar regions). That explains why the regions between the tropics of Cancer (about 30^0 latitude north of the equator) and Capricorn (about 30^0 latitude south of the equator), usually referred to as the tropics, have relatively

hotter climates than the temperate and polar regions which are closer to the poles. The solar radiation, much of which passes through the earth's atmosphere unreflected and unabsorbed,

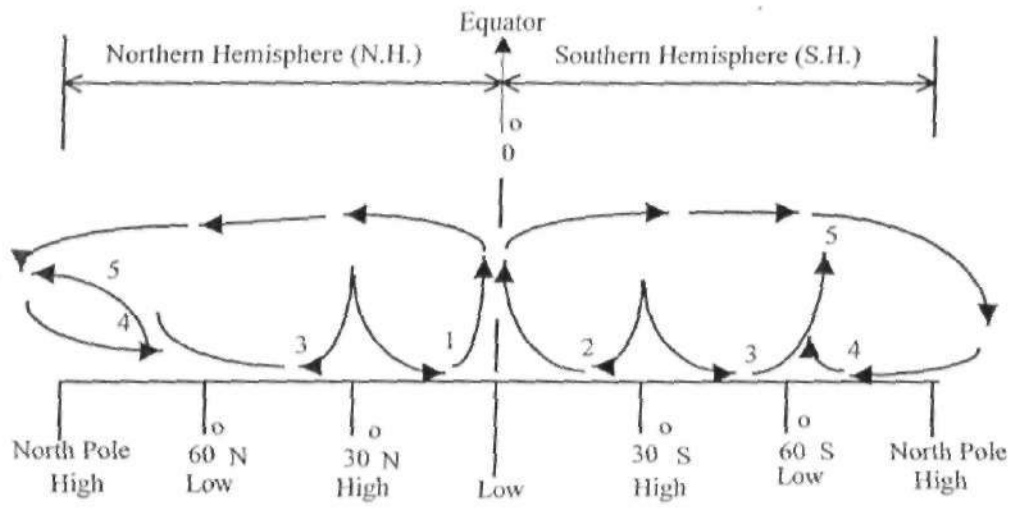

Fig. 2.1 *Vertical Cross-Section Through The Troposphere From The Equator To The Poles, Showing Air Movement At And Above The Earth's Surface.*

Legend	1	2	3	4	5
	North-East Trade Winds	South-East Trade winds	Westerly Winds	Easterly Winds	Polar Fronts

is absorbed by the earth's surface. The earth is heated up by this and then emits energy to the atmosphere in form of terrestrial radiation (that is, a re-radiation of the solar radiation incident on it back to the atmosphere). Globally, the temperature is higher in the tropics, so hot air rises over the tropics to the immediate upper layer of the *troposphere* and forms jet streams of air at the uppermost layer. The jet of air then move toward the poles because of the thermal imbalance (temperature variation).

Simiu and Scanlan (1986) noted that the thermodynamic processes that lead to the occurrence of wind are determined by other factors besides the variable heating of the earth. These factors have also been identified by meteorologists and atmospheric physicists (Houghton and Carruthers, 1976; Kraght, 1976). They include differences of atmospheric

pressure (the pressure gradient), deviating force due to the rotation of the earth (Coriolis Force), effect of surface friction, centrifugal effects on winds with circular paths. All the above factors modify the global circulatory pattern described already. Furthermore, the influence of ground surface characteristics also has its own toll on air motion. A very brief look at these factors mentioned may be necessary.

2.3.1 THE EFFECT OF PRESSURE GRADIENT ON WIND

Pressure is known to increase more rapidly with decreasing altitude. A collorary is that vertical pressure decreases as altitude increases. Though the magnitude of vertical pressure variation can be large, McIntosh and Thom (1973) points out that variation of pressure in the horizontal is more important to practising meteorologists. It is the difference in atmospheric pressure between points of the same altitude that is referred to as the horizontal pressure gradient. and it is the major significant force that initiates and sustains horizontal air motion, that is, wind (Weisberg, 1976; McIntosh and Thom, 1973; Houghton and Carruthers, 1976; Simiu and Scanlan, 1986; Byers, 1974).

The net force per unit mass exerted by the horizontal pressure gradient is often called the pressure gradient force which is denoted by:

$$F_{pg} = -\frac{1}{\rho}\frac{\delta p}{\delta n} \qquad \text{..... (2.2)}$$

where ρ is the air density, p is the mean pressure acting on the lower and higher faces of an infinitesimal volume of air, and n is the horizontal direction in which the pressure increases most rapidly.

The higher the pressure gradient force, the higher will be the speed of wind. Air tends to move from regions of high pressure to regions of low pressure. On meteorological maps, lines are drawn joining points of equal atmospheric pressure. These lines are called Isobars and it is from them the horizontal pressure gradient may be read or obtained.

2.3.2 The Effects Of The Deviating Force (Coriolis Force) Due To Earth's Rotation

Gaspard Gustav de Coriolis demonstrated in 1844 the quantitative character of a certain force initiated by the rotation of the earth. This force deviates the path of bodies in motion (including wind) within the earth rightwards and leftwards in the northern and southern hemispheres respectively. This force named after Gaspard de Coriolis who demonstrated it is represented as follows:

$$F_c = m \times 2v\omega \sin\phi \qquad \text{.....(2.3)}$$

Where m is the mass of particle in motion; and the term $2v\omega\sin\phi$ is the acceleration of the particles in which v is the velocity,ω is the angular velocity vector of the earth[1], ϕ is the latitude of the point on the earth being considered. In the above equation, the term $2\omega\sin\phi$ which is a constant at any given point on the earth with a defined latitude angle ϕ is referred to as the Coriolis parameter, f denoted by:

$$f = 2\omega\sin\phi \qquad \text{.....(2.4)}$$

Hence if Equation (2.3) is re-written with this in mind, we obtain the Coriolis force as

$$\mathbf{F_c = m.v.f} \qquad \text{.....(2.5)}$$

Values of f given as functions of latitudes are given by Simiu and Scanlan (1986). This is shown in Table 2.1

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1. The earth's angular velocity is given as $2\pi \times \frac{366\frac{1}{4}}{365\frac{1}{4}} rads\ day^{-1} = 7.29 \times 10^{-5} rads^{-1}$. All points on the earth rotate in a west-east direction about the polar axis making ond complete revolution ($2\pi rads$) in a day. It makes one extra revolution round the sun in the course of the year.

Table 2.1 *Coriolis Parameter As Functions Of Latitudes (From Simiu And Scanlan, 1986)*[2]

Latitude (degrees)	$f = 2\omega \sin\phi \sec^{-1}$	Latitude (degrees)	$f = 2\omega \sin\phi \sec^{-1}$
5	0.1271×10^{-4}	50	1.1172×10^{-4}
10	0.2533×10^{-4}	55	1.1947×10^{-4}
15	0.3775×10^{-4}	60	1.2630×10^{-4}
20	0.4988×10^{-4}	65	1.3218×10^{-4}
25	0.6164×10^{-4}	70	1.3705×10^{-4}
30	0.7292×10^{-4}	75	1.4087×10^{-4}
35	0.8365×10^{-4}	80	1.4363×10^{-4}
40	0.9375×10^{-4}	85	1.4529×10^{-4}
45	1.0313×10^{-4}	90	1.4584×10^{-4}

Generally, $\mathbf{f} = 1.458 \times 10^{-4} \sin\phi \sec^{-1}$ .....(2.6)

The Coriolis force increases in direct proportion to the angle of the latitude as can be observed from Table 2.1. McIntosh and Thom (1973) note also that it increases in direct proportion to the wind velocity. The force acts at right angles to the wind, hence affecting its direction but not the speed.

2.3.3 The Effect Of Friction On Wind Speed

Moving air behaves in the same manner like moving fluid with respect to any boundary surface. At the interface between a moving fluid and a solid surface, viscosity shows itself in creating shear forces which oppose the direction and retard the speed of the motion of the fluid. The same effect occurs in the case of the surface of the earth and wind.

As wind stream passes over the surface of the earth, the action of viscosity comes into play reducing to almost zero, the speed of the wind adjacent to the surface. This frictional

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2. At the equator where $\phi = 0$, $\omega \sin\phi$ is zero , hence the coriolis parameter, f, is zero at the equator.

drag due to the surface of the earth is least over the oceans and seas whose surfaces are, on the average, much smoother than those of land areas roughened by hills, valleys, trees, buildings etc. It follows that the more irregular the surface and the greater the roughness, the lesser the wind speed. Besides, the effect of this frictional drag upon wind decreases with increasing height above ground level. So the speed increase that occurs along a vertical line is continuous from zero on the surface of the earth to a maximum some distance away from the ground. This is illustrated in Fig. 2.2

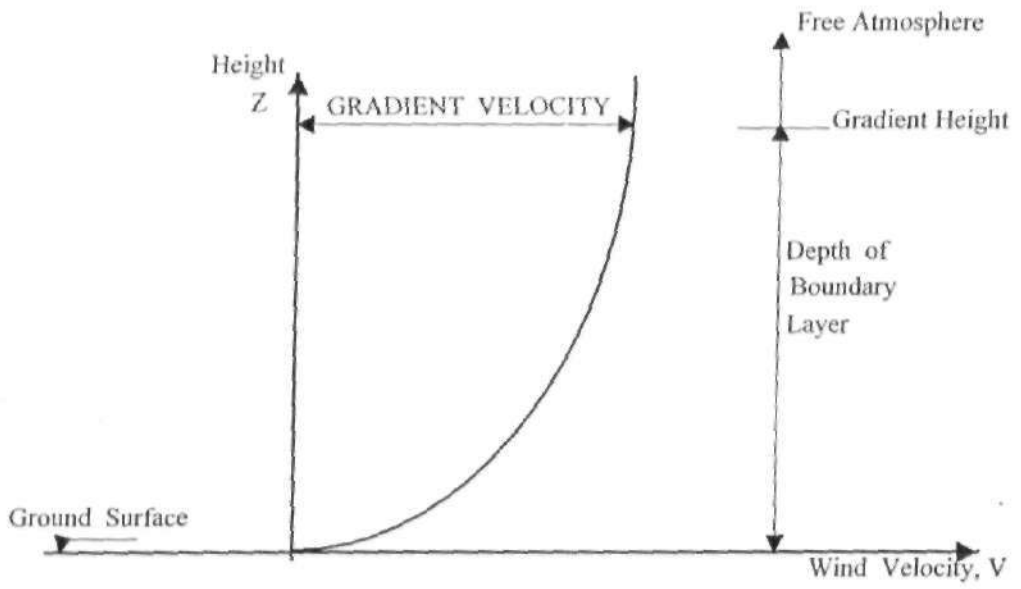

***Fig. 2.2** Variation Of Wind Velocity With Height.*

The velocity of wind continues to increase from zero on the earth's surface until it reaches a steady state at a certain elevation from the ground. The elevation at which the velocity ceases to increase as a result of a zero-effect of the frictional drag force is called the gradient height, and the velocity of wind at that height is referred to as the gradient velocity ($\mathbf{V_G}$). The height above ground level where the gradient wind velocity exists is also called the height of the boundary layer of the atmosphere, δ. Beyond this height, a frictionless wind balance is established and the wind then flows with the gradient velocity along lines of equal

pressure (isobars). The height above the boundary layer is referred to as the free atmosphere (Simiu and Scanlan, 1986; Houghton and Carruthers, 1976). The designer of Civil Engineering structures has interest on wind velocities within the boundary layer only.

It should be mentioned based on the foregoing review that the assumption of NCP:1: Part 3, Section 11 (Wind Loading) of uniform wind pressure 'over the entire vertical faces of the building' being designed has no scientific basis. So if practical design consideration of wind loading must be realistic, then the load must be adjusted along the vertical faces of a structure from the ground surface upward - especially in such towering and tall structures that will be sensitive to wind action.

So far in the consideration of the occurrence of wind and factors that affect it, we have met two main forces - the horizontal pressure gradient force and the Coriolis force. The third one is the centrifugal force which is the force that tends to keep the air motion in a circular or curved horizontal direction or path. The above mentioned forces balance up to produce the actual wind movement (Weisberg, 1976; Donn, 1975; Cole, 1975).

The scale of wind is extremely variable ranging from winds affecting very localized and restricted areas to those which are global in scope. It will be sufficient to conclude on the occurrence of wind that temperature inequalities and varying pressure gradient remain the root causes of wind. Both temperature and pressure within the atmosphere exhibit important variations vertically, horizontally as well as seasonally. And as has already been reviewed, the horizontal pressure gradient provides the force that determines the speed of wind and its initial direction. The greater the difference in pressure between two points, as pointed out by Donn (1975) and several other meteorologist, the steeper the gradient and consequently the greater the wind.

2.4 VARIATION OF MEAN WIND SPEED PROFILE WITH SURFACE ROUGHNESS

When wind flow meets a sharp discontinuity on the earth's surface, its mean speed is modified downward from the speed generated initially by the effect of pressure gradient. The frictional effect which reduces the wind speed due to the presence of such a discontinuity on the earth's surface is a secondary frictional effect and it called an eddy. Eddies, therefore occur when wind flow encounters a secondary frictional effect caused by discontinuities on the earth's surface. Such discontinuities may be obstructions like trees, buildings, mountains, rocks, valleys etc. Sachs (1978) points out that most natural and artificial obstructions cause an eddy in wind flow while some may not cause any. A calm sea and a high speed aircraft are identified by Sachs (1978) as examples of a natural and artificial obstructions respectively that may not cause any eddy.

Surfaces or obstructions that may not cause any eddy are called aerodynamic or streamlined surfaces. Those that cause less eddy than aerodynamic surfaces are referred to as semi-aerodynamic while shapes that fall outside the above mentioned two classes fall into the third class of non-aerodynamic or bluff surfaces. The spread of these obstructions, of course, vary from place to place, hence the effect they have on the mean wind speed also varies depending on the general surface roughness of the location being considered.

Davenport (1960) reiterated that 'surface roughness' is neither the shielding due to individual obstacles nor the orographic effects influencing the airflow in mountain regions, but the cumulative statistical drag effect of many obstructions on the wind. The surface roughness, therefore, is characterized by the density, size, and height of the buildings, trees, vegetation, rocks, etc. on the ground, around and over which the wind must flow. It follows,

therefore, that the denser, larger and taller the buildings, trees, vegetation, rocks etc. in a given location, the greater the cumulative drag effect on the wind caused by these obstructions. Consequently the mean wind speed in such a location at a specified height will be less than the mean speed at the same specified height but at a location with less dense, large and tall buildings, trees, vegetation, rocks etc. Davenport (1961) later gave a classical diagrammatic illustration shown in Fig. 2.3.

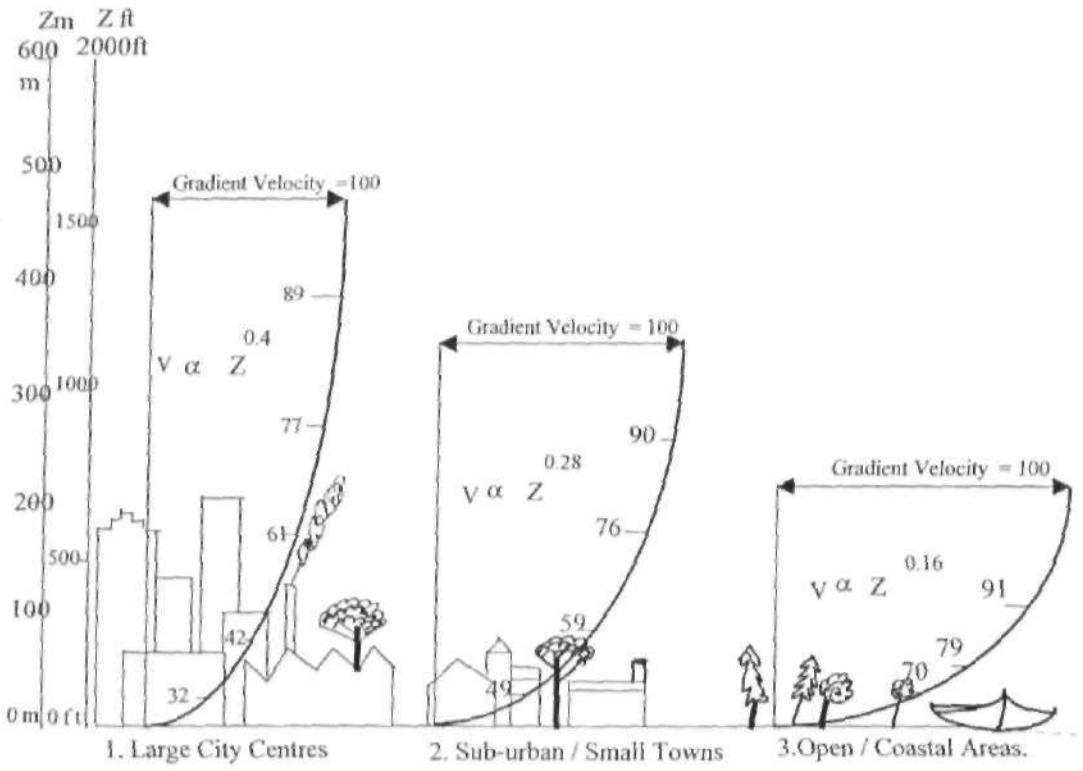

Fig 2.3. *Profiles Of Mean Wind Speed Over Three Different Level Terrains Of Differing Surface Roughness.*

It can be seen from Fig 2.3 that the gradient wind $\mathbf{V_G}$ is attained at different heights in the three different terrains having differing surface roughness. The gradient wind in a large city centre is attained at a much greater height than for a sub-urban/town and open/coastal areas. At a height of about 30m ($\mathbf{Z_{30}}$), the mean wind speed in open coastal areas may be

about double that in a large city centre (Davenport, 1961). Obviously all these wield a lot of influence on wind loading of structures and make it imperative for a designer to understand the characteristics of the surface roughness of a location or site on which his structure will be erected.

2.4.1 Mathematical Representations Of Wind Speed Variation With Height And Surface Roughness.

The presence of bluff and semi-aerodynamic surfaces, the cumulative effect of the surface roughness and the decreasing intensity of the frictional drag force due to the earth's surface, together contribute to the variation of wind speed profile from the ground up to the gradient height. This variation has been represented by various empirical, semi-empirical and theoretical formulae. Simiu and Scanlan (1986) reported that the most familiar ones are the Ekman spiral, the Logarithmic law and the Exponential or Power law profiles. They also noted that the Ekman spiral profile representation has been proved unsatisfactory by observations.

Kraght (1976) mentioned that the Ekman spiral profile representation is idealized, simplified and based on the following assumptions: that within the boundary layer the:

(a) eddy viscosity and density are constant,

(b) motion is horizontal and steady,

(c) isobars are straight and parallel and

(d) geostrophic wind is constant with height.

These assumptions, especially the first , though mathematically convenient, are not physically true. They account for the discrepancies between observations and results obtained using the Ekman spiral profile.

The Logarithmic Law Profile Representation

This profile is derived with the following assumptions (Kraght, 1976):

(a) mean motion is one dimensional,

(b) coriolis force can be neglected,

(c) shearing stress and pressure gradient are independent of height

(d) pressure force can be neglected with respect to the viscous force, and the

(e) mixing length depends only on the fluid and the distance z, from the boundary layer.

The law is given by :

$$\bar{V}_z = \frac{1}{k} U_* \ln \frac{Z}{Z_0} \qquad \text{.....(2.7)}$$

where $\bar{V}_z$ is mean wind speed at height z from the ground ; k is the von Karman's constant ($k \approx 0.4$); Z_0 is a roughness length of which values for different surface roughness are given by Simiu and Scanlan (1986) and is reproduced in Appendix A, Table A.1. U_* is the friction or shear velocity given by :

$$U_* = \left(\frac{\tau_0}{\rho}\right)^{\frac{1}{2}} \qquad \text{.....(2.8)}$$

where τ_0 is the surface shear stress and ρ is the average density of the air $\left(\approx 1.2 kg/m^3\right)$.

Equation (2.7) can be rewritten as

$$\bar{V}_z = \frac{\left(\frac{\tau_0}{\rho}\right)^{\frac{1}{2}}}{0.4} \ln \frac{Z}{Z_0} \qquad \text{.....(2.9)}$$

The Logarithmic law profile was proposed by Prandtl (1935). Prandtl's logarithmic law profile has been reported by Davenport (1963) to accurately define the wind speed profile within the surface or laminar boundary layer which lies within about 30.5m (100ft) and 61m (200ft) from the earth's surface. Houghton and Carruthers (1976) stated that the Logarithmic profile is found to be valid only for a relatively thin region of the full turbulent layer. The relevant layer being from just away from the surface (where viscous effects are more likely to

predominate over the turbulent mechanism) to about 20% of the thickness of the whole turbulent layer. Finally Simiu and Scanlan (1986) pointed out that the profile is presently regarded by meteorologists as a superior representation of strong wind profiles in the lower atmosphere (that is within the surface or laminar boundary layer).

The Exponential Or Power Law Profile Representation

Simiu and Scanlan (1986) reported that the Power law profile representation of the mean wind profile in horizontally homogeneous terrain is historically the first representation of the mean wind profile. The law was proposed by Hellman in 1916. The British Code of Practice on wind loads (CP 3 Chapter V: Part 2: 1972) uses the Power law to relate the wind speed to the height above ground. Houghton and Carruthers (1976) pointed to the fact that the usefulness of this law as a theoretical expression for the wind speed profile within the turbulent boundary layer lies on the fact that the law could be made to approximate to experimentally observed values of mean speed. In addition, the law yields values of resistance or drag which are reasonably correct and which is of great value to the aeronautical designer and engineer.

Furthermore, Davenport (1960) confirmed the dependability of the Power law profile especially for structural purposes and he attested that the profile can be applicable only in the layer extending from the ground up to the height where the gradient wind velocity is first attained (which is usually between 305m (1000ft) and 610m (2000ft)). Fortunate enough, it is within this layer of the atmosphere that the designer of civil engineering structures is concerned. Again, Shellard (1968) examined results of special measurements taken at some selected stations and confirmed that over flat open country in strong winds, Power law profile

with exponents of 0.15 or 0.16 for mean velocities and about 0.9 for gusts are appropriate. He also indicated that this can be applied at heights up to at least 305m (1000ft) above ground.

This profile has, therefore, received a wide range of acceptance both by meteorologists and structural engineers because of its simplicity.

The law can be stated as follows:

$$V_z = KZ^{\frac{1}{\alpha}} \quad \text{.....(2.10)}$$

where V_z is mean wind speed at a height z; K is the drag coefficient which depends on the surface roughness and α is the Power law exponent which also varies with surface roughness. Sometimes, the law is represented in relation to the gradient wind and height. Thus:

$$\frac{V_z}{V_G} = \left(\frac{Z}{Z_G}\right)^{\alpha} \quad \text{.....(2.11)}$$

which yields:

$$V_z = V_G\left(\frac{Z}{Z_G}\right)^{\alpha} \quad \text{.....(2.12)}$$

where $\mathbf{V_G}$ is the gradient mean wind speed at the gradient height $\mathbf{Z_G}$.

Equation (2.11) indicates the proportionality between V_z and Z^{α}. This is, however, true only on the assumption that the Power law holds with a constant exponent α up to the depth of the boundary layer δ or the gradient height $\mathbf{Z_G}$. From Equation (2.12) it follows that if the power law exponent α and the gradient height $\mathbf{Z_G}$ are known, the wind speed at any height within the boundary layer can be expressed as a ratio of the gradient wind $\mathbf{V_G}$. Davenport (1963) also pointed out that both parameters (that is, α and $\mathbf{Z_G}$) are principally functions of the surface roughness. He surveyed measurements of nineteen (19) different localities with differing roughness regimes and came out with consistent and reasonable picture from which values of the two parameters are derived. Besides, Vellozi et al (1970) also gave recommendations on what values could be regarded as appropriate for the two parameters and have now been adopted by the American National Standard in their "Minimum Design Loads for Buildings and Other Structures" ANSI New York, (1982). Values of α and $\mathbf{Z_G}$ recommended by both Davenport and by the American National Standards Institute are given in Table 2.2.

Table 2.2 *Recommended Values Of α And Z_g (K = Drag Coefficient)*

Recommen-dation By:	Coastal Areas 1			Open Terrain 2			Sub-Urban Terrain 3			Large City Centres 4		
	α	k	Z_G	α	k	Z_G	α	k	Z_G	α	k	Z_G
Davenport	-	-	-	0.16	0.005	275	0.28	0.015	400	0.4	0.05	520
Vellozzi et al and ANSI	1/10	-	215	1/7	-	275	1/4.5	-	400	1/3	-	460

2.5 A BRIEF LOOK AT GLOBAL WIND CIRCULATION

Byers (1974) pointed out that global wind circulation is based on the fact that the earth's surface and its atmospheric envelope have strong poleward temperature gradients. The term global or general circulation as it is referred to in many meteorological texts is defined by Petterssen (1977) as commonly used to refer to more or less permanent global wind systems of the *troposphere* and lower atmosphere. The basic currents and the general aspects of disturbances such as the deviating coriolis force superimposed upon such currents are all considered in general circulation.

In general circulation, a wide belt centered at the equator serves as a heat source while the high altitude areas around the poles serve as the heat sinks (Byers, 1974). The heat is transported from the heat source to the heat sink. Cold air is carried equator-ward and warm air poleward. Fig 2.4 shows a schematic representation of the observed zonal wind and pressure belts of the earth. This gives only an idealized view of a general picture of the terrestrial pressure-wind distribution.

Over large areas the actual pattern differs strongly from this picture due to both irregular heating of the earth's surface and the effects of migratory low-high pressure areas. If the circulation is averaged over long periods, local and small-scale irregularities in the circulation disappear and a generalized pattern of winds becomes manifest (Kraght, 1976).

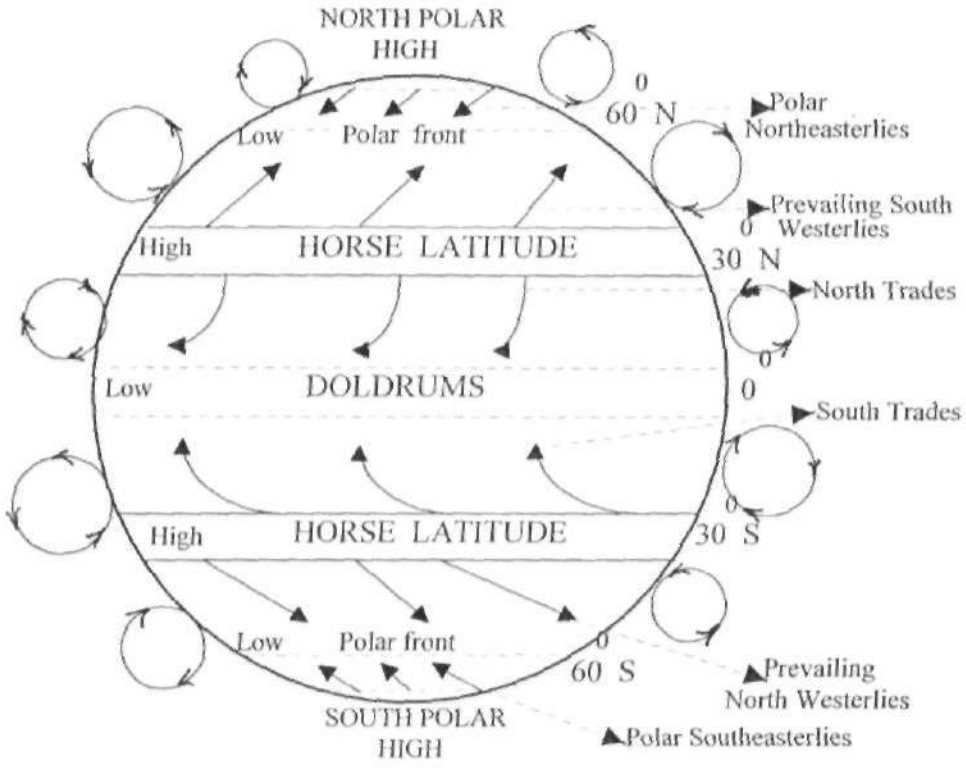

Fig. 2.4 *Schematic Representation Of The Global Circulation.*

Byers (1974) refers to the general circulation pattern emerging in each hemisphere as a tricellular circulation. As shown in Fig 2.4, the net meridional circulation is represented in vertical cross section around the global profile whereas the actual wind directions at the surface of the earth are represented within the circumference. The Doldrums is a belt of little or no wind located in the general vicinity of 5^0 N latitude in the region of the equator.This zone is characterized by extremely low pressures, relatively calm weather and frequent thunderstorm activity. The doldrums is more commonly referred to as the intertropical convergence zone.

The next belt is the horse latitudes also called the subtropical high pressure zones. They are located near 35^0 N and 30^0 S latitudes and is noted for variable and extremely light winds. The region of the horse latitudes is characterized by high pressures.

The third pressure belt is located approximately between 60^0 N and 70^0 S latitudes in the respective hemispheres. These are regions of extremely low pressure and are called the subpolar lows. They are characterized by steady winds.

Each of the three pressure zones described above initiates a cell circulation which moves in a general pattern in-between two adjacent pressure zones. The trade winds occur in-between the subtropical high pressure and intertropical convergence zones. This region is located between about 30^0 and 0^0 in each hemisphere. The trade winds move toward the equator and they take their name from European traders who used them to drive their sailing ships from Europe to the 'New World' (Weisberg, 1976). Trade winds prevail all through the year at speeds of about 16 to 25 Km p.h. (10 - 15 mph). The winds between the subtropical high pressure and the subpolar low zones dominate from a southwestern to a northeastern direction in the northern hemisphere and from a northwestern to a southeastern direction in the southern hemisphere. These winds are called prevailing westerly winds, and are generally centered between about 30^0 and 60^0 latitudes in each hemisphere. This is a zone of strong winds. The third zone of circulation is between the subpolar low and the polar high pressure zones. The zone lies between 60^0 and 90^0 north and south. The characteristic winds are the easterlies which encounter the prevailing westerlies along the polar front. (The polar front is the region which divides the cold polar air from the warm subtropical air).

Meteorologists agree that the general circulation system is not limited to the three defined cells of circulation and that the knowledge of all the circulatory pattern is yet incomplete (Weisberg, 1976; Donn, 1975; Byers, 1974).

2.5.1 Classification Of Wind Types

A rough classification of wind types is as follows (Kraght, 1976):

(1) Winds that are, to a large degree, permanent. They include easterly trade winds of the tropics and the westerly winds that prevail in the temperate zones.

(2) Winds that are seasonal such as the monsoons, the smaller scale diurnal mountain and valley winds and land and sea breezes.

(3) Winds that can be termed as local winds and storms. They temporarily interrupt the more general air movement prevailing at any time. Among these are the great cyclones and anticyclones which are characteristic of North American climates; ocean cyclones (including hurricanes, or typhoons); thunder storms, tornadoes; waterspouts otherwise called ocean tornadoes; foehns (also called Chinooks); and the cold fall winds, mistrals and blizzards.

