ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

POST-GRADUATE PROGRAM

STRUCTURAL ENGINEERING STREAM

REFERENCE BASIC WIND SPEED FOR SELECTED TOWNS/CITIES IN ETHIOPIA

By

Fikadie Alamirew

Research Advisor: Dr. - Ing. Adil Zekaria

July 2016
Addis Ababa

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

POST-GRADUATE PROGRAM

STRUCTURAL ENGINEERING STREAM

RERERENCE BASIC WIND SPEED FOR SELECTED TOWNS/CITIES IN ETHIOPIA

A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Requirements for Degree of Master of Science (MSc) in Structural Engineering.

By
Fikadie Alamirew
ID No. GSR/2129/07

Research Advisor: Dr. - Ing. Adil Zekaria

July 2016
Addis Ababa

Declaration

I declare that, this thesis is my own work and all sources of material used for the thesis have been duly acknowledged.

Name: Fikadie Alamirew

Signature: ___________

Place: Addis Ababa University (AAU)

Addis Ababa institute of Technology (AAiT)

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

POST-GRADUATE PROGRAM

This is to certify that the thesis prepared by Fikadie Alamirew, entitled, **Reference Basic Wind Speed for Selected Towns/Cities in Ethiopia** and submitted in partial fulfillment of the requirements for the Degree of Master of Science (MSc.) in Structural Engineering complies with the regulation of the university and meets the accepted standards with respect to its originality and quality.

Signed by the Examining Committee

Dr. Adil Zekaria: ______________________ ____________________
Advisor Signature Date

Dr. Abreham Gebre: ______________________ ____________________
Internal examiner Signature Date

Dr. Esayas G/Youhannes: ______________________ ____________________
External examiner Signature Date

Dr. Agizew Nigussie: ____________________ __________________
Chairman Signature Date

Abstract

A data on three hourly wind speeds, from 18 meteorological centre of Ethiopia Meteorological Department, have been collected. The daily gust wind data have been processed for annual maximum wind speed in m/sec for each site. This research paper presents an attempt made towards preparing a wind zone map based on observed wind speeds at each weather station in the country. The data used were annual maximum 180 minute average wind speeds recorded at about 10 m above ground level. These 180 minute average wind speeds were changed to 10 minute mean wind speeds by the factor 1.32. Several probability distributions were tested for suitability and Extreme Value Type I (log Gumbel) distribution was found to be the best fitting distribution for the maximum wind speeds at Arba Minch and Hawassa. Log Pearson distribution was found to be the best fitting distribution for the maximum wind speeds at Dire Dawa and Kombolcha. Log Normal distribution was found to be the best fitting distribution for the maximum wind speeds at Addis Ababa, Bahir Dar, Debre Markos, Debre Zeit, Gode, Gondar, Gore, Jimma, Kibre Mengist, Mekelle, Metehara, Negelle, Nekemte and Robe. An attempt to demarcate wind speeds for the selected stations was prepared using the 5, 10, 15, 20, 25, 30, 50, 100, 200, 500 and 1000 year return period wind speeds resulted from the best fitting probability distributions. This map was based on basic wind speeds calculated from actual annual maximum records of each station. The basic wind speed values ranged from 30m/sec to 45m/sec.

Keyword: *Wind speed, Fitting distribution method, Return period*

ACKNOWLEDGEMENTS

Above all, I would like to thank the Almighty God, for His Benevolence, Who is the sole author and provider of knowledge, wisdom and eternal love. Glory is unto you for making everything possible by giving me the strength and courage to do this work from the discoveries of invisibles clouded at perception.

Immeasurable appreciation and deepest gratitude for the help and support is to the following people and institutions who, in one way or another, have contributed in making this study a success. It gives me the greatest pleasure to extend my heartfelt indebtedness to Dr. Ing. Adil Zekaria, my closest research advisor, for his relentless advice, continuous support, valuable comments and suggestions pertinent to the study. I have benefited and learnt a lot from his incessant patience, perpetual motivation, and immense knowledge; he has allotted me a lot of his precious time to discuss regularly with me for each and every work in progress. It was an endless help to successfully finish this study in time. I was the luckiest student to be advised such a towering scholar; once again, I am very much thankful of you, Dr. Ing. Adil Zekaria. Dr. Esayas Gebreyohannes, Scientific Director, Addis Ababa Institute of Technology, has to be given a special place in this dissertation's thanksgiving for his profound support to make this research proceed in its pace.

My special indebtedness goes to my parents, whose continuous prayers, love and care have brought me to this level. Their eternal love, uninterrupted encouragements and support have helped me to succeed in finishing my program here at Addis Ababa Institute of Technology, Addis Ababa University. I would like to express my gratitude and appreciation to all my instructors, classmates and a sheer number of individuals who have contributed directly or indirectly for the success this thesis.

This study was funded by the School of Civil and Environmental Engineering to buy the data from the National Meteorological Agency of Ethiopia. For this, I have great appreciations for their support and commitment to scientific inquiries. Besides, I would like to thank Debre Markos University, which sponsored me to have this great opportunity of studying my MSc. degree.

LIST OF CONTENTS

CONTENTS **PAGE**

LIST OF FIGURES

LIST OF TABLES

This page intentionally left blank

CHAPTER ONE

INTRODUCTION

1.1 Background

Wind speed or wind flow velocity, is a fundamental atmospheric quantity. It is caused by air moving from high pressure to low pressure area, usually, due to change in the temperature of loci. Due to the recent extensive development of major cities in the world, the trend towards building higher and lighter structures has emerged. That is, wind load must be considered during the structural design of high rising buildings and transmission towers, to cite as example. Buildings are liable to sway during wind storms. But, structural innovations and modern technology, for example, light weight constructions, have reduced the stiffness, the mass, and the damping characteristics of modern building [5-6].

Windstorms cause varieties of problems in buildings, especially in high rise buildings.
Hurricane winds are the largest single causes of economic damage, and they usually bring catastrophic demolitions to an area or a nation; they are well ahead of earthquakes and floods in causing wraths of damage. For example, in the United States between 1986 and 1993, hurricanes and tornadoes caused about $41 billion in insured catastrophic losses, compared to $6.18 billion for all other natural hazards combined. Hence, hurricanes are being considered as the largest contributors to the losses of lives and the imbalances of the ecosystem. In Europe in 1900 alone, four winter storms caused $10 billion in insured losses, and an estimated $15 billion in economic losses. According to one insurance industry estimate in 1999, the natural catastrophe which resulted in the largest amount of insured losses up to that date was hurricane Andrew in 1992($16.5 billion) [5].

Oceans temperatures are different from place to place. Around the equator, the water of oceans is hotter and around the pole it is colder. Due to temperature differences the oceans are drawn like those of beck as well as worldwide winds are blown from one part of the world to other parts of the world. Due to this event rotation of the earth affects the ocean flows and wind directions. If there is no earth motion, the motion of ocean and wind are straight line.

Africa content is covered by Atlantic Ocean in the west, Antarctic Ocean in the south and Indian Ocean in the east, Mediterranean Sea in the North and Red Sea in the North East direction. Ethiopia is found in the horn of Africa which is directly affected wind which comes from the Indian Ocean and the Red Sea. Hence care should be taken the wind blows from ocean to content (seasonal wind) may affect our structures in addition to prevailing wind and local winds.

The basic assumption about natural events like wind and earthquake are, they do not occur simultaneously. Therefore, fundamental knowledge regarding the effects of wind and earthquake on high rise buildings is a vital concept behind the formulation endeavors of their critical effects. This is because, designers such, for example, as structural engineers, may unnecessarily waste their precious time while checking for the critical effects. From many natural events, wind is discovered to be the dominant environmental effect when it is compared to other combined natural events. While establishing appropriate designs (e.g. structural designs), bearing in mind on wind speed is a critical first step towards the calculation of designing wind loads for structures.

High wind speeds hold a threat to the integrity of structures, especially those at highly exposed sites such as bridges, wind turbines and transmission towers [5-6]. The basis triggers for this study is, therefore, to develop estimates of wind speeds as a function of return period for locations in Ethiopia that can be used in conjunction with the design wind provisions used in EBCS 1, 1995 and later.

The study was done on 18 selected Cities/Towns with about an average data which was collected for more than 25 years and adequately available for mapping. Attentively, this study was necessitated for the development of designing wind speed zonal maps for the country, Ethiopia. There were different procedures followed to accomplish this thesis. First of all, a procedure to estimate basic wind speeds, extreme value analysis of micro meteorologically homogeneous data collected from well-spaced regional meteorological stations was performed. For these determinations, averaging time, height above the ground, and roughness of surrounding terrain were taken as conditional variables [15]. Therefore, the daily maximum wind speed (with 180 min average) data at the heights of 10 m measured by the Department of Meteorology, National Meteorology Agency of Ethiopia were collected from 18 stations selected to cover different geographical regions of the country. Besides, different probability distributions were tested for suitability of the data at all the weather stations under study. At those moments, the wind zone map was be prepared using the 50 year return period wind speeds obtained from the best fitted frequency analysis. The wind speeds which were calculated based on the 180 minute average were converted to 10 minute average wind speeds in preparing the wind zone map. This is because, modern wind design codes shall be performed based on the peak gust velocity averaged over an interval of about 10 minutes that has had a 50 year return period. It is very important to bear in mind that all the nations' loci may not have a constant figure of 22m/sec wind speed, so the wind zonal map was prepared by taking the best fitted probability distribution method.

1.2 Statement of the Problem

Wind loading is the dominant environmental loading for structures. Typically the design service life building is around 50 years or beyond. Therefore, most existing buildings and other infrastructures of value could be impacted by climate change, and, ultimately, wind load. The establishment of appropriate design for wind speed has to be a critical first step towards the calculation of for design according wind loads for structures. Since its inception, the constant figure, 22 m/sec, has been the basic wind speed for all altitude and temperature throughout the country, Ethiopia. This may possibly be divided at low, medium and high altitude and temperature zones. As a result, the basic wind speed at different altitude and temperature should be varying.

Buildings and manufacturing homes at different locations in Ethiopia shall be designed according to a wind load zone of a determined load. Wind loads have to be resisted by a construction (manufacturing, home, condominiums, etc.). If, we come up with a wind speed zone of three: zone one (low), zone two (medium) and zone three (high), according to the level of wind speed,

then we can set a national (federal) standard of construction to conform to these criteria. To install a home, permissions are building in zone one for one, two for two and three for three.
It is, therefore, very essential for Ethiopia to develop a wind zonal map for each location, which requires structured but basic wind speed measures rather than the constant figure of 22m/sec.

1.3 Objectives

1.3.1 General Objectives

- To demarcate wind zones in Ethiopia based on observed wind speeds to be used in the design of Civil Engineering structures.
- To reasonably classify broadly the country into different wind zones for the purpose of setting the basic wind speeds.
- To model the annual maximum wind speed at different locations using frequency analysis.

1.3.2 Specific Objectives

- To choose appropriate basic wind velocity for selected Towns/Cities in Ethiopia, for the design of buildings and structures.
- To mark Ethiopian typical reference basic wind speed to help structural designers and researchers during the design and approval process.

1.4 Hypothesis/ Questions

- It is possible to prepare a wind hazard map for Ethiopia regarding the basic wind speed.
- The 22 m/sec may not be the constant figure or stagnant basic wind speed in Ethiopia.

1.5 Scope and Limitations

This study was intended to demarcate a reference basic wind speed for our country, Ethiopia. It was done by taking only some selected Cities/Towns which were identified as representative loci for the preparation of this research. The available data collected from the meteorological department for more than the average of 25 years. After the accomplishment of this research, it is an input for updating our old version of building code regarding to the wind part. The reference basic wind speed for selected stations was provided to help structural designers and researchers during a design process. The stations which were selected for this study, I did not trip whether or not carry out the requirements specified in EBCS 1, 1995 or Euro Code.

CHAPTER TWO

STATE OF THE ART

2.1 Nature of wind

Wind is the term used for air in motion and is usually applied to the natural horizontal motion of the atmosphere. Motion in a vertical or nearly vertical direction is called a current. Movement of the air near the surface of the earth is three-dimensional, with horizontal motion much greater than the vertical motion. Vertical air motion is of importance in meteorology, but is of less importance near the ground surface. On the other hand, the horizontal motion of air, particularly the gradual retardation of wind speed and the high turbulence that occurs near the ground surface, are of high importance in building engineering. In urban areas, this zone of turbulence extends to a height of approximately one-quarter of a mile aboveground, and is called the surface boundary layer. Above this layer, the horizontal airflow is no longer influenced by the ground effect. The wind speed at this height is called the gradient wind speed, and it is precisely in this boundary layer where most human activity is conducted. Therefore, how wind effects are felt within this zone is of great concern. Although one cannot see the wind, it is a common observation that its flow is quite complex and turbulent in nature. Imagine taking a walk outside on a reasonably windy day. You no doubt experience the constant flow of wind, but intermittently you may experience sudden gusts of rushing air. This sudden variation in wind speed, which is called gustiness or turbulence, plays an important part in determining building oscillations [5].

2.1.1 Types of wind

Winds that are of interest in the design of buildings can be classified into three major types: prevailing winds, seasonal winds, and local winds.

1. **Prevailing winds**. Surface air moving toward the low-pressure equatorial belt is called prevailing wind or trade wind. In the northern hemisphere, the northerly wind blowing toward the equator is deflected by the rotation of the earth to become northeasterly, and it

comes to be known as the northeast trade wind. The corresponding wind in the southern hemisphere is called the southeast trade wind.

2. **Seasonal winds**. The air over the land is warmer in summer and colder in winter than the air adjacent to oceans during the same seasons. During summer, the continents become seats of low pressure, with wind blowing in from the colder oceans. In winter, the continents experience high pressure with winds directed toward the warmer oceans. These movements of air caused by variations in pressure difference are called seasonal winds. The monsoons of the China Sea and the Indian Ocean are examples.
3. **Local winds**. Local winds are those associated with the regional phenomena and include whirlwinds and thunderstorms. These are caused by daily changes in temperature and pressure, generating local effects in winds. The daily variations in temperature and pressure may occur over irregular terrain, causing valley and mountain breezes. All three types of wind are of equal importance in design. However, for the purpose of evaluating wind loads, the characteristics of the prevailing and seasonal winds are analytically studied together, whereas those of local winds are studied separately. This grouping is to distinguish between the widely differing scales of fluctuations of the winds; prevailing and seasonal wind speeds fluctuate over a period of several months, whereas the local winds vary almost every minute, the variations in the speed of prevailing and seasonal winds are referred to as fluctuations in mean velocity. The variations in the local winds are referred to as *gusts*. The flow of wind, unlike that of other fluids, is not steady and fluctuates in a random fashion. Because of this, wind loads imposed on buildings are studied statistically [5].

Previously done thesis by Betelhem Tibebe; entitled “Assessment of Wind Load Provisions of EBCS 1, 1995 in Relation to Major Building Code of Practices” she had done the reference basic wind speed for the four cities within the five year wind speed data using Gumbel distribution method. The data’s that were collected insufficient and Gumbel distributions were not best fit and she did not convert the collected wind speed data to the standard which is specified in EBCS 1, 1995 and Euro Code. But, this research entitled

Reference Basic Wind Speed for Selected Towns/Cities in Ethiopia were done within an average record of 25 years 18 selected towns/cities wind speed data considering probability plotting technique to select the one which was best fit comparing different probability distribution method and convert the collected wind speed data to the standard which is specified in EBCS 1, 1995 and Euro Code. I have formulated the relationship between the 10 minute mean wind speed and the three hourly collected mean wind speed.

2.2 Wind Speed

Wind speed varies with time. It also varies with the height above the ground or the height above the sea surface. For these reasons, the averaging time for wind speeds and the reference height must always be specified. A commonly used reference height is H = 10 m, and the commonly used averaging times are 1 minute, 10 minutes and 1 hour. When the wind speed changes or the direction of the wind changes, transient wind conditions may occur. Transient wind conditions are wind events which by nature fall outside of what can normally be represented by stationary wind conditions [7].

Basic design wind (BDW) speed is defined as the wind speed at the standard height of 10 meters above ground in open country and associated with an annual probability of 0.02 of being exceeded, i.e. having 50 year mean recurrence interval [1]. Wind speed is measured at a 10-meter height in open and level ground by cup anemometers whereas wind vanes are used to determine wind direction. Basic wind speed (Vb) is the wind speed estimated by different methods to be exceeded on average only once in 50 years [8].

2.2.1 Basic Wind Speed

Basic wind speed is based on peak gust speed average over a short time interval and corresponds to 10m height above the mean ground level in an open terrain [3]. In most codes and standards, the basic wind velocity can be obtained from basic wind speed map. Table 2 summarizes the basic wind speed characteristics used, or recommended, in the codes and standards [ ].

Table 2-1: Basic wind speed in codes and standards

Code	Average time	Return Periods
ASCE 7-98	3 sec	50 years
Euro code 1	10 min	50 years
AS 1170.2	3 sec	1000 years
EBCS 1-1995	10 min	50 years

Source: 2001 john D. Holmes

2.3 Anemometer Height above Ground

Height of 10 m above ground is considered to be the standard instrument height. Wind data measured at any other height are adjusted to the standard height by power law [1].

2.4 Reliability and Homogeneity data

In order for the wind speed data to provide useful information, it must be reliable and form a homogeneous set. Measured data are considered reliable if the recording instruments are adequately calibrated and are not exposed to local effects due to proximity of obstructions. Measured data form a homogeneous set when they are obtained under identical conditions of averaging time and height above ground [1]

2.4.1 Consistency of the data

2.4.1.1 Testing outliers

Outliers are data points that depart significantly from the trend of the remaining data. An outlier is an observation that lies an abnormal distance from other values in a random sample from a population. An outlier is an element of a data set that distinctly stands out from the rest of the data (www.icoachmath.com/math.../outlier.htm).

Example for Gondar

Step one: select out a data set that depart significantly from the trend of the rest of the data. Step two: in the given data set, 40 m/sec is far apart from the remaining data values Step three: so, the outlier of the data set is 40 m/sec

Table2-2: Collected wind speed data and its frequency for Gondar

Collected data(m/sec)	7	8	9	10	11	14	15	16	18	20	23	25	40
Converted data(m/sec)	9.24	10.6	11.9	13.2	14.5	18.5	19.8	21.12	23.8	26.4	30.36	33	52.8
Frequency	1	1	2	6	1	1	3	1	1	1	2	1	1

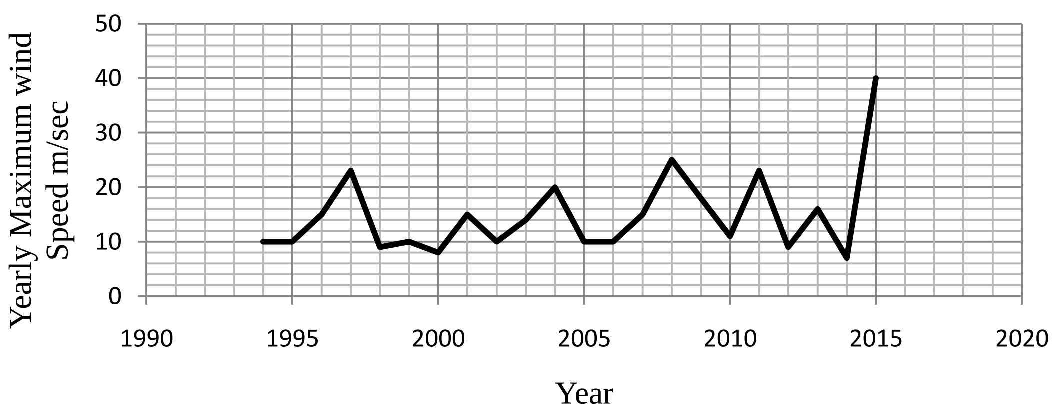

Figure 2-1 Distribution of wind speed with respect to time for Gondar outlier test

From the distribution of wind speed in Figure 2-1 above, it was shown that the 40 m/sec is outlier of the data. This is also possible to test by using theoretical formula or empirical usage:

$Ohl = \ mean\ of\ the\ data \pm k * standard\ deviation\ of\ the\ data \ldots.a$ [10].

Where: Ohl is the higher or lower outlier values and

K is used in one-sided tests that detect outliers at the 10-percent level of significance in normally distributed data.

$Ohl = 1.1298\, m/sec \pm 0.1906\, m/sec \;\; * 2.429 = 1.5927 m/sec$ And 0.667 m/sec

The highest and the lowest outlier in Gondar were, therefore 39.15m/sec and 4.644 m/sec respectively. From this the outlier value which was calculated in the above argument resulted to be not greater than the value of the given of maximum collected wind speed data. Since 40 m/sec totally departed from the collected wind speed data, the remaining recorded wind speed is sufficient to operational zed or estimate the required gust wind speed at a given return period.

2.4.1.2 Double Mass Curve

If the conditions relevant to the recording of a wind station have undergone a significant change during the period of record, inconsistency would arise in the wind data of the station. This inconsistency would be felt from the time the significant change took place. Some of the common causes for inconsistency of record are:

- If the wind gauge station shifted to the new location
- If the neighborhood of the station underwent a marked change
- If change in the ecosystem was recorded due to calamities such as forest fires, landslides, etc.
- If there were occurrence of observational error from a certain date.
- If the checking for inconsistency of a record is done by the double-mass curve technique. This technique is based on the principle, when each recorded data came from the same parent population, they consistent [11]. For more details, see the Appendix C.

2.5 Estimating Missing Data

Given the annual wind speed values W1, W2, W3, …,Wn at neighboring M stations 1, 2, 3…, M respectively, it is required to find the missing annual wind Wx at station X which is not include in the above M stations. Further, the normal annual wind speed N1, N2, N3 … Ni… at each of the above (M+1) stations including station X are known. If the Normal annual wind speed at various stations were within about 10% of the normal annual wind speed at station X, then a simple arithmetic average procedure could be followed to estimate Wx, thus:

$$Wx = \frac{1}{M}\,(W1 + W2 + W3 + \cdots WM) \ldots\ldots\ldots..2$$

If the normal wind speeds vary considerably, Wx is estimated by weighting the wind speed at the various stations by the ratios of normal annual wind speed. This method, is known as the normal ratio method, which gives Wx as [9]

$Wx = \frac{Nx}{M}\left\{\frac{W1}{N1} + \frac{W2}{N2} + \frac{W3}{N3} + \cdots + \frac{Wn}{NM}\right\} \ldots\ldots 3$ [11]. (See Appendix C)

2.6 Statistical Approaches

The logarithmic wind profile is typically given in the form

$U = \frac{U*}{K}\,Ln\left(\frac{Z}{ZO}\right)$ ……………….. (3)

Where U represents the mean wind speed, u* is the friction velocity, which is a measure of shear stress, the *friction velocity u** is defined as $U^{*} = \sqrt{\tau/\rho\alpha}$ where $\boldsymbol{\tau}$ is the surface shear stress and ρα is the air density The friction velocity *u** can be calculated from the 10-minute mean wind speed *U*10 at the height *H* = 10 m as $u* = \sqrt{\beta}\cdot U10$ where β is a surface friction coefficient [15]. k is the von Karman constant and often assumed to have a value of 0.4, *z* represents height, and *zo* is the aerodynamic roughness length[16]. The most common version of the power law is shown by

$\frac{Uz}{Ur} = \left(\frac{Z}{Zr}\right)^{P}$ ………….. (4)

Where Uz is the mean wind speed at a given height z; Ur is a known wind speed at height Zr, and ***P*** represent an exponent which describes the vertical shear for a given atmospheric stability. Given neutral stability conditions, ***P*** is assumed to be 1/7. The use of a constant exponent does not account for surface roughness, displacement height, or changes in atmospheric stability. In order for the engineers to have a better estimation of ***P*** from, zo, Figure 3 is provided, for example, for an open terrain where Zo = 0.02m, ***P***=0.155 and for city area zo = 1m, p = 0.3 [16].

