Evaluation of Wind Characteristics and Feasibility of Wind Energy in the Coastal Areas of Bangladesh

by

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The thesis titled "**Evaluation of Wind Characteristics and Feasibility of Wind Energy in the Coastal Areas of Bangladesh**" submitted by **A.N.M. Mominul Islam Mukut,** Roll no. 100510036P, Session October 2005 has been accepted satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Mechanical Engineering on 3rd February, 2008.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

A.N.M. Mominul Islam Mukut

(A.N.M. Mominul Islam Mukut)

To my Parents

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ABSTRACT

A statistical analysis of Wind characteristics and investigation of feasibility of wind energy has been conducted. Wind characteristics of coastal regions in Bangladesh have been analyzed and hence a compatible design of horizontal axis wind turbine applicable to the pump has been performed.

The available wind data collected by a project work for collecting wind data of the coastal areas in Bangladesh financed by LGED in year 2003 on some stations at a height 10m have been converted for the 20m hub-height using power law. From these data hourly average speed, monthly average speeds have been calculated. It is observed that for few regions of Bangladesh, there is reasonable wind speed available throughout the year to extract power. From this data velocity frequency tables are done and histograms have been plotted for every month for each station and compared with each other. The wind speed distribution is processed and fitted to the Weibull function to determine the nature of wind regime for that site. The shape factor (k) and scale factor (c) of Weibull function are also determined. Then the Weibull function F(v), Weibull density function f(v) and velocity distribution function S(v) are plotted from the observed and calculated values for each month for each regions. The wind energy concentration (Wh/m^2) has also been calculated.

For a prospective regions of Bangladesh a design of wind turbine for water pumping has been performed based on the requirement of water of that region. The design incorporates the generalized procedure for determination of rotor and pump sizes. Thus it can be used for any other region as well having the same wind speed range.

To present a generalized design for Bangladesh, an empirical relation has been developed for the rotor and the pump sizing for a particular region of Bangladesh.

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A	Area
B	Number of blades
C	Blade chord
c	Scale parameter
C_D	Turbine overall drag coefficient= $F_D/½\rho A V_a^2$
C_l	Blade lift coefficient
C_{ld}	Design lift coefficient
C_P	Turbine overall power coefficient=$P_0/½\rho A V_a^2$
D	Rotor diameter
h	Height of turbine, hub height from ground level
h_i	frequency
h_{ref}	Height of a reference point from ground level
k	Shape parameter
P	Turbine power
P_e	Extracted power
r	Local blade radius
r_{hub}	Hub radius
R	Rotor radius
$\overline{V}$	Average wind speed
λ_d	Tip speed ratio
λ_r	Local design speed
φ	Angle of relative velocity
β_T	Twist angle
α	Angle of attack
V_d	Design velocity
q	Pumping rate
H	Total pumping head

LIST OF ABBREVIATIONS

WECS	Wind Energy Conversion Systems
LGED	Local Government Engineering Department
BCAS	Bangladesh Centre for Advanced Studies
BUET	Bangladesh University of Engineering and Technology
BCSIR	Bangladesh Council of Scientific and Industrial Research
WWEA	World Wind Energy Association
BWDB	Bangladesh Water Development Board
BRRI	Bangladesh Rice Research Institute
BAEC	Bangladesh Atomic Energy Commission
REB	Rural Electricity Board
BRAC	Bangladesh Rural Advancement Committee
IEA	International Energy Agency
EC	The European Community
DAE	Directorate of Agricultural Extension

Chapter 1

INTRODUCTION

1.1 General:

Energy is the prime need for modern civilization. Higher rate of energy use indicates the high growing structure of a country. Due to development of modern civilization the demand of energy all over the world is increasing day by day. It is one of the basic inputs in everyday life of human being. Various types of energy sources, like oil, hydro, coal, natural gas, nuclear etc., are used for different purposes all around the world. Among these conventional fuels, only hydro is in nature and other sources are major causes of air pollution and greenhouse effect. Replacing the conventional fuels with renewable energy sources include wind energy, solar (photovoltaic) systems, solar thermal systems, biomass energy (wood and other plant fuels), geothermal energy, fuel cell, municipal waste, etc. The costs of many of these technologies have come down considerably in recent years, particularly wind energy, which is now competitive with conventional power sources in regions with strong winds.

The science of exploitation of wind power is not a new one. For the past few centuries people are extracting energy from the wind in various ways. One means for converting wind energy to a more useful form is through the use of windmills. Recently, due to the fuel crisis, this science is gaining more popularity. Wind energy has become very beneficial, now-a-days, due to its reliability. According to a projection by American Wind Energy Association (AWEA) - wind turbine installation in the world through the end of 2006 is 6,950 MW (in Asia 4455 MW; and Other 2,495MW).