Detailed description of the behaviour of these wind types can be found in several meteorological and a few wind engineering texts (Donn, 1975; Byers, 1974; Petterssen, 1969; Simiu and Scanlan, 1986). Kraght (1976) also stated that wind may be classified according to their origin and movement. Thus:

(i) Gradient Winds: Winds which blow in accordance with existing pressure gradient, centrifugal and coriolis forces. Cyclonic winds blow anticlockwise about regions of relatively low pressure in the Northern hemisphere and clockwise in the Southern hemisphere. Anticyclonic winds blow clockwise about regions of relatively high pressure in the Northern hemisphere and anticlockwise in the Southern hemisphere.

(ii) Geostrophic Winds: They blow in accordance with the pressure gradient balanced only by the coriolis force. They blow in straight or nearly straight lines over the earth and might not possible to occur at the equator because the coriolis force is zero there.

(iii) Cyclostrophic Winds: They blow cyclonically in both hemispheres where the pressure gradient is balanced by the centrifugal force in the absence of the coriolis force. They occur near the equator as hurricanes and other local less intense vortices.

(iv) Antitriptic Winds: These are of small scale and short durations, blowing along the pressure gradients. Land and sea breezes and mountain winds fall into this class.

(v) The Narrow Jet Stream: Which moves at high speed in an irregular easterly courses through the upper air of the temperate zone.

2.5.2 Extra-Ordinary And Well-Behaved Wind Climates

Simiu and Scanlan (1986) named infrequent winds such as hurricanes that are meteorologically distinct from the usual annual extreme winds, extra-ordinary winds. Such winds are considerably stronger than the usual annual extremes. Climates that can be identified as possessing such winds are referred to as extra-ordinary wind climates. In such climates, the winds are of such ferocity that much structural damage results from their passing.

Climates in which extra-ordinary winds have an almost zero probability of occurrence are regarded as well-behaved wind climates. In such climates, such as Nigeria's wind climate whose wind data is used in this research, it will be reasonable to assume that each of the data in a series of the largest annual wind speeds contributes to the description of the probabilistic behaviour of the extreme winds. Simiu and Scanlan (1986) reported that a statistical analysis of such a series are expected to yield useful predictions of long-term wind extremes.

CHAPTER THREE

DEVELOPMENTS IN WIND LOAD MODELLING

(REVIEW OF RELEVANT LITERATURE: PART 2)

3.1 GENERAL REMARKS

Giant strides have been taken over the centuries in the field of wind load modelling as research findings in other branches and disciplines lend themselves for use and application. In this chapter attention is given to the purpose and usefulness of wind load models and modelling as well as to stochastic modelling. Early advances made on wind load modelling are recalled. In addition, recent trends and developments in the field of wind load modelling including current wind load models being used in some countries are discussed.

3.2 THE PURPOSE AND USEFULNESS OF WIND LOAD MODELS AND MODELLING

The purpose of wind load modelling is to try to find a kind of law of sequence (technically, probability distribution and its statistical characteristics) to which the records of wind speed data for meteorological stations in a given wind climate will suitably fit into. When this is done, then estimates for extreme largest wind speeds for specific recurrence interval or return periods which we relate to the lifetime of structures, can be made using the parameters of the probability distribution which forms the model of the prototype.

As soon as appropriate and reliable wind speed estimates are made from the model, and the expected lifetime of an intended structure known, the former can then be used to evaluate wind load that will most likely cause failure of the structure during its lifetime. Furthermore, the model and its statistical properties can be used to predict failure probabilities and their associated potential losses in the assessment of structural safety and reliability.

Summarily, according to Simiu and Filliben (1977), the probability modelling of the behaviour of extreme largest wind speeds is of interest on two accounts. First, an adequate probability model can be conveniently used to specify basic design wind speeds, that is, wind speeds under the action of which the stresses in a structure will not exceed the allowable stress level for the load combination considered in design. Secondly, from a knowledge of the probability distribution of the extreme largest winds direct inferences can be drawn regarding the safety level of structures subjected to wind loads.

3.3 ADVANCES IN WIND LOAD MODELLING

About over a century ago it became a well established principle in structural designs of superstructures to give some allowance for loads imposed by wind action. In such superstructures that are substantially exposed to wind such as tall buildings, telecommunication masts, radio masts, long span bridges etc., the question of wind loading may even become a major criteria to influence initial cost and structural safety. Davenport (1961) reported that during those early days of the emergence of wind load consideration in structural engineering designs and practice, the loads were calculated based on the following assumptions:

(1) The variability or random nature of the wind speed due to gust were "safely disregarded"

(2) The speed were regarded as non-varying with both time and space.

Based on these unrealistic assumptions, wind loads were then determined from simple wind tunnel experiments on models of a steady airflow. From such experiments, certain aero-dynamic (the drag and pressure) coefficients were found and then applied to the highest instantaneous wind speed recorded at a nearby anemometer together with these coefficients.

According to Davenport (1961), this procedure, though simplified, was later realized to be not the ideal. Experiments and research on wind loading followed the realization. Scruton (1963) points out that the Tay Bridge disaster in 1879 is reported to have prompted bridge engineers to make allowances for wind loading. Further, some allowances were suggested (according to Davenport, 1961) by B. Baker, E. Stanton and A. Bailey in their respective research reports on wind pressure experiments. These allowances seemingly provided a little alleviation, but results remained inadequate. Historically, Scruton (1963) reports that a horizontal wind load of 274 Kg/m^2 was adopted in the design of The Forth Bridge. B. Baker is reported to have said in his paper "The Forth Bridge" that "there exists a lamentable lack of data" with respect to actual pressure of wind on large structures (Sachs, 1978). Lack of suitable, sufficient and reliable wind data was one of the major clogs in the advancement of wind load modelling. Scruton (1963) affirmed this and pointed that due inadequate and satisfactory data, recourse was made to wind tunnel investigations.

Wind tunnel experiments, therefore, became the method adopted for modelling wind behaviour on physical models of structures. There were uncertainties in the estimation of wind loading which was as a result of difficulties met in the prediction of maximum wind conditions. In 1947, Sherlock advocated the use of mean instead of highest instantaneous

wind speed in combination with certain "gust factors". The works of Shellard (1963) and Davenport (1963) made valuable contributions to knowledge and understanding of the wind and how design wind speeds could be estimated.

3.3.1 Traditional Procedure For Determining Wind Loads

Wind loads are generally evaluated from the basic hydro-dynamic relationship given below as (Melchers, 1987):

$$W_F = \tfrac{1}{2}\rho V_d^2 C \qquad \text{.....(3.1)}$$

where W_F is wind force per unit area, ρ is the average density of the air (1.2 Kg/m^3), V_d is the design wind speed estimated and C is the wind loading (pressure or force) coefficient determined from wind tunnel experiments and which depends on the shape of the structure and direction of the wind.

Considering Equation (3.1) let $K = \frac{1}{2}\rho$ where K is a constant. K is deterministic because the average air density is constant irrespective of location. We can then rewrite Equation (3.1) as follows:

$$W_F = K V_d^2 C \qquad \text{.....(3.2)}$$

The term $\mathbf{KV_d^2}$ is usually referred to as the dynamic pressure, q. That is :

$$q = K V_d^2 = \tfrac{1}{2}\rho V_d^2 \qquad \text{.....(3.3)}$$

So Equation (3.2) becomes

$$W_F = q.C \qquad \text{.....(3.4)}$$

From Equation (3.4) we deduce that the design wind load is dependent on two parameters, the dynamic pressure, q, and the loading coefficient ,C. However, the dynamic pressure is largely

dependent on the design wind speed, V_d , which has to be squared. Values of the loading coefficient are usually very small compared to values of the design wind speed (which its contribution to the final wind load is magnified by the squaring).

Hence, design wind loads are to a very large extent determined by or dependent on the design wind speed estimated. Taylor (1971), Simiu and Scanlan (1986) and several other authors affirm that the design wind load magnitude is mainly determined by the estimated design wind speed.

Traditionally, the design wind speed adopted used to be the highest instantaneous wind speed recorded at a meteorological station close to the site (Davenport, 1961; Shears, 1971). This has been shown to provide an unsatisfactory basis of design and gives no indication of the risk of the design wind speed being exceeded (Shears, 1971).It is pathetic to notice that the Nigerian Code of Practice NCP1: 1972, Section 11: Wind Loads based design wind speed specified in Table 4 of the code "on the highest gust velocities recorded by the Nigerian Meteorological Services". Irrespective of research findings, better and more appropriate procedure of estimating the design wind speed and consequently the load, the Nigerian Code still remains unrevised.

Davenport (1961) reported that the practice of basing design wind speed on the maximum speed on record (whether this was an average, or instantaneous value) has long been questioned. These made no allowance for the number of years records had been kept and that practice place too much reliance on the instrument operating satisfactorily.

In keeping pace with the trend of research findings, the statistical theory of extreme values (accredited to E. J. Gumbel) began to be found useful and became an alternative in

design wind speed estimation. Hence, wind load modelling has shifted from application of deterministic principles to the use of probability theories.

3.4 MODERN TRENDS IN WIND LOAD MODELLING

Since the emergence of the statistics of extreme values, design winds are now being based on the annual maximum for a number of years instead of a specific critical value such as the mean or instantaneous highest value recorded at the nearest meteorological station. The number of years which their highest wind speeds are extracted from records for analysis is related to the expected lifetime of the structure and this is referred to as the recurrence interval or the return period, T, of the wind speed estimated using the theory of extremes.

3.4.1 Definition Of The Recurrence Interval (Or Return Period) And Its Relationship To Lifetime Of Structure

Let $P\left(\tilde{V}\right)$ be the probability that the extreme wind speed estimated will not exceed the design value $\tilde{V}$. Then the probability that the extreme wind speed will exceed the value $\tilde{V}$ at least once in a given year becomes $1-P\left(\tilde{V}\right)$. The recurrence interval, T, is the reciprocal of the probability of the extreme wind speed exceeding the value $\tilde{V}$ at least once in a year. Mathematically,

$$T\left(\tilde{V}\right) = \frac{1}{1-P\left(\tilde{V}\right)} \qquad \text{.....(3.5)}$$

In relating the lifetime of a structure to the recurrence interval, there exists a probability $P\left(\tilde{N}\right)$ that the design wind is not exceeded within the anticipated lifetime $\left(\tilde{N}-\text{years}\right)$ of the structure . This probability $P\left(\tilde{N}\right)$ is given by:

$$P\left(\tilde{N}\right) = P\left(\tilde{V}\right)^{\tilde{N}} \qquad \text{.....(3.6)}$$

From Equation (3.5)

$$P\left(\tilde{V}\right) = \frac{I\left(\tilde{V}\right)-1}{I\left(\tilde{V}\right)}$$

$$= \left[1-\frac{1}{I\left(\tilde{V}\right)}\right] \quad \text{.....(3.7)}$$

Substituting Equation (3.7) into Equation (3.6),

$$P\left(\tilde{N}\right) = \left[1-\frac{1}{I\left(\tilde{V}\right)}\right]^{\tilde{N}} \quad \text{.....(3.8)}$$

From Equation (3.8) which is the probability of the design wind not being exceeded within the lifetime $\left(\tilde{N}-\text{years}\right)$ of the structure, we can then deduce the probability ,say, P(F) of the design wind being exceeded. This is called the "acceptable risk" or in the general term of structural reliability studies, the probability of failure.

$$P(F) = 1-P\left(\tilde{N}\right)$$

$$P(F) = 1-\left[1-\frac{1}{I\left(\tilde{V}\right)}\right]^{\tilde{N}} \quad \text{.....(3.9)}$$

3.4.2 Terms Of Reference In Formulating Design Wind Loads.

Davenport (1963), Taylor (1971) and Sachs (1978) enumerated the requirements or terms of reference in modern designs of wind sensitive structures which must be properly defined and considered. The first is the definition of the magnitude of the wind speed at the site of intended structure. The second consideration is the time characteristics of the wind speed magnitude defined in relation to the lifetime of the structure and its dynamic response. The third is the spatial characteristics of the site in relation to both height and degree of roughness of terrain or surface roughness.

Simiu and Scanlan (1986) noted that recent researches are also touching on the effect of wind directionality on wind loading for structures. Simple but rigorous probabilistic procedure of describing such effects are being worked upon. However, no wind loading standards has began to incorporate this. Robertson and Flynn in 1979 reiterated that: "Building Codes and Standards , such as those under development and in use in technically advanced portions of the world, now deal with (or will be dealing with) the broad application of the technology of wind engineering . Gone are the complete reliance on steady-state concepts, being replaced with probabilistic approaches associated with the dynamic characteristics of the structure, the random and turbulent characteristics of the wind and the dynamic component of structure response." In view of this well recognized and established principle of modelling design wind loads by the use of probabilistic rationale, several of such models have emerged in many technically advanced countries of the world.

3.5 SOME EXAMPLES OF STOCHASTIC MODELS OF WIND LOADS DEVELOPED

3.5.1 An Argument: Univariate And Bivariate Models Of Wind Loads.

Generally, wind loading is derived from statistical data for wind speeds (Melchers, 1986; Anthony, 1971). Existing models of winds are basically of univariate probability distributions of extreme wind speeds from which the basic design wind speed can be estimated. A question arises from the term "univariate." Does it imply that only one variable is modelled among the three parameters that yield the wind load (see Equation (3.2))?

In modelling only one of the parameters probabilistically, it tends to suggest that the other two are deterministic. That is: assuming W(X) is the wind load and the functions are $g(X_1)$, $g(X_2)$, and $g(X_3)$. Then :

$$W(X) = [\, g(X_1) , g(X_2) , g(X_3) \,] \quad \text{.....(3.10)}$$

Obviously one of the parameters ($K = \frac{1}{2}\rho$) is deterministic because it is a constant. The second parameter which is the design wind speed is a random variable. The third is the loading coefficient. Most wind load models ore models of the extreme wind speed. The third parameter is determined from wind tunnel experiments on various shapes of physical models of structures. It should be noted that if two parameters in Equation (3.10) above are deterministic and only one is a variable, then the model of that single random variable influences the wind loading itself. That is why extreme largest wind speed modelling is basically wind load modelling.

However, Mayne and Cook (1980) have argued that the third parameter $g(X_3)$ which is the loading coefficient is not deterministic. They acquired some loading coefficient data and tried to give their joint probability model together with the wind speed. It is , however, evident that if we must model wind loading coefficient, the data for such a model is not available especially in a country and continent like Nigeria and Africa respectively. Secondly, it can be argued that the process of taking pains, energy and time to develop a bivariate probability models of wind loads with respect to the wind speed and the loading coefficient will only end up as an academic exercise which may not contribute much to practical applications. The basis for such an argument is on the fact that values of the loading coefficient in comparison to those of the design wind speed are too small to become a major determining factor; more so that the wind speed has to be squared (Equation (3.1)).

However, as significant advances occur in wind engineering field, it is now an established fact that wind effects on various structures and their elements do not only depend on the magnitude of the wind speed, but also depend on the wind directions associated with the speed. Simiu and Scanlan (1986) noted that the knowledge of continuos joint distributions of extreme largest wind speed and their directions would be useful for both design and code development. However, no such credible models for such distributions have so far been proposed in the literature.

So in the absence of such models, wind effects and their probability may be estimated in well behaved wind climates on the basis of information consisting of largest annual wind speed recorded for each station over a period of not less twenty (20) years (Simiu and Scanlan, 1986). And where no such data is available, the estimation can be done using short term records. In using short term records, the extreme largest monthly wind speed recorded for five (5) to ten (10) years (which gives a sample size of between sixty (60) to one hundred and twenty (120) respectively) can be used. The use of short term records has been illustrated by Simiu and Scanlan (1986); Grigoriu et al (1987); Simiu et al (1982); Grigoriu, (1982). Hence in the meanwhile it will be sufficient to use continuous univariate probability models selected by using adequate data for wind load modelling.

3.5.2 Examples Of Univariate Wind Load Models.

Thom (1960) initially proposed the Type II distribution of extreme values. He gave it as:

$$F(X_2) = \exp\left[-\left(\frac{X_2}{\beta_2}\right)^{-\gamma}\right] \quad \text{.....(3.11)}$$

where $F(X_2)$ is the probability of a wind speed being less than (or not exceeding) X_2 , β_2 is the scale parameter of the distribution and γ the shape (or tail length) of the distribution.

However, the extreme value Type II distribution (EV-II) is of the general form (Johnson and Kotz, 1970):

$$P(X \leq x) = \exp\left[-\left(\frac{x-u}{\sigma}\right)^{-\gamma}\right] \text{ for } x \geq u \quad \text{.....(3.12)}$$

Simiu and Filliben (1977) noted that Thom (1960, 1968) assumed the value of the location parameter, u, to be zero. That explains why Thom's representation of EV-II is of the form given in Equation (3.11). Whenever the location parameter, u, is zero, the EV-II distribution is called the Frechet distribution, which is basically Thom's (1960) model of the extreme wind data he used.

Thom (1960) used the method of likelihood to estimate the two parameters β_2 and γ and gave the differential equations for their estimation as;

$$\frac{\delta L}{\delta \beta} = \frac{n}{\hat{\beta}} - \hat{\beta}^{\hat{\gamma}-1} \sum_{i=1}^{n} X_i^{\hat{\gamma}} \quad \text{.. .....(3.13)}$$

and

$$\frac{\delta L}{\delta \gamma} = \frac{n}{\hat{\gamma}} - \sum_{i=1}^{n} \log X_i + \frac{n_i \sum_{i=1}^{n} X_i^{\gamma} \log X_i}{\sum_{i=1}^{n} X_i^{\hat{\gamma}}} \quad \text{.....(3.14)}$$

Later, Thom (1968) used a larger sample size and applied some logarithmic transformations to Equation (3.11) to arrive at a new distribution for extreme wind speed in a well behaved climate (which he referred to as nontropical storm). The transformation applied to Equation (3.11) is as follows:

$$X_2 = e^{X_i} \quad \text{.....(3.15)}$$

When the above is applied to Equation 3.11, it is found that:

$$\beta_2 = e^{\alpha} \quad \text{.....(3.16)}$$

and $$\gamma = \frac{1}{\beta_1} \quad \text{.....(3.17)}$$

These operations then transform the Frechet distribution of Equation (3.11) to the EV-I distribution given by Thom as:

$$F(X_1) = \exp\left[-\exp\left\{-\left(\frac{X_1-\alpha}{\beta_1}\right)\right\}\right] \quad \text{.....(3.18)}$$

X_1 is the logarithm of X_2, α is the location parameter and β_1 the scale parameter.

Davenport (1960) in his own work stated that the anemometer records for both extreme indicated gusts and hourly mileages at thirteen (13) stations in Sweden and six (6) in the British Isles were analyzed and the results did not contradict the assumption that the distribution of extreme values of Type I (EV-I) was in close agreement with the distribution of the actual wind speeds. Davenport (1960) also noted that Arnold Court analyzed the records of twenty-five (25) weather stations in the United States of America having thirty-seven (37) years of satisfactory records. According to him "all the wind data seems to follow the same theory." The representation of the EV-I distribution according to Davenport (1960) is of the form:

$$\phi(X) = e^{-e^{-y}} \quad \text{.....(3.19)}$$

where ϕ (X) is the probability of a wind speed being less than X, and y is the reduced or standardized variate given as:

$$\mathbf{y = a\,(x - u)} \quad \text{.....(3.20)}$$

in which a is the scale factor and u is the mode of the extreme value data (same as α in Equation (3.18))

Simiu and Filliben (1977) in reviewing current probabilistic models of extreme wind reported that the nature of the variate suggests that an appropriate model of extreme wind behaviour is provided by the probability distributions of the largest values . The general expression for this family of distributions is given by them as:

$$F(V) = \exp\left[-\left(\frac{v-u}{\sigma}\right)^{-\gamma}\right] \quad \begin{cases} u < v < \infty \\ -\infty < u < \infty \\ 0 < \sigma < \infty \\ \gamma > 0 \end{cases} \quad \text{.....(3.21)}$$

This is the same as the EV-II distribution (Equation (3.12)). u is the location parameter, σ is the scale parameter, and γ is the shape parameter (or tail length). Simiu and Filliben (1977)

argued that as the tail length becomes larger, the tail of the probability curve of Equation (3.21) becomes shorter, which means that the probability of occurrence of any given large value of the variate becomes smaller. So as $\gamma \rightarrow \infty$ the EV-II distributions becomes EV-I,

$$F(V) = \exp\left[-\exp\left\{-\left(\frac{v-u}{\sigma}\right)\right\}\right] \quad \begin{cases} -\infty < v < \infty \\ -\infty < u < \infty \\ 0 < \sigma < \infty \end{cases} \quad \text{.....(3.22)}$$

Simiu and Filliben (1977) reported that recent developments of efficient estimation procedures applied to EV-II distribution do not assume the location parameter, u, to be zero (as did Thom, 1960). The assumption, they stated, "sacrifices the goodness of fit." Further, they reported that "in a well behaved wind climate, it is reasonable to assume that extreme winds are adequately modelled by a Type I (EV-I) distribution of the largest values" (That is, Equation (3.22)).

Simiu and Scanlan (1986) further add that among the several probability distributions so far proposed to model extreme wind behaviour includes the Weibull distribution. They subjected a thirty-seven (37)- year series of five (5) minute largest yearly wind speeds to the probability plot correlation coefficient test to determine the tail length parameter of the best fitting distribution of the largest values and they confidently stated from their result that in well behaved climates extreme wind speeds are modelled more realistically by the Type I (EV-I) than by the Type II (EV-II) distribution with $\gamma = 9$ .They added that this has been reinforced by results from other researches. Hence, structural reliability calculations based on the assumption that EV-I distribution holds are in most cases likely to be conservative.

Soboyejo (1971) used seventeen (17)-year series of wind data for twenty-seven (27) stations to analyze Nigeria's extreme wind. The model he developed turned out to be the Type I distribution. The improvement this present work will add to the above will ensue from the availability of a larger sample size. The smallest sample size available for the present work is twenty (that is, 20 year data) and the highest is forty-one (41).

3.6 ESTIMATION OF MODEL PARAMETERS

After selecting the appropriate probability model that best fits the wind speed data for any wind climate or station, the next step in the modelling process is the estimation of the model parameters. This is done using the available and acquired wind speed data for each meteorological station. Some statistical estimation techniques are employed to estimate these parameters. These methods include: (1)the method of maximum likelihood
(2) the method of moments (3) the method of order statistics and (4) the graphical method.

The objective of estimation is to make inferences on the parameters of the model that describes the behaviour of the population from which the data is extracted, or on the characteristics of the model such as the mean. An estimator is that function of the sample values which is a reasonable approximation of the unknown value of the distribution (or model) parameter. The particular numerical value evaluated using the model and the estimator is called the estimate (Hahn and Shapiro, 1967). Ang and Tang (1984) point out that an ideal estimator should be unbiased, efficient (having as small a variance as possible) and consistent.

The sample size used in estimation is very important. As has already been reviewed from the literature (section 3.4.3), the size should not be less than twenty (20) year record of the largest annual wind speed, and where such is not available the monthly wind speed records for between five (5) and ten (10) years can be used.

3.6.1 Proposed Estimation Methods And Estimators For The Extreme Largest Value Models

Various estimation methods and estimators have been proposed for model parameters of extreme largest wind speed. Thom (1960) proposed the method of maximum likelihood and the estimators for the EV-II model given in Equations (3.13) and (3.14). Ang and Tang (1984) noted that the usual methods of estimation of extremal parameters are the methods of maximum likelihood, the graphical method and the method of moments. They also attested to the use of order statistics developed by J. Lieblien in 1954.

For the EV-I model given by Equation (3.22) the parameters are u, the location parameter or the characteristic largest value of the initial variate v; and σ , the scale parameter or the measure of dispersion of the variate v. In some texts, the EV-I is given as :

$$F;(V) \quad = \quad \exp\left[- \exp\left\{-\alpha(v-u)\right\}\right] \qquad \text{.....(3.23)}$$

where α. is the inverse measure of the dispersion σ of the variate v. So $\alpha; = \frac{1}{\sigma}$ and $\frac{1}{\alpha} = \sigma$.

3.6.1.1 Proposed Estimators By The Method Of Moments

The estimation of the parameters by the method of moments entails the estimation of the approximate sample moments from the sample data (Ang and Tang. 1984; Simiu and Scanlan, 1986). The appropriate sample moments are usually the sample mean $\bar{v}$, and the sample variance s_v^2 (which can also be denoted as Var(v)). The third moment is the skewness. (The procedure for deriving these moments using the Moment Generating Function (MGF) is described in Appendix B). Through the relationships between the parameters of the model and the sample moments, the parameters can then be evaluated. From Equations 3.23 and 3.20, let the standardized or reduced variate ,y , be given as:

$$y \quad = \quad \alpha\,(v-u) \qquad \text{.....(3.24)}$$

From Equation (3.24), the variate, v, is obtained:

$$v \quad = \quad u + \frac{y}{\alpha} \qquad \text{.....(3.25)}$$

The mean and the variance of the standardized variate, y, are:

E(y) $= \mu_y = \gamma =$ 0.577216...(Euler Constant)

Var(y) $= S_y^2 = \frac{\pi^2}{6}$.

From Equation (3.25), the mean and variance of the variate, v , will be given by:

$$\mathbf{E(v)} = \mu_v = u + \frac{\mu_y}{\alpha}$$

$$\Rightarrow \mu_v = u + \frac{\gamma}{\alpha} = u + \frac{0.577216}{\alpha} \quad \text{.....(3.26)}$$

$$\mathbf{Var(v)} = \sigma_v^2 = \frac{1}{\alpha^2} S_y^2 = \frac{1}{\alpha^2} \times \frac{\pi^2}{6} = \frac{\pi^2}{6\alpha^2} \quad \text{.....(3.27)}$$

From which $\sigma_v = \sqrt{\frac{\pi^2}{6\alpha^2}} = \frac{\pi}{\alpha\sqrt{6}}$ .....(3.28)

From the above equation, $\frac{1}{\alpha} = \frac{\sigma_v\sqrt{6}}{\pi}$ and $\alpha = \frac{\pi}{\sigma_v\sqrt{6}}$. The model parameters, u, and α or $\frac{1}{\alpha}$ are obtained by replacing the above population moments, μ_v and σ_v by the corresponding sample moments $\bar{v}$ and s_v. The moment estimators of the EV-I parameters are then given as:

$$\hat{u} = \bar{v} - \frac{\sqrt{6}}{\pi}\gamma s_v = \bar{v} - \frac{\sqrt{6}}{\pi}0.577216 s_v \quad \text{.....(3.29)}$$

and $$\hat{\alpha} = \frac{\pi}{s_v\sqrt{6}} \quad \text{.....(3.30)}$$

where the sample mean and standard deviation ($\bar{v}$;and s_v) are respectively evaluated from:

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \quad \text{.....(3.31)}$$

and $$s_v = \sqrt{\left[\frac{1}{n}\sum_{i=1}^{n}\left(v_i - \bar{v}\right)^2\right]} \quad \text{.....(3.32)}$$

From these estimators a general estimator $\hat{G}_v(p)$[1] of the extreme largest wind speed

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1. $\hat{G}_v(p)$ can also be represented as $\hat{V}_T$ which is defined as the estimated value $\hat{V}_T$ of the T- year wind $\mathbf{V_T}$.

corresponding to a given return period ,T, is constructed and represented by:

$$\hat{G}_v(p) = \hat{G}_{v\left(1-\frac{1}{T}\right)} = \bar{v} + s_v(y - 0.577216)\frac{\sqrt{6}}{\pi} \quad \text{.....(3.33)}$$

where $\mathbf{y = -ln\,(-ln\,p)} = -\ln\left[-\ln\left(1-\frac{1}{T}\right)\right]$

Gumbel is reported to have shown that if $\bar{v}$ and s_v are asymptotically normally distributed, then for large samples the standard deviation of the above general estimator is represented by:

$$SD\left(\hat{G}_v(p)\right) = \left[\frac{\pi}{6} + 1.1396(y; -0.577216)\frac{\pi}{\sqrt{6}} + 1.1(y-0.577216)^2\right]^{\frac{1}{2}}\frac{\sigma}{\sqrt{n}} \quad \text{....(3.34)}$$

3.6.1.2 *Proposed Estimators by Order Statistics*

The use of order statistics for estimating extremal parameters was developed by J. Lieblein. The order statistics estimators $\hat{u}$ and $\frac{1}{\hat{\alpha}}$ are unbiased and efficient, that is, possessing minimum variance (Ang and Tang, 1984). Their efficiency can be accurately evaluated and have been shown to be much higher than other estimators. This method is based on a linear function of a set of ordered sample values $(V_1, V_2, ...V_n)$ The linear function is represented as

$$L = \sum_{i=1}^{n} w_i v_i \quad \text{.....(3.35)}$$

where $V_1 \le V_2 \le .....V_n$ and w_i are weights that may be decomposed into $w_i = a_i + b_i y_p$ where y_p is the value of the standardized variate, y, at an exceedance probability p., That is:

$$\exp(-e^{-y_p}) = 1 - p \qquad \text{or} \qquad y^p = -\ln[-\ln(1-p)]$$

The estimator of Equation (3.35) then becomes:

$$L = \sum_{i=1}^{n} [a_i v_i + (b_i v_i) y_p] \quad \text{.....(3.36)}$$

where the weights a_i and b_i are functions of n and p. The following conditions are imposed to ensure an unbiased and minimum variance estimator L (for given n and p):

$$E(L) = u + \frac{1}{\alpha} y_p \quad \text{.....(3.37)}$$

and $\quad \text{Var}(L) = \text{minimum.} \quad \text{.....(3.38)}$

Equation (3.36) with the values a_i and b_i obtained on the basis of Equations (3.37) and (3.38) then gives the desired estimator function, L. The corresponding unbiased, minimum variance estimators of u and $\frac{1}{\alpha}$ would be:

$$\hat{u} = \sum_{i=1}^{n} a_i v_i \quad \text{.....(3.39)}$$

$$\frac{1}{\hat{\alpha}} = \sum_{i=1}^{n} b_i v_i \quad \text{.....(3.40)}$$

Lieblein obtained the relevant set of the weights a_i and b_i for n = 2 through to 6 with $p > 0.90$. These values are given in Appendix A, Table A2.

3.6.1.3 *Using the Graphical Method*

The parameters of the extreme value models may also be obtained graphically by plotting the sample extreme values on an appropriate probability paper. If a linear trend is observed for the data points on a given extremal probability paper such that a straight line graph can be established, the parameters of the model may then be obtained directly from the straight line. Shellard (1963) demonstrated the use of this method and it has been employed by many others such as Harris (1971), Sachs (1978). The procedure is as follows:

The largest hourly mean wind speed are tabulated for each of n years data obtained for each station. The tabulated values are arranged in order of increasing size or rank. The smallest of the n values is allocated the rank m =1 and so on. Each value is then allocated a plotting position $p = \frac{m}{n+1}$, and the standardized or reduced variate, y, is given by:

$$y = -\ln(-\ln p)$$

Each value of the hourly mean wind speed V can then be plotted against the corresponding value of y.