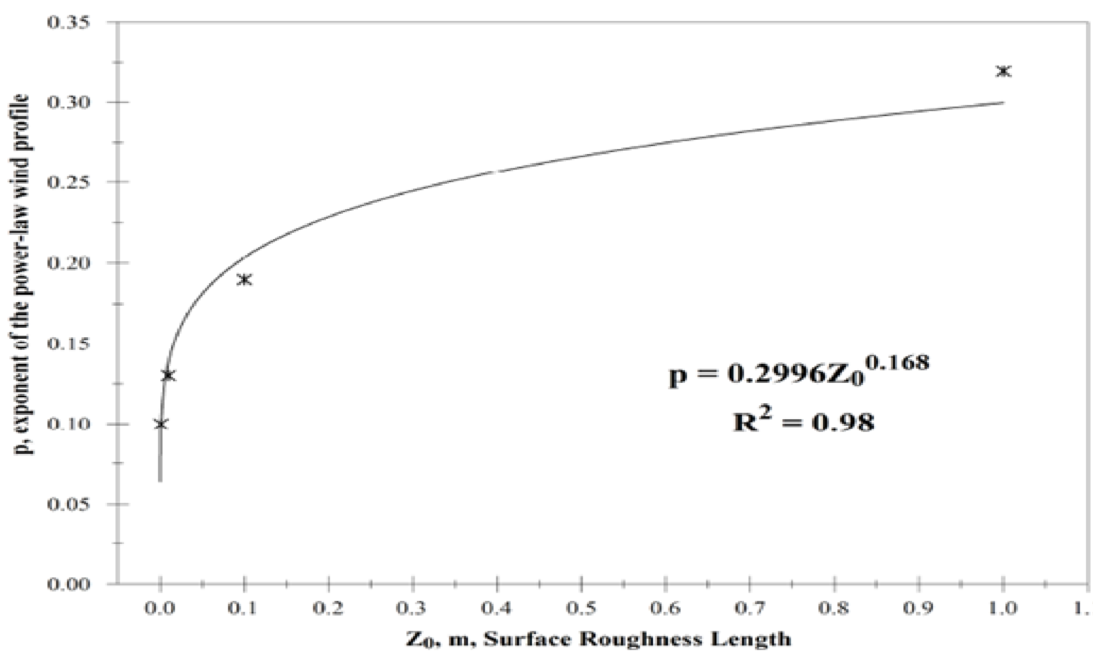

Figure 2-2: The relationship between Zo and P (Source: Justus, 1985)

In most cases, the hurricane gust factor can be described using models developed for standard neutral boundary layer flow conditions [2]

$\sigma u = 2.5\, u *$ ………………………… (5)

Where σu is standard deviation and u* is the friction velocity.

Furthermore according to Hsu (2008) $\frac{u*}{U180\min} = k\rho$ ...…………...……. (6) [17].

Where k = 0.4 is the von Karman constant and ρ is the exponent of the power law wind profile which is defined in equation (5). Besides, Statistical and probabilistic approaches (normal distribution) are used to derive formula for estimating 10- minute gusts from 180-minute sustained wind speeds [17].

2.6.1 Normal distribution

The normal or Gaussian distribution is the most important of all the distributions since it has a wide range of practical applications. The cumulative distribution function of X can be found by using the relation [17].

$$F(z) = probability(Z \leq z) \ldots\ldots 7$$

$$F(z) = probability\left(\frac{X-u}{\sigma} \leq z\right) \ldots\ldots 8$$

$$F(z) = probability(X \leq u + z\sigma) \ldots\ldots 9$$

Table 2-3 probability of standardized variate

Z	0	1	2	2.05	3
F(z)	0.5	0.8413	0.9772	0.9798	0.9986

Source: [17]

Proposed formula for converting 10 minute gusts

For 10-minute gust over one hundred eighty minute period, the probability is 10/180 or 5.56%, therefore from statistics

$$U10\,min = U180min + Z\sigma u = U180\min\left(1 + \frac{Z\,\sigma u}{U180\min}\right) \ldots\ldots 10$$

Where, U_{10min} is the 10 min gust , $U_{180\ min}$ is 180 minute sustained wind speed, and σ_u is the standard deviation of $U_{180\ minute}$ [17].

Here Z can be calculated as follow in two ways:

1. Use –NORMSINV (p) in EXCEL
2. Applying the following formula : The value of *z* corresponding to an exceedance probability of p (p=1/T) [1]

$$z = w - \frac{2.515517 + 0.802853\,w + 0.010328\,w^2}{1 + 1.432788\,w + 0.189269\,w^2 + 0.001308\,w^3} \ldots\ldots 11$$

$$W = \sqrt{ln\left(\frac{1}{P^2}\right)} \quad 0 < P \leq 0.5 \text{ Otherwise, instead of } P \text{ substitute } 1 - p \ldots\ldots 12$$

Substituting equation 2 and 3 in to equation 7 one gets

$U10min = U180\,\min(1 + z\rho) = U180(1 + 2.05\rho)$ ……………………………...13

2.6.2 Estimating 10 minute gusts from collected data

To predict basic wind speed, formula for estimating the 10 minute gust from a 3 hour sustained speed, Eqn. (10) is used. Different terrains can be categorized according to their associated roughness length, Z0. So, Z0 of open terrain is 0.02 [17].

For 50 year return period p=1/50=0.02 which is less than 0.5

$$W = \sqrt{ln\left(\frac{1}{0.02^2}\right)}$$ = 2.797149623 w is intermediate variable

$$z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3} =$$

$$z = 2.797149623 - \frac{2.515517 + 0.802853 * 2.797149623 + 0.010328(2.797149623)^2}{1 + 1.432788 * 2.797149623 + 0.189269(2.797149623)^2 + 0.001308(2.797149623)^3}$$

=2.054189=2.05

Then z=2.05, F (z) =0.9798

0.155*2.05=0.32

1.32 was the multiplied factor to convert from 180 minute to 10 minute

The collected yearly maximum wind speed from National Meteorology Department was a three hour interval data. This three hour wind speed data were changed in to the 10 minute wind speed by adding 32% (for an increase in size) of the collected wind speed data at 180 minute to fit the standards of the requirement.

CHAPTER THREE

METHODOLOGY

3.1. Method

The methodological tasks used to accomplish the objectives and come up with relevant conclusions and recommendations are explained in detail as follows. In Ethiopia, there is no reference map for wind speed. The basic wind speed is used as an assumption data. So, it is very much necessary to analyze the prediction of extreme wind speed based on historical climate data collected from a hub. The common procedure adopted to estimate basic wind speeds is to perform extreme value analysis of micro-meteorologically homogeneous data collected from well-spaced (if not evenly spaced) regional meteorological stations. These conditions are determined, according to [15], by taking the basic determining factor of averaging time, height above the ground, and the roughness of surrounding terrain. Daily maximum wind speed with 10 min average data at the heights of 10m measured by the Department of Meteorology were collected from 18 stations which were selected to proportionally cover the different geographical regions of the country, Ethiopia. Details of these 18 weather stations are described in Table 1 and in figure 1 the depictions pertinent to their locations. The map was drawn by using Arc GIS software.

Table 3-1 Weather stations collected data and its location

No.	**Station**	**Period**	**Number of years**	**Elevation (meter)**	**Longitude (degree)**	**Latitude (degree)**
01	Addis Ababa	1985-2015	22	2386	38.74750	9.0189100
02	Arba Minch	1987-2014	27	1207	37.55783	6.0571670
03	Bahir Dar	1994-2015	22	1827	37.05870	12.5396800
04	Debre Markos	1994-2015	22	2446	37.73920	10.3257000
05	Debre Zeit	1984-2012	21	1900	38.95000	8.7330000
06	Dire Dawa	1994-2015	22	1180	42.53333	9.9666667
07	Gode Met	1985-2015	30	290	43.58000	5.9000000
08	Gondar Ap	1994-2015	22	1973	37.43190	12.5211500
09	Gore	1990-2015	26	2033	35.53300	8.1333333
10	Hawassa	1994-2015	22	1694	38.48306	7.0650000
11	Jimma	1985-2015	24	1718	36.81667	7.6666667
12	Kibre Mengist	1994-2015	21	1680	38.96667	5.8666667
13	Kombolcha	1985-2015	31	1857	39.71763	11.0839000
14	Mekelle	1993-2014				
15	Metehara	1984-2015	32	944	39.91900	8.8586667
16	Negelle	1985-2015	25	1544	39.56667	5.4166667
17	Nekemte	1985-2014	28	2080	36.46333	9.0833000
18	Robe	1985-2015	28	2480	40.05000	7.1330000

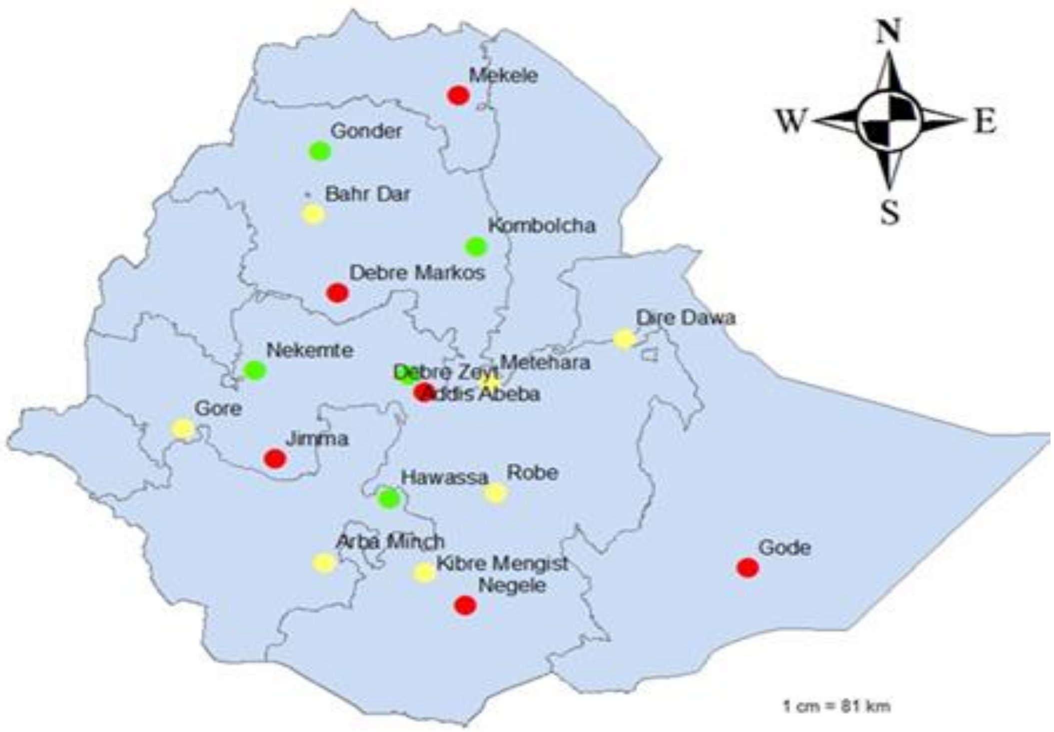

Figure 3-1 selected wind gauge stations

3.2Frequency Analysis

Annual maximum wind speeds were selected from the daily maximum wind speeds recorded at 18 stations. Following these, different probability distributions were tested for suitability for the data at all the weather stations. These distributions were:

- Normal Distribution,
- Log Normal Distribution,
- Pearson Distribution,
- Log Pearson Distribution,
- Gumbel Distribution,
- Log Gumbel Distribution.

Besides, the use of probability plot fitting tests to compare the observed and theoretical cumulative frequencies as predicted by the six distributions and obtain required design values for given return period of exceed were done. After all these rigors, the wind zone map was prepared using the 50 year return period wind speeds that should be obtained from the above frequency analysis. The wind speeds were calculated based on 180 min average was converted to 10 min average wind speeds in the preparation of the map. Because Modern wind design codes are based on the peak gust velocity averaged over an interval of about 10 minutes that has a 50 year return period.

3.3 Select and Design Methods

3.3.1 Probability distribution

The probability of a specific event is a mathematical statement about the likelihood that it will occur. All probabilities are numbers between 0 and 1, inclusive; a probability of 0 means the event will never occur and a probability of 1 means the event will always occur. The sum of the probabilities of all possible outcomes of any event is 1. This is because something unpredictable will happen, so the probability of some outcome occurring is 1.

3.3.1.1 Normal Distribution

The most important, continuous probability distribution in the entire field of statistics is the normal distribution. This describes approximately many phenomena that occur in nature, industry, and research. In 1733, Abraham DeMoivre developed the mathematical equation of the normal curve. It provided a basis for which much of the theory of inductive statistics is founded. The normal distribution is often referred to as the Gaussian distribution, in honor of Karl Fricdrich Gauss (1777-1855), who also derived its equation from a study of errors in repeated measurements of the same quantity [12].

The mean wind speed time series are generated by using a sequence of independent random numbers from the normal distribution [9].

- PDF for normal distribution: $fX(x) = \frac{1}{\sigma\sqrt{2\pi}} \; exp - \frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2$ where μ is the mean and σ is the standard deviation.
- A standard normal distribution is a normal distribution with mean (μ) = 0 and standard deviation (σ) = 1
- Normal distribution is transformed to standard normal distribution by using the following formula:

$$z = \frac{X - \mu}{\sigma} \quad \text{where z is called the standard normal variable.}$$

- The frequency factor for the Normal Distribution is the standard normal variate[9]

$$KT = \frac{XT - Xbar}{S} = zT$$

$$xT = xbar + KT * S = xbar + zT * S \ldots\ldots\ldots (14)$$

- The ways to find zT The value of z corresponding to an exceeding probability of p (p=1/T) [9]

$w = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \; for \; 0 < p \leq 0.5$ Then calculating z using the approximation

$$z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3} \quad \ldots\ldots\ldots (15)$$

In Excel spread sheet z= -NORMSINV (returns the inverse of the standard normal cumulative distribution has a mean of zero and standard deviation one)

3.3.1.2 Log Normal Distribution

The lognormal distribution is used for a wide variety of applications. The distribution applies in cases where a log transformation results in a normal distribution [9]. Applying similar procedure, like that of normal distribution method, the only difference is multiplied the data by logarithm

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi)}} \exp\left(-\frac{(y - \mu y)^2}{2\sigma y^2}\right); \; x > 0 \; \mu y \approx y^{-}, \sigma y = Sy, y = logx$$

Where x is the recorded wind speed [14]

3.3.1.3 Pearson Distribution

The Pearson distribution is a family of continuous probability distributions. It was first published by Karl Pearson in 1895 and subsequently extended by him 1901and 1916 in a series of articles on bio statistics. The probability density function is as follow [14].

$$f(x) = \frac{\left(\lambda^{\beta}(x-\varepsilon)^{\beta-1}e^{-\lambda(x-\varepsilon)}\right)}{\Gamma(\beta)} \quad x \geq \varepsilon$$

$$\text{Where } \lambda = \frac{\sigma x}{\sqrt{\beta}}, \beta = \left(\frac{2}{Cs}\right)^2, \varepsilon = X^{-} - \sigma x\sqrt{\beta}$$

The Pearson distribution has three parameters: ε, the location parameter, which determines the lower bound of the distribution; β, the scale parameter; and λ, shape parameter.

- Estimate the mean, the standard deviation and coefficient of skewness for the given data.
- The frequency factor depends on the return period T and the coefficient of skewness
- When Cs=0, KT equals to the standard normal variable z, when Cs≠0,KT is approximated by[13].
- $KT = z + (z^2-1)k + \frac{1}{3}(z^3-6z)k^2 - (z^2-1)k^3 + zk^4 + \frac{1}{3}k^5 \; where \; k = \frac{Cs}{6}$
- $XT = x\ bar + KT * S$…………..(16)

3.3.1.4 Log Pearson Distribution

- The first step is to take the logarithms of the given data, y = log x.
- Then Ybar, Sy and coeff. of skewness Cs for y series are calculated
- The frequency factor depends on the return period T and the coefficient of skewness
- When Cs=0, kT equals to the standard normal variable z, when Cs≠0,KT is approximated by[13].

$$kT = z + (z^2-1)k + \frac{1}{3}(z^3-6z)k^2 - (z^2-1)k^3 + zk^4 + \frac{1}{3}k^5 \dots\dots\dots\dots\dots\dots(17)$$

$$where \quad k = \frac{Cs}{6} \text{……………………..…..…} \quad (18)$$

$$xT = y\ bar + kT * S \text{…………..} \quad (19)$$

3.3.1.5 Gumbel Distribution

This extreme value distribution was introduced by Gumbel (1941), and it is commonly known as Gumbel's distribution. It is one of the most widely used probability distribution functions for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfalls, maximum wind speed, etc. Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows

The probability distribution is

$$f(x) = \frac{1}{\alpha} * exp\left[-\frac{x-\mu}{\alpha} - exp\left(-\frac{x-\mu}{\alpha}\right)\right] - \infty < x < \infty$$

$$\alpha = \frac{\sqrt{6} * \sigma x}{\Pi}$$

$\mu = x^{-} - 0.5772\alpha$ [14].

If W1, W2…, Wn be a set of daily wind speed or velocity, and let X = max (Wi) be the maximum for the year. If Wi is independent and identically distributed, then for large n, X has an extreme value type I or Gumbel distribution. The cumulative distribution function (c.d.f) of the Gumbel random variable X is given as $F(x) = \exp\left[-exp\left(-\frac{x-u}{\alpha}\right)\right] \quad for - \infty < x < \infty$…………1 where u is the location parameter and α is the scale parameter. The location parameter u is the mode of distribution. The scale parameter is a measure of dispersion and it only depends on the variance of X. The parameter u is a measure of location that depends on both the variance and the mean [11].

$$\alpha = \frac{\sqrt{6}}{\pi}\sigma \text{………………………………………………….…………} \quad (20)$$

$$u + 0.5772\alpha = E[X] = mean\ of\ data \text{ … … … … … … … … … … … …..} (21)$$

$u = E[X] - 0.5772\alpha \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$

$mode\ is\ at\ x = u$

The two equations can be used to estimate α and u if a finite sample of the values taken by X is available, such as the annual maximum wind speeds for a period of n years. To compute the estimated values of α and u, one must estimate the mean and standard deviation of the population based on the sample. A reduced variate y can be defined as [14]:

$$y = \frac{x-u}{\alpha}\ substituting\ this\ value$$

$$F(x) = \exp[-exp(-y)]\ solving\ \ for\ y$$

$$y = -\ln\left[ln\left(\frac{1}{F(x)}\right)\right]$$

$$y\ can\ be\ related\ to\ with\ return\ period\ T$$

$$\frac{1}{T} = p(x \geq xT = 1 - p(x < xT) = 1 - F(xT)$$

$$F(xT) = \frac{T-1}{T}\ substituting\ this\ in\ the\ above\ equation$$

$$yT = -\ln\left[ln\left(\frac{T}{T-1}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 22$$

$For\ Gumbel\ distribution\ xT\ is\ related\ to\ yT\ xT = u + \alpha yT \ldots\ldots\ldots\ldots (23)$

3.3.1.6 Log Gumbel Distribution

The same procedure applied like that of the Gumbel method, and the only difference is the distribution data is multiplied by logarithmic series. After that, it is required to determine the reduced variate with that of a given period. Then it is essential to estimate the mean and the standard deviation of the log multiple data. So, using equation 10, we can determine the variate of this; it is what we want to do so.

$$ForLog\ \ Gumbel\ distribution\ xT\ is\ related\ to\ yT$$

$$xT = uy + \alpha y * yT \ldots (24)$$

Let y=log x where x is the given wind speed which is directly collected yearly wind speed.

$$\alpha y = \frac{\sqrt{6}}{\pi}\sigma y \ldots \ldots \ldots .. (25)$$

$$uy = E[X] - 0.5772\alpha y \ldots \ldots \ldots (26)$$

$$yT = -\ln\left[ln\left(\frac{T}{T-1}\right)\right] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 27$$

3.4 Probability Plot

Probability plot is a graphical tool to assess whether or not the data fits a particular distribution. The data are fitted against a theoretical distribution in such a way that the points should form approximately a straight line (distribution function is linearized). Departures from a straight line indicate departure from the theoretical distribution [13].

3.4.1 Plotting position

Plotting position is a simple empirical technique that related to between the magnitudes of an event verses its probability of exceedance [13].

Plotting position refers to the probability value assigned to each of the data to be plotted. Several empirical methods are used to determine the plotting positions. The two are: Arrange the given series of data in descending order and Assign an order number to each of the data (termed as rank of the data).

Besides, most plotting position formulae are represented by:

$$P(X \geq Xm) = \frac{m-b}{n+1-2b} \ldots \ldots \ldots \ldots \ldots .. (28)$$

Where b is a parameter

E.g., b = 0.5 for Hazen's formula, b = 0.3 for Chegodayev's formula, b = 0 for Weibull's formula, b = 3/8 for Blom's formula, b = 1/3 for Turkey's formula, b = 0.44 for Gringorten's formula [9].

Cunnane (1978) studied the various available plotting position methods based on unbiasedness and minimum variance criteria. If large numbers of equally sized samples are plotted, the average of the plotted points for each value of m lies on the theoretical distribution line. Minimum variance plotting minimizes the variance of the plotted points about the theoretical line. Cunnane concluded that the Weibull's formula is biased and plots the largest values of a sample at very small a return period [9]. For normally distributed data, the best formula is Blom's plotting position formula (b = 3/8). For Extreme Value Type I distribution, the Gringorten formula (b = 0.44) is the best for log Pearson, b depends on the value of the coefficient of skewness, being larger than 3/8 when the data are positively skewed and smaller than 3/8 when the data are negatively skewed.

3.4.1.1 Normal and Log Normal probability Plot

First, rank the data from largest (m=1) to smallest (m=n). Second, Assign plotting position to the data. Here, we shall plot position, an estimate of exceedance probability; and we can also use the

$p = \frac{\left(m - \frac{3}{8}\right)}{(n + 0.15)}$ …………… (29)

Third, we have to find the standard normal variable z corresponding to the plotting position (use-NORMSINV (.) in excel. Finally, we must Plot the data against z. If the data falls on a straight line, the data comes from a normal distribution or log Normal distribution.

3.4.1.2 Gumbel and Log Gumbel probability Plot

1. Sort the data from largest to smallest
2. Assign plotting position using Gringorten formula $pi = \frac{m - 0.44}{n + 0.12}$ ………(30)
3. Calculate reduced variate yi = -ln(-ln(1-pi)) ……………………..…..(31)
4. Plot sorted data against yi

If the data falls on a straight line, the data comes from Gumbel or Log Gumbel distribution.

3.4.1.3 Pearson and Log Pearson probability Plot

1. Sort the data from largest to smallest
2. Assign plotting position using Cunnane formula $pi = \frac{m - b}{n + 1 - 2b}$……….(32)
3. Calculate reduced variate yi = -ln(-ln(1-pi))………………………….….(33)
4. Plot sorted data against yi

If the data falls on a straight line, the data comes from on Pearson or Log Pearson distribution "b" depends on the value of the coefficient of skewness, being Larger than 3/8 when the data are positively skewed and smaller than 3/8 when the data are negatively skewed.