By the end of this decade, it will add, 38 countries whould have at least 50 MW of capacity in place compared with just 10 MW today. The emerging forecast of incremental wind power is shown in Table 1.1.

Table 1.1: Forecasting of future Wind Power

Year	1990	1995	2000	2005	2010
Incremental World Capacity Additions (MW/Yr)	300	727	1761	3861	8465

Source: D.P. Kothari, "Importance of Renewable Energy Sources."-Proceeding ASRE-'97

1.2 Wind as a Source of Energy

For a long time peoples are extracting energy from fossil fuels in almost all the countries. In some of the countries, they are also utilizing nuclear fuel, which is a source of nuclear energy. With the rising demand of the energy and for many other reasons, the prices of the fuels are increasing day by day. So, the people are trying to find alternative sources of energy to exploit them at the cheapest cost. Wind energy is a kind of energy source, which will never be diminished. It is available almost all the time, at all places and in large quantities all over the world. Again fossil and nuclear fuels will be finished some day. These are not available in all countries. Besides these, peoples are interested to be self-dependent; they do not like to rely on imported fuel, which require huge amount of foreign currency. As a result in different parts of the world, people are taking keen interest to develop efficient and economic devices to collect energy from the wind. Recently, the utilization of wind power is increasing in many developed, as well as, under developed countries. Although the wind speed may vary from one location to another location, Wind energy is more effective as it is free and almost available throughout. About twenty years ago, large numbers of experiments were done in the laboratory to develop the appropriate technology for utilization of wind energy. It was quite cost competitive with any thermal and coal power plants. Now a days, wind energy conversion systems (WECS) have been extensively used in Germany, Denmark, Netherlands, UK, Russia, Brazil and Australia. Asian counties, like China, India and Indonesia have also been using this technology. The wind resource assessments have been completed recently in Japan, Thailand, Srilanka and Malaysia. A few wind farms have been installed in Japan, Thailand and Srilanka. Malaysia is also going to install wind farms in wind prospective areas. Compared to other developing countries, Bangladesh is in its initial stage for utilizing WECS. Some organizations like LGED, BCAS, BUET, and BCSIR have already started measuring wind speeds at some typical locations of Bangladesh with modern equipments.

To make proper use of wind energy, proper site selection and wind speed availability are to be considered first. The wind speed and its duration are the key factors to design and to determine the use of wind energy. So to generate accurate and more reliable wind speed data, the wind speed data monitoring system must be carried out before going to take any plan to implement either comprehensive or pilot plant in this regard. With a view to evaluating the actual pattern of wind energy, a typical location is chosen and wind speed is continuously monitored by means of an electronic and computer based apparatus.

1.3 Methodology:

To obtain reliable wind data for evaluating wind energy concentration (kWh/m^2), it is necessary to measure and to record wind speeds continuously at a regular interval by means of a high accuracy modern digital electronic system. The wind data of the coastal areas in Bangladesh from March to September, 2003 have been used for the present research [1]. The data are further analyzed and converted into several useful parameters, like daily mean wind speed, monthly mean wind speed, and mean annual wind speed. After that, the velocity frequency bar graph, energy bar graph, velocity duration curve, etc. have been plotted and analyzed.

The wind speed data of a location has been fitted to Weibull function to find different parameters for that site. The value of Weibull shape factor (k) and Weibull scale factor (c) have been calculated by different methods and compared and plotted them by employing different methods. Then a Wind Turbine has been designed for an effective location for water pumping purpose.

1.4 Objectives:

The following are the main objectives of the present research:

I. To compile and analysis of existing wind speed data for the selected site/station such as Kuakata (Patuakhali), Mongla (Bagherhat), Sandwip (Chittagong), Kutubdia (Cox's Bazar) and Teknaf (Cox's Bazar).

II. Preparing hourly, daily, weekly, monthly, yearly basis average wind speed for each station to find out the wind nature, forecasting the wind speed for the missing time and identify the most effective wind speed and time for effective use of wind speed for each station. To compare the wind speed data among these stations

III. Finally, to study the prospect of wind energy in the coastal region of Bangladesh.

IV. Designing a wind turbine for water pumping for a prospective site.

1.5 Scope of the Thesis:

The prime vision of this thesis work is to analyze the wind characteristics in coastal region of Bangladesh and designing a wind turbine system for a prospective location for water pumping.

In Chapter-1, the historical background of energy utilization is discussed and prospect of "Wind" as a source of energy is also presented. Next the methodology, aim and scope of the study are also given. Review of the existing literatures is also presented. Historical background of energy utilization and present energy scenario of the world has been discussed.

In chapter-2, detail energy utilizations in Bangladesh have been explained according to sector-wise energy utilization. In the same time, the prospect of wind energy in Bangladesh is also discussed here.

In chapter-3, the theory of Weibull distribution and also the method to determine the shape and scale parameter of Weibull distribution have been described in detail.