The model parameters may then be estimated approximately by drawing a straight line through the plotted data points on the Gumbel probability paper. The parameter, u, would then be the value at a cumulative probability of 0.368 or y = 0 and $\frac{1}{\alpha}$ is the slope of the straight line:

that is $\frac{1}{\alpha} = \frac{v-u}{y}$ and therefore, $\alpha = \frac{y}{v-u}$

This method is shown here by using the data obtained for Zaria. The annual maximum wind speeds are tabulated in Table 3.1 and the probability plotting on the Gumbel probability paper shown in Fig.3.1.

Table 3.1 *Annual Maximum Wind Speed At Zaria.* n = 25, $\bar{v}$= 25.93m/sec , s_v = 3.86

YEAR	Rank (m)	p = m/n+1	Wind Speed	y = -ln (-ln p)	Chart B
1986	1	0.04	17.1	-1.18	19.6
1993	2	0.08	20.7	-0.94	20.1
1992	3	0.12	20.8	-0.77	20.6
1983	4	0.15	21.4	-0.63	21.2
1974	5	0.19	22	-0.5	21.7
1969	6	0.23	22.6	-0.38	22.2
1971	7	0.27	23.2	-0.27	22.8
1989	8	0.31	23.8	-0.16	23.3
1981	9	0.35	24.4	-0.06	23.8
1988	10	0.39	24.5	0.05	24.3
1977	11	0.42	25	0.15	24.9
1985	12	0.46	25.5	0.26	25.4
1972	13	0.5	26	0.37	25.9
1975	14	0.54	26.5	0.48	26.5
1973	15	0.58	27	0.6	27
1987	16	0.62	27.4	0.72	27.5
1991	17	0.65	28	0.86	28
1980	18	0.69	28.4	1	28.6
1978	19	0.73	28.5	1.16	29.1
1982	20	0.77	29.2	1.34	29.6
1970	21	0.81	29.9	1.54	30.2
1984	22	0.85	30.6	1.79	30.7
1979	23	0.89	31.2	2.1	31.2
1990	24	0.92	31.9	2.53	31.8
1976	25	0.96	32.6	3.24	32.3
Location Parameter, u		0.37		0	24.1
Scale Parameter,(slope)		$1/\alpha$	=(v-u)/y		2.5
		α	=y/(v-u)		0.4

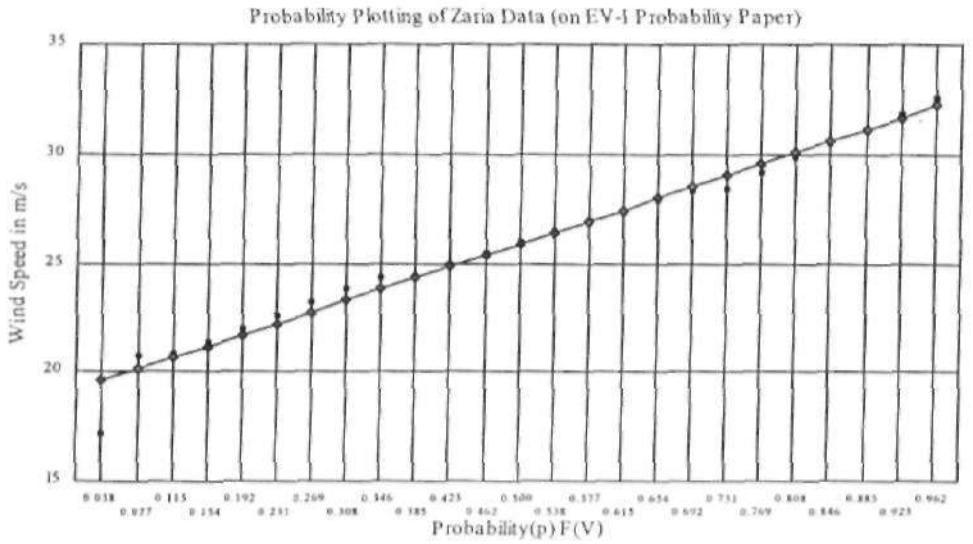

Fig. 3.1 *Probability Plotting of Annual Maximum Wind Speed at Zaria.*

Table 3.2 *Regression Output For Zaria Data.*

	Regression Output:	ZARIA
Constant		19.05
Std Err of Y Est		0.61
R Squared		0.98
No. of Observations		25
Degrees of Freedom		23
X Coefficient(s)	13.77	
Std Err of Coef.	0.44	

CHAPTER FOUR

ACQUISITION OF METEOROLOGICAL DATA

4.1 GENERAL REMARKS

Meteorological stations (US: weather stations) measure and keep meteorological information such as wind speed and direction, rainfall, cloud movement and other weather or climatic processes. They are usually the most reliable sources of any meteorological data. In this chapter, a brief description of how the wind speed data required for a work as this can be obtained and the rationale behind choice of stations for which data are collected are given.

4.2 OBTAINING THE REQUIRED DATA

It has already been established that the structural engineer is only interested in the largest extreme values of wind speed and their direction. The first step in stochastic modelling process is the identification of the random variable(s) . Here we are only concerned with a single load process - wind. The random variable of interest, therefore, will have to be such that failure will occur if and only if the load due to the action of wind exceeds some threshold value. In structural reliability studies, this is referred to as the concept of *first passage probability.*

It is the maximum wind speed that will most likely pass over or through the intended location or site of an intended structure during its lifetime that will most likely have the highest probability of causing failure. Beside this, the effect of repeated loading will lead to

magnification of the problem. So then, we can define our random variable as the maximum or largest wind speed, V_{max} , passing any given location. For a given meteorological station, the random variable of interest to be extracted from the records can be represented as:

$$V = (V_1, V_2, V_3, \ldots\ldots\ldots\ldots V_n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

where V is the random variable, V_1 , V_2 , V_3 ,....V_n are the particular largest annual or monthly wind speed recorded for the specified station.

In Nigeria, values of the random variable identified can be obtained for any particular station for the number of years the records are available from the Nigerian Meteorological Services Department, Oshodi, Lagos. The values of the highest wind speed observed for each day are recorded in FORM MET/100 of the Meteorological Department. So for a given month, say January 1961, values of highest observed wind speed for the thirty-one (31) days of the month are recorded. To obtain the wind speed of interest for the month, the highest of all the recorded values for that month, is picked and recorded in FORM MET.152/2 usually provided by the Meteorological Services Department. This procedure is repeated for all the months of all years for which records are available for each station. This process is a very tedious one and can take several days to extract adequate data, especially if the Meteorological office does not have the information in the computer.

Certain towns and cities are chosen as meteorological stations. At such stations, the instruments for observation of the weather processes are installed. In any country, the choice of where to locate a meteorological station is determined by several factors, among which are locations that will give a fair representation of the whole country. As both manpower for such stations and resources increase, more stations can be opened. Stations selected to be

meteorological locations are called synoptic stations. Fig 4.1 shows thirty-five (35) functional synoptic stations of the Nigerian Meteorological Services Department as at 1993.

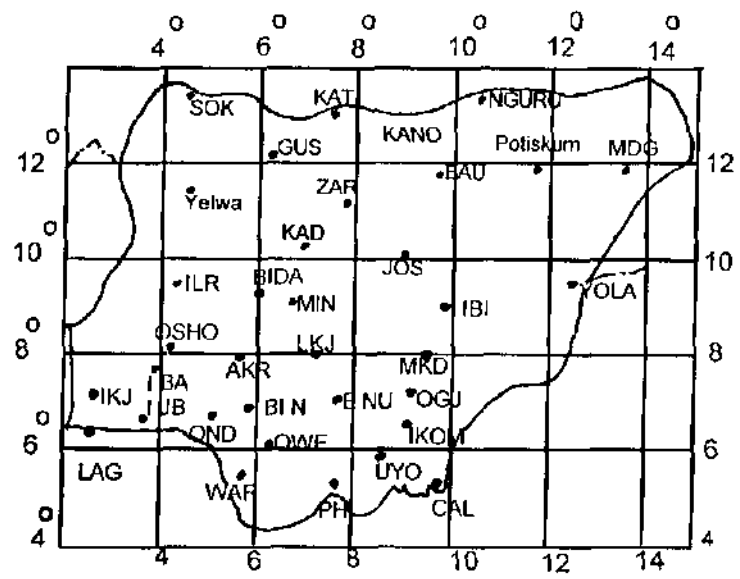

Fig 4.1 Climatological Map Of Nigeria Showing Thirty-Five Functional Synoptic Meteorological Stations.

Out of these thirty-five stations, data for twenty (20) was collected for this work. The number of years for which data is available differ from station to station depending on when measurements began at any given station. The breakdown of available data collected for the selected twenty synoptic stations is given in Table 4.1.

Table 4.1 *Number Of Years And Stations For Which Data Is Obtained.*

	Number Of Years For Which Data Is Available									
No. of Stations And Station Names	20	22	25	30	36	37	38	39	40	41
	1	1	1	1	2	1	1	3	3	6
	Owr.	Ikom	Zaria	Lag	Bau Jos	Enu	Ibi	Kat Min Sok	P.H. War Yol	Calabar, Ibadan, Ilorin, Kaduna Lokoja, M/duguri

4.3 RATIONALE BEHIND CHOICE OF STATIONS

The twenty synoptic stations for which data is obtained provide a reasonable spread over the whole country. They were selected to serve as a fair representation of the whole. Fig 4.2 is the map showing the spread. The whole country is zoned into three namely:

(a) Zone A: Lying between latitudes 10^0 N and 14^0 N

(b) Zone B: Lying between latitudes 6^0 N and 10^0 N

(c) Zone C: Lying between latitudes 4^0 N and 6^0 N.

This zoning helps to give a general overview and makes way for a reasonable choice of locations to reflect the whole.

Eight (8) stations , Bauchi, Jos, Kaduna, Katsina, Maiduguri, Minna, Zaria, and Sokoto are in Zone A. Seven (7) are in Zone B, while five (5) are in Zone C. It can further be explained that the greater or wider the land mass, the more stations we need to select (for a given zone) to have an adequate representation.

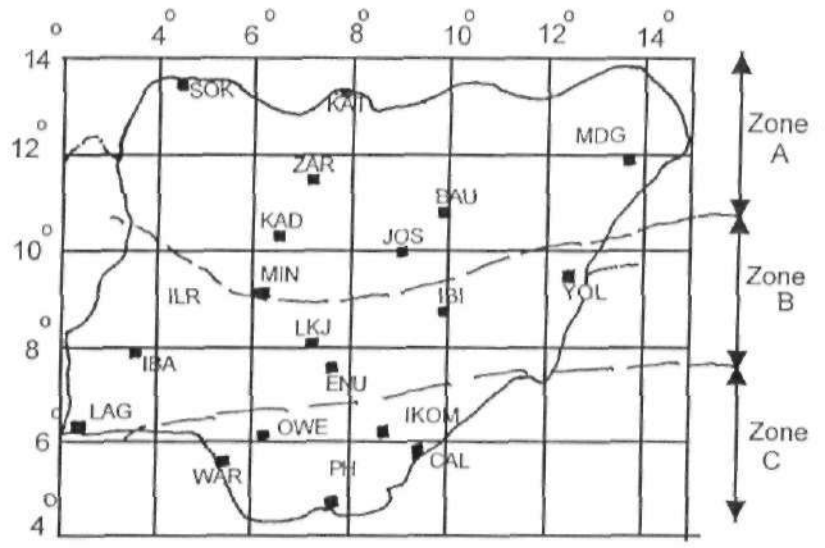

Fig 4.2 *Climatological Map Of Nigeria Showing The Selected Twenty (20) Synoptic Stations.(The line of zoning is arbitrary).*

4.4 METEOROLOGICAL UNITS OF WIND SPEED

Wind velocities are measured in a horizontal plane. The term velocity refers to both magnitude (speed) and direction. Some instruments, however, do not measure both quantities (Sachs, 1978).

Wind speed is measured in a variety of units. The four common ones are Knots (nautical mile per hour), m/s (metres per second), Km/h (kilometre per hour), and m.p.h (miles per hour)[1].The relationship between these four units are tabulated in Table 4.2. However, wind speed is recorded in a qualitative scale of wind force called the Beaufort Scale. The wind record in FORM MET/100 from which raw data are obtained is in the Beaufort Scale. The equivalent of the Beaufort Scale in other units and the description are

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1. It should be noted that the unit used throughout this work is metres per second (m/s)

given in Table 4.3

Table 4.2 *Relation Between Wind Speed Units*

	KNOT	M/SEC.	Km/Hr.	M.P.H.
KNOT	1	0.515	1.853	1.152
M/SEC.	1.943	1	3,600	2,237
Km/Hr.	0.54	0.278	1	0.621
M.P.H.	0.868	0.477	1.609	1

Table 4.3 *Beaufort Scale Of Wind And The Equivalents In Other Wind Speed Units*

Beaufort Scale	Descrip-tive Term	Speed Equivalent At A Standard Height Of 10M Above Open Flat Ground				
		MEAN SPEED				LAND EFFECTS
		Knots	M/Sec.	Km/Hr.	M.P.H.	
0	Calm	< 1	0-0.2	<1	<1	Calm, smoke rises vertically.
1	Light Air	1 - 3	0.3-1.5	1 - 5	1 - 3	Direction of wind shown by smoke drift but not wind vane.
2	Light Breeze	4 - 6	1.6-3.3	6 - 11	4 - 7	Wind felt on face, leaves rustle, ordinary vanes moved by wind.
3	Gentle Breeze	7 - 10	3.4-5.4	12 - 19	8 - 12	Leaves and small twigs in constant motion. Wind extends light flag.
4	Moderate Breeze	11 - 16	5.5-7.9	20 - 28	13 - 18	Raises dust and loose paper, small branches are moved.
5	Fresh Breeze	17 - 21	8.0-10.7	29 - 38	19 - 24	Small trees in leaf begin to sway, crested wavelets form on inland waters.
6	Strong Breeze	22 - 27	10.8-13.8	39 - 49	25 - 31	Large branches in motion, whistling heard in telegraph wire, umbrellas used with difficulty.
7	Near Gale	28 -33	13.9-17.1	50 - 61	32 - 38	Whole trees in motion, inconvenience felt when walking against wind.
8	Gale	34 - 40	17.2-20.7	62 - 74	39 - 46	Brakes twigs of trees, generally impedes progress.
9	Strong Gale	41 - 47	20.8-24.4	75 - 88	47 - 54	Slight structural damage occurs, chimney pots and slates removed.
10	Storm	48 - 55	25.5-28.4	89-105	55 - 63	Seldom experienced inland, trees uprooted, considerable structural damage occur.
11	Violent Storm	56 - 63	28.5-32.6	103-117	64 - 72	Very rarely experienced, accompanied by widespread damage.
12	Hurricane	64 & over	32.7 & over	118 & over	73 & over	

CHAPTER FIVE

MODEL SELECTION AND STATISTICAL ANALYSIS

5.1 GENERAL REMARKS

The understanding of the underlying physical phenomenon being studied gives a basis for model selection. The extreme properties of a stochastic process suggests that an extreme value (EV) model may be a very suitable one. This is strongly supported by previous works found in the literature (e.g. Simiu and Scanlan, 1986). The rationale for model selection is presented here and the model selected is verified. An extreme value Type I (EV-I) model is selected and the verification process proves it to be satisfactory. Empirically, available observational data is plotted on probability paper for the model, and frequency diagram for the set of collected data is also constructed to give a visual comparison. Statistical testing using the Kolmogorov- Smirnov (K-S) Test is also employed in the verification process to buttress the empirical methods.

5.2 SELECTION OF APPROPRIATE STOCHASTIC MODEL

Basically, the selection of model should be based on an understanding of the underlying physical phenomenon (Hahn and Shapiro, 1967). The required model has to be determined empirically and then verified or disproved in the light of available observational data using certain statistical tests known as *goodness-of -fit* test for probability models (Ang and Tang, 1975). Empirical determination consists of either of the following processes or both:

(a) Plotting of data on probability paper for specific distributions. If the data points plot approximately on straight line on a given probability paper, then the model corresponding to this paper may be selected as the appropriate one.

(b) Construction of the frequency diagrams for sets of data and visually comparing a density function with the frequency diagram. (Ang and Tang, 1975).

Both procedures are used for this work. The *goodness-of-fit* test used for verification is the Kolmogorov-Smirnov (K-S) test. Miller and Freund (1987) point out that it is generally a more efficient test than the Chi-square test for *goodness-of-fit* test for small samples. Chi-square test is best for sample sizes over one hundred (100). Since the largest sample size available is forty-one (41), it then implies that the K-S test is more appropriate for the *goodness- of-fit* test.

The properties of the random phenomenon of wind in regard to wind loading on structures is that of extremal characteristics. So from this understanding of the phenomenon, the extreme value Type I (EV) distribution is assumed and the verified.

5.2.1 Probability Plotting Of Data

The Gumbel (or extreme value Type I) probability paper is constructed for each data set for the twenty (20) meteorological stations. The procedure is demonstrated using data sets for three stations: Bauchi, Calabar, and Enugu. Others are presented in Appendix C in Tables C.1 to C.16.

The wind speed data for each station is tabulated and ranked from 1 to n in ascending order. In this sense, n is the rank (m) of the largest wind speed recorded in that station (or

simply the sample size). Plotting positions are allotted to each data point. The plotting position is defined by :

$$p = \frac{m}{n+1} \qquad \text{.....(5.1)}$$

where m is the rank, and n is the sample size or rank (m) of the largest speed recorded for the given station. The standardized variate, y, of the distribution is then evaluated from the relationship:

$$\mathbf{y = -In\ (-In\ p)} \qquad \text{.....(5.2)}$$

Both p and y are plotted on an arithmetic scale along the x-axis while the specific values of the wind speed (v) corresponding to the probabilities (p) are plotted on the y-axis.

The plotting of all data sets shows that the points fall approximately on a straight line on the EV-I probability paper. A regression (that is, best fitting straight) line for each is plotted as Chart B. From the probability plotting, it can be seen that the extreme value Type I distribution is a suitable model for all the stations. The variation of data points from the regression line being minimal. Probability plotting of Bauchi, Calabar and Enugu data are shown in Fig. 5.1, Fig. 5.2 and Fig. 5.3 respectively. The respective tabulated data are shown in Tables 5.1, 5.2 and 5.3. The plots for sixteen of the stations are presented in Appendix C, in Figures C.1 to C.16, while that of Zaria has already been shown in Fig.3.1 (chapter 3).

Table 5.1 *Tabulated Annual Maximum Wind Speed At Bauchi (1955 - 1993)*

Year	Rank (m)	P=m/(n+1)	Wind Speed(m/s)	y= -ln(-lnp)	Chart B
1960	1	0.027	10.8	-1.284	13.4
1958	2	0.054	13.8	-1.071	13.8
1955	3	0.081	13.9	-0.921	14.2
1989	4	0.108	14.7	-0.8	14.6
1979	5	0.135	15.5	-0.694	15.1
1956	6	0.162	16.3	-0.598	15.5
1963	7	0.189	17.1	-0.51	15.9
1968	8	0.216	17.2	-0.426	16.3
1957	9	0.243	17.6	-0.346	16.8
1975	10	0.27	17.9	-0.269	17.2
1973	11	0.297	18.3	-0.193	17.6
1991	12	0.324	18.6	-0.119	18
1984	13	0.351	19	-0.045	18.5
1962	14	0.378	19.3	0.029	18.9
1964	15	0.405	19.7	0.102	19.3
1988	16	0.432	20	0.176	19.7
1981	17	0.459	20.4	0.251	20.1
1980	18	0.486	20.7	0.328	20.6
1983	19	0.514	20.8	0.406	21
1992	20	0.541	21.1	0.486	21.4
1965	21	0.568	21.4	0.568	21.8
1976	22	0.595	21.7	0.654	22.3
1961	23	0.622	22	0.744	22.7
1986	24	0.649	22.3	0.837	23.1
1966	25	0.676	22.6	0.936	23.5
1978	26	0.703	22.9	1.042	24
1990	27	0.73	23.2	1.155	24.4
1971	28	0.757	23.5	1.278	24.8
1982	29	0.784	23.8	1.412	25.2
1985	30	0.811	24.1	1.562	25.6
1970	31	0.838	24.4	1.732	26.1
1987	32	0.865	24.5	1.93	26.5
1974	33	0.892	26.5	2.168	26.9
1977	34	0.919	28.4	2.47	27.3
1972	35	0.946	31	2.89	27.8
1969	36	0.973	33	3.597	28.2
Location Parameter, u		0.368		0	18.7
Scale Parameter,(slope)		$1/\alpha$	=(v-u)/y		2.6
		α	=y/(v-u)		0.4

BAUCHI: $n = 36$, $\bar{v} = 20.78$, $s_v = 4.60$, coefficient of variation = 0.2

Table 5.2 *Tabulated Annual Maximum Wind Speed At Calabar (1953 - 1993)*

Year	Rank (m)	p = m/n+1	Wind Speed	y = -ln (-ln p)	Chart B
1976	1	0.024	10.8	-1.318	11.6
1953	2	0.048	11.8	-1.113	12
1992	3	0.071	12.8	-0.97	12.4
1970	4	0.095	13.8	-0.855	12.8
1986	5	0.119	13.9	-0.755	13.2
1955	6	0.143	14.3	-0.666	13.6
1968	7	0.167	14.6	-0.583	14
1975	8	0.19	15	-0.506	14.4
1964	9	0.214	15.3	-0.432	14.8
1954	10	0.238	15.8	-0.361	15.2
1991	11	0.262	16	-0.293	15.6
1972	12	0.286	16.4	-0.225	16
1966	13	0.31	16.7	-0.159	16.4
1989	14	0.333	17.1	-0.094	16.8
1981	15	0.357	17.2	-0.029	17.1
1979	16	0.381	17.5	0.036	17.5
1957	17	0.405	17.8	0.1	17.9
1983	18	0.429	18.2	0.166	18.3
1961	19	0.452	18.5	0.232	18.7
1977	20	0.476	18.8	0.298	19.1
1993	21	0.5	19.1	0.367	19.5
1982	22	0.524	19.4	0.436	19.9
1969	23	0.548	19.8	0.507	20.3
1980	24	0.571	20.1	0.581	20.7
1990	25	0.595	20.4	0.656	21.1
1973	26	0.619	20.7	0.735	21.5
1971	27	0.643	20.8	0.817	21.9
1985	28	0.667	21.2	0.903	22.3
1959	29	0.69	21.5	0.993	22.7
1963	30	0.714	21.9	1.089	23.1
1978	31	0.738	22.2	1.192	23.5
1988	32	0.762	22.6	1.302	23.9
1974	33	0.786	23	1.422	24.3
1967	34	0.81	23.3	1.554	24.7
1987	35	0.833	23.7	1.702	25.1
1984	36	0.857	24.1	1.87	25.5
1958	37	0.881	24.4	2.066	25.9
1960	38	0.905	28.4	2.302	26.3
1965	39	0.929	28.5	2.602	26.7
1956	40	0.952	30.6	3.02	27.1
1962	41	0.976	32.6	3.726	27.5
Location Parameter, u		0.368		0	17.3
Scale Parameter,(slope)		1/α	=(v-u)/y		2.7

CALABAR: n = 41, v = 19.53, s_v = 4.88, coefficient of variation = 0.2

Table 5.3 *Tabulated Annual Maximum Wind Speed At Enugu (1955 - 1993)*

Year	Rank (m)	p = m/(n+1)	Wind Speed	y = -ln(-ln p)	Chart B
1974	1	0.026	13.8	-1.291	13.9
1975	2	0.053	13.9	-1.08	14.4
1962	3	0.079	14.4	-0.932	14.8
1970	4	0.105	15	-0.812	15.2
1976	5	0.132	15.5	-0.707	15.7
1963	6	0.158	16	-0.613	16.1
1973	7	0.184	16.6	-0.526	16.5
1967	8	0.211	17.1	-0.443	17
1965	9	0.237	17.2	-0.365	17.4
1981	10	0.263	17.8	-0.289	17.8
1958	11	0.289	18.4	-0.215	18.3
1961	12	0.316	19	-0.142	18.7
1955	13	0.342	19.5	-0.07	19.1
1972	14	0.368	20.1	0.001	19.6
1964	15	0.395	20.7	0.073	20
1987	16	0.421	20.8	0.145	20.4
1959	17	0.447	21.2	0.218	20.9
1977	18	0.474	21.6	0.291	21.3
1991	19	0.5	22	0.367	21.7
1982	20	0.526	22.4	0.443	22.2
1960	21	0.553	22.8	0.522	22.6
1956	22	0.579	23.2	0.604	23
1983	23	0.605	23.6	0.689	23.5
1980	24	0.632	24	0.778	23.9
1978	25	0.658	24.4	0.871	24.3
1988	26	0.684	24.5	0.969	24.8
1984	27	0.711	24.9	1.074	25.2
1957	28	0.737	25.3	1.186	25.6
1993	29	0.763	25.7	1.308	26.1
1989	30	0.789	26.1	1.442	26.5
1979	31	0.816	26.5	1.592	26.9
1986	32	0.842	26.8	1.761	27.4
1966	33	0.868	27.2	1.958	27.8
1985	34	0.895	27.6	2.196	28.2
1990	35	0.921	28	2.498	28.7
1971	36	0.947	28.4	2.918	29.1
1,992	37	0.974	32.6	3.624	29.5
Location Parameter, u		0.368		0	19.6
Scale Parameter,(slope)		1/α	=(v-u)/y		2.8
		α	=y/(v-u)		0.4

ENUGU: $n = 37$, $\bar{v} = 21.75$, $s_v = 4.67$, coefficient of variation = 0.2

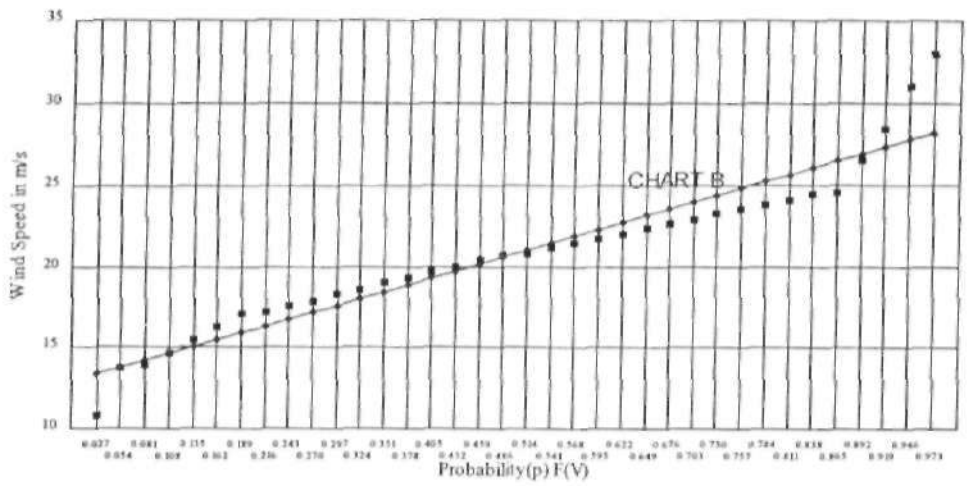


Fig 5.1 *Probability Chart Of Annual Maximum Wind Speed At Bauchi On EV-I Probability Paper.*

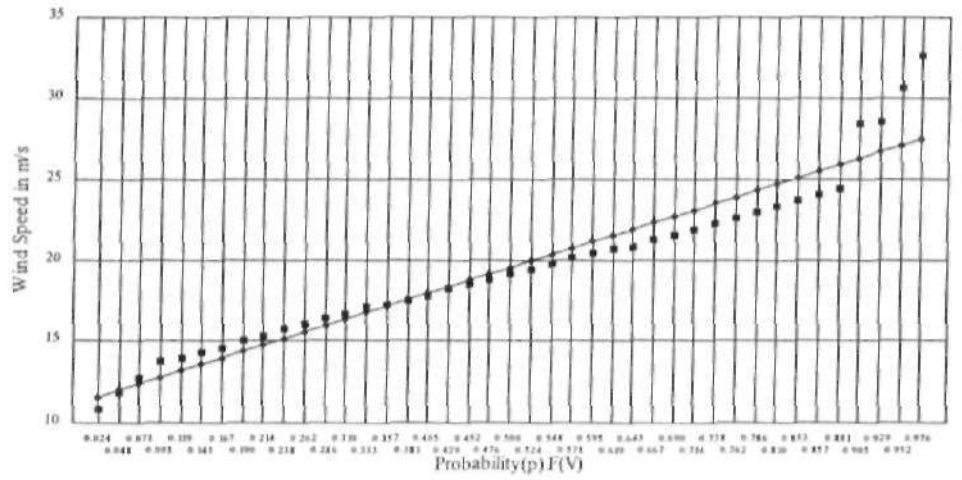


Fig 5.2 *Probability Chart Of Annual Maximum Wind Speed At Calabar On EV-I Probability Paper.*

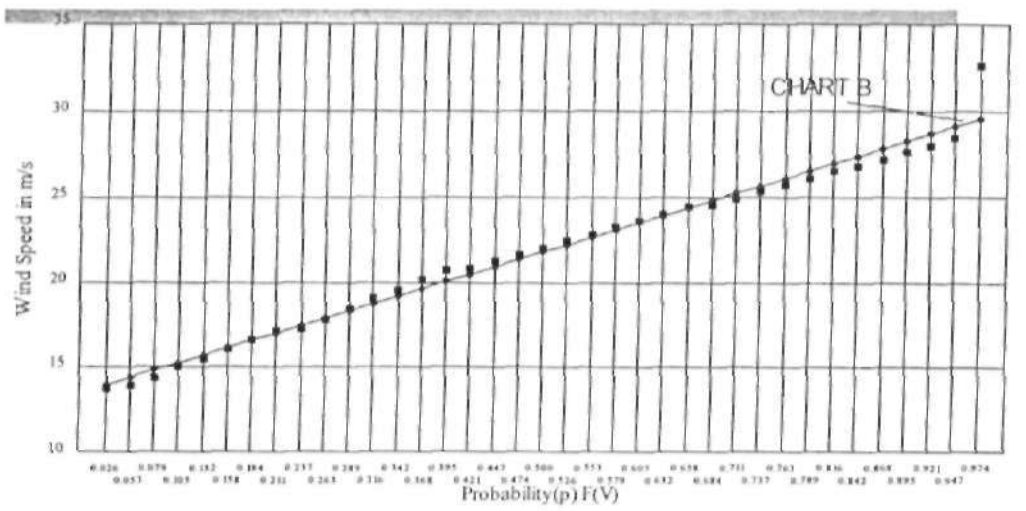


Fig 5.3 *Probability Chart Of Annual Maximum Wind Speed At Enugu On EV-I Probability Paper.*

5.2.2 Histogram Plotting Of The Probability Distribution

Firstly, frequency tables of extreme maximum wind speed data collected are prepared. Each data set is divided into ranges or intervals and the frequencies of occurrence of wind speed within such ranges are determined. Their corresponding probability density functions (PDF), are also evaluated. Then the PDF is plotted against the ranges to give the histogram.

The PDF for each range is evaluated from the following simple relationship:

$$\text{PDF} = \frac{f}{n} \qquad \text{.....(5.3)}$$

where f is the frequency of occurrence of wind speed within a specified range and n is the number of observations for the given station. It is noteworthy to mention that the summation of the probability density functions PDFs of all the ranges in a given stations is unity.