CHAPTER FOUR

ANALYSIS AND VALIDATION

4.1 Modeling of Basic Wind Speed

The probability fittings showed that the log Normal, log Gumbel, and log Pearson distribution are the best fitting distribution for the data set. As examples, the probability distribution for three stations, viz Gondar, Addis Ababa, and Dire Dawa as shown below:

Table 4-1 Sorted Data for Gondar Station

Year	Collected yearly maximum wind speed data m/sec	Converted annual maximum 10-minute gust speeds m/sec	After outlier Test Converted annual maximum 10-minute gust speeds
1994	10	13.2	13.2
1995	10	13.2	13.2
1996	15	19.8	19.8
1997	23	30.36	30.36
1998	9	11.88	11.88
1999	10	13.2	13.2
2000	8	10.56	10.56
2001	15	19.8	19.8
2002	10	13.2	13.2
2003	14	18.48	18.48
2004	20	26.4	26.4
2005	10	13.2	13.2
2006	10	13.2	13.2
2007	15	19.8	19.8
2008	25	33	33
2009	18	23.76	23.76
2010	11	14.52	14.52
2011	23	30.36	30.36
2012	9	11.88	11.88
2013	16	21.12	21.12
2014	7	9.24	9.24
2015	40	52.8	-

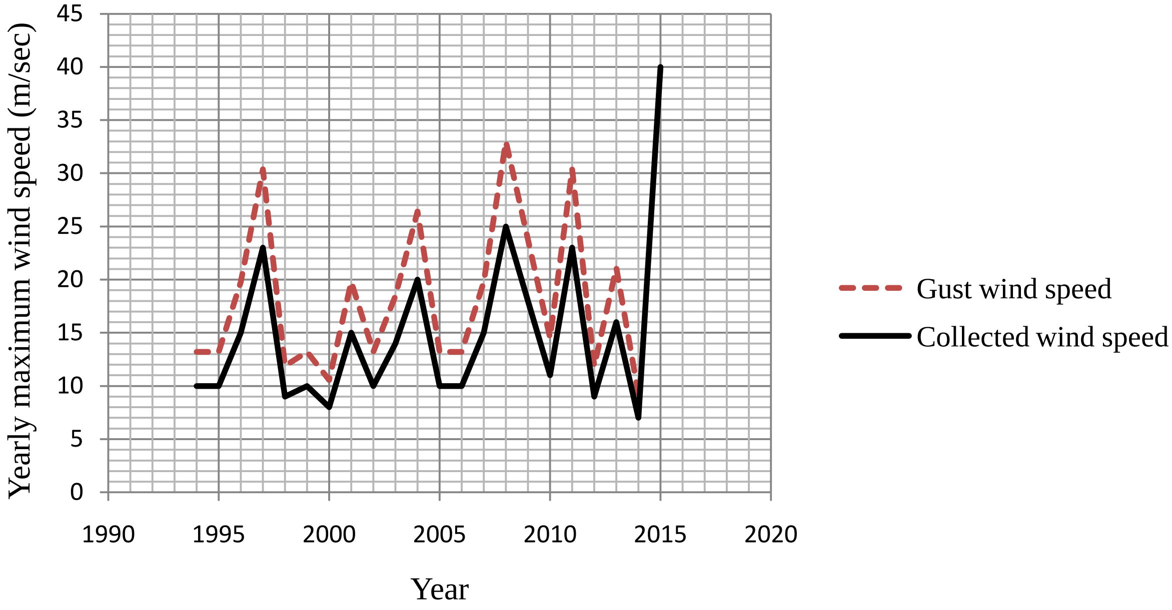

Figure 4-1: Conversion of maximum 10-minute gust wind speed for Gondar

As shown in figure 3-1 40 m/sec is departing significantly from other data sets due to out of the range while checking outlier tests. Hence, 40m/sec is not beyond the range of the data so release it and doing the remaining data for analysis purpose.

The mean, standard deviation, and coefficient of skewness for the annual maximum wind speed estimated from the 21-year record at Gondar in Ethiopia, are 1.227921 m/s, 0.162661 m/s, and 0.365417 respectively.

Example for log Gumbel distribution for Gondar, others are doing in similar fashion. Using equation (24),

$$ForLog\ \ Gumbel\ distribution\ xT\ is\ related\ to\ yT\ xT = uy + \alpha y * yT$$

From equation (25) we have

$$\alpha y = \frac{\sqrt{6}}{\pi}\sigma y = \frac{\sqrt{6}}{\pi} * 0.162661 = 0.126826\ \text{m/sec}$$

From equation (26) we have

$$uy = E[X] - 0.5772\alpha y = 1.227921 - 0.5772 * 0.126826 = 1.154717 \text{ m/sec}$$

From equation (27) we have

$$yT = -\ln\left[ln\left(\frac{T}{T-1}\right)\right] = y50 = -\ln\left[ln\left(\frac{50}{50-1}\right)\right] = 3.901939$$

Then from equation (24) we have,

$$xT = uy + \alpha y * yT = x50 = 1.154717 + 0.126826 * 3.901939 = 1.649585\ m/sec$$

The estimated 50-year required design value **V (ref)** as=antilog of xT =**44.63** m/sec

The probability plot for Gondar

Using Equation (30) Assign plotting position using Gringorten formula

$$pi = (m - 0.44)/(n + 0.12) \leftrightarrow p1 = (1 - 0.44)/(21 + 0.12) = 0.026515$$

$$pi = (m - 0.44)/(n + 0.12) \leftrightarrow p2 = (1 - 0.44)/(21 + 0.12) = 0.073864$$

Using Equation (31) Calculate reduced variate

$$yi = -ln(-ln(1-pi)) \leftrightarrow y1 = -ln(-ln(1 - 0.026515)) = 3.616633$$

$$yi = -ln(-ln(1-pi)) \leftrightarrow y2 = -ln(-ln(1 - 0.073864)) = 2.567413$$

Table 4-2: Probability plot for Gondar station

1	2	3	4	5
Year	Data (Descending order	Rank(m)	Plotting position(Pi)	Reduced variate (Yi)
2008	1.518514	1	0.026515	3.616633
1997	1.482302	2	0.073864	2.567413
2011	1.482302	3	0.121212	2.046303
2004	1.421604	4	0.168561	1.689581

2009	1.375846	5	0.215909	1.413747
2013	1.324694	6	0.263258	1.18575
1996	1.296665	7	0.310606	0.989016
2001	1.296665	8	0.357955	0.813968
2007	1.296665	9	0.405303	0.654497
2003	1.266702	10	0.452652	0.506386
2010	1.161967	11	0.5	0.366513
1994	1.120574	12	0.547348	0.232395
1995	1.120574	13	0.594697	0.1019
1999	1.120574	14	0.642045	-0.02698
2002	1.120574	15	0.689394	-0.15635
2005	1.120574	16	0.736742	-0.28865
2006	1.120574	17	0.784091	-0.42716
1998	1.074816	18	0.831439	-0.57687
2012	1.074816	19	0.878788	-0.74679
2000	1.023664	20	0.926136	-0.95764
2014	0.965672	21	0.973485	-1.28924

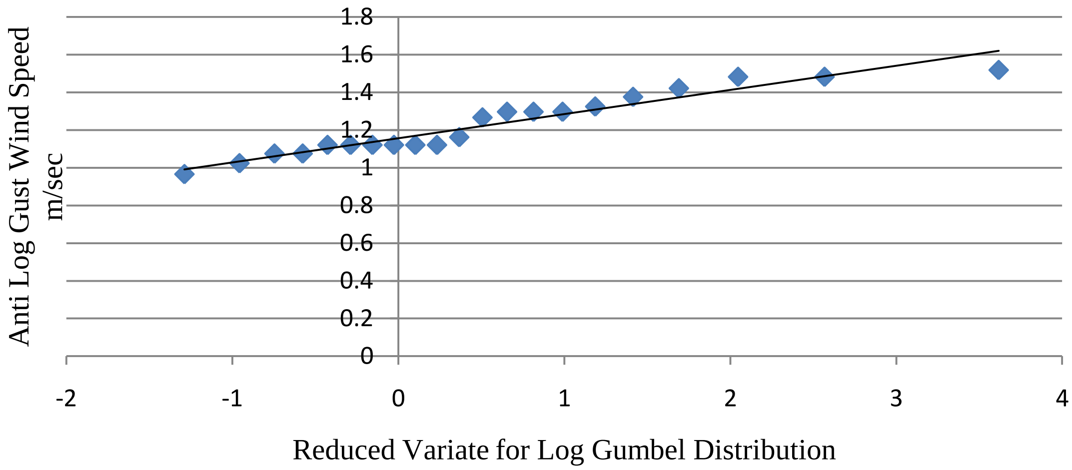

Figure 4-2: Analysis of annual maximum wind gust, using the log Gumbel distribution for Gondar

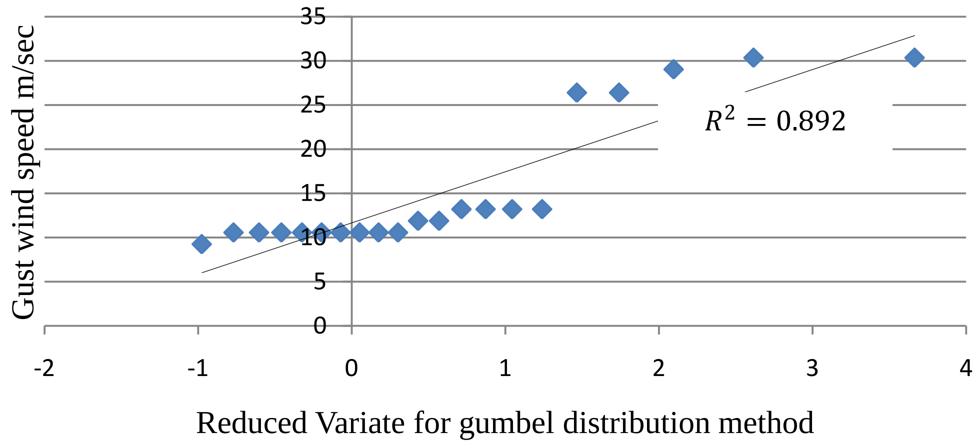

Figure 4-3: Analysis of annual maximum wind gust, using the Gumbel distribution for Gondar

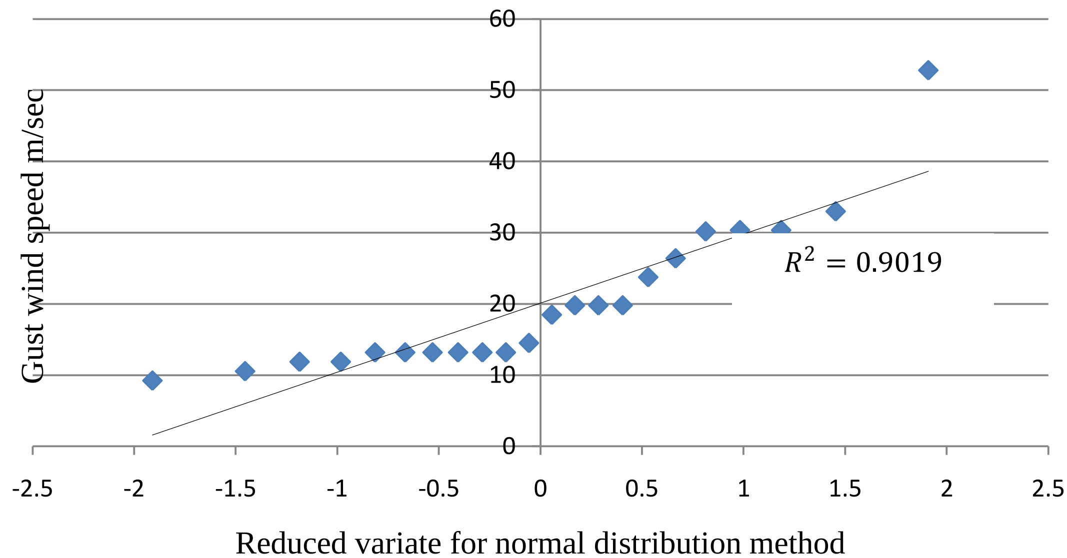

Figure 4-4: Analysis of annual maximum wind gust, using the Normal distribution for Gondar

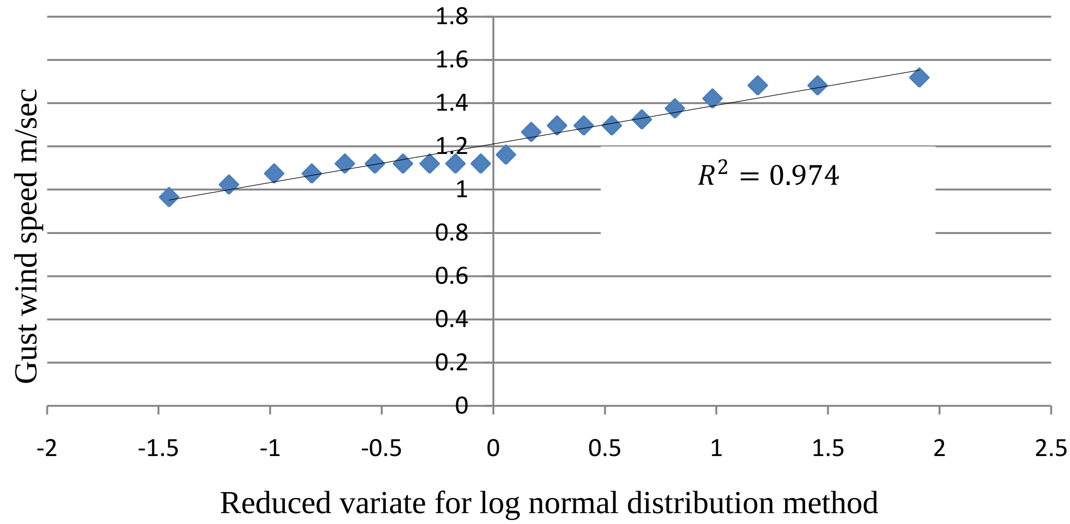

Figure 4-5: Analysis of annual maximum wind gust, using the Log Normal distribution for Gondar

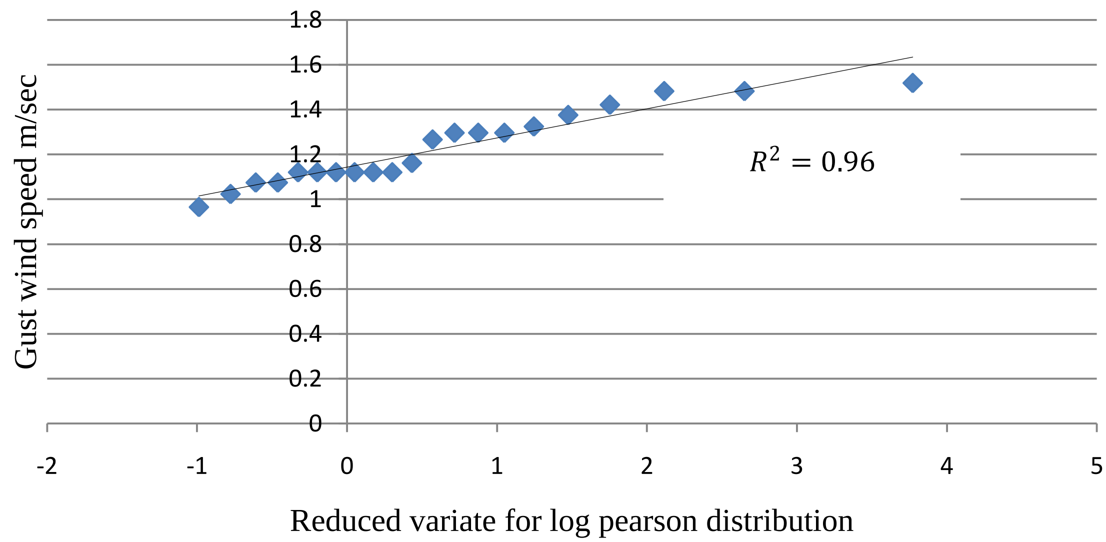

Figure 4-6: Analysis of annual maximum wind gust, using the Log Pearson distribution for Gondar

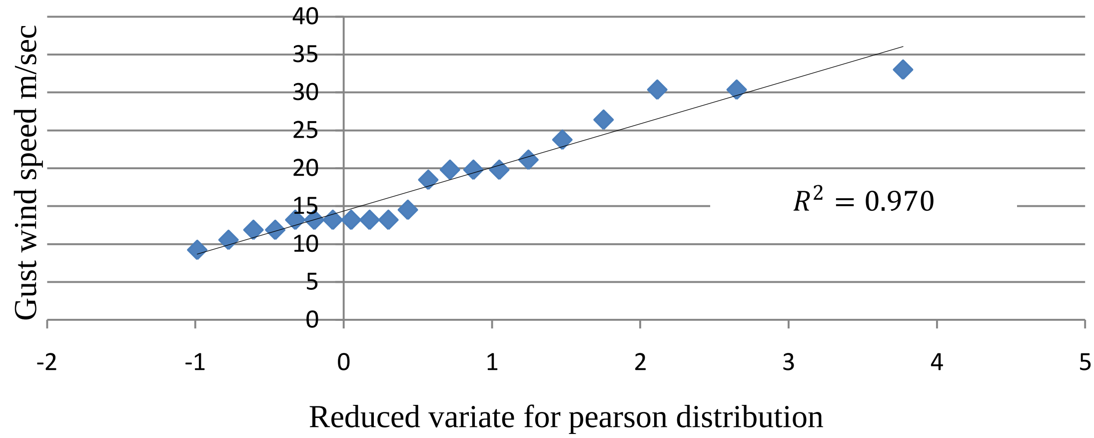

Figure 4-7: Analysis of annual maximum wind gust, using the Pearson distribution for Gondar

Hence: From the above figures, figure 3-2 – figure 3-7 the best fitting probability plot for Gondar station was log Normal distribution having the estimated value of 36 m/sec at 50 year return period.

Table 4-3: Results of predicting gust wind speeds for Gondar using different distribution method

1	2	3	6	7	8	9
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	23.22	22.13	23.60	22.84	24.09	23.16
10	27.38	27.55	27.59	27.75	27.22	27.32
15	29.73	31.18	29.74	30.74	28.78	29.66
20	31.37	34.00	31.21	32.94	29.80	31.30
25	32.63	36.34	32.33	34.69	30.55	32.57
30	33.66	38.36	33.22	36.15	31.15	33.60
50	**36.53**	**44.63**	**35.67**	**40.42**	**32.71**	**36.48**
100	40.41	54.72	38.87	46.67	34.65	40.40
200	44.26	67.04	41.96	53.50	36.42	44.36
500	49.35	87.65	45.94	63.57	38.57	49.68
1000	53.20	107.33	48.87	72.07	40.08	53.78

Discussions for Gondar

From the graph the theoretical distribution and the observed distributions were almost fit each other. The coefficient of correlation and coefficient of determinations were 97.39% and 94.85% respectively. These relations were strong and best suit to estimate the basic wind speed for Gondar. The best method to incorporate the basic reference wind speed for this station was log normal distribution method, and other probability distribution methods were not best fit rather than log normal distribution method. The estimated 50 year required design value V (ref) =36 m/sec. This implies, it can be used as a reference basic wind speed at different return period. The magnitude of the operated basic wind speed increased in 63.6% from the constant.

For Addis Ababa

The best fitting probability distribution for Addis Ababa was Log Normal Distribution. Let's see the procedure

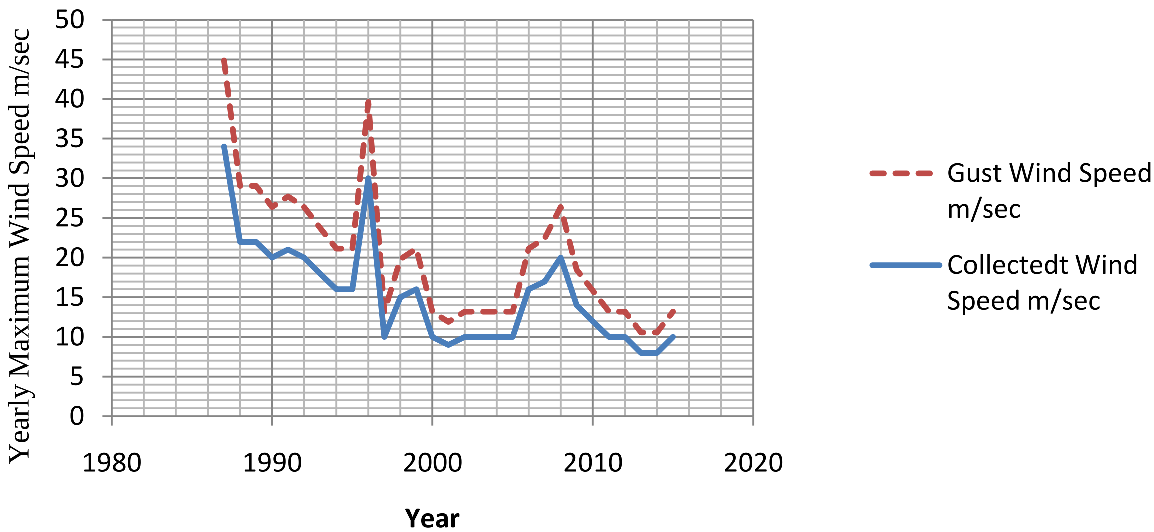

Figure 4-8: Conversion of maximum 10-minute gust wind speed for Addis Ababa

The mean, standard deviation, and coefficient of skewness for the annual maximum wind speed estimated from the 29-year record at Addis Ababa in Ethiopia, are 1.2717m/s, 0.1714 m/s, and 0.3919 respectively because among the alternative probabilistic approaches log Normal distribution is best fit using probability plotting test.

From equation (14) we have

$$xT = xbar + KT * S = xbar + zT * S \ldots\ldots\ldots (14)$$

From equation (15) we have

Then calculating z using the approximation

$$z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3} \quad \ldots\ldots\ldots (15)$$

$$w = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \; for\ 0 < p \leq 0.5$$

$$or\ Alternatively\ Z = -NORMSINV(Pi)$$

Now $p = \frac{1}{T} = \frac{1}{50} = 0.02 \leftrightarrow w = \left[ln\left(\frac{1}{0.02^2}\right)\right]^{\frac{1}{2}} = 2.79715$

Then Z= 2.05375

From equation (14), $xT = xbar + KT * S = xbar + zT * S =$

$$xT = 1.271704248 + 2.05375 * 0.171377969 = \mathbf{1.62367}$$

The estimated 50-year required design value **V (ref)** as=antilog of xT =**42.04** m/sec

Probability plot for Addis Ababa

Using Equation (29) $p = \frac{\left(m - \frac{3}{8}\right)}{(n + 0.15)}$

$P1 = \frac{1 - \frac{3}{8}}{29 + 0.15} = 0.02144$ And calculate standardized variate using Equation (15) or

Z1= -NORMSINV (P1) =2.02486

Then by rearrange the data in descending order giving a plotting position rank for each successive data. Plot the given Normal logarithm base ten data versus the standardized variable variate. If the plotting of the series fall down in a straight line fashion it said to be a best fitting probability distribution.