In chapter-4, the ten minutes interval wind data (rough data) are processed for preparing hourly, daily basis data and also monthly average wind velocity for each station are also calculated. Then the calculated data is processed for Weibull distribution, the shape factor (k) and scale factor (c) are determined for each month.

In chapter-5, the prospect of wind energy for water pumping has been discussed in details.

In chapter-6, a wind turbine is designed for the site of Kutubdia and it is found that this location is more effective for wind turbine application.

In chapter-7, a pump is design for Kutubdia for irrigation and drinking purpose with designing a storage tank.

Then discussion, conclusion and recommendation of this work are given in chapter-8 and chapter-9 respectively.

1.6 Review of Literature:

Due to increase in energy demand throughout the whole world, researchers in different countries are always continuing their research to make the best use of wind as a energy. Some analyze the nature of wind for a specified reason and then designing wind turbine for that location for the effective use of wind. Some papers related to the present thesis work are mentioned below-

Chang and Tu [2], used the wind speed data in the chronological (time-series) format and probabilistic (Weibull) format to estimate the monthly capacity factors of Vestas V47–660 kW turbines in Mailiao. The monthly capacity factors calculated from the chronological and probabilistic approaches are compared with and validated by the measured capacity factors obtained in Mailiao.

Král [3] handled statistical estimates of the ten-minute wind velocity mean values and estimates of the gust wind maxima throughout the Czech Republic to find out the causes behind this difference and to propose the way to be taken to settle the contradiction.

Some of the gust estimates are significantly higher than equivalent gusts determined by means of the peak velocity pressure model from the ten-minute mean velocity estimates.

Moisselin et al. [4] elaborated a new extreme wind speeds map, an homogenization tool is developed that allow the detection and the correction of breaks due to sensor change and modification of measurement environment. Breaks are detected on annual mean wind speed series. Daily maximal wind speed values for about 150 wind speed stations have been selected using this method.

Valeria Durañona et al. [5] prepared a paper that represented an analysis of wind velocity data relating to 11 extreme non-synoptic events obtained from velocity time series pertaining to flow over rural and coastal terrain. The data were measured at a number of locations within Northern Europe and in all cases a sufficient array of anemometry was present to obtain an indication of the velocity profile.

Rajabi and Modarres [6] estimated maximum wind speed. This study used prevalent westerly annual maximum wind speeds for the period of 1983–1998 for East Isfahan station in Isfahan Province, Iran. The frequency analysis of annual maximum wind speeds data obtained by averaging the wind data over some chosen averaging periods.

Wisse and Stigter [7] prepared a paper to find out better wind speed area, quality control of existing data, search of historical archives and generation of data by numerical weather analyses in Africa region.

Gökçek et al. [8] investigated wind characteristics and wind energy potential of Kırklareli province in the Marmara Region, Turkey and analyzed the wind data measured as hourly time series. The wind data used in the study were taken from Electrical Power Resources Survey and Development Administration (EIEI) for the year 2004. The measured wind data were processed as annual, seasonal and monthly basis.

Riahy and M. Abedi [9] worked in wind speed forecasting. The method utilizes the 'linear prediction' method in conjunction with 'filtering' of the wind speed waveform.

The filtering eliminates the undesired parts of the frequency spectrum (i.e. smoothing) of the measured wind speed which is less effective in an application, for example, in a wind energy conversion system. The linear prediction method is intuitively explained with some easy to follow case studies to clarify the complex underlying mathematics. For verification purposes, the proposed method is compared with real wind speed data based on experimental results. The results show the effectiveness of the linear prediction method.

Chowdhury, et al. [10] investigated that the low-cost sail-wing windmill was found to work with greater efficiency compared to other types of windmills recently developed in India. The efficiency of the windmill is maximum (23%) at wind speed of 9 km/hr and found to decrease with an increase in wind speed beyond 9 km/hr. The volume of water that can, be pumped from the water table at varying depths at wind velocities ranging from 8 to 30 km/hr was also determined.

Panda, et al. [11] studied that the proper assessment of a wind resource is a prerequisite for its successful utilization through appropriate wind energy systems. The Southern High Plans of the United States is a region with a wind resource for potential water pumping. In this region, wind speed varies between 5.6 and 6.4 m/s at a 10 m height and between 7 and 8 m/s at a 50 m height: The major objectives of this study were to analysis of long term hourly wind-speed data, comparative study of selected wind pumps, computation of daily discharge, and estimate of reservoir capacity at different risk levels.

The average and peak discharges of both the mechanical wind pumps were almost identical at 30m and 45m operating heads. However, the discharge of the electrical wind pump was more than four times higher than that of its mechanical counterparts at higher wind speeds. Not much difference, except for furling wind speed, was observed in the performance of the electrical wind pump at 30m, 45m, and 60m lift conditions. The discharge was significantly higher for 60m lift condition at higher wind speeds. This wind pump, therefore, is suitable for pumping ground water under the high wind regime conditions of Southern High Plans.