The frequency tables of the extreme maximum wind speed for the twenty (20) meteorological stations are shown in Table 5.4. The histograms for Calaber, Jos, Maiduguri, and Yola are shown in Figures 5.4 to 5.7.

Table 5.4 *Frequency Tables Of Extreme Wind Speed.* (Bauchi, Calabar, Enugu, Ibadan, Ibi, Ilorin, Jos, Kaduna,)

	BAUCHI				**CALABAR**	
Range	PDF	Fequency		Range	PDF	Fequency
12	0.03	1		12	0.05	2
16	0.11	4		16	0.22	9
20	0.31	11		20	0.29	12
24	0.36	13		24	0.29	12
28	0.11	4		28	0.05	2
32	0.06	2		32	0.07	3
36	0.03	1		36	0.02	1
Over 36	0	0		Over 36	0	0
Total	1	36		Total	1	41
	ENUGU				**IBADAN**	
14	0.05	2		11	0.05	2
16	0.11	4		12	0.05	2
20	0.19	7		16	0.24	10
24	0.3	11		20	0.2	8
28	0.3	11		24	0.24	10
32	0.03	1		28	0.1	4
36	0.03	1		32	0.1	4
Over 36	0	0		36	0.02	1
Total	1	37		Total	1	41
	IBI				**ILORIN**	
12	0.08	3		12	0.07	3
16	0.21	8		16	0.17	7
20	0.26	10		20	0.22	9
24	0.29	11		24	0.27	11
28	0.11	4		28	0.17	7
32	0.03	1		32	0.07	3
36	0.03	1		36	0.02	1
Over 36	0	0		Over 36	0	0
Total	1	38		Total	1	41
	JOS				**KADUNA**	
12	0	0		12	0	0
16	0.03	1		16	0.07	3
20	0.08	3		20	0.32	13
24	0.25	9		24	0.41	17
28	0.44	16		28	0.17	7
32	0.14	5		32	0.02	1
36	0.06	2		36	0	0
Over 36	0	0		Over 36	0	0
Total	1	36		Total	1	41

Table 5.4 *Frequency Tables Of Extreme Wind Speed. (Katsina, Lokoja, Maiduguri, Minna, Port Harcourt, Sokoto, Warri, Yola.)*

	KATSINA	
Range	PDF	Frequency
10	0.03	1
12	0.1	4
16	0.26	10
20	0.36	14
24	0.08	3
28	0.15	6
32	0.03	1
Over 32	0	0
Total	1	39

	LOKOJA	
Range	PDF	Frequency
12	0.02	1
16	0.24	10
20	0.41	17
24	0.24	10
28	0.05	2
32	0	0
26	0.02	1
Over 36	0	0
Total	1	41

	M/DUGURI	
12	0.07	3
16	0.07	3
20	0.15	6
24	0.29	12
28	0.15	6
32	0.12	5
36	0.15	6
Over36	0	0
Total	1	41

	MINNA	
12	0.1	4
16	0.15	6
20	0.15	6
24	0.23	9
28	0.26	10
32	0.05	2
36	0.05	2
Over 36	0	0
Total	1	39

	P.H.	
12	0.03	1
16	0.2	8
20	0.3	12
24	0.35	14
28	0.08	3
32	0.03	1
36	0.03	1
Over 36	0	0
Total	1	40

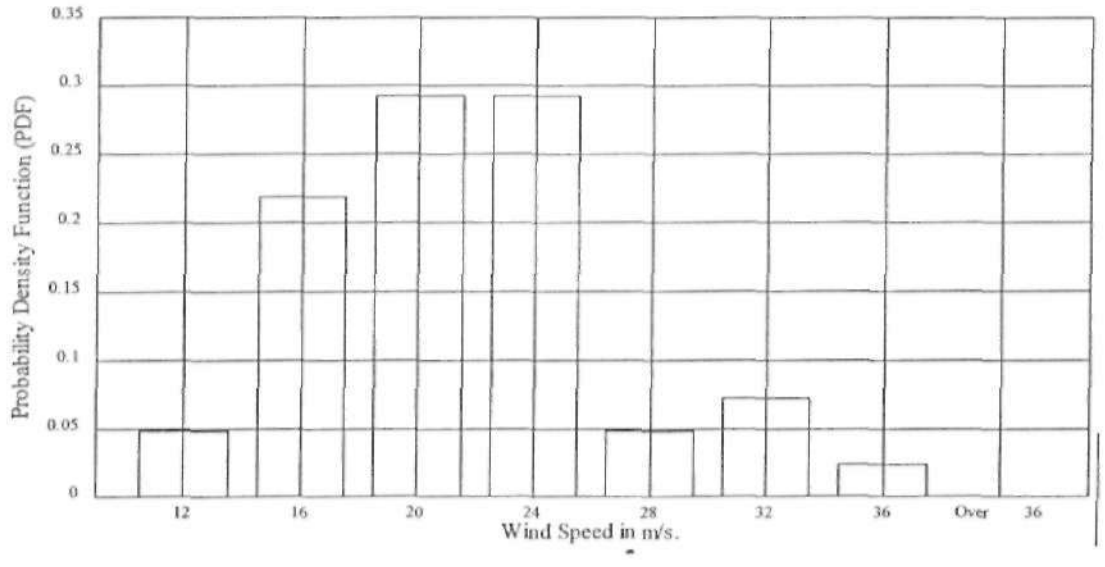
	SOKOTO	
12	0	0
16	0.05	2
20	0.15	6
24	0.28	11
28	0.31	12
32	0.13	5
36	0.08	3
Over 36	0	0
Total	1	39

	WARRI	
8	0.1	4
12	0.18	7
16	0.35	14
20	0.28	11
24	0.08	3
28	0	0
32	0.03	1
Over32	0	0
Total	1	40

	YOLA	
12	0	0
16	0.03	1
20	0.18	7
24	0.35	14
28	0.18	7
32	0.2	8
36	0.08	3
Over 36	0	0
Total	1	40

Table 5.4 *Frequency Tables Of Extreme Wind Speed. (Ikom, Lagos, Owerri, Zaria).*

	IKOM				**LAGOS**	
Range	PDF	Fequency		Range	PDF	Fequency
4	0	0		4	0	0
8	0.05	1		8	0.2	6
12	0.32	7		12	0.17	5
16	0.41	9		16	0.47	14
20	0.09	2		20	0.1	3
24	0.09	2		24	0.03	1
28	0.05	1		28	0	0
Over 28	0	0		Over 28	0.03	1
Total	1	22		Total	1	30
	OWERRI				**ZARIA**	
12	0.1	2		12	0	0
14	0.2	4		16	0	0
16	0.15	3		20	0.04	1
18	0.2	4		24	0.28	7
20	0.15	3		28	0.36	9
22	0.1	2		32	0.28	7
24	0.05	1		36	0.04	1
Over 24	0.05	1		Over 36	0	0
Total	1	20		Total	1	25



.Fig. 5.4 *Histogram Of Annual Maximum Wind Speed At Calabar.*

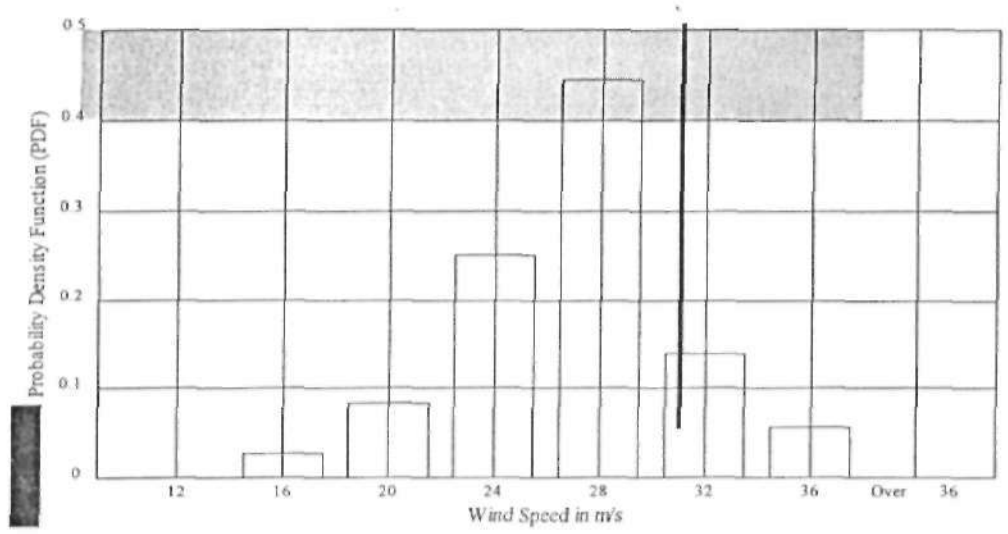


Fig 5.5 *Histogram Of Annual Maximum Wind Speed At Jos.*

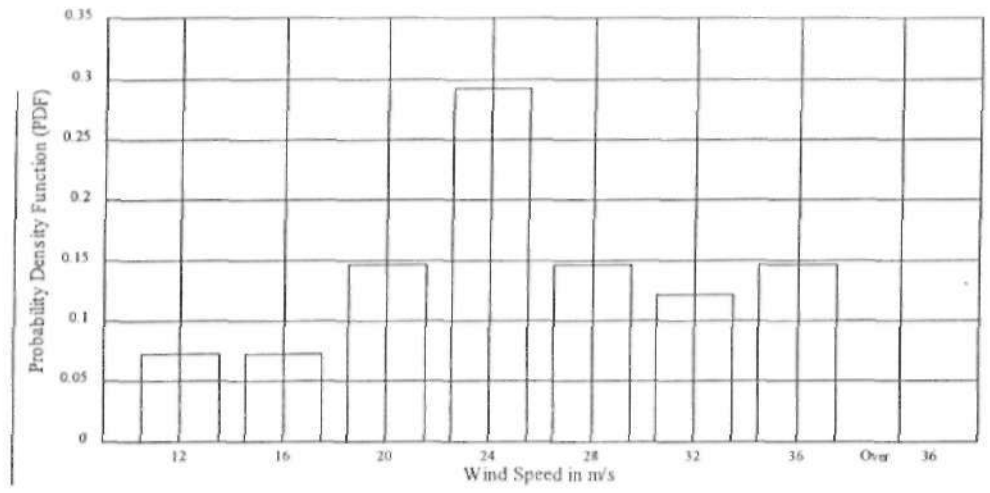


Fig 5.6 *Histogram Of Annual Maximum Wind Speed At Maiduguri.*

It can be seen from these graphs of probability distribution that the distribution is visually consistent with the probability distribution of an extreme value Type I model.

Empirically, therefore, it can be concluded that the EV-I probability distribution is a suitable model that best describes the probability behaviour of the extreme maximum wind speed in these twenty meteorological stations. The validity of this empirical deductions is

verified by statistical testing in Section 5.4. To verify the validity of this model, the parameters of the model must first be estimated.

5.3 ESTIMATION OF THE SELECTED MODEL PARAMETERS.(u, α or $\frac{1}{\alpha}$)

Three methods of extremal parameters estimation of the EV-I distribution are used here and then compared. These are the graphical, moments and order statistics methods.

5.3.1 Graphical Method

The two parameters: the location parameter, u, and the scale parameter, α or $\frac{1}{\alpha}$,are estimated from the probability chart of the annual maximum wind speeds on the EV-I probability (also known as the Gumbel) paper. On the regression line (Chart B), the location parameter, u, corresponds to the value of the wind speed which has its abscissa as:

$F(V) = e^{-1} = 0.368$, or $y = 0$. The estimated parameter, u for Bauchi, Calabar and Enugu are indicated in Tables 5.1, 5.2 and 5.3 respectively. This parameter can also be read off from the probability chart on Gumbel paper.

The scale parameter, α is given by :

$$\alpha = \frac{y}{v-u} \qquad \text{.....(5.4)}$$

$\frac{1}{\alpha}$ is the slope of the straight line and is given by:

$$\frac{1}{\alpha} = \frac{v-u}{y} \qquad \text{.....(5.5)}$$

The output of the scale parameter for each station is given on the Tables of the annual maximum wind speed (that is Tables 5.1 to 5.3 for Bauchi, Calabar and Enugu respectively). Tables and results for the other stations are presented in Appendix C, Tables C1 to C16, except for Zaria which is shown in chapter three, Table 3.1.

5.3.2 Method Of Moments

As has already been reviewed (Section 3.6.1.1), we obtain the parameters of the selected model by simply replacing the population moments by the corresponding sample moments. From Equation (3.26), we make u the subject to obtain :

$$u = \mu_v - \frac{\gamma}{\alpha} \quad \text{.....(5.6)}$$

which implies : $u = \mu_v - \gamma\left(\frac{1}{\alpha}\right)$

But *Equation (3.28) yields the following:*

$$\frac{1}{\alpha} = \sigma_v \frac{\sqrt{6}}{\pi} \quad \text{.....(5.7)}$$

From which $\alpha = \frac{\pi}{\sigma_v\sqrt{6}}$ .....(5.8)

Substituting Equation (5.7) into (5.6) we obtain:

$$u = \mu_v = \frac{\sigma_v\sqrt{6}}{\pi}\gamma \quad \text{.....(5.9)}$$

We now replace the above population moments μ_v and σ_v by the corresponding sample momentsv and s_v . The moment estimators of the EV-I parameters then become:

$$\hat{u} = \bar{v} - \frac{s_v\sqrt{6}}{\pi}\gamma = \bar{v} - \frac{s_v(2.44949)}{3.141593}(0.577216) \quad \text{.....(5.10)}$$

and $\hat{\alpha} = \frac{\pi}{s_v\sqrt{6}} = \frac{3.141593}{s_v(2.44949)}$ .....(5.11)

Equations (5.10) and (5.11) are used directly to evaluate the estimates of the selected model parameters for each station using the method of moments. Results of the estimation are tabulated in Table 5.5.

It should be noted that from Equation (5.11), $\frac{1}{\hat{\alpha}}$ is easily derived.

$$\frac{1}{\hat{\alpha}} = \frac{s_v\sqrt{6}}{\pi} = \frac{s_v(2.44949)}{3.141593} \quad \text{.....(5.12)}$$

So then, in evaluating the cumulative distribution function (CDF), (FV) for any given variate, v, we use Equation (3.22) or (3.23). In Equation (3.22) the term σ should be replaced by $\frac{1}{\alpha}$ and in Equation (3.23) α is used directly.

Table 5.5 *Results Of Estimates Of Selected Model Parameters By Method Of Moments.*

STATION	MEAN	STD (s_x)	u	α	$1/\alpha$
BAUCHI	20.78	4.6	18.7	0.3	3.6
CALABAR	19.53	4.88	17.3	0.3	3.8
ENUGU	21.75	4.67	19.6	0.3	3.6
IBADAN	19.61	5.8	17	0.2	4.5
IBI	19.22	5.29	16.8	0.2	4.1
ILORIN	20.33	5.53	17.8	0.2	4.3
JOS	24.8	4.11	23	0.3	3.2
KADUNA	21.14	3.33	19.6	0.4	2.6
KATSINA	17.78	4.94	15.6	0.3	3.9
LOKOJA	18.59	4	16.8	0.3	3.1
MAIDUGURI	23.01	6.74	20	0.2	5.3
MINNA	20.91	6.22	18.1	0.2	4.8
PORT H/C	19.71	4.52	17.7	0.3	3.5
SOKOTO	24.01	4.92	21.8	0.3	3.8
WARRI	14.74	4.62	12.7	0.3	3.6
YOLA	24.15	4.84	22	0.3	3.8
IKOM	13.93	4.26	12	0.3	3.3
LAGOS	12.9	4.61	10.8	0.3	3.6
OWERRI	16.83	3.69	15.2	0.3	2.9
ZARIA	25.93	3.86	24.2	0.3	3

5.3.3 Method Of Order Statistics

Ang and Tang (1984) point out that Lieblien's method of order statistics is based on the assumption that the set of sample of extreme values constitutes a statistically independent

series of observations and that this assumption should be observed closely in the use of this method. Retaining or preserving the original sequence of observed data usually satisfies this requirement. The original sequence of the data series is divided into consecutive subgroups of size n = 6 or 5 . The sample values of each subgroup are sorted in ascending order and the parameters u and α are then estimated using Equations (3.39) and (3.40) respectively. The weighted averages of $\hat{u}$ and $\frac{1}{\alpha}$ for the subgroups then give the final estimates for $\hat{u}$ and $\frac{1}{\hat{\alpha}}$. This is illustrated in Table 5.7.

Table 5.6 Weights for Leiblein's Order Statistics for Estimator (P > 0.90)

		1	2	3	4	5	6	
n=5	a	0.41893	0.24628	0.16761	0.10882	0.05835		
	b	-0.50313	0.00653	0.13045	0.18166	0.18448		
n=6	a	0.35545	0.22549	0.16562	0.12105	0.08352	0.04887	
	b	-0.45928	-0.03599	0.07319	0.12673	0.14953	0.14581	

Table 5.7 *Parameter Estimation By Method Of Order Statistics*

	BAUCHI						
Subgroup	1	2	3	4	5	6	
V1	10.8	17.1	18.3	15.5	19	14.7	
V2	13.8	17.2	23.5	17.9	20.4	18.6	
V3	13.9	19.3	24.4	20.7	20.8	20	
V4	16.3	19.7	26.5	21.7	22.3	21.1	
V5	17.6	21.4	31	22.9	23.8	23.2	
V6	22	22.6	33	28.4	24.1	24.5	**BAUCHI**
							Mean
u	13.77095	18.42956	23.25453	18.90138	20.6634	18.42076	18.9
1/a	3.4657	1.93168	5.34075	4.06725	1.96075	3.75841	3.4
a	0.28854	0.51768	0.18724	0.24587	0.51001	0.26607	0.3

The estimates shown in Table 5.7 are obtained as follows:

$\hat{u}_{v11}$	$\hat{u}_{v21}$	$\hat{u}_{v31}$	$\hat{u}_{v41}$	$\hat{u}_{v51}$	$\hat{u}_{v61}$	Σ
10.8(0.35545)	13.8(0.22549)	13.9(0.16562)	16.3(0.12105)	17.6(0.8352)	22(0.04887)	
3.83886	3.111762	2.302118	1.973115	1.469952	1.07514	13.770947

$\frac{1}{\hat{\alpha}_{v11}}$	$\frac{1}{\hat{\alpha}_{v21}}$	$\frac{1}{\hat{\alpha}_{v31}}$	$\frac{1}{\hat{\alpha}_{v41}}$	$\frac{1}{\hat{\alpha}_{v51}}$	$\frac{1}{\hat{\alpha}_{v61}}$	$\Sigma \frac{1}{\hat{\alpha}_{subgr}}$
10.8(-0.45928)	13.8(-0.03599)	13.9(0.07319)	16.3(0.12673)	17.6(0.14953)	22(0.14581)	
-4.960224	-0.496662	1.017341	2.065699	2.631728	3.20782	3.465702

The values of $\hat{u}$ and $\frac{1}{\hat{\alpha}}$ for each subgroup are evaluated in the same way as illustrated in the evaluation of the above estimates for subgroup 1. The averages of $\hat{u}$ and $\frac{1}{\hat{\alpha}}$ for all the subgroups gives the final estimates of the parameters.

The results of estimates of $\hat{u}$ and $\frac{1}{\hat{\alpha}}$ for the other nineteen stations using this method are presented in Appendix D (Tables D1 to D19).

5.3.4 Comparison Of Results Of Estimation By The Three Methods Of Parameter Estimation

The results of estimation using the graphical method, the methods of moments and order statistics are compared in Table 5.8. It can be observed that for the values of $\hat{u}$ (the location parameter), there exists no much difference between the results obtained by three methods. However, the difference between the results obtained for α and $\frac{1}{\hat{\alpha}}$ widens when the graphical method is employed than when either the method of moments or order statistics is used. The method of moments and order statistics give a relatively close results. It has been attested to that the order statistics method gives a more efficient and unbiased estimates (Ang and Tang,

1984; Simiu and Scanlan, 1986). Hence the estimates obtained using the method of order statistics can be regarded as more reliable.

Table 5.8 *Comparison Of Estimated Parameters Using Three Methods Of Parameter Estimation*

METHOD	1	2	3	1	2	3	1	2	3
	Graphical Method	Method of Moments	Method of Order Statistics	Graphical Method	Method of Moments	Method of Order Statistics	Graphical Method	Method of Moments	Method of Order Statistics
	Location Parameter						Scale Parameter		
Statio	u	u	u	1/α	1/α	1/α	α	α	α
BAU	18.7	18.7	18.9	2.6	3.6	3.4	0.4	0.3	0.3
CAL	17.3	17.3	17.1	2.7	3.8	4.2	0.4	0.3	0.2
ENU	19.6	19.6	19.9	2.8	3.6	3.3	0.4	0.3	0.3
IBAD	16.9	17	17	3.3	4.5	4.5	0.3	0.2	0.2
IBI	16.8	16.8	16.5	3.1	4.1	5.1	0.3	0.2	0.2
ILR	17.9	17.8	18.5	3.2	4.3	3.5	0.3	0.2	0.3
JOS	23	23	22.8	2.4	3.2	3.6	0.4	0.3	0.3
KAD	19.6	19.6	19.6	1.9	2.6	3	0.5	0.4	0.3
KAT	15.5	15.6	16.1	2.8	3.9	3.6	0.4	0.3	0.3
LKJ	16.9	16.8	16.9	2.1	3.1	3	0.5	0.3	0.3
MDG	19.9	20	20.1	3.8	5.3	5.3	0.3	0.2	0.2
MIN	18	18.1	18.9	3.6	4.8	3.9	0.3	0.2	0.1
P. H.	17.7	17.1	17.6	2.5	3.5	3.8	0.4	0.3	0.3
SOK	21.7	21.8	22.3	2.9	3.8	3.6	0.4	0.3	0.3
WAR	12.7	12.7	12.8	2.6	3.6	3.6	0.4	0.3	0.3
YOLA	21.9	22	22	2.8	3.8	3.2	0.4	0.3	0.3
IKOM	12	12	11.9	2.7	3.3	3.5	0.4	0.3	0.3
LAG	10.9	10.8	10.8	2.7	3.6	3.8	0.4	0.3	0.3
OWE	15.1	15.2	15.3	2.6	2.9	2.7	0.4	0.3	0.4
ZAR	24.1	24.2	23.7	2.5	3	4	0.4	0.3	0.3

5.4 VERIFICATION OF THE SELECTED MODEL

The Kolmogorov-Smirnov (K-S) *goodness-of-fit* test is used to verify the validity or suitability of the EV-I model selected. The procedure for carrying out the test is now illustrated. Each station data is rearranged in increasing order. From these ordered sample, a stepwise cumulative frequency function is developed such that for any data point the cumulative frequency function is given by:

$$S_n(V) = \frac{k}{n} \quad \text{.....(5.13)}$$

In a broader sense it is $S(V) = \frac{k}{n}$ for the range $v_k \le v \le v_{k+1}$
$= 1$ for $v \ge v_n$ and it is 0 for $v < v_1$

where k is the value of the order or rank for a given data point; n is the sample size or the number of observations for a given station and v is the wind speed.

Secondly, the selected theoretical probability distribution function F(V) is calculated using Equation (3.22) or (3.23) and the results obtained in the estimation of parameters in the preceding section. (The results from the method of order statistics are used).

The difference, D, between the cumulative frequency function and the theoretical distribution function are the evaluated for each data point. For each sample data, the largest of D is important and therefore extracted as D_{max} (that is: maximum difference). The maximum difference is then compared to the critical difference, $D_{critical}$ for a specified level of significance.

$$\begin{aligned} D_n &= F(V) - S_n(V) \\ &= F(V) - \frac{k}{n} \quad \text{.....(5.14)} \end{aligned}$$

The discrepancy between the selected theoretical model and the observed data is measured by the maximum difference between $S_n(V)$ and F(V) over the entire range of V. That is;

$$D_{max} = \max[F(V) - S_n(V)] \quad \text{.....(5.15)}$$

$$P(D_{max} \leq D^{\alpha}_{critical}) = 1 - \alpha \quad \text{.....(5.16)}$$

Critical values $D^{\alpha}_{critical}$ at various significance levels are given according to sample size. Generally, the values can be evaluated using the corresponding relationship as given in Table 5.9

Table 5.9 *Relationship For Obtaining Values Of Critical Difference* [1]

α	0.2	0.1	0.05	0.01
$D^{\alpha}_{critical}$	$\frac{1.07}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.36}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

The selected model will be regarded as valid, suitable or satisfactory if the observed difference D_{max} is less than the critical value, at the specified level of significance. Otherwise, the selected model will rejected.

The K-S test is performed for the data series of the twenty meteorological stations and the theoretical model is valid for all the stations at the significance levels of 0.10, 0.05, and 0.01.The result of the test for Calabar station is presented in Table 5.10 as an illustration. A comparative table of the test results for all the stations at 0.10, 0.05, and 0.01 levels of significance is given in Table 5.11.

In view of the results testing valid, it then implies that the extreme value Type I model for largest values is a suitable and an acceptable stochastic model for extreme maximum wind

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1. Taken from Ang and Tang (1975).

speed in any typical well behaved wind climate such as Nigeria.

Graphically, the K-S test is illustrated for only one station as shown in Fig. 5.7.Similar graphical illustrations can be performed for all the other stations simply by plotting the observed wind speed in their ordered form as shown in Table 5.10 against the selected theoretical probability distribution function F(V) and the cumulative frequency function $S_n(V)$ or k/n. The graphical illustration help one to have a visual impression of the degree of difference between F(V) and $S_n(V)$. The maximum positive difference is the point of interest and it can be viewed from the chart. (See Fig.5.7).

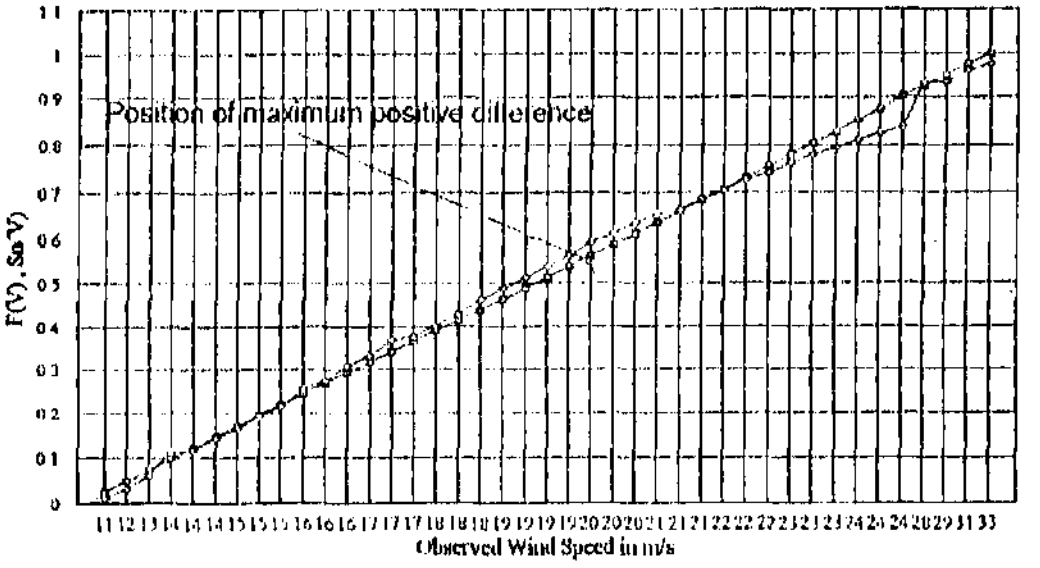

Fig. 5.7 *The K-S Chart For Calabar: A Typical Graphical Illustration.*

Table 5.10 *K-S Test For Relative Goodness-Of- Fit For Calabar*

v	k	k/n, n = 41	F(V)	D = F(V) - k/n
10.8	1	0.024	0.011	-0.013
11.8	2	0.049	0.029	-0.02
12.8	3	0.073	0.062	-0.011
13.8	4	0.098	0.111	0.014
13.9	5	0.122	0.117	-0.005
14.3	6	0.146	0.143	-0.004
14.6	7	0.171	0.163	-0.008
15	8	0.195	0.192	-0.003
15.3	9	0.22	0.215	-0.004
15.8	10	0.244	0.256	0.012
16	11	0.268	0.273	0.004
16.4	12	0.293	0.307	0.014
16.7	13	0.317	0.333	0.016
17.1	14	0.341	0.368	0.026
17.2	15	0.366	0.377	0.011
17.5	16	0.39	0.403	0.013
17.8	17	0.415	0.429	0.014
18.2	18	0.439	0.463	0.024
18.5	19	0.463	0.488	0.025
18.8	20	0.488	0.513	0.025
19.1	21	0.512	0.537	0.025
19.4	22	0.537	0.561	0.024
19.8	23	0.561	0.591	0.03
20.1	24	0.585	0.613	0.028
20.4	25	0.61	0.634	0.024
20.7	26	0.634	0.654	0.02
20.8	27	0.659	0.661	0.002
21.2	28	0.683	0.686	0.003
21.5	29	0.707	0.704	-0.003
21.9	30	0.732	0.727	-0.005
22.2	31	0.756	0.743	-0.013
22.6	32	0.78	0.763	-0.017
23	33	0.805	0.782	-0.023
23.3	34	0.829	0.796	-0.034
23.7	35	0.854	0.812	-0.041
24.1	36	0.878	0.828	-0.05
24.4	37	0.902	0.839	-0.064
28.4	38	0.927	0.934	0.008
28.5	39	0.951	0.936	-0.015
30.6	40	0.976	0.961	-0.015
32.6	41	1	0.975	-0.025
CALABAR	n = 41		Dmax. =	0.030

Table 5.10 (contd) K-S Test For Relative *Goodness-Of-Fit* For Calabar
Dcritical = 1.36/SQRT(n) for significance level of 0.05
Dcritical = 1.36/SQRT(41) = 0.212 Dmax (0.030) < Dcritical (0.212), hence selected model is valid. Dmax (0.030) is still < Dcritical (0.191) for 0.10 significance level. So the selected model is valid.