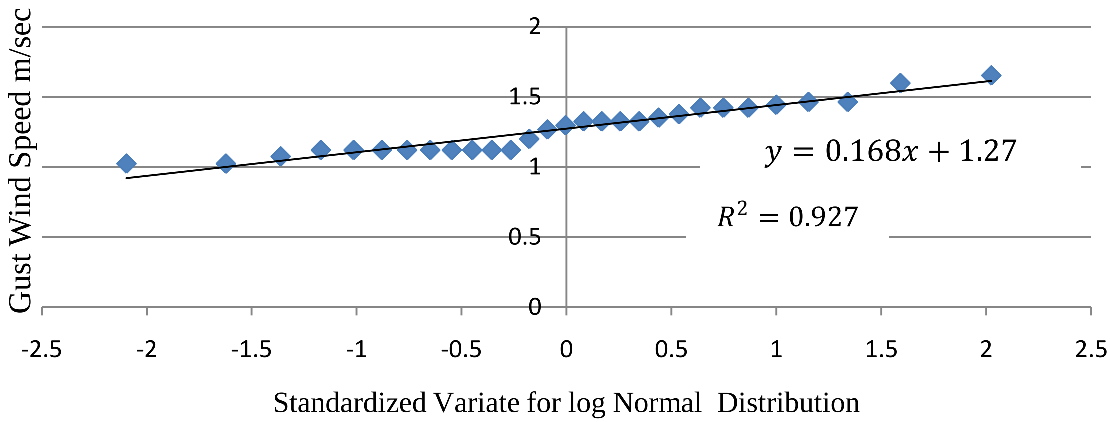

Figure 4-9: Analysis of annual maximum wind gust, using the log Normal distribution for Addis Ababa

Table 4-4: Results of predicting gust wind speeds for Addis Ababa using different distribution method

1	2	3	6	7	8	9
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	26.37	24.83	26.46	25.92	27.42	26.06
10	31.38	31.28	31.18	31.27	31.18	31.00
15	34.21	35.63	33.06	34.43	33.06	33.80
20	36.19	39.04	34.29	36.69	34.29	35.78
25	37.71	41.88	35.20	38.47	35.20	37.30
30	38.95	44.34	35.91	39.94	35.91	38.55
50	**42.41**	**52.00**	**37.80**	**44.15**	**37.80**	**42.04**
100	47.07	64.46	40.13	50.09	40.13	46.82
200	51.71	79.84	42.27	56.35	42.27	51.66

500	57.84	105.89	44.85	65.18	44.85	58.20
1000	62.47	131.08	46.67	72.33	46.67	63.29

Discussions for Addis Ababa

The trend line or the line of best fit illustrates the overall data collected have a strong relation to predict the basic wind speed using the best probability distribution. Among the alternative distributions log normal distribution was better fit than that of Normal, log Normal, Gumbel, log Gumbel, Pearson and log Pearson distributions. For Addis Ababa station the coefficient of determination and coefficient of correlation, in each distribution respectively are; For normal distribution -92.01% and 84.66%, For log normal distribution 96.29% and 92.72%, For Pearson distribution -92.01% and 84.66%,

For Log Pearson distribution -96.18% and 92.51% For Gumbel distribution 93.89% and 88.15%, and For Log Gumbel distribution 95.52% and 91.23%

As a result, all distributions that were used have a strong correlation but log normal distribution was better than the remaining distributions according to the strong correlation coefficient and coefficient determination.

The extreme wind speed analysis at a return period 50 years for Addis Ababa station is 42 m/sec, which is greater than the constant figure, 22 m/sec that is increased by 90.91%, after this it is recommended to use a basic design wind speed for Addis Ababa.

For Dire Dawa

The best fitting probability distribution for Dire Dawa was Log Pearson Distribution. Let's see the procedure

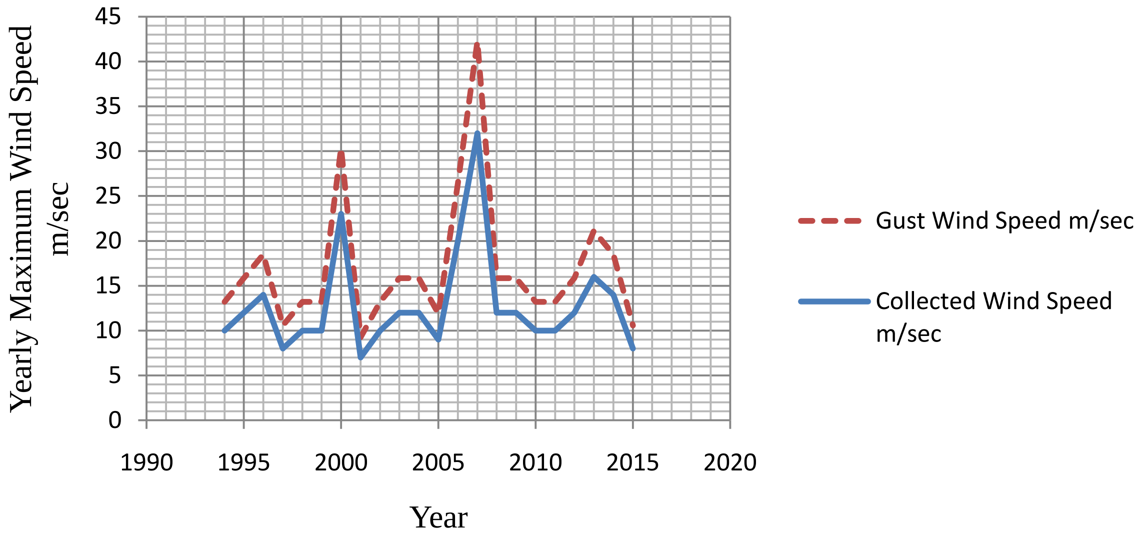

Figure 4-10: Conversion of maximum 10-minute gust wind speed for Dire Dawa

The mean, standard deviation, and coefficient of skewness for the annual maximum wind speed estimated from the 22-year record at Dire Dawa in Ethiopia, for anti-log are 1.199887 m/s, 0.15509 m/s, and 1.185705 respectively, because among the alternative probabilistic approaches log Pearson distribution is best fit using probability plotting test.

From equation (17) we have

$$KT = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5$$

From equation (18) we have

$$where \quad k = \frac{Cs}{6} = 1.185705/6 = 0.197618$$

From equation (15) Z= 2.05418

From equation (17) $KT = 2.054189 + (2.054189^2 - 1) * 0.197618 +$

$$\frac{1}{3}(2.054189^3 - 6 * 2.054189) * 0.197618^2$$

$$- (2.054189^2 - 1) * 0.197618^3 +$$

$2.054189 * 0.197618^4 + \frac{1}{3} 0.197618^5$ =2.621235

Then from equation (19); $XT = 1.199887 + 2.621235 * 0.15509$ =**1.606414**

The estimated 50-year required design value **V (ref)** as=antilog of xT =**40.40** m/sec

Probability plot for Dire Dawa

Using equation (32) Assign plotting position using Cunnane formula

pi = (m – b)/(n + 1-2b)

Here the coefficient of skewness is positive the parameter b being greater than 3/8, so let's take the parameter $b = \frac{4}{8}$ which is equal to 0.5 then the formula was adjusted like this: $\mathrm{pi} = \frac{\mathrm{m}-0.5}{\mathrm{n}+1-2*0.5} = \frac{\mathrm{m}-0.5}{\mathrm{n}}$

$P1 = \frac{1-0.5}{22}$ =0.022727

From equation (27) $yT = -\ln[-ln\,1 - pi]$

$y1 = -ln(-ln(1 - 0.022727)) = 3.772717$

Then by, data was rearranged in descending order which gave a plotting position rank for each successive data. Plot the given Normal logarithm base ten data versus the standardized variable variate. If the plotting of the series fall down in a straight line fashion, it said to be a best fitting probability distribution.

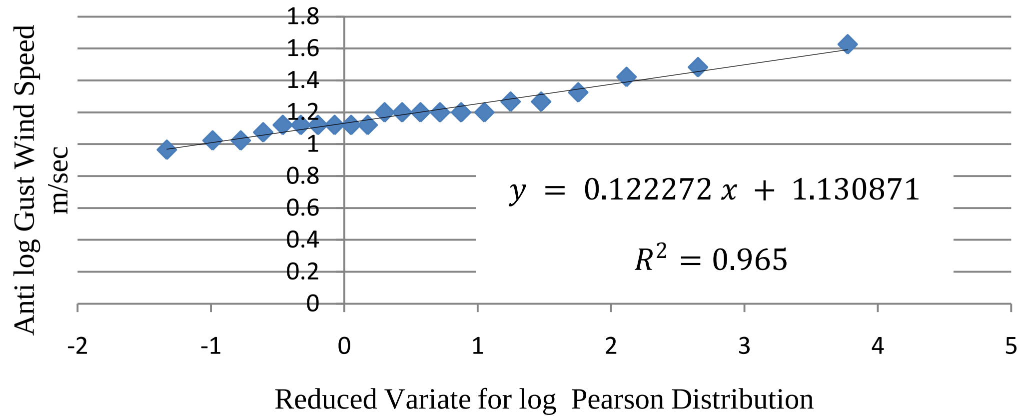

Figure 4-11: Analysis of annual maximum wind gust, using the log Pearson distribution for Dire Dawa

Table4-5: Results of predicting gust wind speeds for Dire Dawa using different distribution method

1	**2**	**3**	**6**	**7**	**8**	**9**
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using **Log Pearson**	Predicted gust speed Using Normal	Predicted gust speed Using Log Normal
5	22.39	20.49	21.23	20.56	23.31	21.40
10	26.80	25.25	26.46	25.51	26.63	25.04
15	29.28	28.41	29.60	28.75	28.28	27.09
20	31.02	30.85	31.85	31.24	29.36	28.51
25	32.36	32.88	33.62	33.29	30.16	29.61
30	33.45	34.62	35.07	35.05	30.78	30.51
50	**36.49**	**39.99**	**39.21**	**40.40**	**32.44**	**33.00**
100	40.59	48.57	44.93	48.82	34.49	36.37
200	44.67	58.95	50.80	58.80	36.37	39.76
500	50.05	76.11	58.74	74.97	38.64	44.29
1000	54.12	92.33	64.89	89.94	40.24	47.77

In similar way the remaining stations was done the same pattern, and their results are shown in Appendix B and best fit probability plot shown below:

Discussions for Dire Dawa

From the graph, the theoretical distribution and the observed distribution were fit each other. The coefficient of determination was 96.5% of which its relation was strong and best suit to estimate the basic wind speed for Dire Dawa. The data points were not departed from the theoretical distribution. It shows, the data falls on a straight line because the data comes from log Pearson distribution. For example the estimated value of extreme wind speed at 50 year return period for the purpose of the building analysis was 40 m/sec; this magnitude was much greater than the constant figure, 22 m/sec, which increased in 81.82% from the stagnant basic wind speed.

For Arba Minch

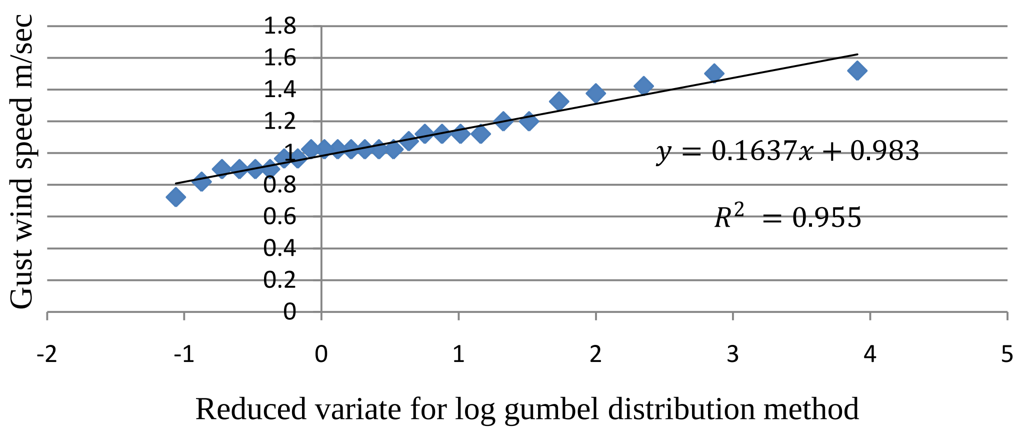

Figure 4-12: Analysis of annual maximum wind gust, using the log Gumbel distribution for Arba Minch

Discussions for Arba Minch

From the graph it shows that the coefficient of determination was 95.5% which shows a strong relation between the data and the independent variable of the empirical plotting position. Hence from the alternative probability distribution, log Gumbel distribution better fit than for all the distributions that were used to operate the extreme wind speed analysis for Arba Minch. The magnitude operated was 40m/sec. This implies, the exceedance probability which is greater than or equal to 40m/sec for this station is 2%, and 98% of the probability is more than or equal to the value which was discovered. At different return period the operation is similar. The best fitted straight line equation was obtained by regression analysis.

For Bahir Dar

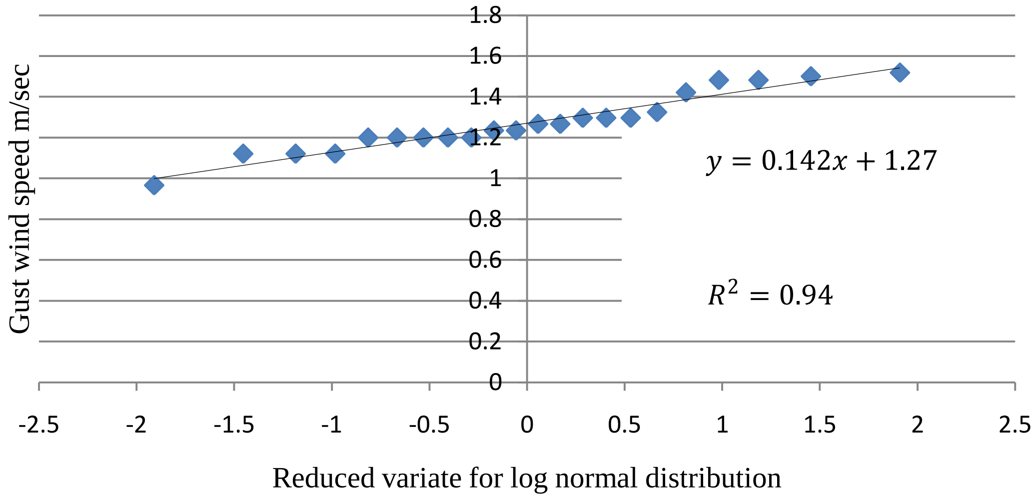

Figure 4-13: Analysis of annual maximum wind gust, using the log Normal distribution for Bahir Dar

The estimated 50-year required design value **V (ref)** as=antilog of xT= **36.39** m/sec

Discussions for Bahir Dar

The regression line and the collected yearly maximum wind speed data were almost fit each other. Hence, log normal distribution method was better fit than among the alternative distribution. The coefficient of determination and coefficient of correlation were greater than 90%. Which shows that log normal distribution was the best one to operate the estimated extreme wind speed at different return periods. For example, for building design process the estimated 50 year required design value for Bahir Dar was 36 m/sec. which was also greater than the value of the constant figure, 22m/sec. After this, 36 m/sec can be used as a reference wind speed for building analysis around Bahir Dar.

For Debre Markos

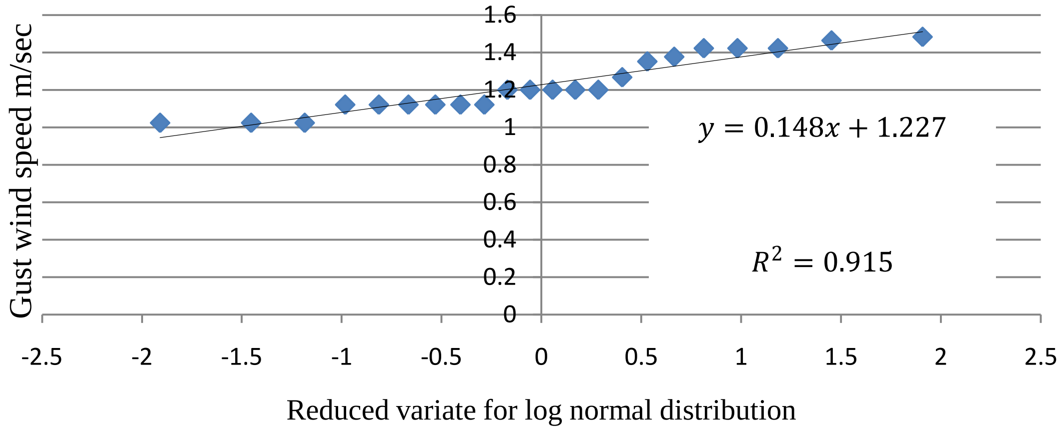

Figure 4-14: Analysis of annual maximum wind gust, using the log Normal distribution for Debre Markos

The estimated 50-year required design value **V (ref)** as=antilog of xT= **34.21** m/sec

Discussions for Debre Markos

The regression line and the reduced variate were almost fit each other because the correlation coefficient and coefficient of determination are greater than 90% which shows a strong relation between the dependant variable and independent variable of the configuration. For this strong relation log normal distribution was better fit than other alternative probability distribution. The equation of the better fit line for Debre Markos was y=0.148x+1.227, where x is the reduced variate and y is the predicted value. The values are operational zed by the antilogarithm principle because the data was multiplied by the logarithmic series. For example, for building design process the estimated 50year required design value for Debre Markos was 34 m/sec which was also greater than the value of the constant figure, 22m/sec. After this, 34 m/sec can be used as a reference basic wind speed for building analysis around Debre Markos.

For Debre Zeit

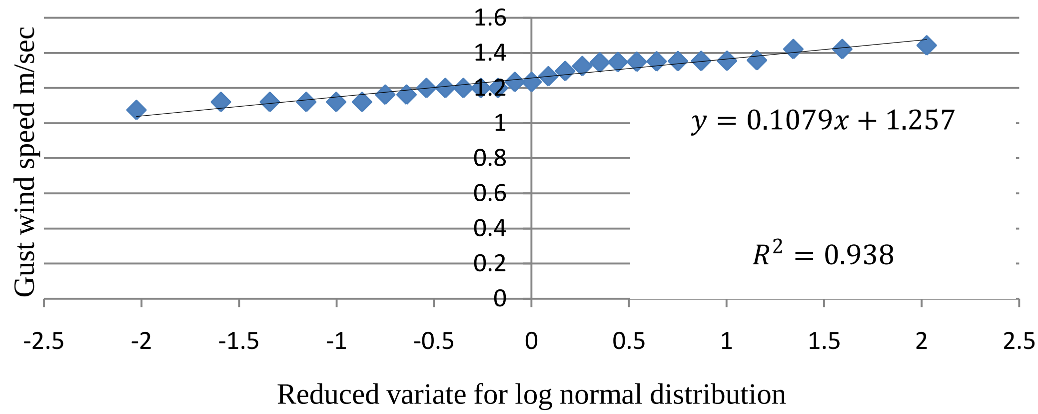

Figure 4-15: Analysis of annual maximum wind gust, using the log Normal distribution for Debre Zeit

The estimated 50-year required design value **V (ref)** as=antilog of xT = **30.18** m/sec

Discussions for Debre Zeit

The dependant variable and the independent variables have a better relation having a coefficient of determination 93.3%, which shows that the data points were more tightly clustered around an imaginary line through their center. It‘s because the correlation coefficient was nearest to the magnitude one, and all the data points fall on a straight line. Therefore, log normal distribution is best fit among the alternative probability distribution. The magnitude of the estimated extreme wind speed at 50 year return period was 30 m/sec for the purpose of building analysis; because, the estimated service life of the building is around 50 years. When compared to the stagnant basic wind speed it increased in 36.4% from the stagnant basic wind speed.

For Gode

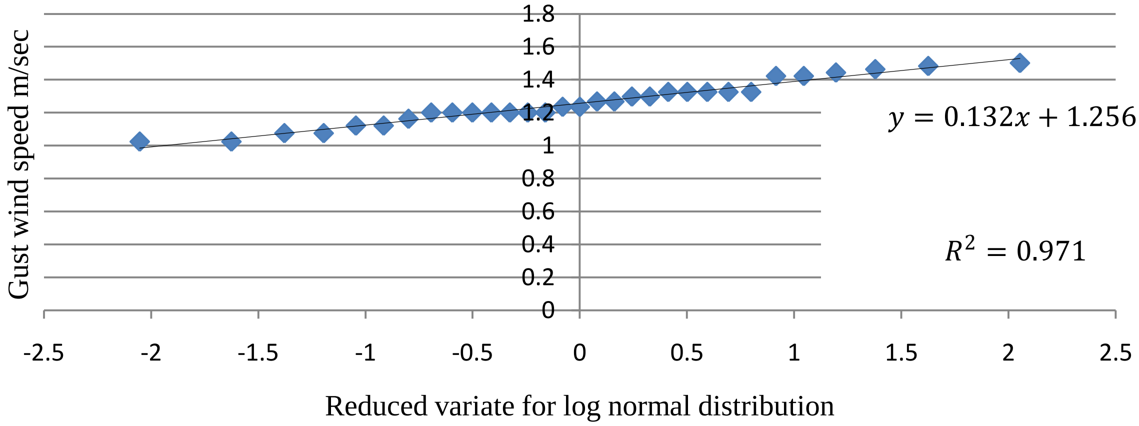

Figure 4-16: Analysis of annual maximum wind gust, using the log Normal distribution for Gode

Discussions for Gode

The estimated 50-year required design value **V (ref)** as=antilog of xT= **33.50** m/sec

As shown the graph, the process of taking the wind data and coming up with an equation of the regression which shows that the data points were more tightly clustered around an imaginary line through their center. There was a perfect relationship between the dependant variable (collected wind speed) and the independent variable (plotting position empirical estimation technique) because the correlation coefficients between the variables were almost near to the magnitude one. This criterion was satisfied by using log normal distribution. The estimated extreme wind speed magnitude at 50 year return period for the purpose of building analysis was 34 m/sec which increased in 54.5% from the stagnant basic wind speed.

For Gore

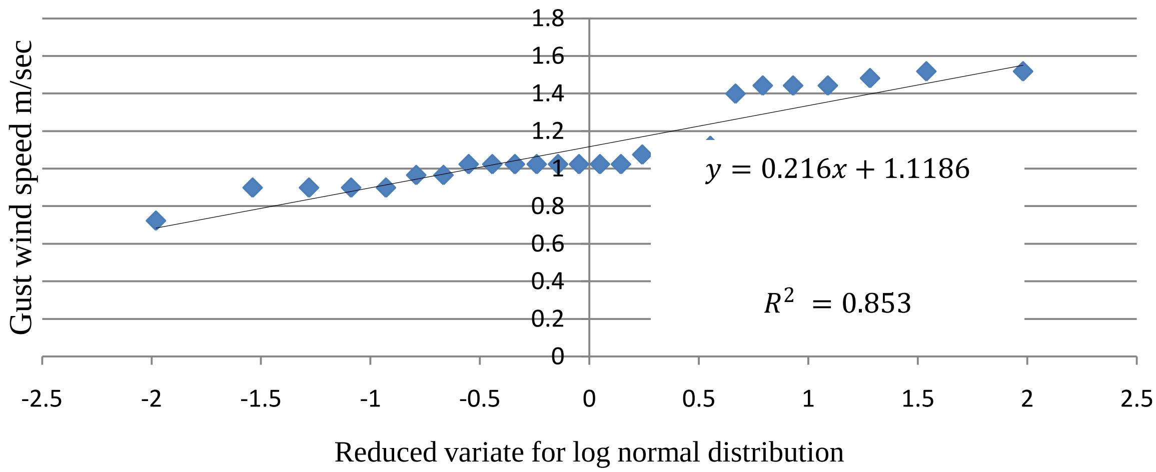

Figure 4-17: Analysis of annual maximum wind gust, using the log Normal distribution for Gore

The estimated 50-year required design value **V (ref)** as=antilog of xT= **38.79** m/sec

Discussions for Gore

The line of best fit helps us to predict future events relating to the data being studied. The regression line and the distribution data come about to be more or less tight with the data points which clustered around an imaginary line through the center. There was almost a better relation between a distribution data and the empirical plotting position with a coefficient of determination 85.3%, log normal distribution method was best fit among alternative probability distribution method. The estimated extreme wind speed at 50 year return period for the purpose of building analysis was 39 m/sec which increased in 77.27% from stagnant basic reference wind speed.