Alam, et al. [12] compared the performance of wind pumping systems (WPS) using centrifugal pumps, coupled by either mechanical or electrical drives. For mechanical transmission between centrifugal pump and wind turbine, overall system performance may be improved by running slowly a larger sized centrifugal pump. Matching of this type is likely to be most beneficial for shallow lifts.

Siddig, M. H. [13] studied the feasibility of wind pumping in Zimbabwe. Wind pump was compared to the two conventional pumping methods: diesel and grid powered pumps. The analysis results in a comparative feasibility chart for Zimbabwe and duty is defined as the volume-head product (QH) of water supply per day. Its main features are:

- The wind turbine is the pumping prime mover at average wind speeds exceeding 3 m/s in all of the duty range considered (0-2000 m^3/day)
- In the average wind speed range 2-3 m/s and where the duty exceeds 900 m^3 /day diesel pumping is the most feasible.
- The duty-wind speed constraint is seen to dictate, in most conditions, use of a 6m diameter rotor. Use of the 7m unit would yield higher output at a slightly higher capital. It does also allow extension of use to high-duty low speed conditions. Use of the 3m rotor is limited to low duty high wind speed condition.
- Grid powered pumping is feasible only where grid connection costs are insignificant and, then, within limited duty and wind-speed ranges.

Swift, R. H. [14] had presented the parametric studies for water pumping windmills, with a view to establishing their characteristics, and the manner in their long term efficiency may be maximized. It had shown that the best results may be achieved by using a controlled leakage pump, that is, one with a small diameter hole drilled through the piston, to reduce the starting torque. By virtue of the reduction in starting torque, a windmill with a given H/R^3 value, would be capable of achieving 50% higher maximum long-term efficiency when coupled to a controlled leakage pump, than when equipped with an unmodified piston pump.

Yongfen, W. [15] reported that almost 90% of the small wind turbines operating in China were found in the Autonomous Region of Inner Mongolia, where they had been used predominantly for battery charging. The wind region is not uniform across the region, however, and in many areas the electricity generated is available only for part of the time and involves unfavorable charge cycling, and hence shorter life of the batteries. The high price of the batteries then renders the systems uneconomic. Increasing use if, therefore, now being made of solar cell arrays in conjunction with the wind turbines to produce more continuous power throughout the year and reduce the severity of the charging cycle.

Suresh et al. [16] carried out the study includes system design, operational status, performance in the field and to carry out a financial study of deep well wind pumps installed under the demonstration program by Ministry of Non-conventional Energy Sources in India. Eight of the twenty-two systems surveyed were found functional and detailed technical evaluations were also carried out. The paper highlights the issues and problems both technical, as well as, policy wise faced by this sector. Recommendations are made to improve the system performance and better propagation of the technology.

Robert, et al. [17] derived the equations for the simple near optimum design of wind turbines with mechanically driven centrifugal pumps. According to similarities laws for wind turbines and centrifugal pumps the optimal gear box ratio, the wind speed of optimal total efficiency and the cut-in wind speed can be calculated. The only required data for the turbine series are the power coefficient and the tip speed ratio, in the optimal point. The pump characteristics are described by the data of the nominal pump (nominal speed, impeller diameter, as well as, shaft power and total head at nominal speed, both as a function of capacity), static head and the diameter ratio of turbine rotor and pump impeller. Results of computer calculations conform the validity of this simple design method.

Siddig, M. H. [18] suggested the procedures for maximizes system efficiency and secures continuous within the design range and predicts the starting and stopping behavior of wind-power piston pumps.

Sarkar et al. [19] collected the hourly wind speed data of the coastal area of Chittagong for the years 1978-81. From the hourly average wind speed, the hourly and monthly energy outputs were computed for three commercial machines (22 kW, 16 kW and 4 kW) having different cut-in wind speed. The 22kW machine was found to produce higher energy output per m^2 than the other two for the selected energy region. The hourly and monthly energy variation of the 22 kW machine was studied and the cost per kWh of energy produced by the machine was obtained. Considering the wind speed distribution of Bangladesh, it appears that a wind machine in combination with a conventional diesel back up system will be economically viable for electricity generation in the off-shore islands.

Hussain, et al. [20] studied the characteristics of wind data for three recent years, recorded at 14 stations of the Bangladesh Meteorological Department. The data have been used to compute the monthly average wind speed and wind energy available for; the stations. Average values of monthly wind speed for 1931-1960 have been employed to obtain the energy availability from the energy pattern factor, and the two sets of results have been compared. It has been found that, for the Chittagong station, the frequency distributions have good fits of the Weibull type.