Table 5.11 *Comparative Results Of The Goodness-Of-Fit Test For Bauchi, Calabar, Enugu, And Ibadan Stations At 0.10, 0.05, And 0.01, Significance Levels.*

STATION	Level of Sig. α	$D^{\alpha}_{critical}$		D_{max}	Accept or Reject
BAUCHI	0.1	$1.22/\sqrt{n}$	= 0.203	0.055	Accept The Model
n = 36	0.05	$1.36/\sqrt{n}$	= 0.227		Accept The Model
	0.01	$1.63/\sqrt{n}$	= 0.272		Accept The Model
CALABAR	0.1	$1.22/\sqrt{n}$	= 0.191	0.030	Accept The Model
n = 41	0.05	$1.36/\sqrt{n}$	= 0.212		Accept The Model
	0.01	$1.63/\sqrt{n}$	= 0.255		Accept The Model
ENUGU	0.1	$1.22/\sqrt{n}$	= 0.201	0.101	Accept The Model
n = 37	0.05	$1.36/\sqrt{n}$	= 0.224		Accept The Model
	0.01	$1.63/\sqrt{n}$	= 0.268		Accept The Model
IBADAN	0.1	$1.22/\sqrt{n}$	= 0.191	0.059	Accept The Model
n = 41	0.05	$1.36/\sqrt{n}$	= 0.212		Accept The Model
	0.01	$1.63/\sqrt{n}$	= 0.255		Accept The Model

Table 5.11 *Comparative Results Of The Goodness-Of-Fit Test For Ibi, Ikom, Ilorin, Jos Kaduna, Katsina, Lagos, Lokoja, M/Duguri, Minna, And Owerri Stations At 0.10, 0.05, And 0.01, Significance Levels.*

STATION	Level of Sig. α	$D^{\alpha}_{critical}$		D_{max}	Accept or Reject Model
IBI	0.1	$;1.22/\sqrt{n}$	= 0.198	0.051	Accept The Model
n = 38	0.05	$;1.36/\sqrt{n}$	= 0.221		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.264		Accept The Model
IKOM	0.1	$;1.22/\sqrt{n}$	= 0.260	0.017	Accept The Model
n = 22	0.05	$;1.36/\sqrt{n}$	= 0.290		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.348		Accept The Model
ILORIN	0.1	$;1.22/\sqrt{n}$	= 0.191	0.076	Accept The Model
n = 41	0.05	$;1.36/\sqrt{n}$	= 0.212		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.255		Accept The Model
JOS	0.1	$;1.22/\sqrt{n}$	= 0.203	0.138	Accept The Model
n = 36	0.05	$;1.36/\sqrt{n}$	= 0.227		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.272		Accept The Model
KADUNA	0.1	$;1.22/\sqrt{n}$	= 0.191	0.038	Accept The Model
n = 41	0.05	$;1.36/\sqrt{n}$	= 0.212		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.255		Accept The Model
KATSINA	0.1	$;1.22/\sqrt{n}$	= 0.195	0.059	Accept The Model
n = 39	0.05	$;1.36/\sqrt{n}$	= 0.218		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.216		Accept The Model
LAGOS	0.1	$;1.22/\sqrt{n}$	= 0.223	0.111	Accept The Model
n = 30	0.05	$;1.36/\sqrt{n}$	= 0.248		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.298		Accept The Model
LOKOJA	0.1	$;1.22/\sqrt{n}$	= 0.191	0.023	Accept The Model
n = 41	0.05	$;1.36/\sqrt{n}$	= 0.212		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.255		Accept The Model
M/DUGURI	0.1	$;1.22/\sqrt{n}$	= 0.191	0.068	Accept The Model
n = 41	0.05	$;1.36/\sqrt{n}$	= 0.212		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.255		Accept The Model
MINNA	0.1	$;1.22/\sqrt{n}$	= 0.195	0.117	Accept The Model
n = 39	0.05	$;1.36/\sqrt{n}$	= 0.218		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.216		Accept The Model
OWERRI	0.1	$;1.22/\sqrt{n}$	= 0.272	0.048	Accept The Model
n = 20	0.05	$;1.36/\sqrt{n}$	= 0.304		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.364		Accept The Model

Table 5.11 *Comparative Results Of The Goodness-Of-Fit Test For Port Harcourt, Sokoto, Warri, Yola, And Zaria Stations At 0.10, 0.05, And 0.01, Significance Levels.*

STATION	Level of Sig.	$D^{\alpha}_{critical}$		D_{max}	Accept or Reject Model
PORT HARCOURT n = 40	0.1	$;1.22/\sqrt{n}$	= 0.193	0.046	Accept The Model
	0.05	$;1.36/\sqrt{n}$	= 0.215		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.258		Accept The Model
SOKOTO n = 39	0.1	$;1.22/\sqrt{n}$	= 0.195	0.040	Accept The Model
	0.05	$;1.36/\sqrt{n}$	= 0.218		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.216		Accept The Model
WARRI n = 40	0.1	$;1.22/\sqrt{n}$	= 0.193	0.119	Accept The Model
	0.05	$;1.36/\sqrt{n}$	= 0.215		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.258		Accept The Model
YOLA n = 40	0.1	$;1.22/\sqrt{n}$	= 0.193	0.123	Accept The Model
	0.05	$;1.36/\sqrt{n}$	= 0.215		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.258		Accept The Model
ZARIA n = 25	0.1	$;1.22/\sqrt{n}$	= 0.244	0.072	Accept The Model
	0.05	$;1.36/\sqrt{n}$	= 0.272		Accept The Model
	0.01	$;1.63/\sqrt{n}$	= 0.326		Accept The Model

CHAPTER SIX

EXTREME LARGEST WIND SPEED PREDICTIONS FOR SPECIFIED RETURN PERIODS

6.1 GENERAL REMARKS

Having selected a theoretical stochastic model that suitably and reliably describes the probabilistic behaviour of extreme largest wind for a well behaved wind climate and having verified the selected model as acceptable, the next step in the process of reliable assessment of wind loading is the prediction of the largest wind speed that may be expected to pass over a specified location for a specified return period or mean recurrence interval, T. This is the focus of this chapter.

Predictions are carried out for twelve (12) different return periods namely 2, 5, 10, 20, 25, 30, 50, 75, 100,125, 150, and 1000 years. The predictions are based on the estimated parameters of the selected model using the methods of moments and order statistics and the graphical method.

Finally, the output from these predictions are compared with results from the work of Soboyejo (1971).

6.2 PREDICTIONS USING RESULTS FROM METHODS OF MOMENTS AND ORDER STATISTICS

The selected model is given in Equations (3.22) and (3.23) respectively as:

$$F_v(V) = \exp\left[-\exp-\left(\frac{v_i-u}{\sigma}\right)\right]$$

and

$$F_v(V) = \exp\left[-\exp-\alpha(v-u)\right]$$

in which $F_v(V)$ is the probability p that the extreme largest wind speed v will not be exceeded within a specified return period T, and $\frac{1}{\sigma}=\alpha$ or $\frac{1}{\alpha}=\sigma$.

Let us now express the above equation as:

$$p = e^{-e^{-\alpha(v-u)}} \quad \text{.....(6.1)}$$

This implies that $\ln p = -e^{-\alpha(v-u)}$

$$-\ln(\ln p) = -\alpha(v-u)$$

$$-\ln(-\ln p) = \alpha(v-u)$$

from which we obtain

$$y = \alpha(v-u) = -\ln(-\ln p) \quad \text{.....(6.2)}$$

Simplifying further we construct a general estimator of the extreme largest wind speed v that is not likely to pass over a specified location for a specified return period T.

$$y = \alpha v - \alpha u$$

making v the subject we obtain :

$$v = \frac{y}{\alpha}+u \Rightarrow v = u + \frac{y}{\alpha} \quad \text{.....(6.3)}$$

We can now replace u and $\frac{1}{\alpha}$ with the values of the estimators $\hat{u}$ and $\frac{1}{\hat{\alpha}}$ obtained from the methods of moments and order statistics. So Equation (6.3) becomes:

$$\hat{V}_T = \hat{u} + \frac{y}{\hat{\alpha}} \quad \text{.....(6.4)}$$

where $\hat{V}_T$ is the predicted or estimator for the extreme largest wind speed for a specified return period T, and y is given by:

$$y = -\ln(-\ln p) =; -\ln\left[-\ln\left(1-\frac{1}{T}\right)\right] \quad \text{.....(6.5)}$$

Corresponding values of y for twelve different return periods are tabulated in Table 6.1

Table 6.1 *Values of y For Twelve (12) Return Periods And The Corresponding p = 1- 1/T*

Return Period, T (in years)	2	5	10	20	25	30	50	75	100	125	150	1000
$y=-\ln\left(-\ln\left(1-\frac{1}{T}\right)\right)$	0.367	1.5	2.25	2.97	3.199	3.384	3.902	4.311	4.6	4.824	5.007	6.907
$p = 1-\frac{1}{T}$	0.5	0.8	0.9	0.95	0.96	0.97	0.98	0.987	0.99	0.992	0.993	0.999

Equation (6.4) is used directly to predict the extreme largest wind speed using the results obtained from the methods of order statistics. The estimates of the estimators $\hat{u}$ and $\frac{1}{\hat{\alpha}}$ obtained by this method is substituted directly into Equation (6.4) to obtain $\hat{V}_T$.

For prediction using the results from the method of moments, Equation (6.4) is expanded further as follows:

$$\hat{V}_T = \hat{u} + \frac{y}{\hat{\alpha}}$$

Substituting the equivalent of $\hat{u}$ as given in Equation (3.29) $\hat{u} = \bar{v} - \frac{1}{\hat{\alpha}}\gamma$ we obtain :

$$\hat{V}_T = \bar{v} - \frac{1}{\hat{\alpha}}\gamma + \frac{y}{\hat{\alpha}} \quad \text{.....(6.6)}$$

Simplifying Equation (6.6)

$$\hat{V}_T = \bar{v} + \frac{1}{\hat{\alpha}}(y-\gamma)$$

with γ being the Euler Constant ($\gamma = 0.577216..$)

Substituting the equivalent of $\frac{1}{\hat{\alpha}}$ as given in Equation (3.30), $\frac{1}{\hat{\alpha}} = \frac{\sqrt{6}}{\pi}s_v$

$$\hat{V}_T = \bar{v} + \frac{\sqrt{6}}{\pi}s_v(y-\gamma) = \bar{v} + s_v(y-\gamma)\frac{\sqrt{6}}{\pi} \quad \text{.....(6.7)}$$

where $\bar{v}$ is the sample mean of the observed data and s_v its standard deviation. y has already been defined by Equation (6.5) and tabulated for various return periods in Table 6.1. The term $\frac{\sqrt{6}}{\pi}$ can be regarded as a constant as far as Equation (6.7) is concerned. Thus Equation (6.7) can now be rewritten as:

$$\hat{V}_T = \bar{v} + s_v(y-0.577216)0.77970 \quad \text{.....(6.8)}$$

Equation (6.8) is now used directly to obtain $\hat{V}_T$ for the different return periods and different locations having different sample means and standard deviations.

All the results obtained using the above general estimators of $\hat{V}_T$; for both the moment method and the method of order statistics are presented in a tabulated form. See Table 6.2. Simiu and Scanlan (1986) as well as Ang and Tang (1984) affirm that the method of order statistics yields more efficient estimators both for the model parameters and the general estimator $\hat{V}_T$; of the extreme largest wind speed for a specified return period.

Table 6.2. *Predictions Of Extreme Wind Speed Using The Selected Model*

Predictions Using Results Obtained By The Methods Of Moments And Order Statistics.						
		BAUCHI			**CALABAR**	
RETURN PERIOD,T (in years)	**y = -ln(-ln p)**	**V_T From Method Of:**			**V_T From Method Of:**	
		Moments	**Order Statistics**		**Moments**	**Order Statistics**
2	0.367	20.02	20.15		18.73	18.64
5	1.5	24.09	24		23.04	23.4
10	2.25	26.78	26.55		25.9	26.55
20	2.97	29.36	29		28.64	29.57
25	3.199	30.18	29.78		29.5	30.53
30	3.384	30.85	30.41		30.21	31.31
50	3.902	32.7	32.17		32.18	33.49
75	4.311	34.17	33.56		33.74	35.21
100	4.6	35.21	34.54		34.84	36.42
125	4.824	36.01	35.3		35.69	37.36
150	5.007	36.67	35.92		36.39	38.13
1000	6.907	43.48	42.38		43.62	46.11

Table 6.2.(contd) *Predictions Of Extreme Wind Speed Using The Selected Model*

Predictions Using Results Obtained By The Methods Of Moments And Order						
RETURN PERIOD,T (in years)	**y = -ln(-ln p)**	**V_T From Method Of:**			**V_T From Method Of:**	
		Moments	**Order Statistics**		**Moments**	**Order Statistics**
		ENUGU			**IBADAN**	
2	0.367	20.98	21.11		18.66	18.65
5	1.5	25.11	24.85		23.78	23.75
10	2.25	27.84	27.33		27.18	27.13
20	2.97	30.46	29.7		30.43	30.37
25	3.199	31.29	30.46		31.46	31.39
30	3.384	31.97	31.07		32.3	32.23
50	3.902	33.86	32.78		34.65	34.56
75	4.311	35.34	34.13		36.49	36.4
100	4.6	36.4	35.08		37.8	37.7
125	4.824	37.21	35.82		38.82	38.71
150	5.007	37.88	36.42		39.64	39.53
1000	6.907	44.8	42.69		48.24	48.08
		IBI			**ILORIN**	
2	0.367	18.35	18.37		19.42	19.78
5	1.5	23.03	24.15		24.31	23.75
10	2.25	26.12	27.98		27.54	26.38
20	2.97	29.09	31.65		30.65	28.9
25	3.199	30.03	32.81		31.63	29.69
30	3.384	30.8	33.76		32.43	30.35
50	3.902	32.93	36.4		34.67	32.16
75	4.311	34.62	38.48		36.43	33.59
100	4.6	35.81	39.96		37.68	34.6
125	4.824	36.74	41.1		38.64	35.39
150	5.007	37.49	42.04		39.43	36.03
1000	6.907	45.33	51.73		47.62	42.68

Table 6.2.(contd) *Predictions Of Extreme Wind Speed Using The Selected Model*

Predictions Using Results Obtained By The Methods Of Moments And Order						
RETURN PERIOD,T (in years)	y = -ln(-ln p)	V_T From Method Of:			V_T From Method Of:	
		Moments	Order Statistics		Moments	Order Statistics
		JOS			KADUNA	
2	0.367	24.12	24.12		20.59	20.7
5	1.5	27.76	28.2		23.54	24.1
10	2.25	30.16	30.9		25.48	26.35
20	2.97	32.47	33.49		27.35	28.51
25	3.199	33.2	34.31		27.95	29.2
30	3.384	33.8	34.98		28.43	29.75
50	3.902	35.45	36.85		29.77	31.31
75	4.311	36.76	38.32		30.83	32.53
100	4.6	37.69	39.36		31.59	33.4
125	4.824	38.41	40.17		32.17	34.07
150	5.007	39	40.83		32.64	34.62
1000	6.907	45.09	47.67		37.58	40.32
		KATSINA			LOKOJA	
2	0.367	16.97	17.42		17.93	18
5	1.5	21.33	21.5		21.47	21.4
10	2.25	24.22	24.2		23.81	23.65
20	2.97	27	26.79		26.05	25.81
25	3.199	27.88	27.61		26.77	26.5
30	3.384	28.59	28.28		27.34	27.05
50	3.902	30.59	30.15		28.96	28.61
75	4.311	32.16	31.62		30.23	29.83
100	4.6	33.28	32.66		31.14	30.7
125	4.824	34.14	33.47		31.84	31.37
150	5.007	34.84	34.13		32.41	31.92
1000	6.907	42.16	40.97		38.33	37.62

Table 6.2.(contd) *Predictions Of Extreme Wind Speed Using The Selected Model*

Predictions Using Results Obtained By The Methods Of Moments And Order						
RETURN PERIOD,T (in years)	y = -In(-In p)	V_T From Method Of:			V_T From Method Of:	
		Moments	Order		Moments	Order Statistics
		MAIDUGURI			MINNA	
2	0.367	21.9	22.04		19.89	20.33
5	1.5	27.86	28.05		25.38	24.75
10	2.25	31.8	32.03		29.02	27.68
20	2.97	35.59	35.84		32.52	30.48
25	3.199	36.79	37.05		33.62	31.37
30	3.384	37.76	38.04		34.52	32.1
50	3.902	40.48	40.78		37.03	34.12
75	4.311	42.63	42.95		39.02	35.71
100	4.6	44.15	44.48		40.42	36.84
125	4.824	45.33	45.67		41.51	37.71
150	5.007	46.29	46.64		42.39	38.43
1000	6.907	56.28	56.71		51.61	45.84
		PORT HARCOURT			SOKOTO	
2	0.367	18.97	18.99		23.2	23.62
5	1.5	22.96	23.3		27.55	27.7
10	2.25	25.61	26.15		30.43	30.4
20	2.97	28.14	28.89		33.19	32.99
25	3.199	28.95	29.75		34.07	33.81
30	3.384	29.6	30.46		34.78	34.48
50	3.902	31.43	32.43		36.76	36.35
75	4.311	32.87	33.98		38.33	37.82
100	4.6	33.89	35.08		39.44	38.86
125	4.824	34.68	35.93		40.3	39.67
150	5.007	35.32	36.63		41	40.33
1000	6.907	42.02	43.85		48.29	47.17

Table 6.2.(contd) *Predictions Of Extreme Wind Speed Using The Selected Model*

Predictions Using Results Obtained By The Methods Of Moments And Order						
RETURN PERIOD,T (in years)	y = -In(-In p)	V_T From Method Of:			V_T From Method Of:	
		Moments	Order Statistics		Moments	Order Statistics
		WARRI			YOLA	
2	0.367	13.98	14.12		23.35	23.17
5	1.5	18.06	18.2		27.63	26.8
10	2.25	20.77	20.9		30.46	29.2
20	2.97	23.36	23.49		33.18	31.5
25	3.199	24.18	24.31		34.04	32.24
30	3.384	24.85	24.98		34.74	32.83
50	3.902	26.72	26.85		36.7	34.49
75	4.311	28.19	28.32		38.24	35.79
100	4.6	29.23	29.36		39.33	36.72
125	4.824	30.04	30.17		40.18	37.44
150	5.007	30.7	30.83		40.87	38.02
1000	6.907	37.54	37.67		48.04	44.1
		IKOM			LAGOS	
2	0.367	13.23	13.18		12.14	12.19
5	1.5	16.99	17.15		16.22	16.5
10	2.25	19.49	19.78		18.91	19.35
20	2.97	21.88	22.3		21.5	22.09
25	3.199	22.64	23.09		22.32	22.95
30	3.384	23.25	23.75		22.99	23.66
50	3.902	24.97	25.56		24.85	25.63
75	4.311	26.33	26.99		26.32	27.18
100	4.6	27.29	28		27.36	28.28
125	4.824	28.04	28.79		28.17	29.13
150	5.007	28.64	29.43		28.82	29.83
1000	6.907	34.96	36.08		35.65	37.05

Table 6.2.(contd) *Predictions Of Extreme Wind Speed Using The Selected Model*

Predictions Using Results Obtained By The Methods Of Moments And Order						
RETURN PERIOD, T (in years)	y = -In(-In p)	Moments	Order Statistics		Moments	Order Statistics
		OWERRI			ZARIA	
2	0.367	16.22	16.29		25.3	25.17
5	1.5	19.48	19.35		28.71	29.7
10	2.25	21.64	21.38		30.97	32.7
20	2.97	23.71	23.32		33.13	35.58
25	3.199	24.37	23.94		33.82	36.49
30	3.384	24.91	24.44		34.38	37.24
50	3.902	26.4	25.84		35.94	39.31
75	4.311	27.57	26.94		37.17	40.94
100	4.6	28.4	27.72		38.04	42.1
125	4.824	29.05	28.33		38.71	43
150	5.007	29.58	28.82		39.26	43.73
1000	6.907	35.04	33.95		44.98	51.33

6.3 PREDICTIONS USING RESULTS FROM THE GRAPHICAL METHOD.

Here use is made of the probability plotting of data on extreme value Type I probability paper (the Gumbel probability paper). A third x-axis can be charted on the probability plotting such that the third x-axis is expressed as the return period, T. From $p = 1 - \frac{1}{T}$ we can obtain :

$$T = \frac{1}{1-p} \quad \text{.....(6.9)}$$

From this third x-axis ($T = \frac{1}{1-p}$), one can read off the extreme largest wind speed that may be expected for a given return period from the regression line. From the regression output, the equation of the straight (or regression) line is given by:

$$y_i' = \alpha + \beta x \quad \text{.....(6.10)}$$

where α is a constant and β a coefficient obtained from the regression analysis. The results of α and β from the regression analysis are all given the tables of annual maximum wind speeds for the various stations. (That is: Tables 8.0 to 10.0 and Appendix C, Tables C.1 to C.16). The use of Equation (6.10) yields the required prediction for $\hat{V}_T$ by this method.

EXAMPLE:

Using results obtained for Zaria, $\alpha = 19.045$, β(ie the x coefficient) = 13.766. x in Equation (6.10) becomes p evaluated from $p = 1 - \frac{1}{T}$ for the respective return periods. The values of p for the twelve return periods are given in Table 6.1. y_i' which now becomes $\hat{V}_T$ is then obtained by:

$$\hat{V}_T = 19.045 + 13.766\,(1 - 1/T)$$
$$= 19.045 + 13.766\,(p)$$

For T = 75 years, p = 0.987, therefore,

$$\hat{V}_{75} = 19.045 + 13.766\,(0.987)$$
$$= 32.6 \text{ m/sec.}$$

The above procedure is used to predict the extreme wind for all the stations at specified return periods. And the results are presented in Table 6.3.

From the results it can be observed that the predictions made by the use of this method are conventionally lower for large return periods than for those obtained by the use of the previous methods. The results from the graphical method exhibit pure asymptotic behaviour as the return period becomes large.

In estimating wind loads for civil engineering structures it will be reasonable to use such estimates characterized by unbiasedness and minimum variance (that is: high efficiency). It has been widely acknowledged that the order statistics estimators satisfy these requirements (Ang and Tang , 1984).

***Table 6.3 Predictions** Of Extreme Wind Speed Using The Selected Model(Graphical Method)*

Predictions Using Results Obtained By The Graphical Method.							
	BAUCHI				CALABAR		IBI
RETURN PERIOD,T (in years)	**y = - In (- Inp) -In[-In(1-1/T)]**	**p = 1-(1/T)**	**V_T**		**V_T**		**V_T**
2	0.367	0.5	20.8		19.5		19.2
5	1.5	0.8	25.5		24.5		24.7
10	2.25	0.9	27		26.2		26.6
20	2.97	0.95	27.8		27		27.5
25	3.199	0.96	28		27.2		27.7
30	3.384	0.967	28.1		27.3		27.8
50	3.902	0.98	28.3		27.5		28.1
75	4.311	0.987	28.4		27.6		28.2
100	4.6	0.99	28.5		27.7		28.2
125	4.824	0.992	28.5		27.7		28.3
150	5.007	0.993	28.5		27.7		28.3
1000	6.907	0.999	28.6		27.8		28.4
	ENUGU				IBADAN		ILORIN
2	0.367	0.5	21.7		19.6		20.3
5	1.5	0.8	26.7		25.7		26.1
10	2.25	0.9	28.3		27.7		28.1
20	2.97	0.95	29.2		28.7		29
25	3.199	0.96	29.3		28.9		29.2
30	3.384	0.967	29.4		29.1		29.4
50	3.902	0.98	29.7		29.3		29.6
75	4.311	0.987	29.8		29.5		29.7
100	4.6	0.99	29.8		29.6		29.8
125	4.824	0.992	29.8		29.6		29.8
150	5.007	0.993	29.9		29.6		29.9
1000	6.907	0.999	30		29.7		30

Table 6.3(contd) *Predictions Of Extreme Wind Speed Using The Selected Model(Graphical Method)*

Predictions Using Results Obtained By The Graphical Method.							
RETURN PERIOD, T (in years)	**y = -ln(-lnp) -ln[-ln(1-1/T)]**	**p = 1-(1/T)**	**V_T**		**V_T**		**V_T**
			JOS		KADUNA		MAIDUGURI
2	0.367	0.5	24.8		21.1		23
5	1.5	0.8	29		24.6		30
10	2.25	0.9	30.4		25.8		32.4
20	2.97	0.95	31.1		26.4		33.5
25	3.199	0.96	31.2		26.5		33.8
30	3.384	0.967	31.3		26.6		33.9
50	3.902	0.98	31.5		26.7		34.2
75	4.311	0.987	31.6		26.8		34.4
100	4.6	0.99	31.7		26.8		34.5
125	4.824	0.992	31.7		26.9		34.5
150	5.007	0.993	31.7		26.9		34.6
1000	6.907	0.999	31.8		26.9		34.7
		KATSINA			LOKOJA		MINNA
2	0.367	0.5	17.8		18.6		20.9
5	1.5	0.8	22.9		22.5		27.5
10	2.25	0.9	24.6		23.8		29.7
20	2.97	0.95	25.5		24.5		30.8
25	3.199	0.96	25.6		24.6		31
30	3.384	0.967	25.8		24.7		31.1
50	3.902	0.98	26		24.9		31.4
75	4.311	0.987	26.1		25		31.6
100	4.6	0.99	26.2		25		31.7
125	4.824	0.992	26.2		25		31.7
150	5.007	0.993	26.2		25		31.7
1000	6.907	0.999	26.3		25.1		31.8

Table 6.3(contd) *Predictions Of Extreme Wind Speed Using The Selected Model(Graphical Method)*

Predictions Using Results Obtained By The Graphical Method.						
RETURN PERIOD, T (in years)	**y=-In(-Inp) = -In[-In(1-1/T)]**	**p = 1-(1/T)**	**V_T**	**V_T**	**V_T**	**V_T**
			P. H.	SOKOTO	IKOM	OWERRI
2	0.367	0.5	19.7	24	13.9	16.8
5	1.5	0.8	24.3	29.2	18.3	20.8
10	2.25	0.9	25.9	30.9	19.7	22.1
20	2.97	0.95	26.7	31.8	20.4	22.8
25	3.199	0.96	26.8	31.9	20.6	22.9
30	3.384	0.967	26.9	32.1	20.7	23
50	3.902	0.98	27.1	32.3	20.9	23.2
75	4.311	0.987	27.2	32.4	21	23.3
100	4.6	0.99	27.3	32.5	21	23.3
125	4.824	0.992	27.3	32.5	21.1	23.4
150	5.007	0.993	27.3	32.5	21.1	23.4
1000	6.907	0.999	27.4	32.6	21.2	23.5
			WARRI	YOLA	LAGOS	ZARIA
2	0.367	0.5	14.7	24.1	12.9	25.9
5	1.5	0.8	19.5	29.2	17.4	30.1
10	2.25	0.9	21	30.9	18.9	31.4
20	2.97	0.95	21.8	31.8	19.7	32.1
25	3.199	0.96	22	32	19.8	32.3
30	3.384	0.967	22.1	32.1	19.9	32.4
50	3.902	0.98	22.3	32.3	20.2	32.5
75	4.311	0.987	22.4	32.4	20.3	32.6
100	4.6	0.99	22.4	32.5	20.3	32.7
125	4.824	0.992	22.5	32.5	20.3	32.7
150	5.007	0.993	22.5	32.5	20.4	32.7
1000	6.907	0.999	22.6	32.6	20.4	32.8

6.4 COMPARISON OF RESULTS

It was mentioned in chapter three that Soboyejo (1971) used seventeen-year data to analyze extreme largest wind speed for Nigeria. The results of that work is presently being used by many designers in Nigeria to estimate their design wind speed and, of course, the design wind load. Credit must be given to his work even though he was limited by unavailability of sufficient data series. The advantage of this present work, as will soon be observed from its results, is basically because of the larger size of sample used. It also follows that as available data increases, further research can be carried out on this subject in order to arrive at more realistic estimation of design wind speeds.

Table 6.4 compares the results of Soboyejo (1971) with the results obtained in this work. Three results have been obtained in this work having used three different methods of estimation. All the three are tabulated alongside with the results of Soboyejo (1971) which were obtained using the traditional graphical method of estimation. It will be observed that the results from Soboyejo (1971) are higher than those from this work for many of the meteorological stations and for each return period. The results he got for Warri are exceptionally high. The predicted wind speed increases with over 30% higher from 2-years return period to about 49% at 1000-years return period when compared with results gotten by the method of order statistics.

The general inference that can be drawn from the comparison is that design wind speed are overestimated and hence wherever these results are being used in design of structures the wind loading estimation is traditionally higher than what can actually be expected.

Furthermore, there are some practical consequences in terms of economy attached to this. It can be recalled from the review (Section 3.3) that for highly wind-sensitive structures such as tall buildings, telecommunication masts and long span bridges, wind loading may become a major criteria to influence initial cost of structure. Secondly, wind speed is the major parameter in the evaluation of the design wind loading. Hence, any overestimation of the wind speed in the design process will definitely have far reaching consequences in the overall cost of the structure. So it can be concluded that wind speed estimates obtained in this work should be preferred to those which have hitherto been in use.