For Hawassa

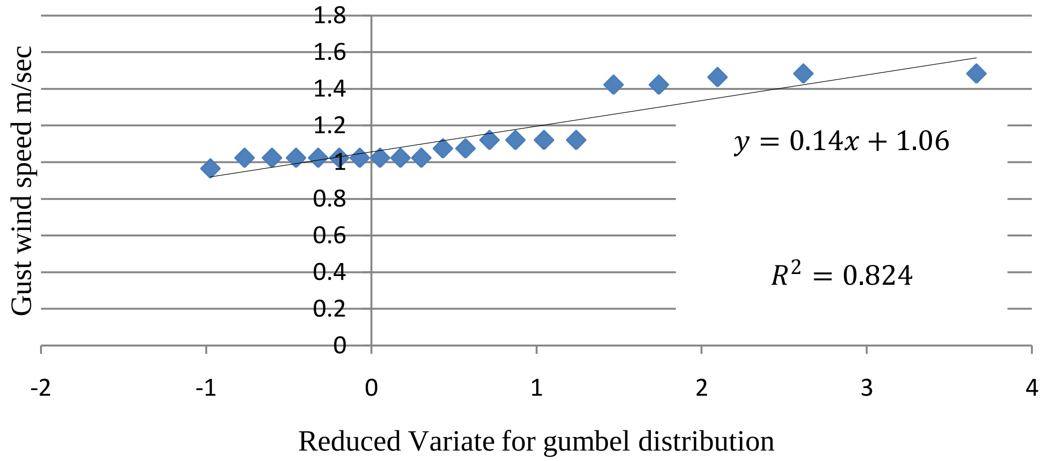

Figure 4-18: Analysis of annual maximum wind gust, using the log Gumbel distribution for Hawassa

The estimated 50-year required design value **V (ref)** as=antilog of xT = **41.41** m/sec

Discussions for Hawassa

Among the alternative probability distribution, log Gumbel distribution was best fit. Having a correlation coefficient and a coefficient determination are 90.77% and 82.4% respectively. The estimated extreme wind speed at 50 year return period for the purpose of building analysis was 41 m/sec which increased in 86.36% from stagnant basic reference wind speed. From the graph, the theoretical distribution and the observed distribution were fit each other. Their relations were strong and best suit to estimate the basic wind speed for Hawassa.

For Jimma

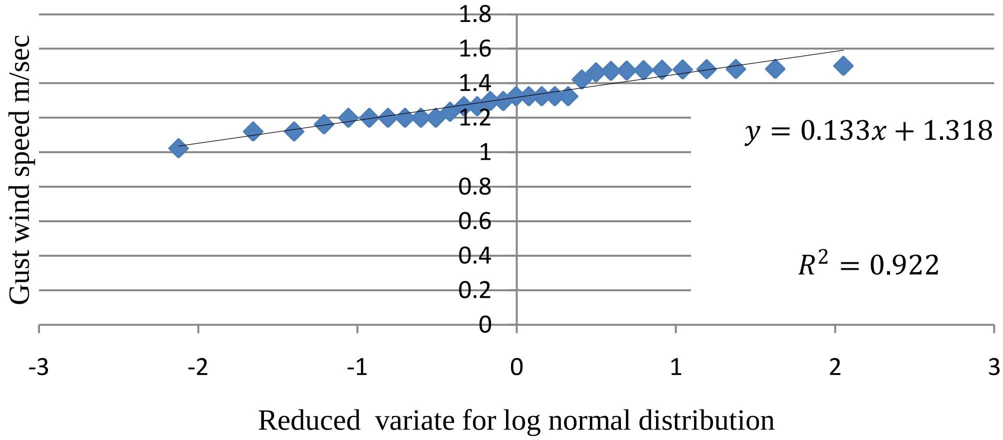

Figure 4-19: Analysis of annual maximum wind gust, using the log Normal distribution for Jimma

The estimated 50-year required design value **V (ref)** as=antilog of xT = **39.50** m/sec

Discussions for Jimma

Different probability distributions were used to estimate the basic reference wind speed in Jimma such as Gumbel, log Gumbel, Normal, log Normal, Pearson and log Pearson distributions. Among the listed distributions, log normal distribution was found to be the fit distribution. The dependant variable and the independent variable were more tightly correlated which clustered around an imaginary line through the center. The correlation coefficient and coefficient of determination for Jimma were 96% and 92.18% respectively. The estimated extreme wind speed at 50 year return period for the purpose of building analysis, the value was 39 m/sec which increased in 77.27% from stagnant basic reference wind speed.

For Kibre Mengist

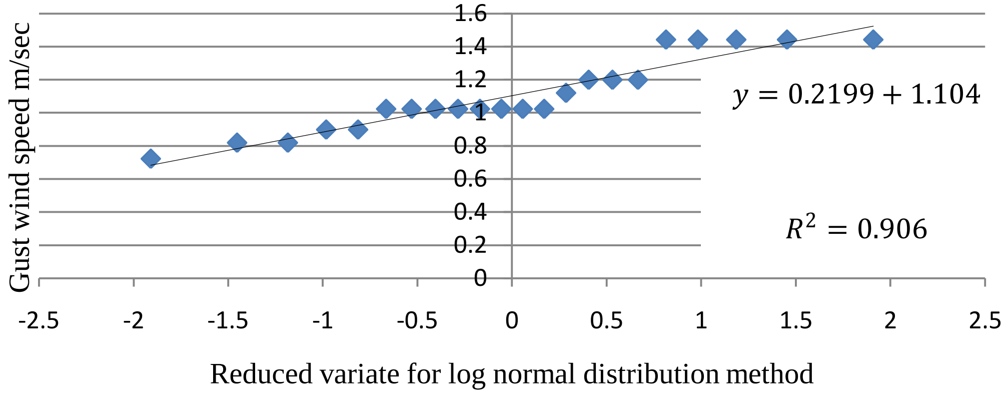

Figure 4-20: Analysis of annual maximum wind gust, using the log Normal distribution for Kibre Mengist

The estimated 50-year required design value **V (ref)** as=antilog of xT = **36.47** m/sec

Discussions for Kibre Mengist

The graph of the probability fit shows that log normal distribution was best fit when compared to other probability distributions. The correlation coefficient 95.2% and the coefficient of determination 90.63%, which were greater than 70%, shows that the error is minimized and there is a strong relationship between the dependant variable(wind speed) and the independent variable (Cunnane equations which is unbiased). The estimated extreme wind speed at 50 year return period for the purpose of building analysis became 36 m/sec. This finding was an increase in 63.4% from stagnant basic reference wind speed.

For Kombolcha

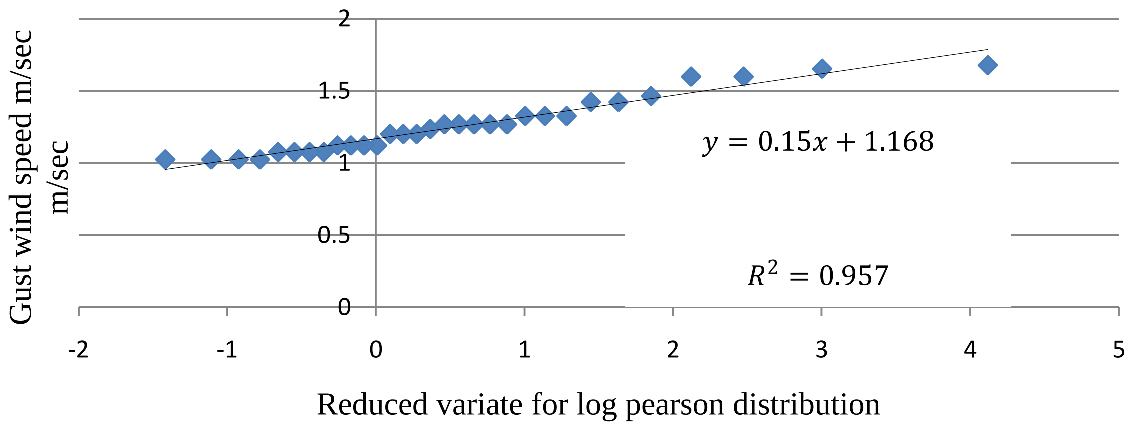

Figure 4-21: Analysis of annual maximum wind gust, using the log Pearson distribution for Kombolcha

The estimated 50-year required design value **V (ref)** as=antilog of xT = **41.90** m/sec

Discussions for Kombolcha

As shown in the graph, the process of taking the wind data and coming up with an equation of the regression indicated a more tightly cluster of the data points around an imaginary line through their center. There was a perfect relationship between the dependant variable (collected wind speed) and the independent variable (plotting position empirical technique estimation) because the correlation coefficient between the variables was almost near to the magnitude one. This criterion was satisfied by using log Pearson distribution. The estimated extreme wind speed magnitude at 50 year return period for the purpose of building analysis was 42 m/sec, which was an increase in 90.91% from the stagnant basic wind.

For Mekelle

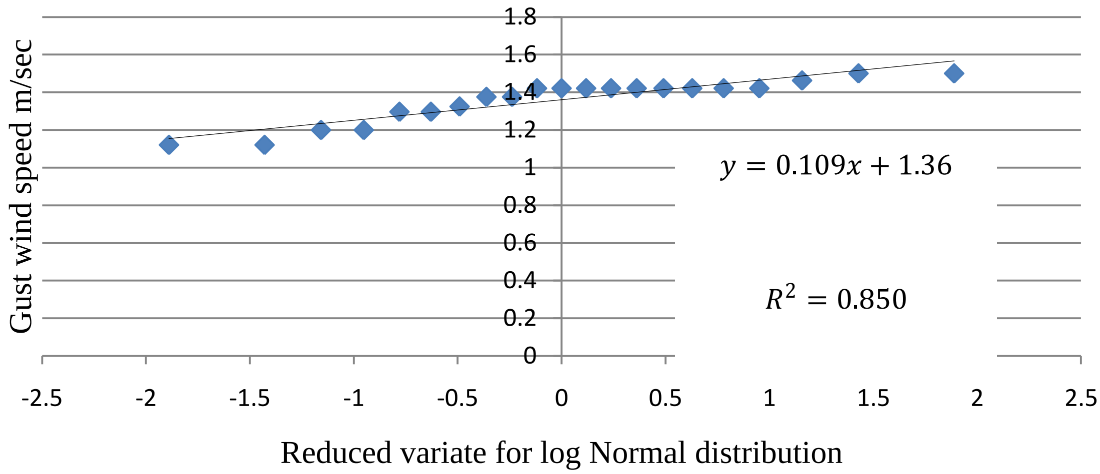

Figure 4-22: Analysis of annual maximum wind gust, using the log Normal distribution for Mekelle

The estimated 50-year required design value **V (ref)** as=antilog of xT = **39.33** m/sec

Discussions for Mekelle

The regression line and the reduced variate were almost fit each other. This is because the correlation coefficient and the coefficient of determination were greater than 80%. This has shown a strong relationship between the dependant variable and independent variable of the configuration. The strong relation indicator, log normal distribution, was a better fit than the other alternative probability distributions. The equation of the better fit line for Mekelle was y=0.109x+1.36, where x is the reduced variate and y is the predicted value. The values were operational by the antilogarithm principle because the data was multiplied by the logarithmic series. For example, for building design process, the estimated 50year required design value for Mekelle was 39 m/sec which was also greater than the value of the constant figure, 22m/sec. After this, 39 m/sec can be used as a reference basic wind speed for building analysis rather than the previously used value.

For Metehara

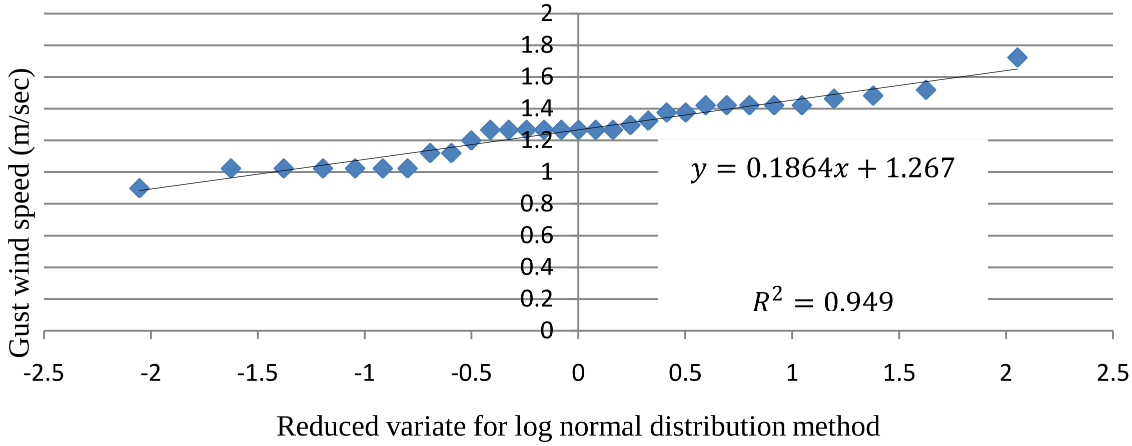

Figure 4-23: Analysis of annual maximum wind gust, using the log Normal distribution for Metehara

The estimated 50-year required design value **V (ref)** as=antilog of xT = **44.66** m/sec

Discussions for Metehara

From the graph, it was possible to read that the coefficient of determination was 94.9% which shows a strong relationship between the data and the independent variable of the empirical plotting position. Hence, from the alternative probability distribution, log Normal distribution was best fit for all the distributions that were used to operate the extreme wind speed analysis for Metehara. The magnitude operated was 45m/sec. This means, the exceedance probability which is greater than or equal to 45m/sec for this station is 2%, and 98% of the probability is more than or equal to the value which was discovered. At different return periods, the operation can be similar. The best fit straight line equation was obtained by regression analysis. The estimated extreme wind speed magnitude at 50 year return period for the purpose of building analysis was 45 m/sec which increased in 104.54% from the stagnant basic wind.

For Negelle

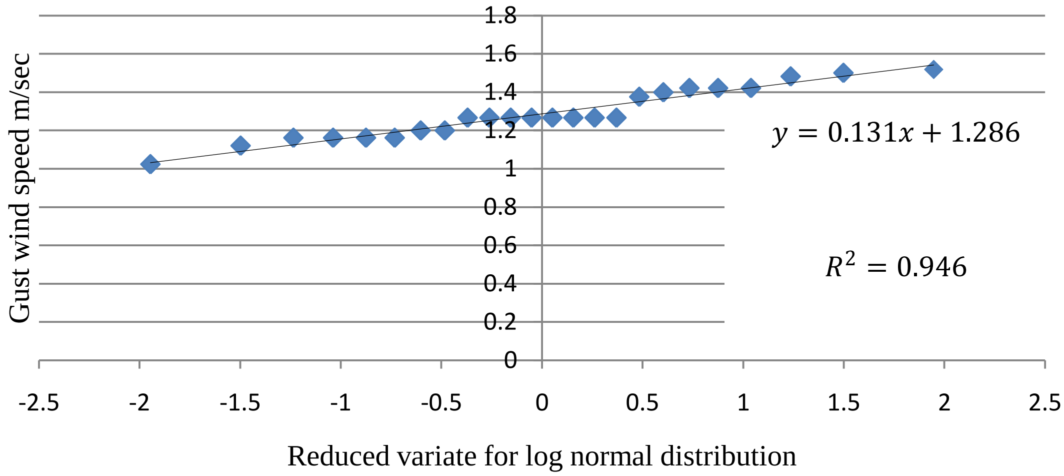

Figure 4-24: Analysis of annual maximum wind gust, using the log Normal distribution for Negelle

The estimated 50-year required design value **V (ref)** as=antilog of xT = **35.21** m/sec

Discussions for Negelle

The line of best fit helps us to predict future events relating to the data being studied. The regression line and the distribution data were more or less tight at the data points which clustered around an imaginary line through their center. There was almost a better relation between a distribution data and the empirical plotting position with a coefficient of determination equal to 94.6%. For this, log normal distribution method was best fit among alternative probability distribution method. The estimated extreme wind speed at 50 year return period for the purpose of building analysis the value was 35 m/sec, which was an increase in 59.09% from stagnant basic reference wind speed.

For Nekemte

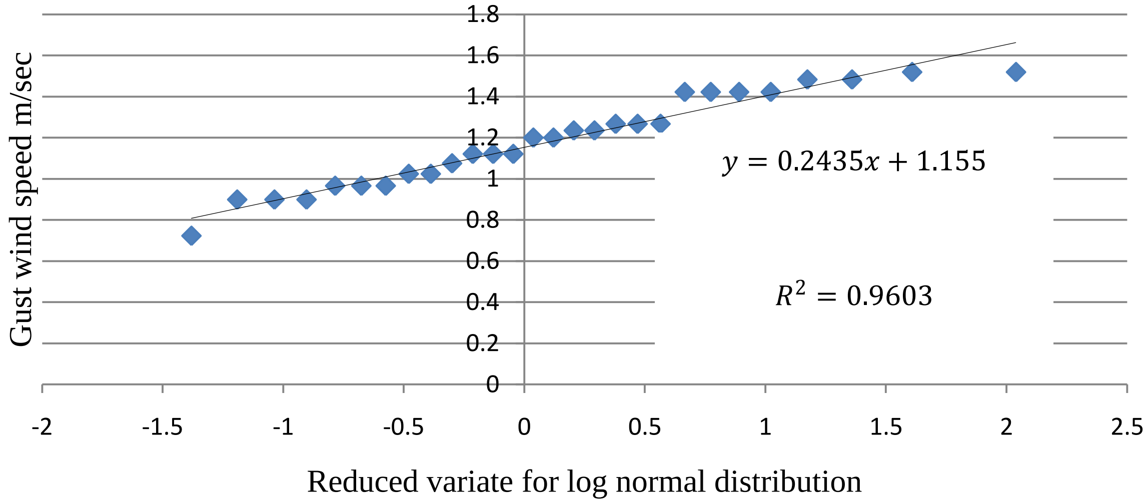

Figure 4-25: Analysis of annual maximum wind gust, using the log Normal distribution for Nekemte

The estimated 50-year required design value **V (ref)** as=antilog of xT = **45.15** m/sec

Discussions for Nekemte

The dependant variable and the independent variable have shown a better relation with a coefficient of determination 96.03%. That came out with the tightly clustered data points around an imaginary line through their center. This occurred for the correlation coefficient was nearest to the magnitude one and all the data points fall on a straight line. As a result, log normal distribution was the best fit among the alternative probability distributions. The magnitude of the estimated extreme wind speed at 50 year return period was 45 m/sec for the purpose of building analysis, so the estimated service life of the building is around 50 years. When compared to the stagnant basic wind speed, there was an increase in 104.54%.

For Robe

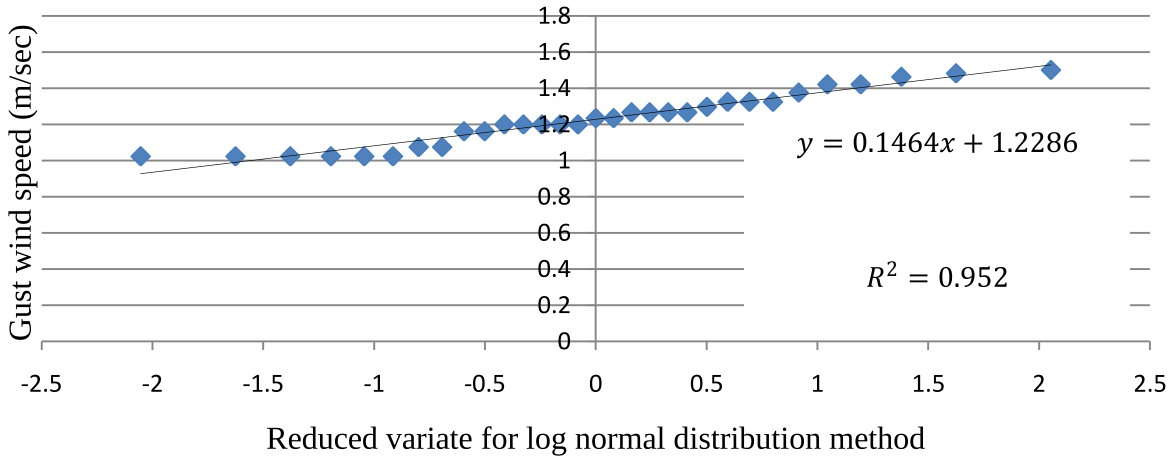

Figure 4-26: Analysis of annual maximum wind gust, using the log Normal distribution for Robe

The estimated 50-year required design value **V (ref)** as=antilog of xT = **33.78 m**/sec

Discussions for Robe

From the graph, it was found that the theoretical distribution and the probability distribution fitted each other. The coefficient of determination was 95.2% of which its relations were strong and best suit to estimate the basic wind speed for Robe. The data points did not depart from the theoretical distribution. It was shown so that the data fall on a straight line, and the data came from log Normal distribution. For example, the estimated value of extreme wind speed at 50 year return period for the purpose of the building analysis was 34 m/sec; this magnitude was much greater than the constant figure, 22 m/sec, and the increase was 54.54% from the stagnant basic wind speed.

The general best fitting equation for selected Towns/Cities $y = \alpha x + \beta$

Where the coefficient α , the constant β and the station fitting probability distributions are shown in the following table and x are determined from the standardized variate for log Normal and log Pearson distributions and reduced variate for log Gumbel distribution.