1.7 Historical Uses of Wind Energy:

No one knows when exactly the use of wind energy took place. The first breakthrough must have been the use of sails for navigation. Wind energy has been used to propel ships for a long time. In the past, many countries supported their prosperity on their ability to navigate, America being discovered by such type of navigated ships. Roughly wind was the only power to move ships until James Watt developed the steam. [21] Inshore Windmills were used from many centuries ago. There is an evidence of windmills being used for grinding grains by the Egyptians in the 36th BC. The Buddhist monks in Tibet had religious inscriptions (mantras) on drums which were rotated by the wind. A similar technique was known to have been used in Egyptian, Persian and early Christian places of worship. Hammurabi [21], emperor of the Babylonian Empire, used windmills for irrigation, around 17th century BC. Extensive use of windmills was made from the time of Hammaurabi till the 15th century AD. in Persia and adjoining areas. The 10th century Arab writer Al Istahri has mentioned windmills in Seitan, a land near the present boundary between Iran and Afghanistan. Hero from Alexandria, who lived during the 3rd century BC, described simple windmills with a horizontal axis, which was used to produce the power for an organ working with compressed air. The Persian people utilized windmills extensively by the middle of the 7th century BC. The machine was mounted on a horizontal axis and used axially disposed sails. It is difficult to access whether this kind of machine was commonly used in the Egypt. However, it could be said that the meridian part of the Mediterranean Sea, as in China, where only vertical axis machine were known.

It was only in Middle Ages that windmills appeared in Italy, France, Portugal and Spain. Somewhat later, windmills were found in the United Kingdom, Holland, and Germany. Some authors have suggested that the introduction of the windmills into Europe be due to the Crusades, when the Crusader returned from the Middle East. The first English windmills dates back to 1191AD and the first windmills for milling appeared in Holland in 1439 AD [21].

The multi-blade windmills appeared in the 14th century. However, in the Schauplatz de Wasser Kunste (Journal of Hydraulic Arts.) printed in Leipzing in 1724, an eight-bladed windmill could be found. The blades rotate about an axis changing their orientation as the wind varies its speed. The construction of such types of multi-blade machines started in America, in 1870. They were spread every where and then they returned to Europe in 1876. In the middle of the 15th century, a simple type of multi-blade windmill was developed to pump water from underground and was used during the America West colonization. It is believed that at least 6.5 millions of these units were constructed between 1830 and 1930 by different companies. A great number of these units are still under operation. The use of wind power started to drop during the Industrial Revolution, when the Steam Engine was invented and cheap fossil fuels become widely available.

In the aftermath of the "oil crisis", there was world-wide interest in the revival of wind power harnessing and major research programs were initiated in industrialized countries towards the development of modern wind turbines for large-scale electricity generation. Along with these, some institutions, notably the Consultancy Services for Wind Energy in Developing Countries in the Netherlands, IT Power Ltd. in the Great Britain and Northern Ireland initiated programs for development and dissemination of new generation of wind pumps for application in rural areas in developing countries. Emphasis of these programs was to develop designs of wind pumps, which were less costly than the traditional multi-bladed wind pump and could be locally manufactured in most developing countries. The designs evolved through these efforts are still being improved, but many of them could be considered mature enough for application under low to medium pumping head conditions. Compared to traditional multi-bladed wind pumps the modern designs seem to lack the reliability and robustness required for prolonged unattended operation in remote locations. But in many situations, the cost effectiveness of these machines could far outweigh the demand for frequent maintenance requirements [36].

1.8 Present Day Wind Electric Generators (WEG):

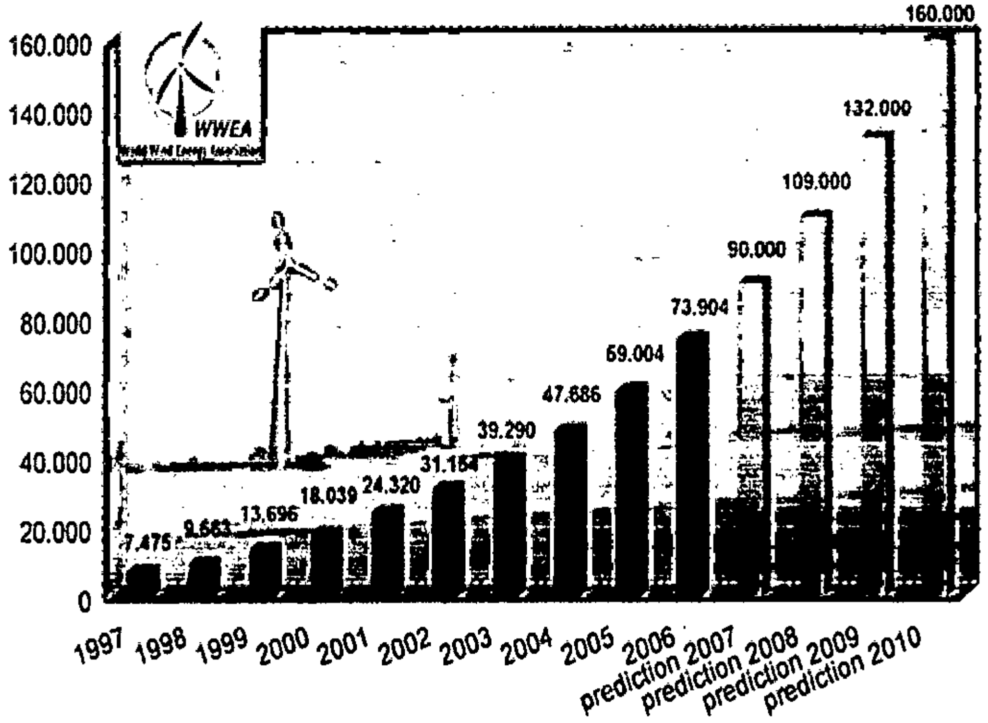
Present day phase of wind electric generators (WEG) started with the oil crisis of Middle East during 1975, when renewed need was felt for the development of New and Renewable Sources of Energy. Work on the development of wind electric generators started in many countries notably Denmark, Germany, the USA, the UK, the