Table 6.4 *Comparison Of Extreme Wind Prediction Results From Soboyejo (1971) And The Three Methods Employed In This Work. (Values of wind speed are in m/sec.).*

Return Period	Results from:	1 BAU	2 CAL	3 ENU	4 IBA	5 IBI	6 ILR	7 JOS	8 KAD	9 KAT	10 LKJ
2 Years	ABOS	21.67	20.95	23.83	23.08	22.34	17.63	27.44	20.63	17.62	20.35
	PLOT	20.8	19.5	21.7	19.6	19.2	20.3	24.8	21.1	17.8	18.6
	MOM	20.02	18.73	20.98	18.66	18.35	19.42	24.12	20.59	16.97	17.93
	MOS	20.15	18.64	21.11	18.65	18.37	19.78	24.12	20.7	17.42	18
5 Years	ABOS	27.54	26.48	27.45	27.13	27.48	20.23	31.56	24.55	22.39	24.36
	PLOT	25.5	24.5	26.7	25.7	24.7	26.1	29	24.6	22.9	22.5
	MOM	24.09	23.04	25.11	23.78	23.03	24.31	27.76	23.54	21.33	21.47
	MOS	24	23.4	24.85	23.75	24.15	23.75	28.2	24.1	21.5	21.4
10 Years	ABOS	32.88	30.66	30.19	30.19	31.37	22.21	34.68	27.52	26.01	27.4
	PLOT	27	26.2	28.3	27.7	26.6	28.1	30.4	25.8	24.6	23.8
	MOM	26.78	25.9	27.84	2,718	26.12	27.54	30.16	25.48	24.22	23.81
	MOS	26.55	26.55	27.33	2,713	27.98	26.38	30.09	26.35	24.2	23.65
25 Years	ABOS	39.26	36.2	33.81	34.24	36.51	24.82	38.79	31.44	30.78	31.41
	PLOT	28	27.2	29.3	28.9	27.7	29.2	31.2	26.5	25.6	24.6
	MOM	30.18	29.5	31.29	31.46	30.03	31.63	33.2	27.95	27.88	26.77
	MOS	29.78	30.53	30.46	31.39	32.81	29.69	34.31	29.2	27.61	26.5
50 Years	ABOS	44.88	40.38	36.55	37.3	40.4	26.79	41.91	34.41	34.4	34.45
	PLOT	28.3	27.5	29.7	29.3	28.1	29.6	31.5	26.7	26	24.9
	MOM	32.7	32.18	33.86	34.65	32.93	34.67	35.45	29.77	30.59	28.96
	MOS	32.17	33.49	32.78	34.56	36.4	32.16	36.85	31.31	30.15	28.61
75 Years	ABOS	46.91	42.83	38.16	39.09	42.67	27.94	43.73	36.15	36.51	36.22
	PLOT	28.4	27.6	29.8	29.5	28.2	29.7	31.6	26.8	26.1	25
	MOM	34.17	33.74	35.34	36.49	34.62	36.43	36.76	30.83	32.16	30.23
	MOS	33.56	35.21	34.13	36.4	38.48	33.59	38.32	32.53	31.62	29.83
100 Years	ABOS	48.91	44.57	39.29	40.36	44.29	28.76	45.02	37.38	38.01	37.48
	PLOT	28.5	27.7	29.8	29.6	28.2	29.8	31.7	26.8	26.2	25
	MOM	35.21	34.84	36.4	37.8	35.81	37.68	37.69	31.59	33.28	31.14
	MOS	34.54	36.42	35.08	37.7	39.36	34.6	39.36	33.4	32.66	30.7

LEGEND

ABOS Results Obtained By A. B. O. Soboyejo (1971)
PLOT Results Obtained From The Graphical Method
MOM Results Obtained From The Method Of Moments
MOS Results Obtained From The Method Of Order Statistics

Table 6.4 (Contd.) *Comparison Of Extreme Wind Prediction Results From Soboyejo (1971) And The Three Methods Employed In This Work. (Values of wind speed are in m/sec.).*

Return Period	Results from:	11 MDG	12 MIN	13 PHC	14 SOK	15 WAR	16 YOL	17 IKOM	18 LAG	19 OWE	20 ZAR
2 Years	ABOS	29.17	25.12	19.19	20.03	23.49	24.41	-	-	-	-
	PLOT	23	20.9	19.7	24	14.7	24.1	13.9	12.9	16.8	25.9
	MOM	21.9	19.89	18.97	23.2	13.98	23.35	13.23	12.14	16.22	25.3
	MOS	22.04	20.33	18.99	23.62	14.12	23.17	13.18	12.19	16.29	25.17
5 Years	ABOS	33.04	28.69	22.43	23.15	31.57	28.31	-	-	-	-
	PLOT	30	27.5	24.3	29.2	19.5	29.2	18.3	17.4	20.8	30.1
	MOM	27.86	25.38	22.96	27.55	18.06	27.63	16.99	16.22	19.48	28.71
	MOS	28.05	24.75	23.3	27.7	18.2	26.8	17.15	16.5	19.35	29.7
10 Years	ABOS	35.97	31.39	24.88	25.51	37.68	31.27	-	-	-	-
	PLOT	32.4	29.7	25.9	30.9	21	30.9	19.7	18.9	21.1	31.4
	MOM	31.8	29.02	25.61	30.43	20.77	30.46	19.49	18.91	21.64	30.97
	MOS	32.03	27.68	26.15	30.4	20.9	29.2	19.78	19.35	21.38	32.7
25 Years	ABOS	39.85	34.95	28.12	28.64	45.76	35.17	-	-	-	-
	PLOT	33.8	31	26.8	31.9	22	32	20.6	19.8	22.9	32.3
	MOM	36.79	33.62	28.95	34.07	24.18	34.04	22.64	22.32	24.37	33.82
	MOS	37.05	31.37	29.75	33.81	24.31	32.24	23.09	22.95	23.94	36.49
50 Years	ABOS	42.78	37.6	30.57	31	51.87	38.12	-	-	-	-
	PLOT	34.2	31.4	27.1	32.3	22.3	32.3	20.9	20.2	23.2	32.5
	MOM	40.48	37.03	31.43	36.76	26.72	36.7	24.97	24.85	26.4	35.94
	MOS	40.78	34.12	32.43	36.35	26.85	34.49	25.56	25.63	25.84	39.31
75 Years	ABOS	44.49	39.23	32	31.35	55.45	39.85	-	-	-	-
	PLOT	34.4	31.6	27.2	32.4	22.4	32.4	21	20.3	23.3	32.6
	MOM	42.63	39.02	32.87	38.33	28.19	38.24	26.33	26.32	27.57	37.17
	MOS	42.95	35.71	33.98	37.82	28.32	35.79	26.99	27.18	26.94	40.94
100 Years	ABOS	45.71	40.35	33.02	33.36	57.98	41.08	-	-	-	-
	PLOT	34.5	31.7	27.3	32.5	22.4	32.5	21	20.3	23.3	32.7
	MOM	44.15	40.42	33.89	39.44	29.23	39.33	27.29	27.36	28.4	38.04
	MOS	44.48	36.84	35.08	38.86	29.36	36.72	28	28.28	27.72	42.1

LEGEND

ABOS Results Obtained By A. B. O. Soboyejo (1971)
PLOT Results Obtained From The Graphical Method
MOM Results Obtained From The Method Of Moments
MOS Results Obtained From The Method Of Order Statistics

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 GENERAL REMARK

In this final chapter a recall is made on the aim and methodology adopted, the findings are summarized and a few recommendations made.

7.2 SUMMARY AND FINDINGS

The aim of this work has been the development of a stochastic model that can be used to predict reliable and acceptable design wind speeds for the evaluation of reliable wind loads that can be regarded as suitable for design purposes for structures in a well behaved wind climate. Again, such a model will be useful in reliability analysis and estimation of risk levels with regard to wind loading. An acceptable probability model following the Type I (EV-I) model of extreme values given by Equation (3.22) or (3.23) (with the following transformation in mind, $\alpha = \frac{1}{\sigma}$ and $\frac{1}{\alpha} = \sigma$) has been selected.

The same model can be shown to be the best fitting model for extreme wind speeds in any wind climate where extra-ordinary winds have a zero probability of occurrence. To arrive at the selected model, the annual maximum wind speed data for twenty (20) stations in Nigeria are analyzed. The means, variances and coefficients of variation for all the twenty stations are evaluated. This is followed by the empirical selection of the most suitable

stochastic model based on a good understanding of the physical phenomenon and the existing literature.

The results of this theoretical and empirical selection are tested using the data collected. Two different tests are employed for the verification process, namely probability plotting of data on the probability paper of the selected model, and the statistical testing of the model for 0.01, 0.05, and 0.10 levels of significance using the Kolmogorov-Smirnov (K-S) test of the goodness-of-fit. Both verification processes adequately show that the selected model is acceptable.

The parameters of the selected model are then estimated using three different methods of model parameter estimation namely: the graphical method and the methods of moments and order statistics. The results are compared and the estimates of the method of order statistics are found to be conservatively more efficient and unbiased. Furthermore, predictions of extreme wind speeds for the twenty meteorological stations for twelve return periods or mean recurrence intervals are made based on the developed model. The results of the predictions are compared with those obtained by Soboyejo (1971).

It is found that design wind speeds being presently used in Nigeria either by the use of NCP 1 wind regulations or by the use of Isopleth maps developed from Soboyejo's results or any similar works, are all conventionally higher than the true situation. Even though Soboyejo's distribution of extreme wind speeds in Nigeria is an extreme value Type I model, yet the predictions are high. This can be accounted for by his use of a seventeen-year series of wind speed data which is not a statistically sufficient sample size for such an analysis. Perhaps, if Soboyejo had applied the method of estimation or prediction of design wind

speeds from short term records, a more acceptable and realistic wind speed predictions would have been obtained.

This leaves us with an area of further investigation. That is: use can be made of a ten-tear series of data for all stations and the monthly maximum wind speed model developed. From that, predictions can then be made and results compared with results obtained both by Soboyejo (1971) and those obtained in this particular work.

With regard to general structural design economy, it is obvious that the use of the design wind speed estimates higher than the more realistic estimates will mean allocating scarce resources to areas where there are no necessary need. It will not give appropriate balance needed to be stricken between safety and economy in modern design philosophies, especially in this generation (age) of scarce resources. Perhaps an investigation into the cost difference between wind sensitive structures designed with overestimated design wind speeds and those designed with balanced estimates will reveal how much have been lost and is still being lost through such overestimation. It is true that such a cost investigation can be rigorous, but simple design implications should be sufficient to convince us to adopt more balanced and appropriate design wind speed estimates in the evaluation of wind loads.

Another important thing that must be mentioned is the necessity of customizing or adjusting design wind speed estimates to both height and location of structure to be designed. All results obtained in chapter six (6) apply to expected highest wind speed at a standardized height of ten metres (10m) in a location with fairly open terrain . In estimating the design wind speed for any given structure and for a given location, the question to be asked should not only be " What is the probable highest wind speed that is likely to pass over the intended

structure during its expected lifetime?" The results of the predictions obtained answer this initial question for standardized height of 10m at a fairly open terrain.

The second question should be with regard to the surface roughness of the location where the structure will be erected. The design wind speed will have to be reviewed downward from a location with less dense, small and low obstructions to wind (like buildings, trees, vegetation, rocks, etc.) to another location with denser, large-sized and tall obstructions. That implies that we cannot use the same design wind speed for a structure if it were to be erected both in a city centre and in an open coastal area. The wind speed to be used for design for the structure in the location of an open coastal surface roughness regime will double that to be used for the same structure at about 30m if it were to be erected in a city centre.

The third question to be asked in estimating the design wind speed is, of course, the height of the consideration. The wind estimate obtained and adjusted with respect to the roughness regime of the location should also be customized to the different height levels of the structure. In tall buildings, the wind at a height of $\mathbf{Z_m}$ will differ from that at a higher height of say, $\mathbf{(Z+h)_m}$ where $\mathbf{h \geq 10m}$.

For the customization of the predicted wind speed estimates to the roughness regime and height of an intended structure, use can be made of Equation (2.10) or Equation (2.12) in conjunction with Table 2.2. These are procedures that should not pose any problems to the designer. When all these steps have been taken, the respective design wind speeds estimated for the different height levels are then applied to Equation (3.2) to arrive at the design wind load. The design wind load obtained is then used together with other load combination being considered for design.

7.3 RECOMMENDATIONS

The following recommendations are hereby made based on the findings of this research;

1. The body or organization in Nigeria vested with the responsibility of establishing design wind loading standards should completely re-calibrate the NCP 1 wind loading regulations.
2. Designers of structures that will be subjected to wind action should adopt the new estimates of basic design wind speed obtained in this work for their design purposes.
3. Sensitive wind speed measuring equipment should be acquired and mounted at different heights and locations to measure actual highest wind speed for stated return periods. That is, after several years samples of the highest wind speed that occurred for 2-year, 5-year, 10-year, 20-year etc. return periods can be looked at and then compared with the results from predictions.
4. Finally, it will be necessary to undertake further research to come out with a stochastic model of wind speeds for design wind loads which takes wind directionality into consideration. Such a model will be purely a joint probability model of the wind speed and direction.

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APPENDIX A

TABLE A.1 *Values Of Roughness Length (Z_0) And Of Surface Drag Coefficients For Various Types Of Terrain (Taken from Simiu and Scanlan, 1986).*

Type of Surface	Z_0 (cm)	10^3 k
Sand	0.01 - 0.1	1.2 - 1.9
Snow surface	0.1 - 0.6	
Mown grass(~ 0.01m)	0.1 - 1	1.9 - 3.4
Low grass, steppe	1- 4	3.4 - 5.2
Fallow field	2 - 3	4.1 - 4.7
High grass	4 - 10	5.2 - 7.6
Palmetto	10 - 30	7.6 - 13.0
Pine forest (mean height of trees 15m; one tree/10m^2; z_d ~ 12m)	90 - 100	28.0 - 30.0
Sparsely built-up suburbs	20 - 40	10.5 - 15.4
Densely built-up suburbs, towns	80 - 120	25.1 - 35.6
Centres of large cities.	200 - 300	61.8 -110.4

Table A.2 *Weights a_i and b_i for Leiblein's Order Statistics Estimator ($p \geq 0.90$)** (Taken from Ang and Tang, 1984)*

n	WEIGHTS a_i AND b_i FOR $V_1 < V_2 < \ldots\ldots V_n$						
	i =	1	2	3	4	5	6
2	a_i	0.91637	0.08363				
	b_i	-0.72135	0.72135				
3	a_i	0.65632	0.25571	0.08797			
	b_i	-0.63054	0.25582	0.37473			
4	a_i	0.511	0.26394	0.15368	0.07138		
	b_i	-0.55862	0.0859	0.22392	0.2488		
5	a_i	0.41893	0.24628	0.16761	0.10882	0.05835	
	b_i	-0.50313	0.00653	0.13045	0.18166	0.18448	
6	a_i	0.35545	0.22549	0.16562	0.12105	0.08352	0.04887
	b_i	-0.45928	-0.03599	0.07319	0.12673	0.14953	0.14581

APPENDIX B

PROCEDURE FOR DERIVING THE MOMENTS OF THE STANDARDED VARIATE (y) OF THE EV-I MODEL

The Moment Generating Function (MGF) of the EV-I's standard variate, is :

$$MGF_y(t) = E(e^{ty}) = \int_{-\infty}^{\infty} e^{ty}\, e^{-y}\, e^{-e^{-y}}\, dy \quad \text{.....(B.1)}$$

Let $\mathbf{r} = \mathbf{e}^{-y}$, Therefore, $dy = \frac{-dr}{r}$

That implies: $MGF_y(t) = \int_{-\infty}^{\infty} e^{ty}\, e^{-r}\, dr = \int_{0}^{\infty} e^{-t\ln r}\, e^{-r}\, dr$

$$= \int_{0}^{\infty} r^{-t} e^{-r}\, dr \quad \text{.....(B.2)}$$

Equation (B.2) is the Gamma Function $\Gamma(1-t)$.
Therefore, $MGF_y(t) = \Gamma(1-t)$

if $t = 0$, the function then yields the respective moments of y. The nth. derivative of the function, $\Gamma(1-t)$ is given as :

$$\Gamma^{(n)}(1-t) = \int_{0}^{\infty} r^{-t}\, e^{-r(\ln r)^n}\, dr \quad \text{.....(B.3)}$$

Gumbel was reported to have evaluated the various derivatives of this function at $t = 0$ as follows: (Ang and Tang, 1984)

$$\frac{d\Gamma(1)}{dt} = \gamma = 0.577216\ldots \text{ (The Euler Constant) .....(B.4)}$$

$$\frac{d^2\Gamma(1)}{dt^2} = \gamma^2 + \frac{\pi}{6} \quad \text{.....(B.5)}$$

$$\frac{d^3\Gamma(1)}{dt^3} = \gamma^3 + \frac{\pi}{2}\gamma + 2S_3 \quad \text{.....(B.6)}$$

$$\frac{d^4\Gamma(1)}{dt^4} = \gamma^4 + \pi^2\gamma^2 + 8\gamma S_3 + \frac{3\pi^4}{20} \quad \text{.....(B.7)}$$

where $S_3 = 1.20205690$.

APPENDIX C

TABLES OF ANNUAL MAXIMUM WIND SPEED AND PROBABILITY PLOTTING ON EV-I PROBABILITY PAPER

Table C.1 *Tabulated Annual Maximum Wind Speed At Ikom*

Year	Rank (m)	P=m/(n+1)	Wind Speed (m/s)	y = -In(-Inp)	Chart B
1972	1	0.043	8	-1.143	7.3
1988	2	0.087	8.7	-0.893	7.9
1990	3	0.13	9.4	-0.711	8.6
1975	4	0.174	10	-0.559	9.2
1973	5	0.217	10.7	-0.423	9.8
1979	6	0.261	10.8	-0.295	10.5
1985	7	0.304	11.2	-0.174	11.1
1992	8	0.348	11.7	-0.055	11.7
1974	9	0.391	12.1	0.064	12.4
1978	10	0.435	12.5	0.183	13
1989	11	0.478	12.9	0.304	13.6
1987	12	0.522	13.4	0.43	14.2
1991	13	0.565	13.8	0.561	14.9
1977	14	0.609	13.9	0.7	15.5
1986	15	0.652	14.5	0.85	16.1
1981	16	0.696	15.2	1.014	16.8
1976	17	0.739	15.8	1.196	17.4
1984	18	0.783	16.5	1.406	18
1983	19	0.826	17.1	1.655	18.7
1982	20	0.87	20.8	1.968	19.3
1993	21	0.913	23	2.397	19.9
1980	22	0.957	24.4	3.113	20.5
Location Parameter, u		0.368		0	12
Scale Parameter, (slope)		1/α	=(v-u)/y		2.7
		α	=y/(v-u)		0.4
		Regression Output:		*IKOM*	
	Constant			6.682	
	x coefficient			14.991	

Table C.2 *Tabulated Annual Maximum Wind Speed At Ibadan*

Year	Rank (m)	p = m/(n+1)	Wind Speed	y = -ln(-lnp)	Chart B
1982	1	0.024	10.6	-1.318	9.9
1992	2	0.048	10.8	-1.113	10.4
1955	3	0.071	11.4	-0.97	10.9
1993	4	0.095	12	-0.855	11.4
1976	5	0.119	12.6	-0.755	11.9
1977	6	0.143	13.2	-0.666	12.4
1983	7	0.167	13.8	-0.583	12.8
1954	8	0.19	13.9	-0.506	13.3
1959	9	0.214	14.3	-0.432	13.8
1987	10	0.238	14.6	-0.361	14.3
1986	11	0.262	15	-0.293	14.8
1957	12	0.286	15.3	-0.225	15.3
1956	13	0.31	15.7	-0.159	15.7
1988	14	0.333	16	-0.094	16.2
1989	15	0.357	16.4	-0.029	16.7
1991	16	0.381	16.7	0.036	17.2
1984	17	0.405	17.1	0.1	17.7
1963	18	0.429	17.2	0.166	18.2
1953	19	0.452	17.8	0.232	18.6
1968	20	0.476	18.4	0.298	19.1
1990	21	0.5	19	0.367	19.6
1985	22	0.524	19.5	0.436	20.1
1961	23	0.548	20.1	0.507	20.6
1960	24	0.571	20.7	0.581	21.1
1978	25	0.595	20.8	0.656	21.5
1971	26	0.619	21.3	0.735	22
1962	27	0.643	21.9	0.817	22.5
1967	28	0.667	22.2	0.903	23
1964	29	0.69	22.6	0.993	23.5
1972	30	0.714	23.1	1.089	24
1965	31	0.738	23.5	1.192	24.4
1974	32	0.762	24	1.302	24.9
1970	33	0.786	24.4	1.422	25.4
1980	34	0.81	24.5	1.554	25.9
1979	35	0.833	25.8	1.702	26.4
1966	36	0.857	27.1	1.87	26.9
1973	37	0.881	28.4	2.066	27.3
1969	38	0.905	28.5	2.302	27.8
1981	39	0.929	29.9	2.602	28.3
1958	40	0.952	31.2	3.02	28.8
1975	41	0.976	32.6	3.726	29.3
Location Parameter, u		0.368		0	16.9
Scale Parameter, (slope)		1/α	=(v-u)/y		3.3
		α	=y/(v-u)		0.3
Regression Output :		Constant = 9.46		x coefficient =	20.29463

Table C.3 *Tabulated Annual Maximum Wind Speed At Ibi*

Year	Rank (m)	p = m/(n+1)	Wind Speed	y = -In(-In p)	Chart B
1977	1	0.026	7.9	-1.298	10.5
1967	2	0.051	10.7	-1.089	11
1991	3	0.077	10.8	-0.942	11.4
1983	4	0.103	12.3	-0.823	11.9
1993	5	0.128	13.8	-0.72	12.4
1974	6	0.154	13.9	-0.627	12.8
1955	7	0.179	14.3	-0.541	13.3
1961	8	0.205	14.6	-0.46	13.8
1966	9	0.231	15	-0.383	14.3
1973	10	0.256	15	-0.308	14.7
1975	11	0.282	15.7	-0.236	15.2
1982	12	0.308	16.4	-0.164	15.7
1960	13	0.333	16.7	-0.094	16.1
1992	14	0.359	16.7	-0.024	16.6
1962	15	0.385	17.1	0.046	17.1
1988	16	0.41	17.2	0.115	17.6
1957	17	0.436	17.7	0.186	18
1971	18	0.462	18.2	0.257	18.5
1987	19	0.487	18.7	0.33	19
1956	20	0.513	19.2	0.404	19.5
1972	21	0.538	19.7	0.48	19.9
1963	22	0.564	20.2	0.558	20.4
1989	23	0.59	20.7	0.639	20.9
1959	24	0.615	21.2	0.723	21.3
1954	25	0.641	21.5	0.81	21.8
1981	26	0.667	21.9	0.903	22.3
1965	27	0.692	22.2	1	22.8
1958	28	0.718	22.6	1.105	23.2
1979	29	0.744	23	1.216	23.7
1964	30	0.769	23.3	1.338	24.2
1,980	31	0.795	23.7	1.472	24.6
1984	32	0.821	24	1.62	25.1
1953	33	0.846	24.4	1.789	25.6
1978	34	0.872	24.4	1.986	26.1
1976	35	0.897	26.5	2.224	26.5
1986	36	0.923	28	2.525	27
1985	37	0.949	28.4	2.944	27.5
1990	38	0.974	32.6	3.651	27.9
Location Parameter, u		0.368		0	16.8
Scale Parameter,(slope)		1/α	=(v-u)/y		3.1
		α	=y/(v-u)		0.3
Regression Output:		Constant = 10.01138		x coefficient = 18.40882	

Table C.4 *Tabulated Annual Maximum Wind Speed At Ilorin.*

Year	Rank (m)	P=m/(n+1)	Wind	y= -ln(-lnp)	Chart B
1961	1	0.024	7.9	-1.318	11.1
1954	2	0.048	10.7	-1.113	11.6
1958	3	0.071	10.9	-0.97	12
1960	4	0.095	13.8	-0.855	12.5
1968	5	0.119	13.9	-0.755	13
1967	6	0.143	14.3	-0.666	13.4
1959	7	0.167	14.7	-0.583	13.9
1963	8	0.19	15.1	-0.506	14.3
1953	9	0.214	15.5	-0.432	14.8
1957	10	0.238	15.9	-0.361	15.3
1965	11	0.262	16.3	-0.293	15.7
1956	12	0.286	16.7	-0.225	16.2
1969	13	0.31	17.1	-0.159	16.6
1976	14	0.333	17.2	-0.094	17.1
1962	15	0.357	17.7	-0.029	17.6
1966	16	0.381	18.2	0.036	18
1974	17	0.405	18.7	0.1	18.5
1982	18	0.429	19.2	0.166	19
1988	19	0.452	19.7	0.232	19.4
1972	20	0.476	20.2	0.298	19.9
1964	21	0.5	20.7	0.367	20.3
1992	22	0.524	20.8	0.436	20.8
1971	23	0.548	21.2	0.507	21.3
1993	24	0.571	21.5	0.581	21.7
1984	25	0.595	21.9	0.656	22.2
1975	26	0.619	22.2	0.735	22.6
1970	27	0.643	22.6	0.817	23.1
1977	28	0.667	23	0.903	23.6
1990	29	0.69	23.3	0.993	24
1973	30	0.714	23.7	1.089	24.5
1983	31	0.738	24.1	1.192	24.9
1978	32	0.762	24.4	1.302	25.4
1955	33	0.786	24.5	1.422	25.9
1979	34	0.81	25.3	1.554	26.3
1980	35	0.833	26.1	1.702	26.8
1991	36	0.857	26.8	1.87	27.2
1986	37	0.881	27.7	2.066	27.7
1985	38	0.905	28.4	2.302	28.2
1981	39	0.929	28.5	2.602	28.6
1987	40	0.952	30.6	3.02	29.1
1989	41	0.976	32.6	3.726	29.5
Location Parameter, u		0.368		0	17.8
Scale Parameter, (slope)		$1/\alpha$	=(v-u)/y		3.2
		α	=y/(v-u)		0.3
Regression Output:		Constant = 10.6622		x coefficient = 19.33902	

Table C.5 *Tabulated Annual Maximum Wind Speed At Jos*

Year	Rank(m)	P=m/(n+1)	Wind Speed	y= -In(-Inp)	Chart B
1953	1	0.027	13.8	-1.284	18.2
1954	2	0.054	17	-1.071	18.6
1959	3	0.081	17.2	-0.921	18.9
1980	4	0.108	19	-0.8	19.3
1970	5	0.135	20.7	-0.694	19.7
1992	6	0.162	20.8	-0.598	20.1
1977	7	0.189	21.3	-0.51	20.5
1968	8	0.216	21.7	-0.426	20.8
1963	9	0.243	22.2	-0.346	21.2
1986	10	0.27	22.6	-0.269	21.6
1982	11	0.297	23.1	-0.193	22
1978	12	0.324	23.5	-0.119	22.3
1964	13	0.351	24	-0.045	22.7
1969	14	0.378	24.4	0.029	23.1
1962	15	0.405	24.5	0.102	23.5
1973	16	0.432	24.5	0.176	23.9
1987	17	0.459	24.5	0.251	24.2
1972	18	0.486	25.2	0.328	24.6
1984	19	0.514	25.2	0.406	25
1971	20	0.541	25.8	0.486	25.4
1976	21	0.568	25.8	0.568	25.7
1985	22	0.595	25.8	0.654	26.1
1960	23	0.622	26.5	0.744	26.5
1965	24	0.649	26.5	0.837	26.9
1991	25	0.676	26.5	0.936	27.3
1975	26	0.703	27.1	1.042	27.6
1966	27	0.73	27.8	1.155	28
1983	28	0.757	27.8	1.278	28.4
1988	29	0.784	27.8	1.412	28.8
1961	30	0.811	28.4	1.562	29.2
1979	31	0.838	28.4	1.732	29.5
1989	32	0.865	28.4	1.93	29.9
1990	33	0.892	28.5	2.168	30.3
1967	34	0.919	31	2.47	30.7
1981	35	0.946	32.6	2.89	31
1974	36	0.973	33	3.597	31.4
Location Parameter, u		0.368		0	23
Scale Parameter, (slope)		1/α	=(v-u)/y		2.4
		α	=y/(v-u)		0.4
Regression Output:		Constant = 17.80492		x Coefficient = 13.99571	

Table C.6 *Tabulated Annual Maximum Wind Speed At Kaduna*

YEAR	RANK (m)	P=m/(n+1)	Wind Speed(m/s)	y= -In(-Inp)	Chart B
1968	1	0.024	13.9	-1.318	15.6
1963	2	0.048	15	-1.113	15.9
1955	3	0.071	16	-0.97	16.2
1980	4	0.095	17.1	-0.855	16.4
1967	5	0.119	17.2	-0.755	16.7
1985	6	0.143	17.5	-0.666	17
1960	7	0.167	17.7	-0.583	17.3
1974	8	0.19	18	-0.506	17.5
1982	9	0.214	18.2	-0.432	17.8
1954	10	0.238	18.5	-0.361	18.1
1962	11	0.262	18.7	-0.293	18.4
1978	12	0.286	19	-0.225	18.7
1972	13	0.31	19.2	-0.159	18.9
1981	14	0.333	19.5	-0.094	19.2
1959	15	0.357	19.7	-0.029	19.5
1969	16	0.381	20	0.036	19.8
1961	17	0.405	20.2	0.1	20
1975	18	0.429	20.5	0.166	20.3
1979	19	0.452	20.7	0.232	20.6
1989	20	0.476	20.8	0.298	20.9
1953	21	0.5	21	0.367	21.1
1987	22	0.524	21.3	0.436	21.4
1976	23	0.548	21.5	0.507	21.7
1957	24	0.571	21.8	0.581	22
1964	25	0.595	22	0.656	22.3
1973	26	0.619	22.2	0.735	22.5
1992	27	0.643	22.5	0.817	22.8
1988	28	0.667	22.7	0.903	23.1
1965	29	0.69	23	0.993	23.4
1986	30	0.714	23.2	1.089	23.6
1991	31	0.738	23.4	1.192	23.9
1983	32	0.762	23.7	1.302	24.2
1990	33	0.786	23.9	1.422	24.5
1977	34	0.81	24.2	1.554	24.7
1971	35	0.833	24.4	1.702	25
1958	36	0.857	24.5	1.87	25.3
1984	37	0.881	25.3	2.066	25.6
1993	38	0.905	26.1	2.302	25.9
1970	39	0.929	26.8	2.602	26.1
1956	40	0.952	27.6	3.02	26.4
1966	41	0.976	28.4	3.726	26.7
Location Parameter, u		0.368		0	19.6
Scale Parameter, (slope)		1/α	=(v-u)/y		1.9
		α	=y/(v-u)		0.5
Regression Output:		Constant = 15.32683		x Coefficient = 11.63415	

Table C.7 *Tabulated Annual Maximum Wind Speed At Katsina*

Year	Rank (m)	P=m/(n+)	Wind Speed(m/s)	y= -In(-Inp)	Chart B
1959	1	0.025	8.5	-1.305	9.7
1973	2	0.05	10.7	-1.097	10.1
1968	3	0.075	10.8	-0.952	10.5
1972	4	0.1	11.3	-0.834	10.9
1953	5	0.125	11.8	-0.732	11.4
1954	6	0.15	12.3	-0.64	11.8
1976	7	0.175	12.8	-0.556	12.2
1966	8	0.2	13.3	-0.476	12.6
1960	9	0.225	13.8	-0.4	13.1
1964	10	0.25	13.9	-0.327	13.5
1983	11	0.275	14.3	-0.255	13.9
1970	12	0.3	14.7	-0.186	14.4
1965	13	0.325	15.1	-0.117	14.8
1958	14	0.35	15.5	-0.049	15.2
1962	15	0.375	15.9	0.019	15.6
1969	16	0.4	16.3	0.087	16.1
1957	17	0.425	16.7	0.156	16.5
1982	18	0.45	17.1	0.225	16.9
1955	19	0.475	17.2	0.295	17.3
1991	20	0.5	17.5	0.367	17.8
1984	21	0.525	17.7	0.44	18.2
1971	22	0.55	18	0.514	18.6
1987	23	0.575	18.3	0.592	19.1
1980	24	0.6	18.6	0.672	19.5
1985	25	0.625	18.8	0.755	19.9
1986	26	0.65	19.1	0.842	20.3
1956	27	0.675	19.4	0.934	20.8
1975	28	0.7	19.6	1.031	21.2
1977	29	0.725	19.9	1.134	21.6
1961	30	0.75	20.2	1.246	22.1
1974	31	0.775	20.4	1.367	22.5
1979	32	0.8	20.7	1.5	22.9
1978	33	0.825	24.4	1.648	23.3
1989	34	0.85	24.5	1.817	23.8
1981	35	0.875	25.3	2.013	24.2
1988	36	0.9	26.1	2.25	24.6
1992	37	0.925	26.8	2.552	25
1990	38	0.95	27.6	2.97	25.5
1963	39	0.975	28.4	3.676	25.9
Location Parameter, u		0.368		0	15.5
Scale Parameter, (slope)		1/α	=(v-u)/y		2.8
		α	=y/(v-u)		0.4
Regression Output:		Constant = 9.22753		x coefficient = 17.09879	