Table4-6: Fitting probability distribution, best fitting equation coefficient of determination and Gust wind speed for each stations

No.	Stations	Fitting Prob. distribution	Best Fitting Equation $y = \alpha x + \beta$	Coefficient of determination	Gust wind speed @ 50 year return period (m/sec)
1	Addis Ababa	LN	$y = 0.168x + 1.27$	$R^2 = 0.927$	42
2	Arba Minch	LG	$y = 0.164x + 0.983$	$R^2 = 0.955$	40
3	Bahir Dar	LN	$y = 0.142x + 1.270$	$R^2 = 0.940$	36
4	Debre Markos	LN	$y = 0.148x + 1.227$	$R^2 = 0.915$	34
5	Dire Dawa	LP	$y = 0.122x + 1.131$	$R^2 = 0.966$	40
6	Debre Zeit	LN	$y = 0.108x + 1.257$	$R^2 = 0.938$	30
7	Gode	LN	$y = 0.132x + 1.256$	$R^2 = 0.976$	34
8	Gondar	LG	$y = 0.178x + 1.212$	$R^2 = 0.949$	36
9	Gore	LN	$y = 0.216x + 1.119$	$R^2 = 0.853$	39
10	Hawassa	LG	$y = 0.140x + 1.060$	$R^2 = 0.824$	41
11	Jimma	LN	$y = 0.133x + 1.318$	$R^2 = 0.922$	39
12	Kibre Mengist	LP	$y = 0.220x + 1.104$	$R^2 = 0.906$	36
13	Kombolcha	LN	$y = 0.150x + 1.168$	$R^2 = 0.957$	42
14	Mekelle	LN	$y = 0.109x + 1.36$	$R^2 = 0.850$	39
15	Metehara	LN	$y = 0.186x + 1.267$	$R^2 = 0.949$	45
16	Negelle	LN	$y = 0.131x + 1.286$	$R^2 = 0.946$	35
17	Nekemte	LN	$y = 0.244x + 1.155$	$R^2 = 0.960$	45
18	Robe	LN	$y = 0.146x + 1.229$	$R^2 = 0.952$	34

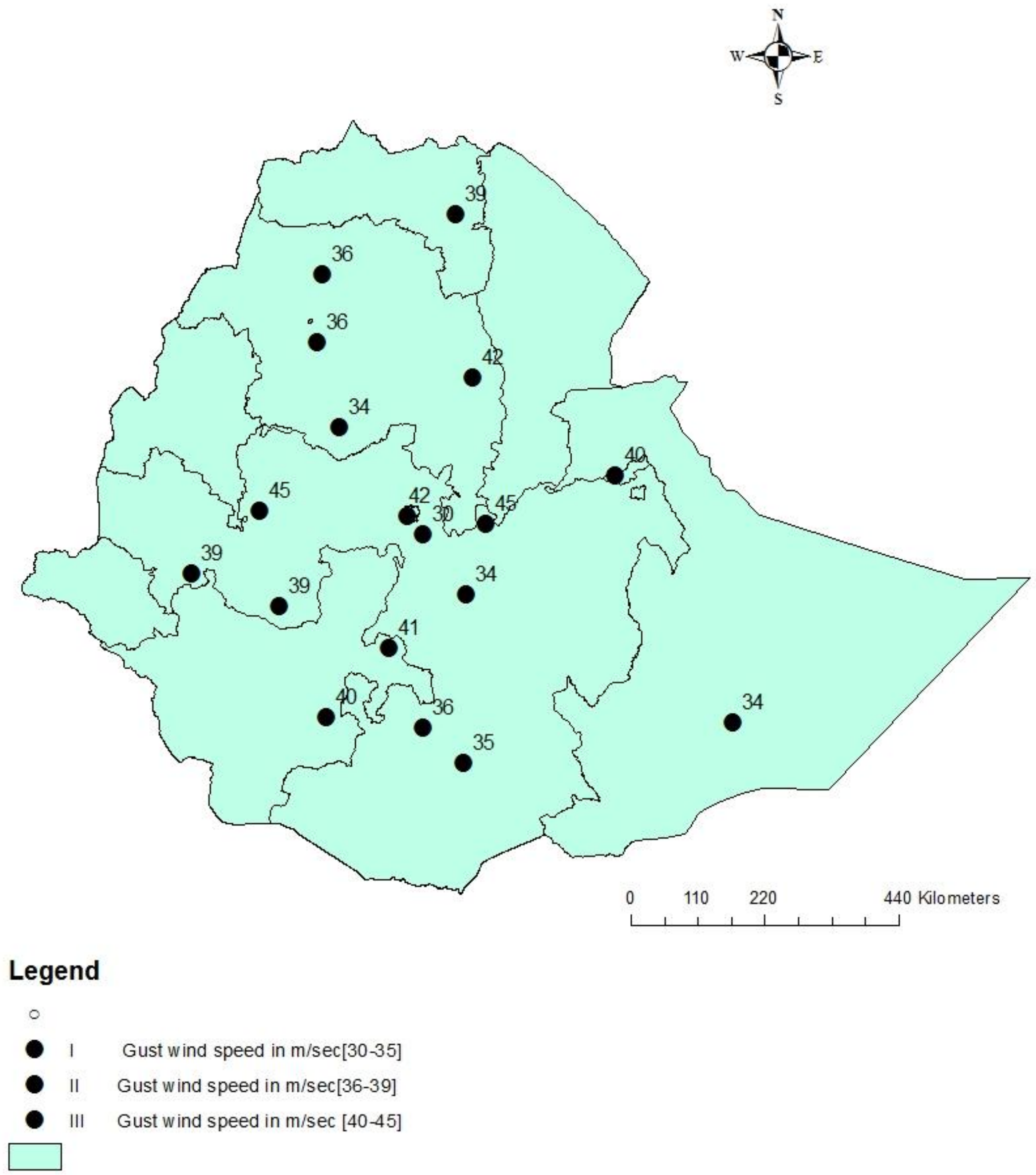

Figure 4-27: Gust wind speed, at 50 year return period, zonal map for selected stations

Table4-7: Results of predicting Gust wind speeds for each station at different return periods

No.	Stations	Speed @5 yr return period	Speed @10 yr return period	Speed @15 yr return period	Speed @20 yr return period	Speed @25 yr return period	Speed @30 yr return period
1	Addis Ababa	26	31	34	36	37	39
2	Arba Minch	17	22	26	29	31	29
3	Bahir Dar	25	28	30	32	33	34
4	Debre Markos	23	26	28	30	31	32
5	Dire Dawa	21	26	29	31	33	35
6	Debre Zeit	22	25	26	27	28	29
7	Gode	23	27	28	30	31	31
8	Gondar	23	27	30	31	33	34
9	Gore	20	26	29	31	33	35
10	Hawassa	19	24	28	31	33	35
11	Jimma	27	31	33	35	36	37
12	Kibre Mengist	20	25	27	30	31	33
13	Kombolcha	23	28	34	33	35	37
14	Mekelle	29	32	34	35	36	37
15	Metehara	27	32	35	37	39	41
16	Negelle	25	28	30	31	32	33
17	Nekemte	23	29	33	36	38	40
18	Robe	22	26	28	29	31	31

Cont…

No.	Stations	Speed @50 yr return period	Speed @100 yr return period	Speed @200 yr return period	Speed @500 yr return period	Speed @1000 yr return period
1	Addis Ababa	42	47	52	58	63
2	Arba Minch	40	52	67	93	119
3	Bahir Dar	36	40	43	48	51
4	Debre Markos	34	38	41	45	49
5	Dire Dawa	40	49	59	75	90
6	Debre Zeit	30	32	34	37	39
7	Gode	34	36	39	43	46
8	Gondar	36	40	44	50	54
9	Gore	39	45	51	60	67
10	Hawassa	41	52	65	88	110
11	Jimma	39	43	47	51	55
12	Kibre Mengist	36	42	48	56	62
13	Kombolcha	42	49	58	70	81
14	Mekelle	39	42	45	49	52
15	Metehara	45	50	56	64	70
16	Negelle	35	38	41	45	48
17	Nekemte	45	53	61	72	81
18	Robe	34	37	40	45	48

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The wind speed data available in 18 meteorological stations have been studied for obtaining the basic wind speed. Based on the scientific analysis of data, the selected stations require up gradation to higher wind speeds rather than a constant figure. A basic wind speed for selected towns/cities in the country has been provided.

The wind zone map for the country prepared based on wind speed data collected at 18 locations in the country is observed to be different to the constant figure, which is in use at present. The constant basic wind speed that is being used at present has not been prepared based on observed wind speed data.

In this study, the data from 18 major climate stations of Ethiopia were used. A country should not have a constant figure or stagnant basic wind speed throughout the nations. Based on the data, different basic wind speeds were modeled at different stations with a required return period.

The paper presented a frequency analysis procedure for estimation of 10 minute average extreme wind speed for each station. The basic wind speed is based on peak gust velocity averaged over a short time interval of about 10 minutes and corresponds to 10 meter height above mean sea level with a return period of 5, 10, 15, 20, 25, 30, 50, 100, 200, 500 and 1000 corresponds to $50^{th,}$ 90^{th}, 93.3^{th}, 95^{th}, 96^{th}, 96.67^{th}, 98^{th}, 99^{th}, 99.5^{th}, 99.8^{th}, and 99.9^{th} percentile of the distribution respectively. The wind speed data available in these stations have been studied for obtaining the basic wind speed. A basic wind speed map for the country has been suggested at different return periods.

5.2 Recommendations

- Different locations will have different wind speed distributions. According to weather conditions in Ethiopia it is classified in to five zones such as Frosty Weather, High land, Temperate, Low land, and Desert. EBCS1, 1995, the reference basic wind speed in Ethiopia generally was taken to be 22m/sec is not appropriate for design process. Since the reference basic wind speed should be taken from the wind hazard map which is appropriate for your design location and the manual and commentary of EBCS 1, 1995 should be prepared.
- The wind speed data that formally bought from meteorological agency of Ethiopia, the values that were recorded in some stations for example Addis Ababa observatory the magnitudes of the wind speed extensively large before 1990. After this year, the values are very small relatively. Meteorological agency of Ethiopia should be checked the wind gauge stations weather the anemometer position affected by urbanization or properly calibrated.
- In the future the rest of stations rather than these stations should be estimated the basic reference wind speed for generally classify the wind zones in Ethiopia and the basic wind speed developed in this thesis is recommended for use as a guide for structural design in Ethiopia.

References

[1] M. Arafah, Assistant Professor, Department of Civil Engineering, College of Engineering, Riyadh, Saudi Arabia and G. H. Siddiqi Associate Professor, Department of Civil Engineering, College of Engineering, Riyadh, Saudi Arabia "Estimation of the design wind speeds for the kingdom of Saudi Arabia based on Short-term records"

[2] Aucoin, F., D. Caissie, N. El-Jabi and N. Turkkan Department of Fisheries and Oceans Gulf Region Oceans and Science Branch Diadromous Fish Section P.O. Box 5030, Moncton, NB, E1C 9B6 Canadian Technical Report of Fisheries and Aquatic Sciences 2920, 2011 "Flood Frequency Analyses for New Brunswick Rivers"

[3] EBCS-1, "Basis of Design and Actions on Structures", Ministry of Works and Urban Development, Addis Ababa, 1995

[4] Paul Chiou, Weiwen Miao, and T.C. HO, International Journal of Environmental Science And Development "The Annual Maximum Wind Speed at Pisa Airport In Italy" vol.3 No. 3, June 2012

[5] Bungale S.Ternath Ph.D., S.E. John A. Martin &Associates Structural Engineers 1212S "Wind and Earthquake Resistant Buildings, Structural Analysis and Design", Flower Street Los Angles, California 90015, October 2004

[6] J P Palutikof and D H Lister1, Climatic Research Unit, University of East Anglia, Norwich NR4 7TJ, UK, B B Brabson, Department of Physics, Indiana University, Bloomington, Indiana 47405, USA, S T Adcock, Department of Meteorology, University of Reading, Reading RG6 6BB, UK, "A review of methods to calculate extreme wind speeds", Meteorol. Appl. 6, 119–132 (1999)

[7] Det Norske Veritas "Environmental conditions and Environmental loads" Recommended practice April 2007

[8] A.S. Alnuaimia, M.A. Mohsinb and K.H. Al-Riyam, Department of Civil & Architectural Engineering, Sultan Qaboos University, POB 33, PC 123, Muscat, Oman Department of Civil and Architectural Engineering, College of Engineering, University of Buraimi, PO Box 890, Buraimi512, Oman. Senior Structural Engineer, Central Design

Office, Royal Court Affairs, PO Box 949, Muscat 100, Oman. "A Basic Wind Speed Map for Oman", the Journal of Engineering Research, Vol. 11, No. 2 (2014) 64-78

[9] Chow, V. T., Frequency analysis of hydrologic data with special application to rainfall intensities, bulletin no. 414, University of Illinois Eng. Expt. Station, 1953.

[10] Benson, M. A., Uniform flood-frequency estimating methods for federal agencies, Water Resour.Res., vol. 4, no. 5, pp. 891-908, 1968.

[11] K Subramanya Former Professor of Civil Engineering Indian Institute of Technology Kanpur Tata McGraw-Hill Publishing Company Limited New Delhi, "Engineering Hydrology, Third Edition"

[12] Ronald E. Walpole, Roanoke College, Raymond H. Myers, Virginia Polytechnic Institute and State University, Sharon L. Myers, Radford University, Keying Ye, University of Texas at San Antonio "Probability & Statistics for Engineers & Scientists" Eighth Edition, Pearson Education International

[13] Kite, G. W., "Frequency and Risk Analysis in Hydrology, Water Resources Publications", Fort Collins, Colorado, 1977

[14] Keith A. Cherkauer, Purdue University "A Guide to Statistical Methods Useful in Hydrology", Revised March 8th, 2007

[15] Simiu, E. and Scanlan, R. H., "Wind effects on structures- An introduction to wind engineering," A Wiley Interscience Publication, New York, 1978.

[16] Ian M. Giammanco, John L. Schroeder and Mark D. Powell "Observed characteristics of tropical cyclone vertical wind profiles" Wind Science and Engineering Research Center, Texas Tech University, Lubbock, Texas USA NOAA/AOML Hurricane Research Division, Miami, Florida, USA (Received March 2, 2011, Revised June 15, 2011, Accepted July 7, 2011) Wind and Structures, Vol. 15, No. 1 (2012) 65-86

[17] S.A. Hsu "Estimating 3-second and maximum instantaneous gusts from 1 minute sustained wind speeds during a hurricane" Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana, USA Electronic Journal of Structural Engineering (2008)

This page intentionally left blank

APPENDIX A

Outlier test, Correlation Coefficient and Regression Analysis

Table A-1: Outlier Test Kn values

Sample size n	Kn	Sample size n	Kn	Sample size n	Kn
1	0.000	12	2.134	23	2.448
2	0.000	13	2.175	24	2.467
3	0.000	14	2.213	25	2.486
4	0.000	15	2.247	26	2.502
5	0.000	16	2.279	27	2.519
6	0.000	17	2.309	28	2.534
7	0.000	18	2.335	29	2.549
8	0.000	19	2.361	30	2.563
9	0.000	20	2.385	31	`2.577
10	2.036	21	2.408	32	2.591
11	2.088	22	2.429	33	2.604

Source: U.S. Water Resources Council, 1981. This table contains one sided 10 percent significance level Kn values for the Normal distribution [10].

TableA- 2: Correlation coefficient

Correlation coefficient	Strength of relationship
$\pm 0.70 - 1.00$	Strong
$\pm 0.30 - 0.69$	Moderate
$\pm 0.00 - 0.29$	None (.00) to weak

The stronger the correlation, the more tightly the data points cluster around an imaginary line through their center. When there is a perfect correlation (± 1.00), the data points all fall on a straight line [12].

Regression Analysis

It involves determining the equation for the best fitting line for a data set

$$y' = mx + b$$

y'= is the predicted value on the y variable

$m =$ Slope of the line

$x =$ Represents individual score

$$m = r * \frac{\sigma y}{\sigma x}\ ; r = correlation\ coefficiennt$$

$$b = ybar - m * xbar$$

$$r = \frac{N\sum xy - \sum x \sum y}{\sqrt{(N\sum X^2 - (\sum X)^2} * \sqrt{N\sum Y^2 - (\sum Y)^2}}$$

For example, Gondar

The standard deviation and the mean of Gondar for both the dependant and independent variables and the correlation coefficient of the collected data are 0.1627, 0.8879, 1.2279, 0.0909 and 0.974 respectively. Then

$m = r\frac{\sigma y}{\sigma x} = 0.974 * \frac{0.1627}{0.8879} = 0.1784$

Therefore: the equation for the best fitting line for a data set

$y' = mx + b = 0.1784x + b$

Where $b = ymean - m * x\ mean = 1.2279 - 0.1784 * 0.0909 = 1.2117$

$y' = mx + b = 0.1784x + 1.2117$

APPENDIX B

Predicting Gust Wind Speed

Table B-1 Results of predicting Gust wind speeds for Addis Ababa using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	26.37	24.83	26.46	25.92	27.42	26.06
10	31.38	31.28	31.18	31.27	31.18	31.00
15	34.21	35.63	33.06	34.43	33.06	33.80
20	36.19	39.04	34.29	36.69	34.29	35.78
25	37.71	41.88	35.20	38.47	35.20	37.30
30	38.95	44.34	35.91	39.94	35.91	38.55
50	**42.41**	**52.00**	**37.80**	**44.15**	**37.80**	**42.04**
100	47.07	64.46	40.13	50.09	40.13	46.82
200	51.71	79.84	42.27	56.35	42.27	51.66
500	57.84	105.89	44.85	65.18	44.85	58.20
1000	62.47	131.08	46.67	72.33	46.67	63.29

Table B-2 Results of predicting Gust wind speeds for Arba Minch using different distribution method

	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using **Log Gumbel**	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using Log Normal
5	18.90	17.00	20.94	19.24	23.71	20.09
10	23.18	22.27	28.07	26.10	28.25	25.38
15	25.59	25.93	32.34	30.83	30.52	28.51
20	27.28	28.85	35.41	34.57	32.00	30.77
25	28.59	31.31	37.81	37.70	33.09	32.55
30	29.65	33.48	39.78	40.44	33.95	34.02
50	**32.60**	**40.33**	**45.38**	**48.99**	**36.21**	**38.23**
100	36.58	51.83	53.14	63.07	39.02	44.18
200	40.54	66.57	61.06	80.65	41.60	50.43
500	45.78	92.59	71.79	110.76	44.71	59.20
1000	49.73	118.82	80.08	140.18	46.90	66.25

Table B-3 Results of predicting Gust wind speeds for Bahir Dar using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	24.38	23.56	24.73	24.40	25.19	24.51
10	28.26	28.50	28.46	28.83	28.11	28.29
15	30.45	31.74	30.47	31.51	29.56	30.39
20	31.98	34.22	31.85	33.48	30.52	31.85
25	33.16	36.26	32.90	35.04	31.22	32.97
30	34.11	38.02	33.74	36.34	31.77	33.87
50	**36.79**	**43.36**	**36.04**	**40.14**	**33.22**	**36.39**
100	40.39	51.77	39.04	45.67	35.03	39.76
200	43.98	61.77	41.96	51.69	36.68	43.13
500	48.72	77.98	45.70	60.52	38.68	47.59
1000	52.31	92.99	48.47	67.95	40.09	50.99

Table B-4 Results of predicting Gust wind speeds for Debre Markos using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	22.50	21.61	22.93	22.35	23.29	22.54
10	26.26	26.43	26.43	26.53	26.11	26.23
15	28.38	29.61	28.31	29.00	27.53	28.29
20	29.87	32.07	29.58	30.78	28.45	29.72
25	31.01	34.09	30.55	32.17	29.13	30.83
30	31.94	35.84	31.32	33.33	29.66	31.72
50	**34.53**	**41.18**	**33.42**	**36.65**	**31.08**	**34.21**
100	38.03	49.66	36.15	41.37	32.83	37.58
200	41.52	59.86	38.78	46.36	34.43	40.95
500	46.11	76.58	42.13	53.46	36.37	45.44
1000	49.59	92.25	44.59	59.24	37.74	48.88

Table B-5 Results of predicting Gust wind speeds for Debre Zeit using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	22.45	22.21	23.22	23.23	22.56	22.30
10	25.32	25.92	25.60	26.44	24.60	24.89
15	26.94	28.28	26.82	28.25	25.62	26.29
20	28.08	30.07	27.63	29.51	26.29	27.25
25	28.95	31.52	28.22	30.49	26.78	27.98
30	29.66	32.75	28.70	31.28	27.17	28.57
50	**31.64**	**36.43**	**29.96**	**33.50**	**28.19**	**30.18**
100	34.31	42.07	31.55	36.53	29.46	32.30
200	36.97	48.56	33.03	39.59	30.62	34.38
500	40.48	58.67	34.86	43.73	32.02	37.07
1000	43.13	67.69	36.16	46.94	33.01	39.09

Table B-6 Results of predicting Gust wind speeds for Dire Dawa using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using **Log Pearson**	Predicted gust speed Using Normal	Predicted gust speed Using Log Normal
5	22.39	20.49	21.23	20.56	23.31	21.40
10	26.80	25.25	26.46	25.51	26.63	25.04
15	29.28	28.41	29.60	28.75	28.28	27.09
20	31.02	30.85	31.85	31.24	29.36	28.51
25	32.36	32.88	33.62	33.29	30.16	29.61
30	33.45	34.62	35.07	35.05	30.78	30.51
50	**36.49**	**39.99**	**39.21**	**40.40**	**32.44**	**33.00**
100	40.59	48.57	44.93	48.82	34.49	36.37
200	44.67	58.95	50.80	58.80	36.37	39.76
500	50.05	76.11	58.74	74.97	38.64	44.29
1000	54.12	92.33	64.89	89.94	40.24	47.77

Table B-7 Results of predicting Gust wind speeds for Gode Met using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	23.03	23	23.97	23.21	23.74	23.25
10	26.42	26	27.48	26.65	26.29	26.55
15	28.34	28	29.36	28.58	27.56	28.36
20	29.68	30	30.63	29.93	28.40	29.62
25	30.71	31	31.59	30.97	29.01	30.58
30	31.55	33	32.36	31.81	29.49	31.36
50	**33.89**	**36**	**34.46**	**34.17**	**30.77**	**33.50**
100	37.04	41	37.18	37.38	32.35	36.37
200	40.19	46	39.79	40.60	33.79	39.21
500	44.33	55	43.12	44.94	35.54	42.94
1000	47.47	63	45.56	48.29	36.77	45.77

Table B-8 Results of predicting Gust wind speeds for Gondar Air Port using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using **Log Gumbel**	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using Log Normal
5	23.22	22.13	23.60	22.84	24.09	23.16
10	27.38	27.55	27.59	27.75	27.22	27.32
15	29.73	31.18	29.74	30.74	28.78	29.66
20	31.37	34.00	31.21	32.94	29.80	31.30
25	32.63	36.34	32.33	34.69	30.55	32.57
30	33.66	38.36	33.22	36.15	31.15	33.60
50	**36.53**	**44.63**	**35.67**	**40.42**	**32.71**	**36.48**
100	40.41	54.72	38.87	46.67	34.65	40.40
200	44.26	67.04	41.96	53.50	36.42	44.36
500	49.35	87.65	45.94	63.57	38.57	49.68
1000	53.20	107.33	48.87	72.07	40.08	53.78

Table B-9 Results of predicting Gust wind speeds for Gore using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	21.60	19.14	21.81	19.87	22.70	20.42
10	26.86	26.09	27.13	26.44	26.66	25.77
15	29.83	31.07	30.07	30.78	28.63	28.95
20	31.91	35.11	32.09	34.13	29.93	31.24
25	33.51	38.58	33.64	36.90	30.88	33.04
30	34.81	41.65	34.89	39.27	31.63	34.53
50	**38.44**	**51.57**	**38.32**	**46.52**	**33.60**	**38.79**
100	43.34	68.80	42.88	57.96	36.05	44.81
200	48.22	91.67	47.34	71.56	38.30	51.14
500	54.65	133.88	53.13	93.58	41.02	60.01
1000	59.52	178.26	57.46	113.92	42.92	67.14

Table B-10 Results of predicting Gust wind speeds for Hawassa using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using **Log Gumbel**	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using Log Normal
5	20.90	18.94	20.85	19.04	23.79	21.54
10	25.37	24.18	25.57	24.48	27.66	26.35
15	27.90	27.76	28.21	28.13	29.59	29.14
20	29.66	30.57	30.05	30.98	30.86	31.13
25	31.02	32.93	31.46	33.35	31.79	32.67
30	32.13	34.98	32.61	35.39	32.52	33.94
50	**35.22**	**41.41**	**35.78**	**41.72**	**34.45**	**37.54**
100	39.38	51.99	40.03	51.92	36.85	42.52
200	43.52	65.21	44.24	64.37	39.04	47.67
500	48.99	87.94	49.75	85.18	41.70	54.74
1000	53.13	110.23	53.90	105.06	43.56	60.33