Netherlands etc. This development took into two directions: one large size and other small size. Development of large megawatt size WEG started after 1975 in countries using the latest knowledge available in aerodynamic and structural analysis design tools, composite materials technology as fiber reinforced plastics and latest in electronics and microprocessor based on controller technology. Till 1992 about 25 different machines with rated capacity of more than 1000kW capacities, have been installed. However, all of the machines faced one or more technical problem and did not run for any longer duration. Some of them were partially technically viable but failed miserably on economic front. Most of these machines were one- off technical demonstrator prototype [22]. While most of the countries concentrated on development of large MW size wind electric generators, Denmark followed a different path and started with the development of a smaller size machine, which happen to be 55kW capacities. These machines appeared in the USA and Denmark during 1981 that were found to be techno-commercial viable and were manufactured in large scale. These were up rated progressively; keeping the basic design features almost the same as the Gedser design. Various sizes of machines, which were developed subsequently, are 100kW; 150kW, 200kW, 250kW, 300kW, 400kW, 500kW, 600kW and now even 1000kW to 1500kW machines are being introduced [22]. Now a days, many countries, like Germany, the USA, the UK, Australia, Japan, China, even India are manufacturing very small capacities i.e. 25 watts to 10 kW WEGs for very low wind speeds (1 m/s~5 m/s).

1.9 Growth of Wind Parks in the World:

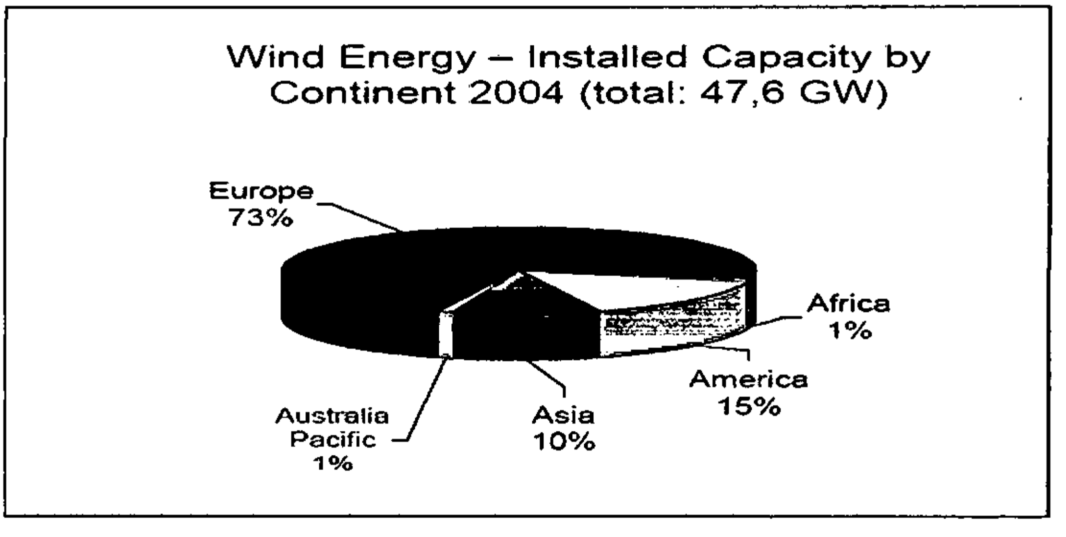
The present total installed capacity in the world was about 6000MW by the year 1996. This installed capacity is increasing day by day in all over the world. It was 4900MW by 1995 [23]. The first wind parks are installed in California in the USA in 1981. This installed

capacity was 10MW with 140 machines in 1981. This peaked to 1640MW in 1991.In addition to the USA installation have also taken place in many other countries, such as, Germany, Denmark, Holland, the UK, USSR, China, India, Thailand etc. The details of installations are as follows:



Source: World Wind Energy Association

Fig 1.9.1: Total Installed World Wind Capacity (MW) and Prediction 1997-2010



Source: World Wind Energy Association

Fig 1.9.2: Total Installed World Wind Capacity (GW) in 2004

Wind energy continued its dynamic growth worldwide in the year 2006, according to figures released by the World Wind Energy Association about 14 900 MW were added in the past year making a global installed capacity of 73,904 MW by the end of December 2006,

The added capacity equals a growth rate of 25 per cent, after 24 per cent in 2005. The currently installed wind power capacity generates more than one per cent of the global electricity consumption. Based on the accelerated development, World Wind Energy Association (WWEA) has increased its prediction for 2010 and expects now 160 000 MW to be installed by the end of 2010.

Five countries added more than 1000 MW: the USA (2454 MW), Germany (2194 MW), India (1840 MW) and Spain (1587 MW) were able to secure their leading market positions and China (1.45 MW) join the group of the now top five markets and is now number five in terms of added capacity, showing a market growth of 91 per cent.

Five countries added more than 500 MW and showed excellent growth rates: France (810 MW, 107 per cent growth), Canada (768 MW, 112 per cent), Portugal (628 MW, 61 per cent) and the UK (610 MW, 45 per cent). The most dynamic market in 2006, Brazil, faced its long expected take off and added 208 MW, which equals a sevenfold increase of installed capacity within one year.

At present the USA is the 1st, Germany is the 2nd and India is the 3rd position in the world as the installed capacity of Wind parks. The wind parks installation can be classified into four groups according to the available average wind speed and WEGS sizes they are as follows:

1st Group	Installation of WEGS (small scale) with capacities from 25W to 10 kW for Mechanical pumping, battery charger, lighting, radio and television within average wind speed of 2.5 m/s to 4.0 m/s.

2nd Group	Installation of WEGS (medium scale) with capacities from 10 kW to 55 kW for pumping, cold storage, lighting etc. within average wind speed range of 4.0 m/s to 5.0 m/s.
3rd Group	Installation of large scale WEGS with capacities from 55 kW and above for national grid connection with average wind speed of 5 m/s and above.
4th Group	Wind installations operating in hybrid system i.e. wind with diesel, wind with solar, wind with gas generator, wind with Bio-gas generator etc. capacities with 5kW to 100 kW for low speed wind sites,

Chapter 2

COUNTRY BACKGROUND
AND
ENERGY SCENARIO OF BANGLADESH

2.1 Geography:

Bangladesh is located between 20°34' and 26°38' north latitudes and between 88°01' and 92°41' east longitudes. Its terrain is mostly flat, being a delta formation of the network of major rivers and their tributaries. Total area of the country is about 144,000 sq. km. It has 744-km long coastal beach along the Bay of Bengal. There are a lot of hilly, haor, beels, riversides and free areas in Bangladesh. However, only 10% to 15% forest areas are present in Bangladesh. There are also many offshore islands in the sea areas of Bangladesh.

2.2 Climate:

Bangladesh is situated in the sub-tropical regions. It has a sub-tropical climate, which is warm and humid, with two pronounced monsoon seasons. Bangladesh is subjected to wind climate of Indian Ocean, that is south-west wind from May to August and north-east wind from October to February. During the period March to August, the winds are uniformly strong over Bangladesh and the rest periods, October to February are relative weaker, though higher winds are also available during a part of this period on some off-shore islands of Bangladesh. Daily temperatures vary little throughout the year. The annual mean temperature is 30°C, with maximum average of 36-38°C and a minimum of 25°C[25]. The relative humidity ranges from 65% to 80%. Annual average rainfall is 2,000mm. Monthly variations in rainfall are significant, ranging from 12.3mm in February to 300 mm in June-July. While there are occasional gales (on average 12 days a year) and tropical thunderstorm or cyclones