Table C.8 *Tabulated Annual Maximum Wind Speed At Lagos*

Year	Rank (m)	p = m/n+1	Wind Speed	y = -In (-In	Chart B
1982	1	0.032	5.4	-1.234	5.8
1993	2	0.065	5.5	-1.008	6.3
1984	3	0.097	6.3	-0.848	6.8
1977	4	0.129	7.1	-0.717	7.3
1992	5	0.161	7.9	-0.601	7.8
1986	6	0.194	8	-0.496	8.3
1964	7	0.226	9.4	-0.397	8.8
1985	8	0.258	10.7	-0.303	9.2
1972	9	0.29	10.8	-0.212	9.7
1967	10	0.323	11.6	-0.123	10.2
1981	11	0.355	11.6	-0.035	10.7
1970	12	0.387	12.3	0.052	11.2
1979	13	0.419	12.3	0.14	11.7
1983	14	0.452	12.3	0.23	12.2
1990	15	0.484	12.3	0.32	12.7
1991	16	0.516	13.1	0.413	13.1
1973	17	0.548	13.8	0.51	13.6
1978	18	0.581	13.8	0.61	14.1
1987	19	0.613	13.8	0.714	14.6
1969	20	0.645	13.9	0.825	15.1
1975	21	0.677	14.7	0.943	15.6
1988	22	0.71	14.7	1.07	16.1
1966	23	0.742	15.1	1.209	16.6
1974	24	0.774	15.4	1.363	17
1968	25	0.806	15.9	1.537	17.5
1976	26	0.839	16.3	1.738	18
1980	27	0.871	16.7	1.979	18.5
1989	28	0.903	17.1	2.285	19
1965	29	0.935	20.7	2.708	19.5
1971	30	0.968	28.4	3.418	20
Location Parameter, u		0.368		0	10.9
Scale Parameter, (slope)		1/α	=(v-u)/y		2.7
		α	=y/(v-u)		0.4
Regression Output:		Constant = 5.33977		x Coefficient = 15.11379	

Table C.9 *Tabulated Annual Maximum Wind Speed At Lokoja*

Year	Rank (m)	P=m/(n+1)	Wind Speed	y= -In (-In p)	Chart B
1967	1	0.024	7.9	-1.318	12.4
1993	2	0.048	13.9	-1.113	12.7
1961	3	0.071	14.1	-0.97	13
1989	4	0.095	14.4	-0.855	13.3
1977	5	0.119	14.6	-0.755	13.6
1965	6	0.143	14.8	-0.666	13.9
1991	7	0.167	15	-0.583	14.2
1990	8	0.19	15.3	-0.506	14.5
1987	9	0.214	15.5	-0.432	14.9
1988	10	0.238	15.7	-0.361	15.2
1970	11	0.262	16	-0.293	15.5
1979	12	0.286	16.2	-0.225	15.8
1976	13	0.31	16.4	-0.159	16.1
1981	14	0.333	16.6	-0.094	16.4
1978	15	0.357	16.9	-0.029	16.7
1982	16	0.381	17.1	0.036	17
1973	17	0.405	17.2	0.1	17.3
1958	18	0.429	17.5	0.166	17.7
1974	19	0.452	17.7	0.232	18
1992	20	0.476	18	0.298	18.3
1980	21	0.5	18.2	0.367	18.6
1964	22	0.524	18.5	0.436	18.9
1954	23	0.548	18.7	0.507	19.2
1957	24	0.571	19	0.581	19.5
1986	25	0.595	19.2	0.656	19.8
1972	26	0.619	19.5	0.735	20.1
1975	27	0.643	19.7	0.817	20.5
1985	28	0.667	20	0.903	20.8
1966	29	0.69	20.2	0.993	21.1
1962	30	0.714	20.5	1.089	21.4
1959	31	0.738	20.7	1.192	21.7
1963	32	0.762	20.8	1.302	22
1953	33	0.786	21.3	1.422	22.3
1971	34	0.81	21.8	1.554	22.6
1955	35	0.833	22.3	1.702	22.9
1968	36	0.857	22.8	1.87	23.3
1956	37	0.881	23.2	2.066	23.6
1983	38	0.905	23.7	2.302	23.9
1960	39	0.929	24.2	2.602	24.2
1984	40	0.952	24.4	3.02	24.5
1969	41	0.976	32.6	3.726	24.8
Location Parameter, u		0.368		0	16.9
Scale Parameter, (slope)		1/α	=(v-u)/y		2.1
		α	=y/(v-u)		0.5
Regression Output:		Constant = 12.04963		x Coefficient = 13.07634	

Table C.10 *Tabulated Annual Maximum Wind Speed At Maiduguri*

Year	Rank(m)	P=m/(n+1)	Wind Speed (m/s)	y= -In(-Inp)	Chart B
1961	1	0.024	7.6	-1.318	11.9
1953	2	0.048	8.2	-1.113	12.4
1954	3	0.071	10.7	-0.97	13
1992	4	0.095	13.9	-0.855	13.5
1983	5	0.119	15	-0.755	14.1
1993	6	0.143	16	-0.666	14.7
1991	7	0.167	17.1	-0.583	15.2
1985	8	0.19	17.2	-0.506	15.8
1987	9	0.214	17.8	-0.432	16.3
1958	10	0.238	18.4	-0.361	16.9
1975	11	0.262	19	-0.293	17.4
1962	12	0.286	19.5	-0.225	18
1967	13	0.31	20.1	-0.159	18.6
1986	14	0.333	20.7	-0.094	19.1
1990	15	0.357	20.8	-0.029	19.7
1970	16	0.381	21.1	0.036	20.2
1957	17	0.405	21.5	0.1	20.8
1984	18	0.429	21.8	0.166	21.3
1972	19	0.452	22.1	0.232	21.9
1960	20	0.476	22.4	0.298	22.5
1980	21	0.5	22.8	0.367	23
1959	22	0.524	23.1	0.436	23.6
1973	23	0.548	23.4	0.507	24.1
1988	24	0.571	23.8	0.581	24.7
1971	25	0.595	24.1	0.656	25.2
1976	26	0.619	24.4	0.735	25.8
1966	27	0.643	24.5	0.817	26.4
1965	28	0.667	25.5	0.903	26.9
1989	29	0.69	26.5	0.993	27.5
1968	30	0.714	27.4	1.089	28
1955	31	0.738	28.4	1.192	28.6
1969	32	0.762	28.5	1.302	29.1
1963	33	0.786	29.5	1.422	29.7
1964	34	0.81	30.6	1.554	30.3
1977	35	0.833	31.6	1.702	30.8
1956	36	0.857	32.6	1.87	31.4
1978	37	0.881	32.6	2.066	31.9
1981	38	0.905	32.7	2.302	32.5
1974	39	0.929	33	2.602	33
1979	40	0.952	33.4	3.02	33.6
1982	41	0.976	34.2	3.726	34.2
Location Parameter, u		0.368		0	19.9
Scale Parameter, (slope)		1/α	=(v-u)/y		3.8
		α	=y/(v-u)		0.3
Regression Output:		Constant = 11.30707		x Coefficient = 23.41024	

Table C.11 *Tabulated Annual Maximum Wind Speed At Minna*

Year	Rank (m)	P=m/(n+1)	Wind	y= -ln(-lnp)	Chart B
1971	1	0.025	8.2	-1.305	10.5
1960	2	0.05	10.7	-1.097	11
1972	3	0.075	10.8	-0.952	11.6
1955	4	0.1	11.6	-0.834	12.1
1963	5	0.125	12.3	-0.732	12.7
1961	6	0.15	13.1	-0.64	13.2
1962	7	0.175	13.8	-0.556	13.8
1957	8	0.2	13.9	-0.476	14.3
1966	9	0.225	15	-0.4	14.9
1964	10	0.25	16	-0.327	15.4
1958	11	0.275	17.1	-0.255	16
1956	12	0.3	17.2	-0.186	16.5
1970	13	0.325	17.8	-0.117	17.1
1965	14	0.35	18.4	-0.049	17.6
1982	15	0.375	19	0.019	18.2
1985	16	0.4	19.5	0.087	18.7
1975	17	0.425	20.1	0.156	19.3
1976	18	0.45	20.7	0.225	19.8
1986	19	0.475	20.8	0.295	20.4
1959	20	0.5	21.3	0.367	20.9
1981	21	0.525	21.8	0.44	21.5
1983	22	0.55	22.3	0.514	22
1987	23	0.575	22.9	0.592	22.6
1977	24	0.6	23.4	0.672	23.1
1993	25	0.625	23.9	0.755	23.7
1954	26	0.65	24.4	0.842	24.2
1979	27	0.675	24.5	0.934	24.7
1969	28	0.7	24.9	1.031	25.3
1990	29	0.725	25.4	1.134	25.8
1989	30	0.75	25.8	1.246	26.4
1973	31	0.775	26.2	1.367	26.9
1980	32	0.8	26.7	1.5	27.5
1988	33	0.825	27.1	1.648	28
1974	34	0.85	27.5	1.817	28.6
1978	35	0.875	28	2.013	29.1
1991	36	0.9	28.4	2.25	29.7
1953	37	0.925	29.5	2.552	30.2
1992	38	0.95	32.5	2.97	30.8
1984	39	0.975	33	3.676	31.3
Location Parameter, u		0.368		0	18
Scale Parameter, (slope)		1/a	=(v-u)/y		3.6
		a	=y/(v-u)		0.3
Regression Output:		Constant = 9.950742		x Coefficient = 21.91903	

Table C.12 *Tabulated Annual Maximum Wind Speed At Owerri.*

Year	Rank (m)	p = m/n+1	Wind Speed	y = -ln(-lnp)	Chart B
1989	1	0.048	10.8	-1.113	10.8
1979	2	0.095	11.6	-0.855	11.4
1983	3	0.143	12.3	-0.666	12.1
1981	4	0.19	13.1	-0.506	12.7
1990	5	0.238	13.8	-0.361	13.3
1980	6	0.286	13.9	-0.225	14
1976	7	0.333	14.5	-0.094	14.6
1992	8	0.381	15.2	0.036	15.2
1982	9	0.429	15.8	0.166	15.9
1986	10	0.476	16.5	0.298	16.5
1978	11	0.524	17.1	0.436	17.1
1984	12	0.571	17.2	0.581	17.8
1993	13	0.619	17.9	0.735	18.4
1974	14	0.667	18.6	0.903	19
1988	15	0.714	19.3	1.089	19.7
1987	16	0.762	20	1.302	20.3
1985	17	0.81	20.7	1.554	20.9
1991	18	0.857	20.8	1.87	21.6
1975	19	0.905	23	2.302	22.2
1977	20	0.952	24.4	3.02	22.8
Location Parameter, u		0.368		0	15.1
Scale Parameter, (slope)		$1/\alpha$	=(v-u)/y		2.6
		α	=y/(v-u)		0.4
Regression Output:		Constant = 10.17526		x Coefficient = 13.29947	

Table C.13 *Tabulated Annual Maximum Wind Speed At Port Harcourt.*

Year	Rank(m)	P=m/(n+1)	Wind	y = -ln(-lnp)	Chart B
1954	1	0.024	10.8	-1.312	12.4
1965	2	0.049	12.3	-1.105	12.7
1958	3	0.073	13.8	-0.961	13.1
1960	4	0.098	13.9	-0.845	13.5
1956	5	0.122	14.3	-0.744	13.9
1990	6	0.146	14.7	-0.653	14.2
1973	7	0.171	15.1	-0.57	14.6
1963	8	0.195	15.5	-0.491	15
1986	9	0.22	15.9	-0.416	15.4
1964	10	0.244	16.3	-0.344	15.7
1957	11	0.268	16.7	-0.274	16.1
1972	12	0.293	17.1	-0.206	16.5
1987	13	0.317	17.2	-0.139	16.9
1992	14	0.341	17.5	-0.072	17.3
1953	15	0.366	17.8	-0.006	17.6
1961	16	0.39	18.2	0.061	18
1969	17	0.415	18.5	0.127	18.4
1982	18	0.439	18.8	0.195	18.8
1959	19	0.463	19.1	0.262	19.1
1970	20	0.488	19.4	0.332	19.5
1978	21	0.512	19.8	0.402	19.9
1962	22	0.537	20.1	0.474	20.3
1966	23	0.561	20.4	0.548	20.6
1971	24	0.585	20.7	0.625	21
1967	25	0.61	20.8	0.704	21.4
1985	26	0.634	21.1	0.786	21.8
1989	27	0.659	21.4	0.873	22.2
1974	28	0.683	21.7	0.964	22.5
1977	29	0.707	22	1.061	22.9
1993	30	0.732	22.3	1.164	23.3
1981	31	0.756	22.6	1.274	23.7
1988	32	0.78	22.9	1.395	24
1976	33	0.805	23.2	1.528	24.4
1979	34	0.829	23.5	1.676	24.8
1983	35	0.854	23.8	1.844	25.2
1991	36	0.878	24.1	2.04	25.5
1975	37	0.902	25.5	2.276	25.9
1984	38	0.927	28	2.577	26.3
1980	39	0.951	28.4	2.996	26.7
1955	40	0.976	33	3.701	27.1
Location Parameter, u		0.368		0	17.7
Scale Parameter, (slope)		$1/\alpha$	=(v-u)/y		2.5
		α	=y/(v-u)		0.4
Regression Output:		Constant = 11.98192		x Coefficient = 15.44615	

Table C.14 *Tabulated Annual Maximum Wind Speed At Sokoto.*

Year	Rank (m)	P=m/(n+1)	Wind	y= -ln (-ln p)	Chart B
1954	1	0.025	13.8	-1.305	15.8
1957	2	0.05	14.2	-1.097	16.2
1970	3	0.075	17	-0.952	16.7
1960	4	0.1	17.2	-0.834	17.1
1993	5	0.125	17.8	-0.732	17.5
1953	6	0.15	18.4	-0.64	18
1984	7	0.175	19	-0.556	18.4
1961	8	0.2	19.5	-0.476	18.8
1971	9	0.225	20.1	-0.4	19.3
1959	10	0.25	20.7	-0.327	19.7
1968	11	0.275	20.8	-0.255	20.1
1958	12	0.3	21.2	-0.186	20.6
1965	13	0.325	21.5	-0.117	21
1963	14	0.35	21.9	-0.049	21.4
1967	15	0.375	22.2	0.019	21.8
1966	16	0.4	22.6	0.087	22.3
1962	17	0.425	23	0.156	22.7
1976	18	0.45	23.3	0.225	23.1
1980	19	0.475	23.7	0.295	23.6
1992	20	0.5	24.1	0.367	24
1964	21	0.525	24.4	0.44	24.4
1973	22	0.55	24.5	0.514	24.9
1975	23	0.575	24.9	0.592	25.3
1979	24	0.6	25.3	0.672	25.7
1972	25	0.625	25.7	0.755	26.2
1969	26	0.65	26.1	0.842	26.6
1991	27	0.675	26.5	0.934	27
1989	28	0.7	26.8	1.031	27.5
1981	29	0.725	27.2	1.134	27.9
1988	30	0.75	27.6	1.246	28.3
1987	31	0.775	28	1.367	28.8
1974	32	0.8	28.4	1.5	29.2
1977	33	0.825	28.5	1.648	29.6
1990	34	0.85	29.5	1.817	30
1985	35	0.875	30.6	2.013	30.5
1978	36	0.9	31.6	2.25	30.9
1982	37	0.925	32.6	2.552	31.3
1983	38	0.95	33	2.97	31.8
1986	39	0.975	33	3.676	32.2
Location Parameter, u		0.368		0	21.7
Scale Parameter, (slope)		$1/\alpha$	=(v-u)/y		2.9
		α	=y/(v-u)		0.4
Regression Output:		Constant = 15.37214		x Coefficient = 17.26379	

Table C.15 *Tabulated Annual Maximum Wind Speed At Warri.*

Year	Rank(m)	P=m/(n+1)	Wind	y= -In (-In p)	Chart B
1960	1	0.024	5.6	-1.312	7.3
1978	2	0.049	6.7	-1.105	7.7
1970	3	0.073	7.9	-0.961	8
1979	4	0.098	8	-0.845	8.4
1969	5	0.122	8.5	-0.744	8.8
1974	6	0.146	9.1	-0.653	9.2
1977	7	0.171	9.6	-0.57	9.6
1972	8	0.195	10.2	-0.491	10
1973	9	0.22	10.7	-0.416	10.3
1986	10	0.244	10.8	-0.344	10.7
1961	11	0.268	11.6	-0.274	11.1
1971	12	0.293	12.3	-0.206	11.5
1976	13	0.317	13.1	-0.139	11.9
1962	14	0.341	13.8	-0.072	12.3
1987	15	0.366	13.9	-0.006	12.6
1963	16	0.39	14.1	0.061	13
1993	17	0.415	14.3	0.127	13.4
1991	18	0.439	14.5	0.195	13.8
1954	19	0.463	14.8	0.262	14.2
1989	20	0.488	15	0.332	14.6
1968	21	0.512	15.2	0.402	14.9
1957	22	0.537	15.4	0.474	15.3
1965	23	0.561	15.6	0.548	15.7
1992	24	0.585	15.8	0.625	16.1
1982	25	0.61	16	0.704	16.5
1985	26	0.634	16.2	0.786	16.9
1967	27	0.659	16.5	0.873	17.2
1983	28	0.683	16.7	0.964	17.6
1975	29	0.707	16.9	1.061	18
1981	30	0.732	17.1	1.164	18.4
1984	31	0.756	17.2	1.274	18.8
1955	32	0.78	17.7	1.395	19.1
1988	33	0.805	18.2	1.528	19.5
1990	34	0.829	18.7	1.676	19.9
1966	35	0.854	19.2	1.844	20.3
1958	36	0.878	19.7	2.04	20.7
1980	37	0.902	20.2	2.276	21.1
1964	38	0.927	20.7	2.577	21.4
1953	39	0.951	24	2.996	21.8
1956	40	0.976	28.2	3.701	22.2
Scale Parameter, (slope)		0.368		0	12.7
Scale Parameter, (slope)		1/α	=(v-u)/y		2.6
		α	=y/(v-u)		0.4
Regression Output:		Constant = 6.885769		x Coefficient = 15.71346	

Fig. C.4 Probability Plotting Of Annual Maximum Wind Speed At Ilorin.

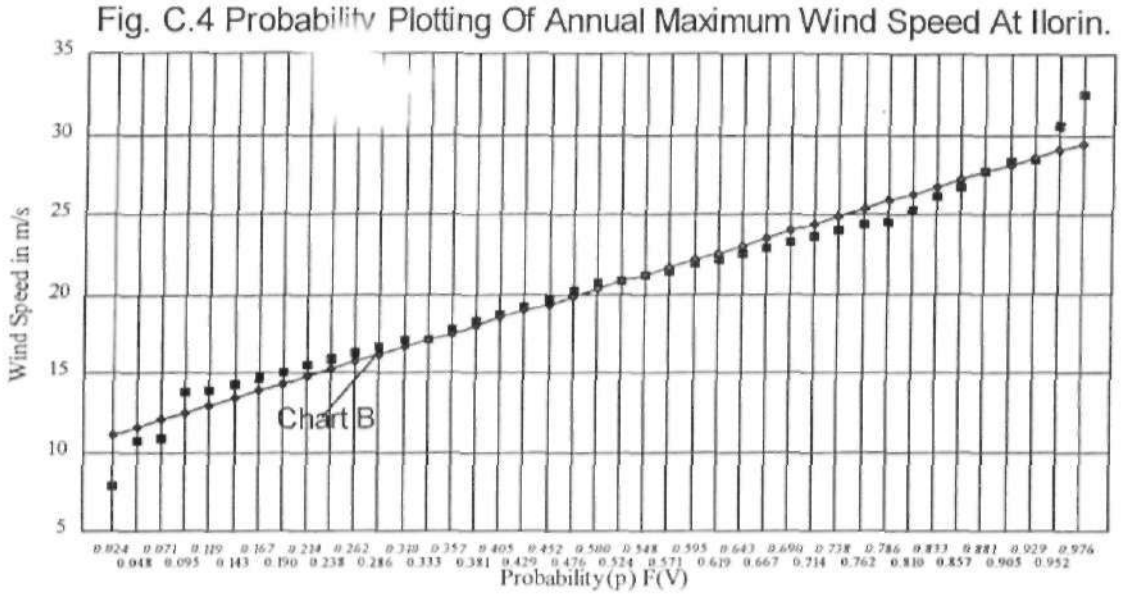


Fig. C.5 Probaility Plotting Of Annual Maximum Wind Speed At Jos

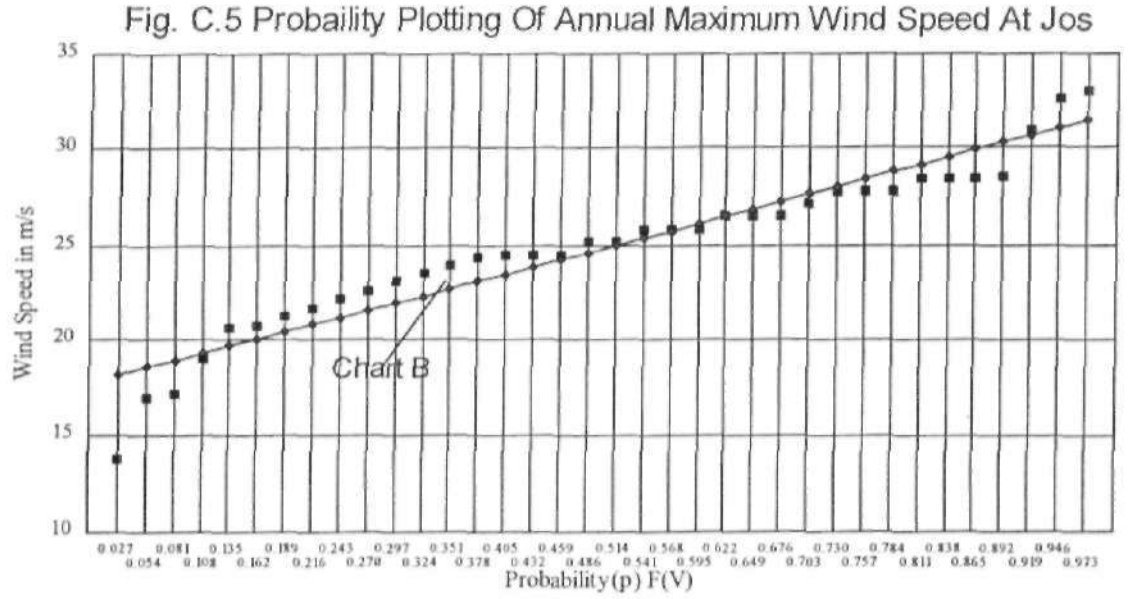


Fig. C.6 Prbability Plotting Of Annual Maximum Wind Speed At Kaduna.

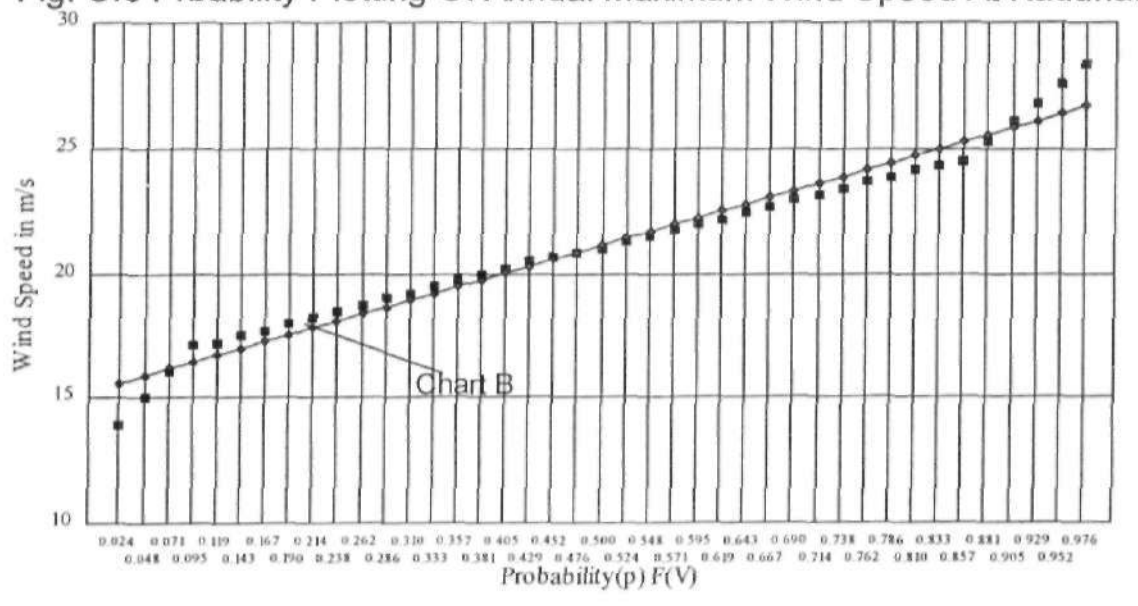


Fig. C.7 Probability Plotting Of Annual Maximum Wind Speed At Katsina.

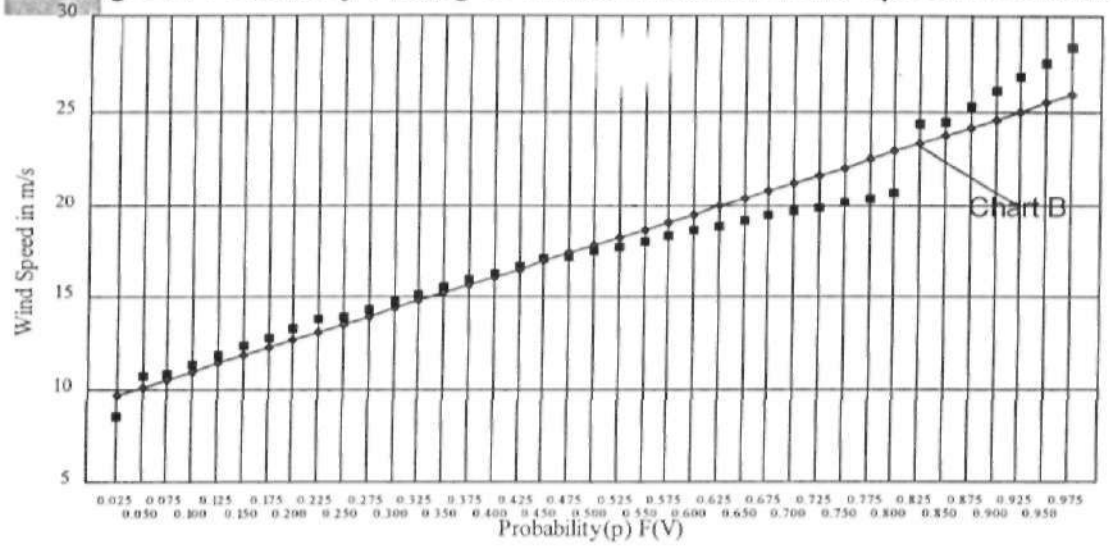


Fig. C.8 Probability Plotting Of Annual Maximum Wind Speed At Lagos.

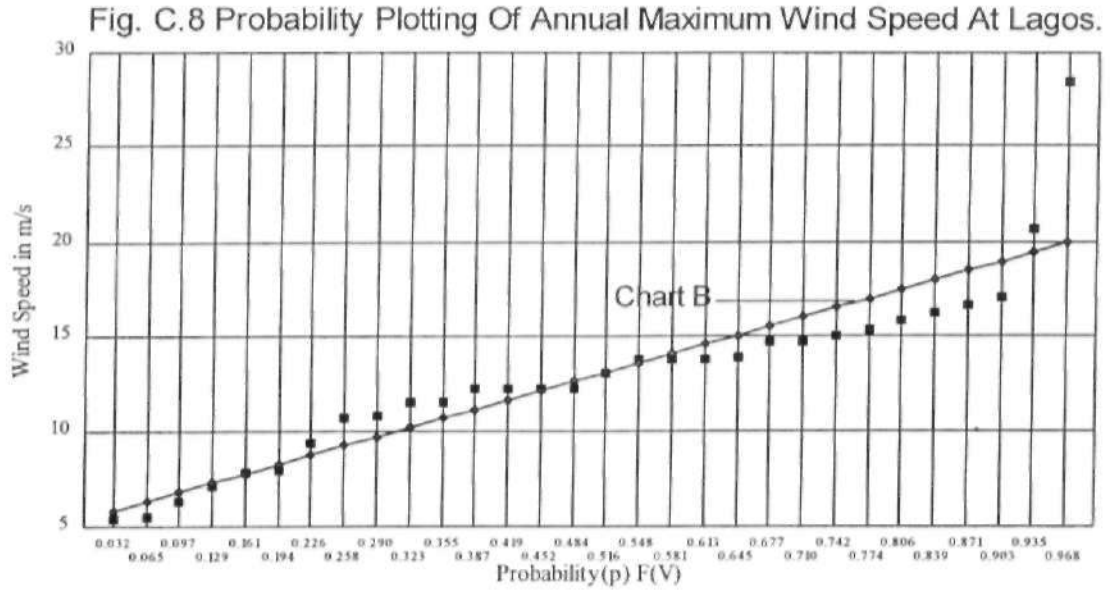


Fig. C.9 Probability Plotting Of Annual Maximum Wind Speed At Lokoja.