Table B-11 Results of predicting Gust wind speeds for Jimma using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	24.85	24.67	26.02	26.40	25.02	27.00
10	30.19	34.77	30.42	32.79	28.79	31.00
15	33.20	42.20	32.67	36.33	30.67	33.21
20	35.31	48.33	34.17	38.78	31.90	34.74
25	36.94	53.65	35.28	40.66	32.80	35.91
30	38.26	58.41	36.16	42.17	33.51	36.86
50	**41.94**	**74.02**	**38.50**	**46.33**	**35.40**	**39.50**
100	46.91	101.88	41.47	51.82	37.73	43.02
200	51.87	140.06	44.23	57.16	39.86	46.52
500	58.40	213.14	47.65	64.02	42.45	51.15
1000	63.34	292.75	50.09	69.08	44.26	54.66

Table B-12 Results of predicting Gust wind speeds for Kibre Mengist using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	20.12	19.32	20.44	19.34	21.08	19.56
10	24.73	25.95	24.97	24.92	24.55	24.53
15	27.33	30.65	27.44	28.42	26.28	27.46
20	29.15	34.43	29.14	31.02	27.41	29.56
25	30.55	37.67	30.43	33.12	28.25	31.21
30	31.69	40.52	31.47	34.89	28.90	32.58
50	**34.87**	**49.66**	**34.33**	**40.10**	**30.63**	**36.47**
100	39.15	65.34	38.08	47.89	32.78	41.95
200	43.42	85.88	41.74	56.58	34.74	47.69
500	49.06	123.17	46.46	69.66	37.12	55.70
1000	53.31	161.77	49.97	80.91	38.79	62.10

Table B-13 Results of predicting Gust wind speeds for Kombolcha using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using **Log Pearson**	Predicted gust speed Using Normal	Predicted gust speed Using Log Normal
5	23.68	22.00	23.33	22.53	24.64	23.03
10	28.25	27.42	28.35	27.70	28.07	27.18
15	30.82	31.05	31.23	30.95	29.78	29.53
20	32.63	33.87	33.25	33.38	30.91	31.17
25	34.02	36.22	34.81	35.34	31.73	32.44
30	35.15	38.25	36.08	36.99	32.38	33.47
50	**38.30**	**44.52**	**39.64**	**41.90**	**34.10**	**36.36**
100	42.54	54.65	44.44	49.28	36.22	40.29
200	46.77	67.02	49.25	57.62	38.17	44.25
500	52.36	87.74	55.62	70.35	40.53	49.59
1000	56.58	107.55	60.46	81.48	42.18	53.70

Table B-14 Results of predicting Gust wind speeds for Mekelle using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	27.58	27.70	28.33	28.64	28.25	28.60
10	30.79	32.30	30.17	30.77	30.67	32.11
15	32.61	35.23	31.01	31.73	31.88	34.01
20	33.88	37.43	31.54	32.32	32.66	35.32
25	34.85	39.22	31.91	32.74	33.25	36.32
30	35.65	40.75	32.20	33.05	33.70	37.12
50	**37.86**	**45.30**	**32.93**	**33.83**	**34.91**	**39.33**
100	40.85	52.26	33.77	34.69	36.41	42.25
200	43.83	60.27	34.48	35.38	37.77	45.11
500	47.76	72.73	35.27	36.09	39.43	48.83
1000	50.72	83.83	35.78	36.51	40.60	51.63

Table B-15 Results of predicting Gust wind speeds for Metehara using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	26.76	25.19	26.44	26.53	27.87	26.54
10	32.08	32.38	32.23	32.11	31.87	32.06
15	35.08	37.30	35.53	35.33	33.86	35.23
20	37.17	41.19	37.84	37.62	35.17	37.47
25	38.79	44.46	39.62	39.40	36.13	39.21
30	40.11	47.31	41.08	40.86	36.89	40.64
50	**43.77**	**56.25**	**45.12**	**44.98**	**38.89**	**44.66**
100	48.72	71.05	50.58	50.70	41.36	50.20
200	53.65	89.67	56.03	56.58	43.63	55.87
500	60.15	121.89	63.23	64.66	46.37	63.60
1000	65.06	153.7185	68.68	71.02	48.30	69.66

Table B-16 Results of predicting Gust wind speeds for Negelle using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	25.18	24.43	25.65	25.28	25.16	24.60
10	29.02	29.33	29.18	29.31	27.86	28.02
15	31.18	32.52	31.06	31.60	29.20	29.90
20	32.70	34.95	32.34	33.22	30.08	31.20
25	33.87	36.95	33.30	34.47	30.72	32.19
30	34.82	38.66	34.07	35.49	31.23	32.99
50	**37.46**	**43.85**	**36.16**	**38.38**	**32.58**	**35.21**
100	41.04	51.98	38.88	42.35	34.24	38.16
200	44.59	61.58	41.48	46.42	35.77	41.08
500	49.29	77.00	44.79	51.98	37.62	44.92
1000	52.84	91.17	47.21	56.35	38.91	47.82

Table B-17 Results of predicting Gust wind speeds for Nekemte using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	23.35	22.11	24.09	23.74	23.81	22.84
10	28.41	30.35	28.57	29.53	27.66	29.25
15	31.27	36.29	30.92	32.84	29.58	33.09
20	33.28	41.13	32.51	35.17	30.84	35.88
25	34.82	45.29	33.70	36.97	31.76	38.08
30	36.07	48.98	34.64	38.44	32.49	39.90
50	**39.57**	**60.94**	**37.20**	**42.54**	**34.41**	**45.15**
100	44.29	81.83	40.49	48.12	36.79	52.62
200	48.99	109.75	43.62	53.73	38.97	60.54
500	55.18	161.68	47.55	61.23	41.62	71.74
1000	59.87	216.6667	50.41	66.97	43.47	80.82

Table B-18 Results of predicting Gust wind speeds for Robe using different distribution method

1	2	3	4	5	6	7
Return Period (years)	Predicted gust speed Using Gumbel dsn.	Predicted gust speed Using Log Gumbel	Predicted gust speed Using Pearson	Predicted gust speed Using Log Pearson	Predicted gust speed Using Normal	Predicted gust speed Using **Log Normal**
5	22.29	16.33	22.70	22.42	23.04	22.46
10	25.87	19.89	26.03	26.16	25.73	26.05
15	27.89	22.22	27.82	28.28	27.08	28.05
20	29.31	24.02	29.03	29.77	27.96	29.44
25	30.40	25.50	29.94	30.93	28.61	30.50
30	31.29	26.77	30.68	31.87	29.12	31.37
50	**33.76**	**30.67**	**32.67**	**34.52**	**30.46**	**33.78**
100	37.09	36.83	35.26	38.14	32.13	37.02
200	40.41	44.20	37.75	41.83	33.66	40.26
500	44.80	56.23	40.93	46.83	35.51	44.57
1000	48.11	67.45	43.26	50.74	36.81	47.87

APPENDIX C

Missing Data Estimation and Double Mass Calculation

Weather condition in Ethiopia is divided into five zones these are;

1. 3300 meter height from mean sea level and above, Frosty weather(Wurch or Kur), the annual average temperature is below 10 degree siliceous
2. Between 2300m and 3300m height from mean sea level, High land (Dega), the annual average temperature is between 10-15 degree siliceous
3. Between 1500m and 2300m height from mean sea level, Temperate (Weina Dega), the annual average temperature is between 15-20 degree siliceous
4. Between 500m and 1500m height from mean sea level, Low land (Kola), the annual average temperature is between 20-30 degree siliceous
5. 500 meter height from mean sea level and below, Wild region, desert(Bereha), the annual average temperature is between 30-40 degree siliceous

Based on these criteria the selected stations fall under between desert (Bereha) and High land (Dega).

Stations group based on altitude

Group 1

- Addis Ababa obs
- Debre Markos
- Gore
- Mekelle AP obs
- Nekemte
- Robe

Group 3

- Arba Minch
- Dire Dawa
- Gode Met
- Metehara

Group 2

- Bahir Dar
- Debre Zeit
- Gondar AP
- Hawassa
- Jimma
- Kibre Mengist
- Kombolcha
- Negelle

This grouping is important for estimating the missing data and checking the consistency of the data by drawing the double mass curve.

Missing data calculation

For Addis Ababa

Normal annual wind speed for Addis Ababa obs is 17.14 m/sec, Normal annual wind speed for Debre Markos is 13.54 m/sec, Normal annual wind speed for Gore is 11.46 m/sec, Normal annual wind speed for Mekelle AP obs is 17.91 m/sec, Normal annual wind speed for Nekemte is 12.21 m/sec and Normal annual wind speed for Robe is 13.79 m/sec.

10% of 17.14=1.714 from here 17.14-1.714 and 17.14+1.714 are 15.426 and 18.854 respectively. The normal annual wind speed of the remaining stations such as Debre Markos, Gore, Mekelle AP obs, Nekemte and Robe are not within 10% of Normal annual wind speed for Addis Ababa. Hence Normal Ratio Method is applied to estimate the missing data of 1991, 1995, 1998, 1999, 2006, 2007, 2008, 2009, and 2010

Table C-1 Collected yearly maximum wind speed for Addis Ababa without forecasting

Year	1985	1986	1987	1988	1989	1990	**1991**	1992	1993	1994	**1995**
Speed @180 min	40	34	40	22	22	20		20	18	16	
Speed @10 min	52.8	44.88	52.8	29.04	29.04	26.4		26.4	23.76	21.12	
Year	1996	1997	**1998**	**1999**	2000	2001	2002	2003	2004	2005	
Speed @180 min	30	10			10	9	10	10	10	10	
Speed @10 min	39.6	13.2			13.2	11.88	13.2	13.2	13.2	13.2	
Year	**2006**	**2007**	**2008**	**2009**	**2010**	2011	2012	2013	2014	2015	
Speed @180 min						10	10	8	8	10	
Speed @10 min						13.2	13.2	10.56	10.56	13.2	

$Wx = \frac{Nx}{M}\left\{\frac{W1}{N1} + \frac{W2}{N2} + \frac{W3}{N3} + \cdots + \frac{Wn}{NM}\right\}$……from equation 3

$$WAA\ obs = \frac{NAA}{M}\left\{\frac{WDM}{NDm} + \frac{WGore}{NGore} + \frac{WMekelle}{NMekelle} + \frac{W\ Nekemte}{N\ Nekemte} + \frac{W\ Robe}{N\ Robe}\right\}$$

$$W1991 = \frac{17.14}{3}\left\{\frac{0}{13.54} + \frac{19}{11.46} + \frac{0}{17.91} + \frac{14}{12.21} + \frac{12}{13.79}\right\} = 22\ m/sec$$

$$W1995 = \frac{17.14}{5}\left\{\frac{12}{13.54} + \frac{6}{11.46} + \frac{10}{17.91} + \frac{20}{12.21} + \frac{16}{13.79}\right\} = 16\ m/sec$$

$$W1998 = 15\frac{m}{sec}\ ;\ W1999 = 16\frac{m}{sec};\ W2006 = 16\frac{m}{sec}; W2007 = 17\frac{m}{sec};$$

$$W2008 = 20\frac{m}{sec}; W2009 = 14; \frac{m}{sec}; W2010 = 12\frac{m}{sec}$$

Table C-2 Forecasting the missing wind speed data for Addis Ababa

Year	1991	1995	1998	1999	2006	2007	2008	2009	2010
Speed (m/sec)	22	16	15	16	16	17	20	14	12

Table C-3 Collected yearly maximum wind speed for Addis Ababa with forecasting

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Speed @180 min	40	34	40	22	22	20	21	20	18	16	16
Speed @10min	52.8	44.88	52.8	29.04	29.04	26.4	27.72	26.4	23.76	21.12	21.12
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	30	10	15	16	10	9	10	10	10	10	
Speed @10min	39.6	13.2	19.8	21.12	13.2	11.88	13.2	13.2	13.2	13.2	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	16	17	20	14	12	10	10	8	8	10	
Speed @10min	21.12	22.44	26.4	18.48	15.84	13.2	13.2	10.56	10.56	13.2	

Note: Speed means Average wind speed at 180 minute time interval

Missing Estimation for Nekemte in 1987, and 2013

$$Nekemte\ 1987 = \frac{12.214}{3}\left\{\frac{40}{17.14} + \frac{24}{13.79} + \frac{30}{15.323}\right\} = 25\ m/sec$$

$$Nekemte\ 2013 = \frac{12.214}{4}\left\{\frac{8}{13.545} + \frac{8}{17.14} + \frac{8}{11.462} + \frac{12}{17.9}\right\} = 7\ m/sec$$

Table C-4 Collected yearly maximum wind speed for Nekemte with forecasting

Year	1985	1986	**1987**	1988	1989	1990	1991	1992	1993	1994
Speed @180 min	20	10	25	4	25	20	14	13	10	12
Speed @10min	26.4	13.2	33	5.28	33	26.4	18.48	17.16	13.2	15.84
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Speed @180 min	20	10	9	6	12	7	8	20	23	23
Speed @10min	26.4	13.2	11.88	7.92	15.84	9.24	10.56	26.4	30.36	30.36
Year	2005	2006	2007	2008	2009	2010	2011	2012	**2013**	2014
Speed @180 min	14	13	6	8	6	4	14	7	7	4
Speed @10min	18.48	17.16	7.92	10.56	7.92	5.28	18.48	9.24	9.24	5.28

Applying similar procedures, to estimate the missing wind speed for each station

Table C-5: Collected yearly maximum wind speed for Arba Minch

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Speed @180 min	24	20	12	40	16	18	10	10	9	8
Speed @10min	31.68	26.4	15.84	52.8	21.12	23.76	13.2	13.2	11.88	10.56
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	8	8	8	25	7	4	6	5	8	
Speed @10min	10.56	10.56	10.56	33	9.24	5.28	7.92	6.6	10.56	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Speed @180 min	8	12	6	10	8	6	6	10	7	
Speed @10min	10.56	15.84	7.92	13.2	10.56	7.92	7.92	13.2	9.24	

Table C-6 Collected yearly maximum wind speed for Bahir Dar

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Speed 180 min	10	20	23	10	10	14	15	23	12	24	12
Speed 10 min	13.2	26.4	30.36	13.2	13.2	18.48	19.8	30.36	15.84	31.68	15.84
Year	2005	2006	2007	2008	2009	2010	2011	2012	**2013**	2014	2015
Speed 180 min	12	12	13	15	14	25	13	12	16	7	15
Speed 10 min	15.84	15.84	17.16	19.8	18.48	33	17.16	15.84	21.12	9.24	19.8

Table C-7 Collected yearly maximum wind speed for Debre Markos

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Speed 180 min	10	12	12	12	10	12	10	18	10	20	20
Speed 10 min	13.2	15.84	15.84	15.84	13.2	15.84	13.2	23.76	13.2	26.4	26.4
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Speed 180 min	14	12	10	20	17	10	22	23	8	8	8
Speed 10 min	18.48	15.84	13.2	26.4	22.44	13.2	29.04	30.36	10.56	10.56	10.56

Table C-8 Collected yearly maximum wind speed for Gondar

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
180 min	10	10	15	23	9	10	8	15	10	14	20
10 min	13.2	13.2	19.8	30.36	11.88	13.2	10.56	19.8	13.2	18.48	26.4
Year	2005	2006	2007	2008	2009	2010	2011	2012	**2013**	2014	2015
180 min	10	10	15	25	18	11	23	9	16	7	40
10 min	13.2	13.2	19.8	33	23.76	14.52	30.36	11.88	21.12	9.24	52.8

Table C-9 Collected yearly maximum wind speed for Hawassa

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
180 min	10	20	8	8	8	8	9	10	20	10	8
10 min	13.2	26.4	10.56	10.56	10.56	10.56	11.88	13.2	26.4	13.2	10.56
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
180 min	23	22	10	7	8	8	8	23	9	8	28.2
10 min	30.36	29.04	13.2	9.24	10.56	10.56	10.56	30.36	11.88	10.56	37.224

Table C-10 Collected yearly maximum wind speed for Kibre Mengist

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
180 min	21	8	21	12	21	8	10	6	8	8	8
10 min	27.72	10.56	27.72	15.84	27.72	10.56	13.2	7.92	10.56	10.56	10.56
Year	2005	2006	2007	2008	2009	2010	2011	2012	**2013**	2014	2015
180 min	21	12	8	6	4	8	8	21	12	5	5
10 min	27.72	15.84	10.56	7.92	5.28	10.56	10.56	27.72	15.84	6.6	6.6

Table C-11 Collected yearly maximum wind speed for Gore

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
180 min	6	19	6	9	8	6	10	8	4	6	8	8	8
10 min	7.92	25.08	7.92	11.88	10.56	7.92	13.2	10.56	5.28	7.92	10.56	10.56	10.6
Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
180 min	21	8	21	8	25	25	7	7	21	23	8	9	9
10 min	27.72	10.56	27.72	10.56	33	33	9.24	9.24	27.72	30.36	10.56	11.88	11.9

Table C-12 Collected yearly maximum wind speed for Gode

Year	1985	1986	1987	1988	1989	1990	**1991**	**1992**	1993	1994	1995
Speed @180 min	10	12	8	8	9	9	20	21	12	13	10
Speed @10min	13.2	15.8	10.6	10.6	11.9	11.9	26.4	27.7	15.8	17.2	13.2
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	13	12	15	16	23	11	12	15	20	14	
Speed @10min	17.2	15.8	19.8	21.1	30.4	14.5	15.8	19.8	26.4	18.5	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	22	24	16	16	16	16	12	12	12	14	
Speed @10min	29.0	31.7	21.1	21.1	21.1	21.1	15.8	15.8	15.8	18.5	

Table C-13 Collected yearly maximum wind speed for Dire Dawa

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Speed @180 min	10	12	14	8	10	10	23	7	10	12	12
Speed @10min	13.2	15.8	18.5	10.6	13.2	13.2	30.4	9.2	13.2	15.8	15.8
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Speed @180 min	9	20	32	12	12	10	10	12	16	14	8
Speed @10min	11.9	26.4	42.2	15.8	15.8	13.2	13.2	15.8	21.1	18.5	10.6

Table C-14 Collected yearly maximum wind speed for Kombolcha

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Speed @180 min	30	34	30	20	16	16	16	12	12	10	9
Speed @10min	39.6	44.9	39.6	26.4	21.1	21.1	21.1	15.8	15.8	13.2	11.9
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	10	14	14	14	8	10	13	9	12	20	
Speed @10min	13.2	18.5	18.5	18.5	10.6	13.2	17.2	11.9	15.8	26.4	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	9	14	14	8	10	22	8	8	9	36	
Speed @10min	11.9	18.5	18.5	10.6	13.2	29.0	10.6	10.6	11.9	47.5	

Table C-15 Collected yearly maximum wind speed for Metehara

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Speed @180 min	16	20	20	18	40	25	22	23	14	14	20
Speed @10min	21.12	26.4	26.4	23.76	52.8	33	29.04	30.36	18.48	18.48	26.4
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	20	20	18	14	14	14	8	8	15	8	
Speed @10min	26.4	26.4	23.76	18.48	18.48	18.48	10.56	10.56	19.8	10.56	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	14	12	10	14	8	6	8	8	10	14	
Speed @10min	18.48	15.84	13.2	18.48	10.56	7.92	10.56	10.56	13.2	18.48	

Table C-16 Collected yearly maximum wind speed for Mekelle

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Speed @180 min	12	10	10	20	15	22	24	24	15	20	20	18
Speed @10min	15.84	13.2	13.2	26.4	19.8	29	31.68	31.68	19.8	26.4	26.4	23.76
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	20	20	20	20	20	20	16	18	12	13	11	
Speed @10min	26.4	26.4	26.4	26.4	26.4	26.4	21.12	23.76	15.84	17.16	14.52	

Table C-17 Collected yearly maximum wind speed for Jimma

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Speed @180 min	4	20	3								8
Speed @10min	5.28	26.4	3.96								10.56
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	10	15	10	10	11	10	8	9	20	23	
Speed @10min	13.2	19.8	13.2	13.2	14.52	13.2	10.56	11.88	26.4	30.36	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	8	8	12	10	20	9	9	23	6	6	
Speed @10min	10.56	10.56	15.84	13.2	26.4	11.88	11.88	30.36	7.92	7.92	

Table C-18 Collected yearly maximum wind speed for Negelle

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Speed @180 min	12	9						20	20	20	12
Speed @10min	15.8	11.9						26.4	26.4	26.4	15.8
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	12	14	10	25	14	11	18	11	14	23	
Speed @10min	15.8	18.5	13.2	33	18.5	14.5	23.8	14.5	18.5	30.4	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	11	11	14	14	14	14	14	16	24	8	
Speed @10min	14.5	14.5	18.5	18.5	18.5	18.5	18.5	21.1	31.7	10.6	

Table C-19 Collected yearly maximum wind speed for Debre Zeit

Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Speed @180 min	20	20									12
Speed @10min	26.4	26.4									15.84
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Speed @180 min	10	10	10	10	13	12	12	10	14	12	11
Speed @10min	13.2	13.2	13.2	13.2	17.16	15.84	15.84	13.2	18.48	15.84	14.52
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Speed @180 min	12	16	13	21	15	11	9	14	7	20	
Speed @10min	15.84	21.12	17.16	27.72	19.8	14.52	11.88	18.48	9.24	26.4	

Table C-20 Collected yearly maximum wind speed for Robe

Year	1985	1986	1987	1988	1989	**1990**	1991	1992	**1993**	1994	1995
Speed @180 min	13	20	24	12	13	15	12	11	11	12	16
Speed @10min	17.16	26.4	31.68	15.84	17.16	19.8	15.84	14.52	14.52	15.84	21.12
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Speed @180 min	16	16	23	14	18	20	14	12	14	12	
Speed @10min	21.12	21.12	30.36	18.48	23.76	26.4	18.48	15.84	18.48	15.84	
Year	2006	2007	2008	2009	2010	2011	2012	**2013**	2014	2015	
Speed @180 min	14	8	8	9	9	8	8	8	22	8	
Speed @10min	18.48	10.56	10.56	11.88	11.88	10.56	10.56	10.56	29.04	10.56	

Double Mass Curve for Each Station

Table C-21 Double mass curve for Addis Ababa

year	Addis Ababa	Debre Markos	Gore	Mekelle	Nekemte	Robe	Average annual wind speed for the group
1987	34				10	20	21.33
1988	22				4	12	12.67
1989	22				25	13	20.00
1990	20		6		20	15	15.25
1991	21		19		14	12	16.50
1992	20		6		13	11	12.50
1993	18		9	12	10	11	12.00
1994	16	10	8	10	12	12	11.33
1995	16	12	6	10	20	16	13.33
1996	30	12	10	20	10	16	16.33
1997	10	12	8	15	9	16	11.67
1998	15	10	4	22	6	23	13.33
1999	16	12	6	24	12	14	14.00
2000	10	10	8	24	7	18	12.83
2001	9	18	8	15	8	20	13.00
2002	10	10	8	20	20	14	13.67
2003	10	20	21	20	23	12	17.67