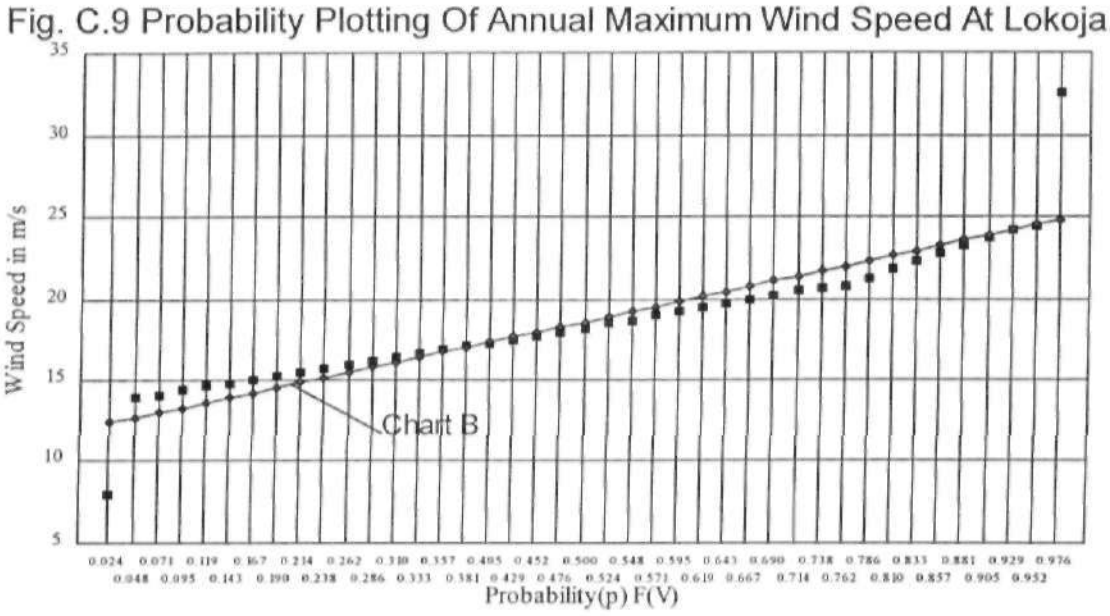


Fig. C.10 Probability Plotting Of Annual Maximum wind Speed At Maiduguri

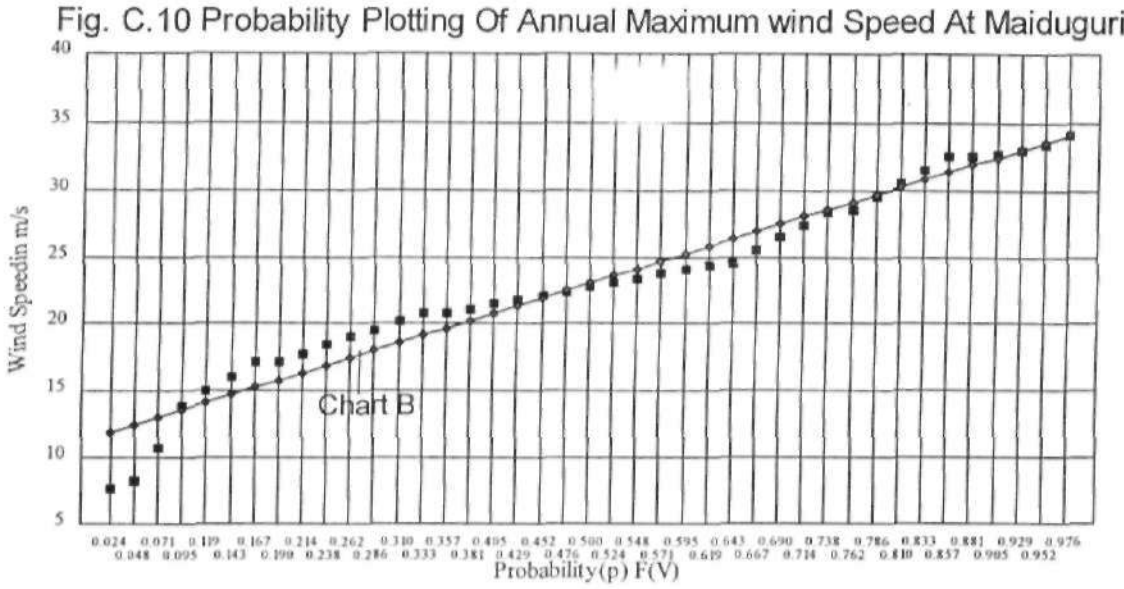


Fig. C.11 Probability Plotting Of Annual Maximum Wind Speed At Minna

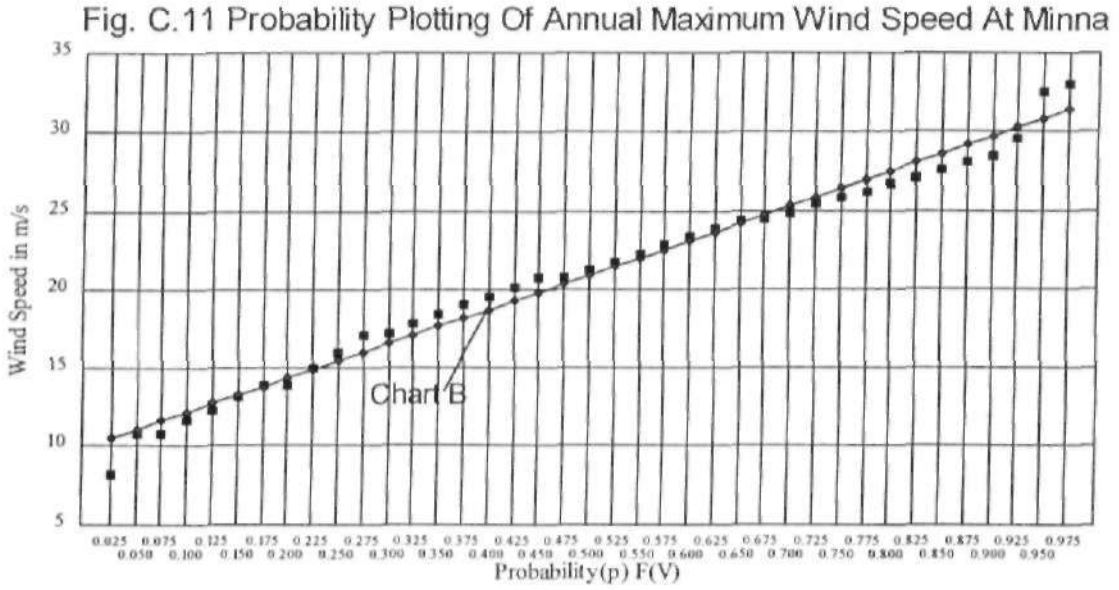


Fig. C.12 Probability Plotting Of Annual Maximum Wind Speed At Owerri.

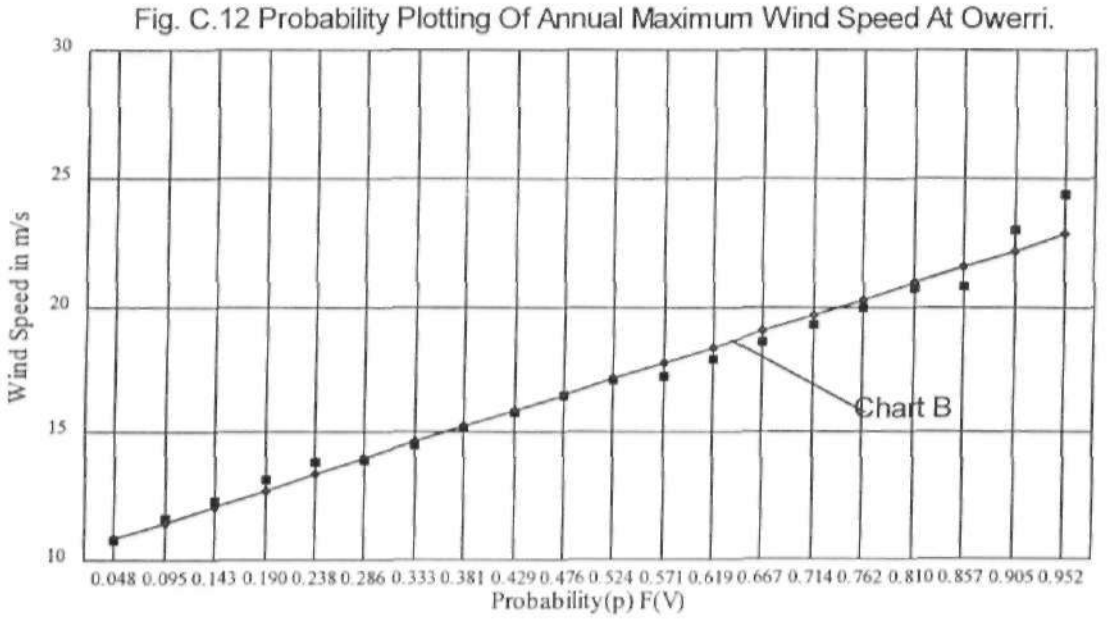


Fig. C.13 Probability Plotting Of Annual Maximum Wind Speed At Port Harcourt.

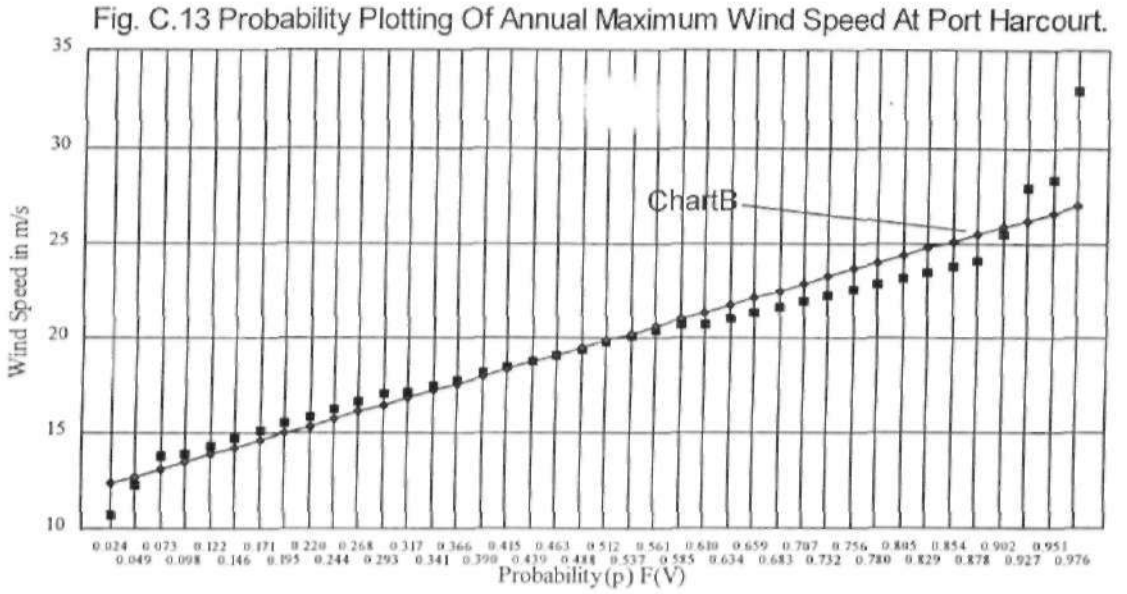


Fig.C.14 Probability Plotting Of Annual Maximum Wind Speed At Sokoto.

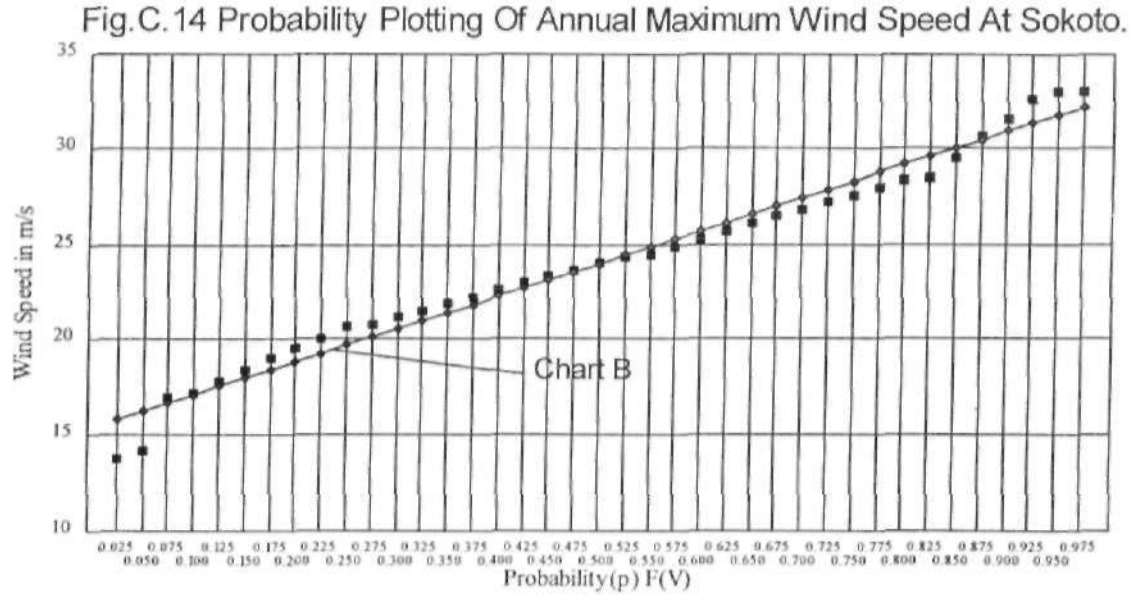


Fig. C.15 Probability Plotting Of Annual Maximum Wind Speed At Warri.

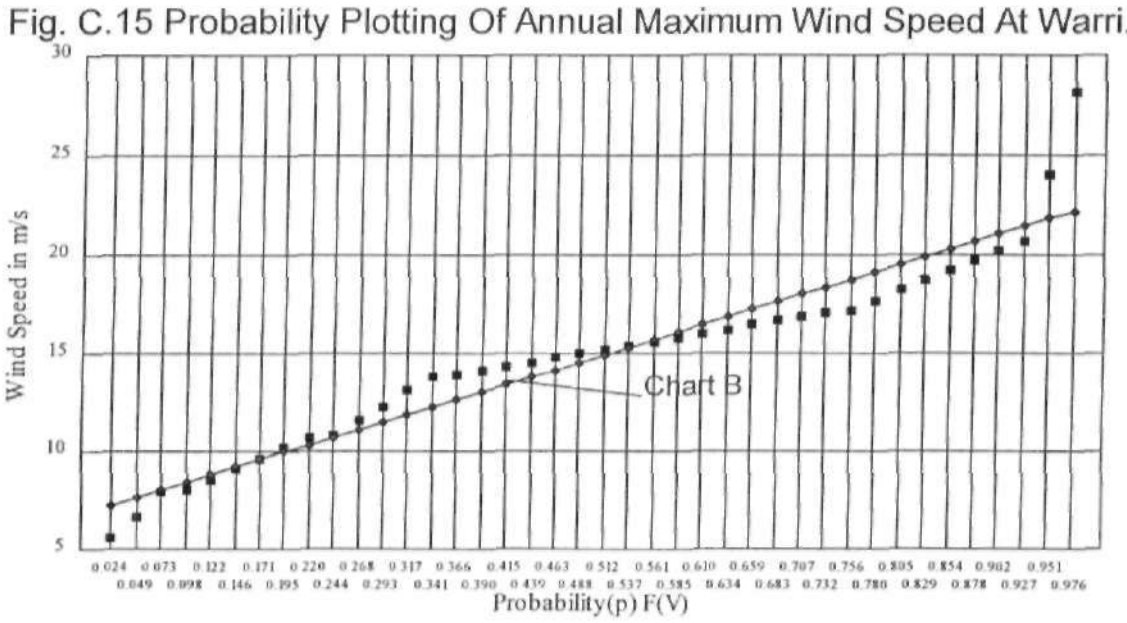
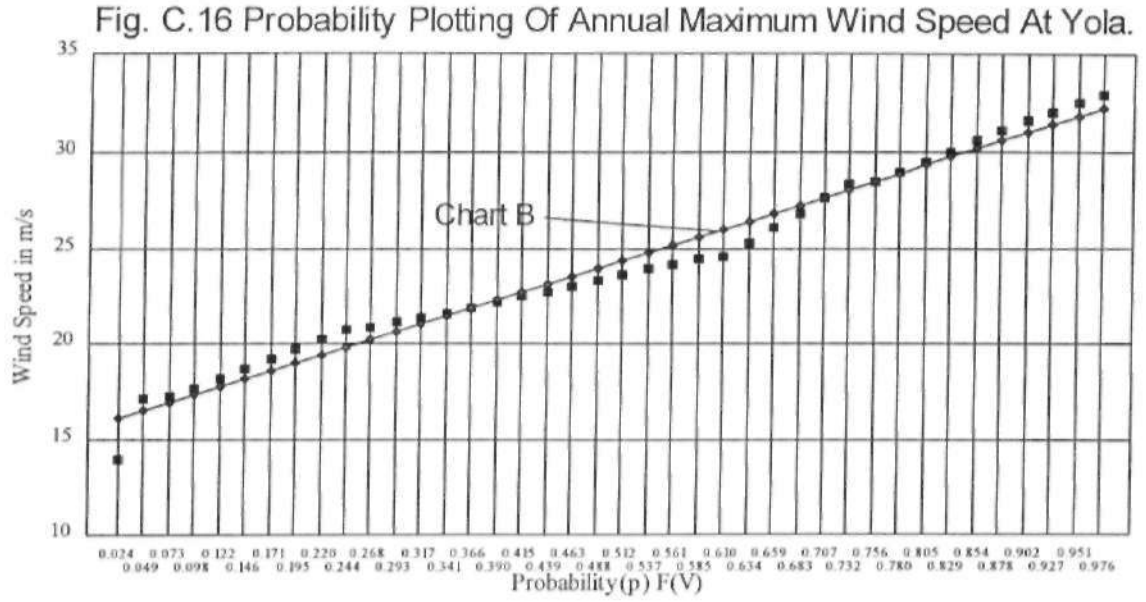


Fig. C.16 Probability Plotting Of Annual Maximum Wind Speed At Yola.



APPENDIX D

TABLES OF RESULTS OF ESTIMATION OF SELECTED MODEL PARAMETERS USING THE METHOD OF ORDER STATISTICS

Table D.1 CALABAR

Subgroup	1	2	3	4	5	6	7	
V1	11.8	15.3	13.8	10.8	17.2	13.9	12.8	
V2	14.3	18.5	14.6	15	17.5	18.2	16	
V3	15.8	21.5	16.7	16.4	18.8	21.2	17.1	
V4	17.8	21.9	19.8	20.7	19.4	22.6	19.1	
V5	24.4	28.4	23.3	20.8	20.1	23.7	20.4	
V6	30.6	32.6	28.5	23	22.2	24.1	CALABAR	
								Mean
u	15.72	19.79	16.7	15.3	18.29	18.45	15.44	17.1
1/α	5.59	5.66	4.51	4.79	1.55	4.43	3.13	4.2
α	0.18	0.18	0.22	0.21	0.65	0.23	0.32	0.2

Table D.2 ENUGU

Subgroup	1	2	3	4	5	6	7	
V1	18.4	14.4	15	13.8	17.8	20.8	22	
V2	19.5	16	16.6	13.9	22.4	24.5	25.7	
V3	21.2	17.2	17.1	15.5	23.6	24.9	26.1	
V4	22.8	19	20.1	21.6	24	26.8	28	
V5	23.2	20.7	28.4	24.4	26.5	27.6	32.6	
V6	25.3	27.2				ENUGU		Mean
u	20.38	16.93	17.08	15.58	21.09	23.45	24.87	19.9
1/α	2.45	3.54	3.68	3.59	3.52	2.9	3.6	3.3
α	0.41	0.28	0.27	0.28	0.28	0.34	0.28	0.3

Table D.3 ILORIN

Subgroup	1	2	3	4	5	6	7	
V1	10.7	7.9	13.9	17.2	19.2	19.7	20.8	
V2	10.9	13.8	14.3	18.7	23	21.9	21.5	
V3	15.5	14.7	16.3	20.2	24.4	24.1	23.3	
V4	15.9	15.1	17.1	21.2	25.3	27.7	26.8	
V5	16.7	17.7	18.2	22.2	26.1	28.4	32.6	
V6	24.5	20.7	22.6	23.7	28.5	30.6	ILORIN :	Mean
u	13.35	12.67	15.56	19.25	22.69	23.15	22.73	18.5
1/α	3.91	4.53	2.48	2.37	3.4	4.15	3.6	3.5
α	0.26	0.22	0.4	0.42	0.29	0.24	0.28	0.3

Table D.4 KADUNA

Subgroup	1	2	3	4	5	6	7	
V1	16	15	13.9	18	17.1	17.5	20.8	
V2	18.5	17.7	17.2	19.2	18.2	21.3	22.5	
V3	21	18.7	20	20.5	19	22.7	23.4	
V4	21.8	19.7	23	21.5	19.5	23.2	23.9	
V5	24.5	20.2	26.8	22.2	20.7	23.7	26.1	
V6	27.6	22	28.4	24.4	24.2	25.3	KADUNA: Mean	
u	19.37	17.57	18.54	19.77	18.6	20.81	22.3	19.6
1/α	3.97	2.57	5.52	2.14	1.98	3.03	1.89	3
α	0.25	0.39	0.18	0.47	0.51	0.33	0.53	0.3

Table D.5 MAIDUGURI

Subgroup	1	2	3	4	5	6	7	
V1	8.2	7.6	20.1	19	22.8	15	13.9	
V2	10.7	19.5	21.1	22.1	31.6	17.2	16	
V3	18.4	22.4	24.5	23.4	32.6	17.8	17.1	
V4	21.5	23.1	25.5	24.1	32.7	20.7	20.8	
V5	28.4	29.5	27.4	24.4	33.4	21.8	26.5	
V6	32.6	30.6	28.5	33	34.2	23.8	M/DUGURI:Mean	
u	14.94	17.56	22.73	22.18	29.05	17.65	16.44	20.1
1/α	8.92	9.25	3.29	3.71	4.9	3.15	4.01	5.3
α	0.11	0.11	0.3	0.27	0.2	0.32	0.25	0.2

Table D.6 PORT HARCOURT

Subgroup	1	2	3	4	5	6	7	
V1	10.8	13.9	12.3	15.1	18.8	15.9	14.7	
V2	13.8	15.5	18.5	17.1	19.8	17.2	17.5	
V3	14.3	16.3	19.4	21.7	22.6	21.1	21.4	
V4	16.7	18.2	20.4	22	23.5	22.9	22.3	
V5	17.8	19.1	20.7	23.2	23.8	28	24.1	
V6	33	20.1	20.8	25.5	28.4	PORT HARCOURT :Mean		
u	14.44	15.92	16.97	18.66	21.11	18.56	17.89	17.6
1/α	5.18	2.34	3.82	4.01	2.99	4.19	4.01	3.8
α	0.19	0.43	0.26	0.25	0.34	0.24	0.25	0.3

Table D.7 WARRI

Subgroup	1	2	3	4	5	6	7	
V1	14.8	5.6	7.9	9.1	6.7	10.8	14.3	
V2	15.4	11.6	8.5	9.6	8	13.9	14.5	
V3	17.7	13.8	12.3	10.2	16	16.2	15	
V4	19.7	14.1	15.2	10.7	16.7	17.2	15.8	
V5	24	15.6	16.5	13.1	17.1	18.2	18.7	
V6	28.2	20.7	19.2	16.9	20.2		WARRI: Mean	
u	17.43	10.91	10.92	10.3	11.27	13.6	14.89	12.8
1/α	4.14	5.16	4.16	2	5.42	3.25	1.18	3.6

Table D.8 IBADAN

Subgroup	1	2	3	4	5	6	7	
V1	11.4	14.3	18.4	12.6	10.6	13.8	10.8	
V2	13.9	17.2	22.2	21.3	13.2	14.6	12	
V3	15.3	20.1	23.5	23.1	20.8	15	16.4	
V4	15.7	20.7	24.4	24	24.5	16	16.7	
V5	17.8	21.9	27.1	28.4	25.8	17.1	19	
V6	31.2	22.6	28.5	32.6	29.9	19.5	IBADAN: Mean	
u	14.63	17.73	22.05	19.98	16.77	15	13.15	17
1/α	4.58	3.48	3.77	7.18	7.5	1.66	3.32	4.5
α	0.22	0.29	0.27	0.14	0.13	0.6	0.3	0.2

Table D.9 IBI

Subgroup	1	2	3	4	5	6	7	
V1	14.3	14.6	10.7	7.9	12.3	17.2	10.8	
V2	17.7	16.7	15	13.9	16.4	18.7	13.8	
V3	19.2	17.1	15	15.7	21.9	24	16.7	
V4	21.5	20.2	18.2	24.4	23	28	20.7	
V5	22.6	21.2	19.7	26.5	23.7	28.4	32.6	
V6	24.4	23.3	22.2			IBI: Mean		
u	17.94	17.14	14.6	13.57	16.75	20.54	14.88	16.5
1/α	3.86	3.07	4.13	7.49	5.33	4.92	6.61	5.1
α	0.26	0.33	0.24	0.13	0.19	0.2	0.15	0.2

Table D.10 KATSINA

Subgroup	1	2	3	4	5	6	7	
V1	11.8	8.5	10.8	10.7	17.1	14.3	17.5	
V2	12.3	13.8	13.3	11.3	18.6	17.7	24.5	
V3	15.5	13.9	14.7	12.8	20.7	18.3	26.1	
V4	16.7	15.9	15.1	19.6	24.4	18.8	26.8	
V5	17.2	20.2	16.3	19.9	25.3	19.1	27.6	
V6	19.4	28.4	18	20.4		KATSINA : Mean		
u	13.94	13.43	13.34	13.5	19.35	16.58	22.27	16.1
1/α	2.79	5.79	2.61	4.05	3.32	2.25	4.72	3.6
α	0.36	0.17	0.38	0.25	0.3	0.45	0.21	0.3

Table D.11 JOS

Subgroup	1	2	3	4	5	6		
V1	13.8	21.7	20.7	19	22.6	20.8		
V2	17	22.2	24.4	21.3	23.1	24.5		
V3	17.2	24	24.5	23.5	25.2	26.5		
V4	24.5	26.5	25.2	25.8	25.8	27.8		
V5	26.5	27.8	25.8	27.1	27.8	28.4		
V6	28.4	31	33	28.4	32.6	28.5	JOS: Mean	
u	18.15	23.74	23.74	22.22	24.45	24.44	22.8	
1/α	5.52	3.03	3.27	3.69	2.81	3.43	3.6	
α	0.18	0.33	0.31	0.27	0.36	0.29	0.3	

Table D.12 LOKOJA

Subgroup	1	2	3	4	5	6	7	
V1	17.5	14.1	7.9	16.4	14.6	15.5	13.9	
V2	18.7	18.5	14.8	17.2	16.2	15.7	14.4	
V3	19	20.5	16	17.7	16.6	19.2	15	
V4	21.3	20.7	20.2	19.5	16.9	20	15.3	
V5	22.3	20.8	22.8	19.7	17.1	23.7	18	
V6	23.2	24.2	32.6	21.8	18.2	24.4	LOKOJA: Mean	
u	19.16	18	14.74	17.71	15.96	17.82	14.6	16.9
1/α	2.1	3.62	7.73	1.74	1.28	3.36	1.16	3
α	0.48	0.28	0.13	0.57	0.78	0.3	0.86	0.3

Table D.13 MINNA

Subgroup	1	2	3	4	5	6	7	
V1	11.6	10.7	8.2	20.1	19	19.5	23.9	
V2	13.9	12.3	10.8	20.7	21.8	20.8	25.4	
V3	17.1	13.1	15	23.4	22.3	22.9	25.8	
V4	17.2	13.8	17.8	26.2	24.5	27.1	28.4	
V5	24.4	16	18.4	27.5	26.7	33	32.5	
V6	29.5	21.3	24.9	28			MINNA : Mean	
u	15.65	12.79	12.74	22.52	21.29	22	25.58	18.9
1/α	5.55	2.85	5.58	3.25	2.87	4.32	2.66	3.9
α	0.18	0.35	0.18	0.31	0.35	0.23	0.38	0.3

Table D.14 SOKOTO

Subgroup	1	2	3	4	5	6	7	
V1	13.8	19.5	17	23.3	23.7	19	17.8	
V2	14.2	21.5	20.1	24.5	25.3	27.6	24.1	
V3	17.2	21.9	20.8	24.9	27.2	28	26.5	
V4	18.4	22.6	22.2	28.4	32.6	30.6	26.8	
V5	20.7	23	25.7	28.5	33	33	29.5	
V6	21.2	24.4	26.1	31.6		SOKOTO :Mean		
u	15.95	21.26	20.13	25.29	26.19	24.71	22.47	22.3
1/α	2.93	1.73	3.45	2.71	3.8	5.92	4.97	3.6
α	0.34	0.58	0.29	0.37	0.26	0.17	0.2	0.3

Table D.15 YOLA

Subgroup	1	2	3	4	5	6	7	
V1	17.7	13.9	21.4	23.6	26.1	17.2	18.2	
V2	20.7	17.1	21.6	24.5	27.6	21.1	19.2	
V3	20.8	18.7	22.2	26.8	29	23.3	19.7	
V4	21.9	22.5	23.9	28.4	31.1	25.3	20.2	
V5	22.7	28.5	24.4	29.5	32.6	31.6	23	
V6	24.1	32.1	30.6	30	33	YOLA : Mean		
u	20.13	18.57	22.58	25.72	28.4	20.9	19.2	22.2
1/α	2.33	6.16	2.16	2.63	2.77	4.95	1.45	3.2
α	0.43	0.16	0.46	0.38	0.36	0.2	0.69	0.3

Table D.16 IKOM

Subgroup	1	2	3	4		
V1	8	10.8	8.7	9.4		
V2	10	12.5	11.2	11.7		
V3	10.7	15.2	13.4	12.9		
V4	12.1	17.1	14.5	13.8		
V5	13.9	20.8	16.5	23		
V6	15.8	24.4		IKOM: Mean		
u	10.27	14.17	11.19	11.83	11.9	
1/α	2.66	4.54	3.12	3.78	3.5	
α	0.38	0.22	0.32	0.26	0.3	

Table D.17 OWERRI

Subgroup	1	2	3	4		
V1	14.5	11.6	16.5	10.8		
V2	17.1	12.3	17.2	13.8		
V3	18.6	13.1	19.3	15.2		
V4	23	13.9	20	17.9		
V5	24.4	15.8	20.7	20.8		
V6				OWERRI : Mean		
u	17.33	12.52	17.77	13.63	15.3	
1/α	3.92	1.39	1.78	3.73	2.7	
α	0.25	0.72	0.56	0.27	0.4	

Table D.18 LAGOS

Subgroup	1	2	3	4	5	
V1	9.4	10.8	7.1	5.4	5.5	
V2	11.6	12.3	11.6	6.3	7.9	
V3	13.9	13.8	12.3	8	12.3	
V4	15.1	14.7	13.8	10.7	13.1	
V5	15.9	15.4	16.3	12.3	14.7	LAGOS
V6	20.7	28.4	16.7	13.8	17.1	:Mean
u	12.43	13.35	11.02	7.66	9.42	10.8
1/α	3.59	3.91	3.84	3.09	4.44	3.8
α	0.28	0.26	0.26	0.32	0.23	0.3

Table D.19 ZARIA

Subgroup	1	2	3	4	5	
V1	22.6	22	21.4	17.1	20.7	
V2	23.2	25	24.4	24.5	20.8	
V3	26	26.5	28.4	25.5	23.8	
V4	27	28.5	29.2	27.4	28	
V5	29.9	32.6	31.2	30.6	31.9	
V6					ZARIA : Mean	
u	24.22	24.82	24.73	22.24	22.69	23.7
1/α	2.59	3.74	4.16	5.51	3.8	4
α	0.39	0.27	0.24	0.18	0.26	0.3

APPENDIX E

MEANS, VARIANCES AND COEFFICIENTS OF VARIATION OF RESPECTIVE STATION'S DATA

	Bauchi	Calabar	Enugu	Ibadan	Ibi	Ilorin	Jos	Kaduna	Katsina	Lokoja
Sum	748	800.6	804.6	803.9	730.2	833.6	892.9	866.9	693.3	762.1
No. of Observ-ations	36	41	37	41	38	41	36	41	39	41
Mean	20.78	19.53	21.75	19.61	19.22	20.33	24.8	21.14	17.78	18.59
Std	4.6	4.88	4.67	5.8	5.29	5.53	4.11	3.33	4.94	4
Var	21.15	23.8	21.8	33.61	28.01	30.61	16.9	11.08	24.39	15.97
Coef. Of Var	0.22	0.25	0.21	0.3	0.28	0.27	0.17	0.16	0.28	0.21

	M/Duguri	Minna	Port H/C	Sokoto	Warri	Yola	Ikom	Lagos	Owerri	Zaria
Sum	943.5	815.5	788.2	936.2	589.7	965.8	306.4	386.9	336.5	648.2
No.of Observ-ations	41	39	40	39	40	40	22	30	20	25
Mean	23.01	20.91	19.71	24.01	14.74	24.15	13.93	12.9	16.83	25.93
Std	6.74	6.22	4.52	4.92	4.62	4.84	4.26	4.61	3.69	3.86
Var	45.48	38.72	20.43	24.17	21.34	23.45	18.14	21.28	13.6	14.92
Coef. Of Var.	0.29	0.3	0.23	0.2	0.31	0.2	0.31	0.36	0.22	0.15

Note: Wind speed values are in m/s.