2004	10	20	8	18	23	14	15.50
2005	10	14	21	20	14	12	15.17
2006	16	12	8	20	13	14	13.83
2007	17	10	25	20	6	8	14.33
2008	20	20	25	20	8	8	16.83
2009	14	17	7	20	6	9	12.17
2010	12	10	7	20	4	9	10.33
2011	10	22	21	16	14	8	15.17
2012	10	23	23	18	7	8	14.83
2013	8	8	8	12	7	8	8.50
2014	8	8	9	13	4	22	10.67
2015	10	8	9	11		8	9.20

Table C-22 Double mass Technique for Addis Ababa

1	2	3	4	5	6	7
Year	Wm	sum(Wm)	W average	sum(W average)	sum(Wm)	sum(W average)
2015	10	10	9.20	9.20	0	10.00
2014	8	18	10.67	19.87	0	8.00
2013	8	26	8.50	28.37	0	8.00
2012	10	36	14.83	43.20	0	10.00
2011	10	46	15.17	58.37	0	10.00
2010	12	58	10.33	68.70	0	12.00
2009	14	72	12.17	80.87	0	14.00
2008	20	92	16.83	97.70	0	20.00
2007	17	109	14.33	112.03	0	17.00
2006	16	125	13.83	125.87	0	16.00
2005	10	135	15.17	141.03	0	10.00
2004	10	145	15.50	156.53	0	10.00
2003	10	155	17.67	174.20	0	10.00
2002	10	165	13.67	187.87	0	10.00
2001	9	174	13.00	200.87	0	9.00
2000	10	184	12.83	213.70	0	10.00
1999	16	200	14.00	227.70	0	16.00
1998	15	215	13.33	241.03	0	15.00
1997	10	225	11.67	252.70	0	10.00
1996	30	255	16.33	269.03	0	30.00

1995	16	271	13.33	282.37	0	16.00
1994	16	287	11.33	293.70	0	16.00
1993	18	305	12.00	305.70	0	18.00
1992	20	325	12.50	318.20	0	20.00
1991	21	346	16.50	334.70	0	21.00
1990	20	366	15.25	349.95	0	20.00
1989	22	388	20.00	369.95	0	22.00
1988	22	410	12.67	382.62	0	22.00
1987	34	444	21.33	403.95	0	34.00

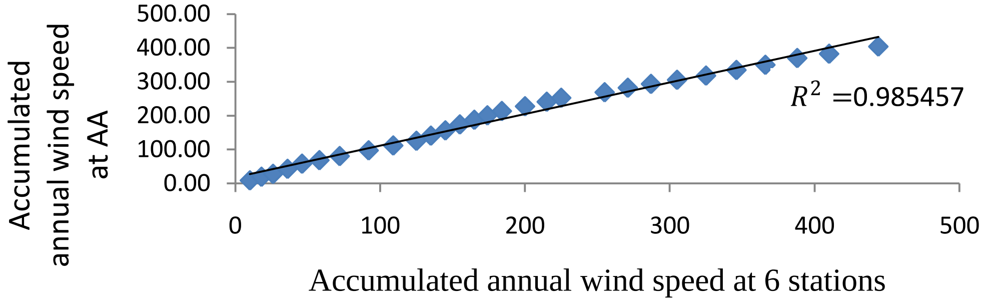

Figure C- 1 Double mass curve for Addis Ababa station

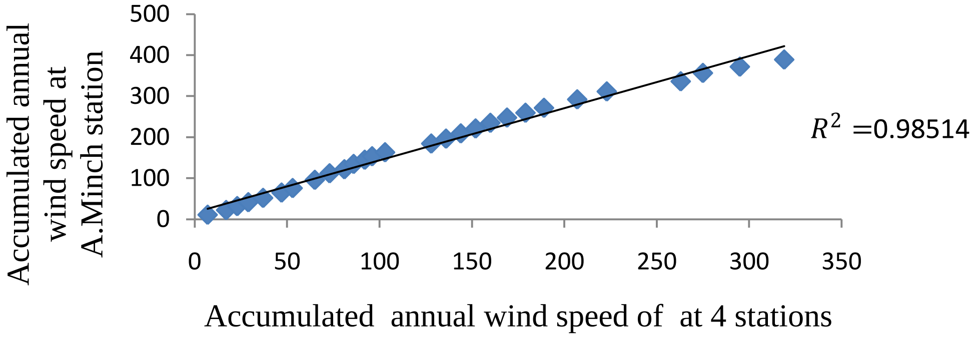

Figure C- 2 Double mass curve for Arba Minch station

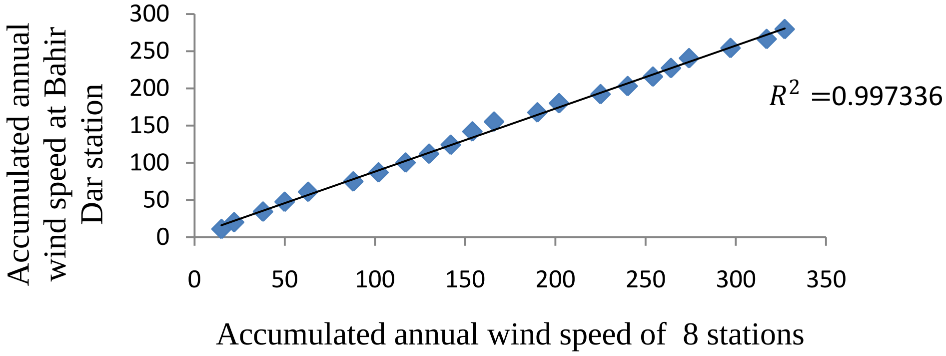

Figure C- 3 Double mass curve for Bahir Dar station

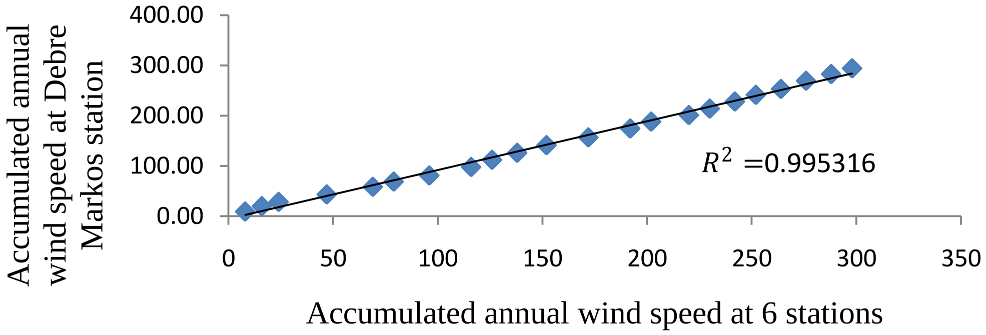

Figure C- 4 Double mass curve for Debre Markos station

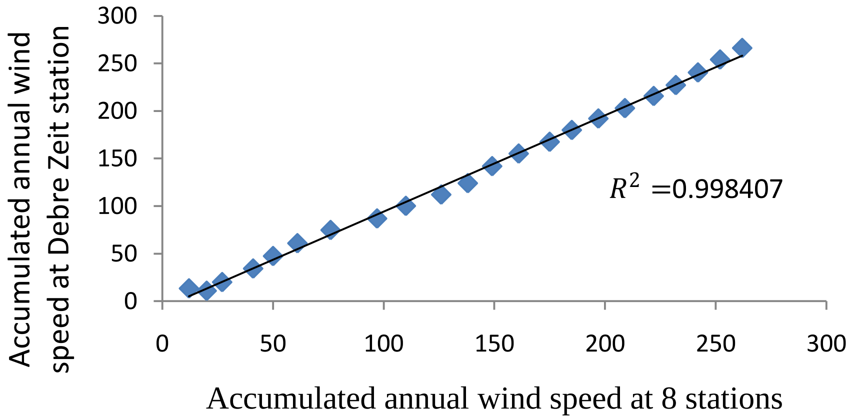

Figure C- 5 Double mass curve for Debre Zeit station

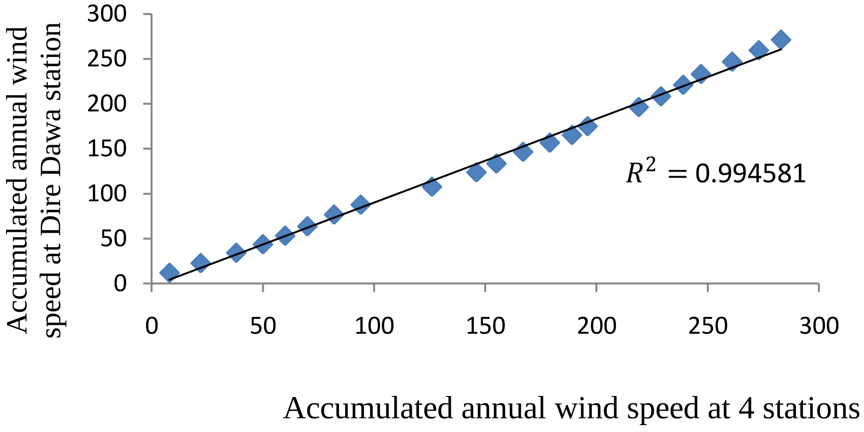

Figure C- 6 Double mass curve for Dire Dawa station

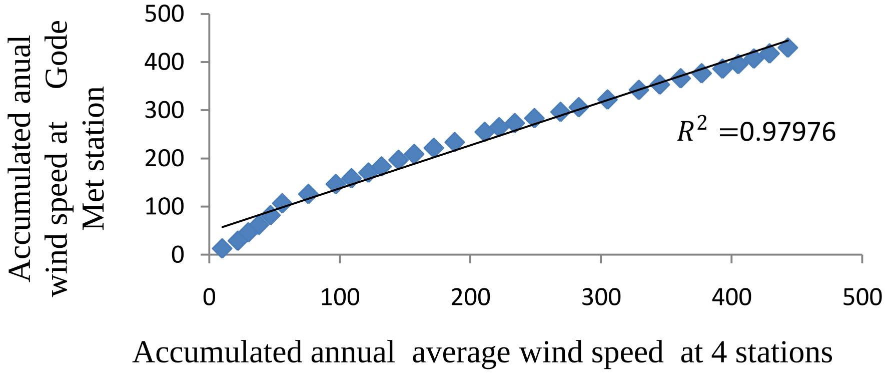

Figure C- 7 Double mass curve for Gode station

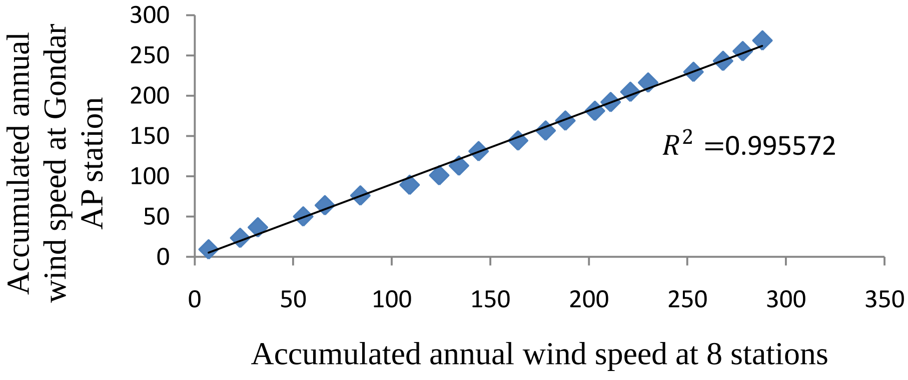

Figure C- 8 Double mass curve for Gondar station

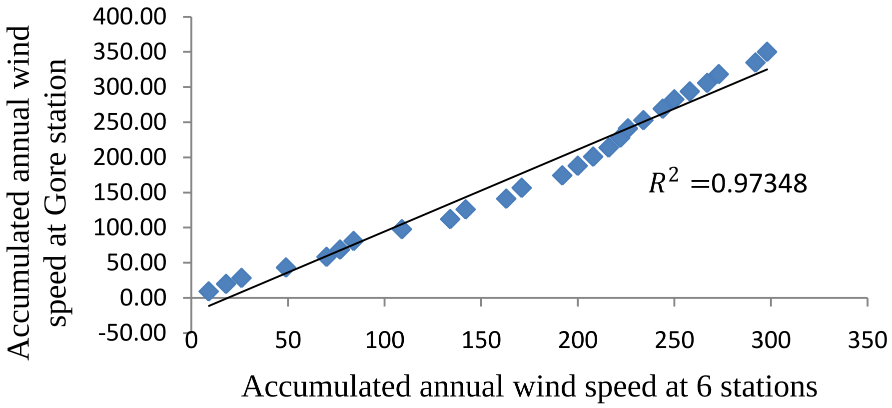

Figure C- 9 Double mass curve for Gore station

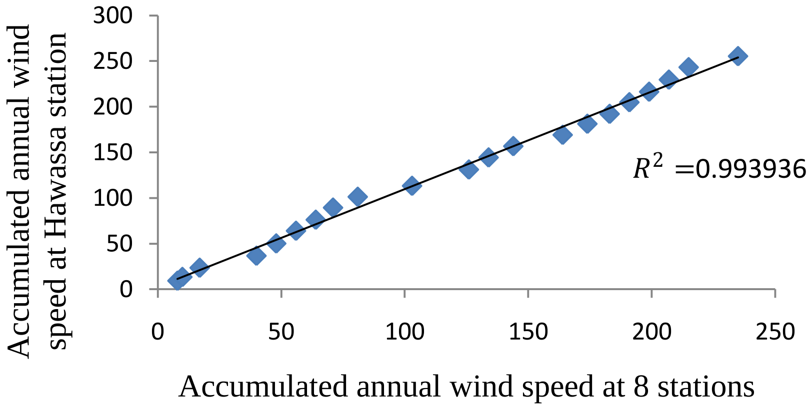

Figure C- 10 Double mass curve for Hawassa station

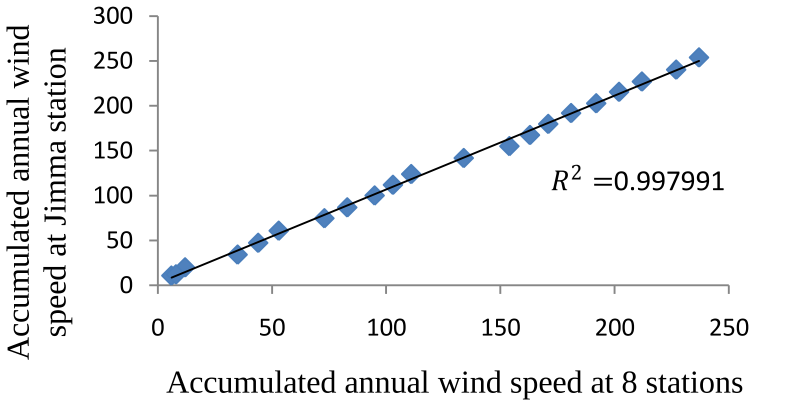

Figure C- 11 Double mass curve for Jimma station

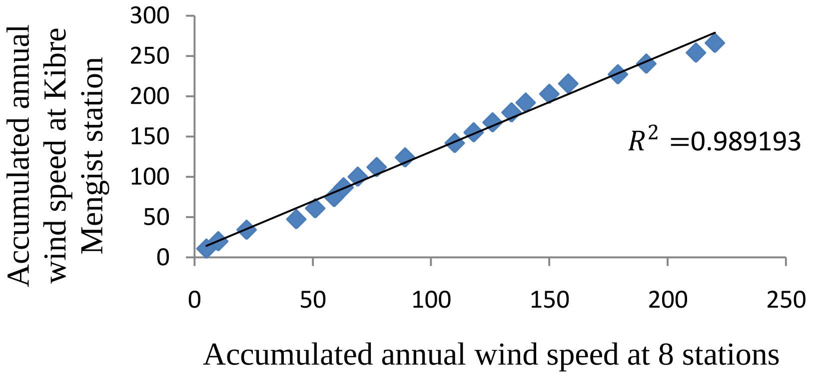

Figure C- 12 Double mass curve for Kibre Mengist

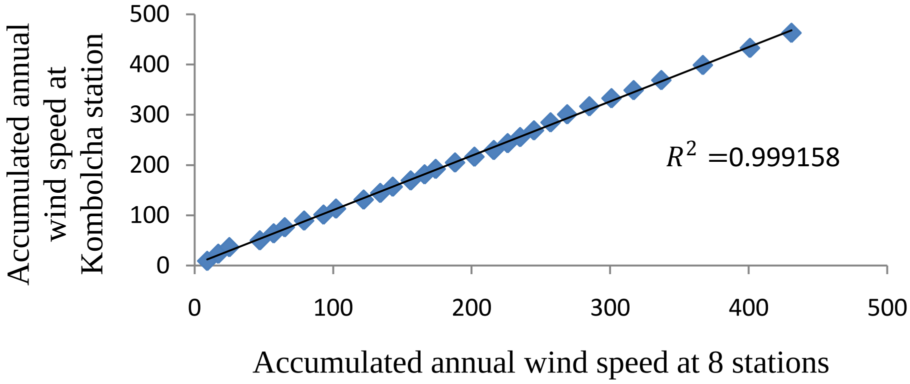

Figure C- 13 Double mass curve for Kombolcha

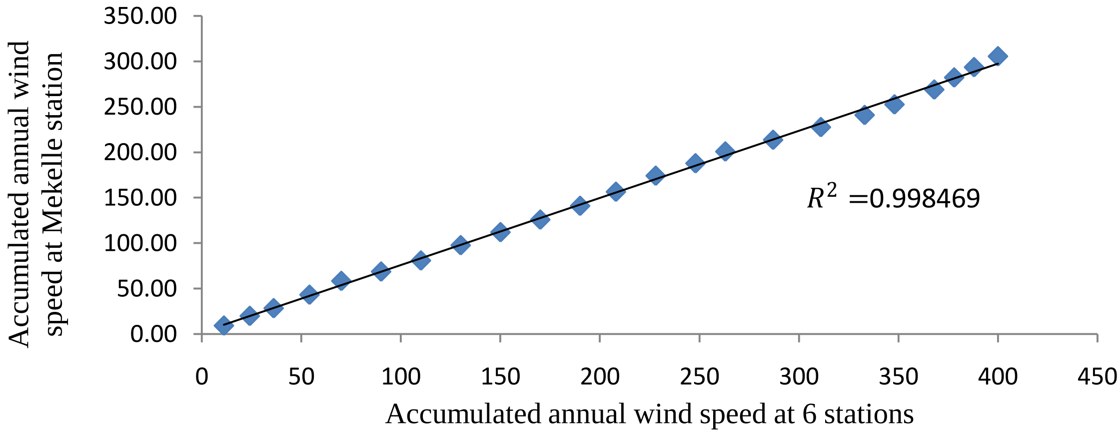

Figure C- 14 Double mass curve for Mekelle

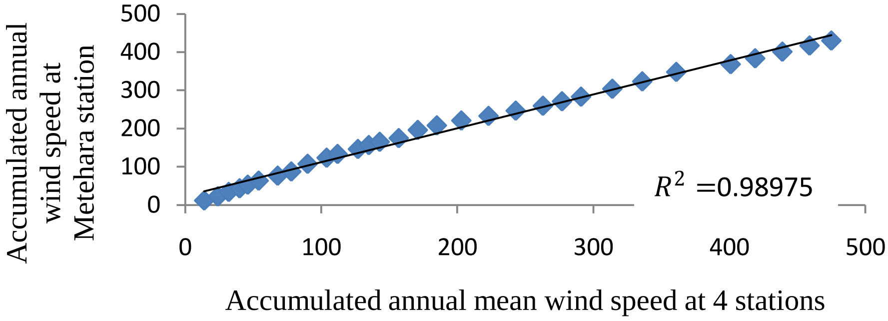

Figure C- 15 Double mass curve for Metehara

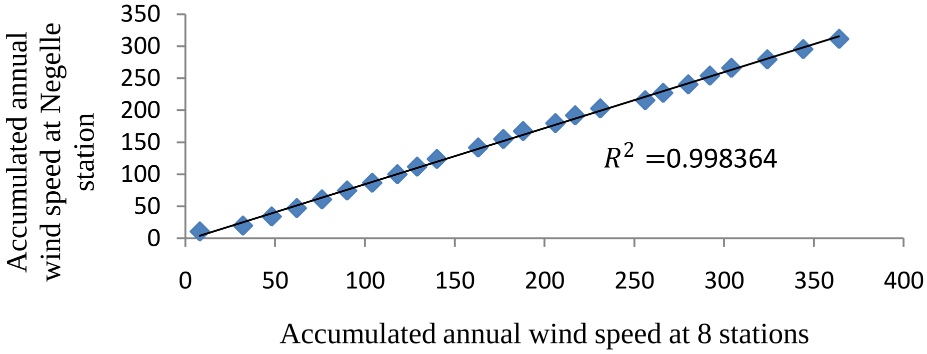

Figure C- 16 Double mass curve for Negelle station

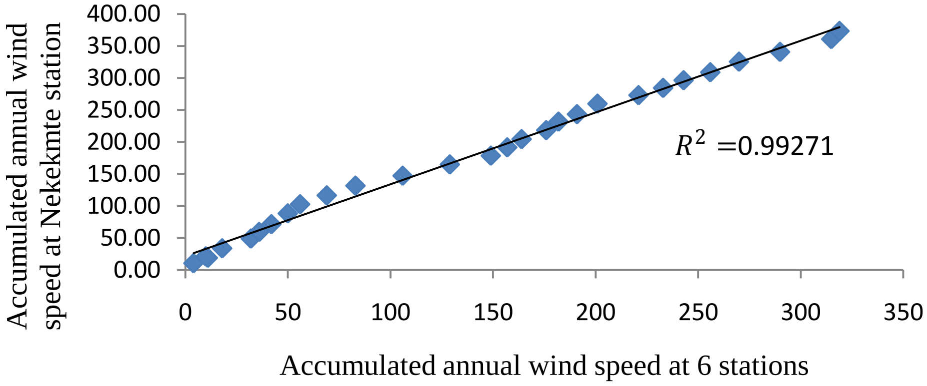

Figure C- 17 Double mass curve for Nekemte station

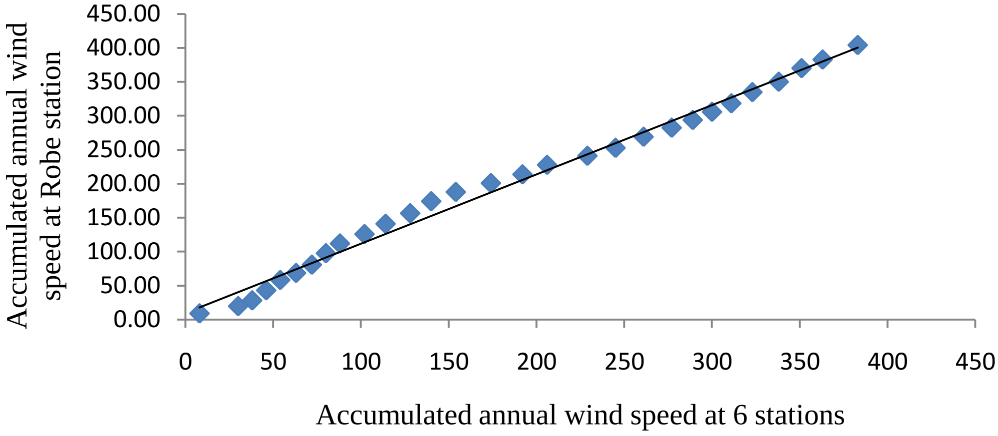

Figure C- 18 Double mass curve for Robe station

This page intentionally left blank