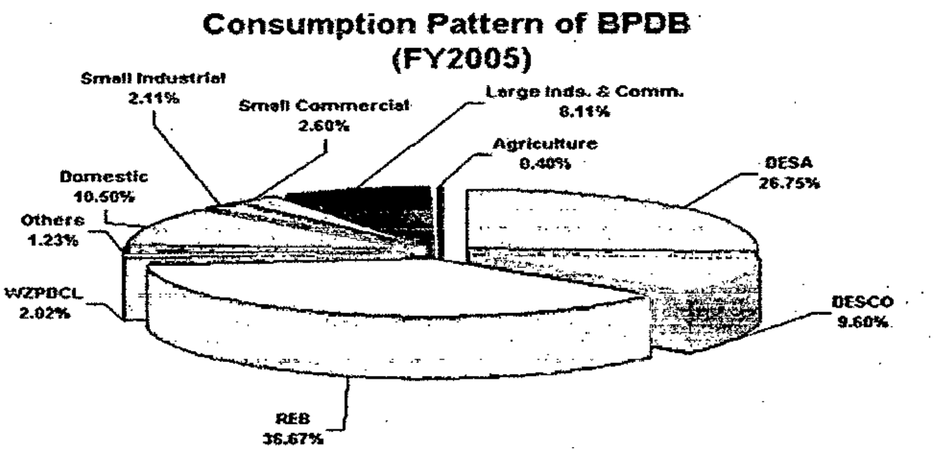
2.3 Population:

Bangladesh is one of the most density-populated countries of the world. The present population is about 140 million meaning 835 habitants per sq. km. About 85% people live in villages. The rest of the population is distributed among 492 urban locations and population centers. Many people also live in the offshore islands of Bangladesh.

2.4 Energy Demand and Supply:

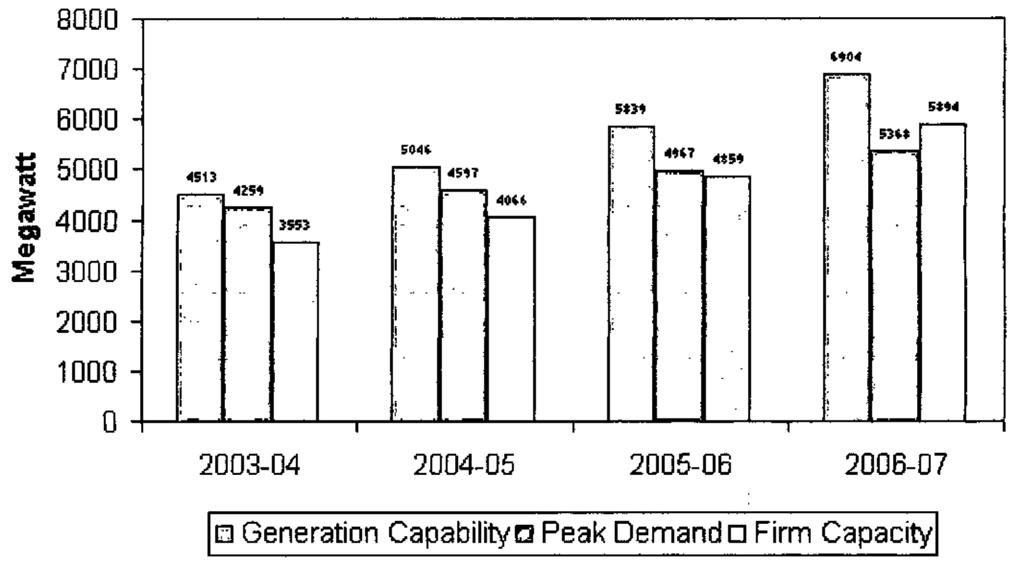
The demand for energy is increasing day by day in Bangladesh, due to various reasons, such as, increasing population; the aspiration for improved living standards and general economic and industrial growth. Every year the demand increases 6% to 7% in Bangladesh [23]. The per capita consumption of energy is about 200kg which is $1/10^{th}$ of the world and $1/4^{th}$ of the Asian average [24]. The per capita generation of electricity has been increasing from 71 kWh to 95 kWh from 1990 to 1996. The reserve electricity generation becomes zero since 1995. Therefore, now a days load shedding has become a part of our daily life. It is about 250MW to 300 MW per day. The present demand of electricity is increasing day by day. Even though, most of the people don't have the access to electricity. Bangladesh Government has realized the problem that the present installed capacity is not sufficient to meet up with the future demand. . To raise the installed capacity of power generation, the Government of Bangladesh has taken the initiative to install 12 Burg Mounted Power Plants (100-120 MW each) and one 300 MW coal Power Plant, which have come into operation by the year 2000 and 2001 respectively. Bangladesh Government also encourages private organization through foreign investment and joint ventures in these sectors. To operate these power plants it needs huge amount of petroleum, oil and natural gases.

Seventy to eighty percent of our foreign exchange is spent to purchase the oil from OPEC. On the other hand the reserve natural gas and coal will be exhausted by the year 2020 to 2030, if they are consumed at the present rate (2.85×10^6 m^3) [25]. To reduce the dependency on imported fuel and the pressure on natural gas the present power generation system must be diversified and at the same time indigenous energy sources have to be explored and developed. Wind energy is one form of new and renewable energy and appropriate extraction can contribute significantly to our national energy supply. Another important aspect that the pollution and emission from conventional energy (coal, oil, gas) this rise to-green house effect and acid rain with adverse consequences for health and climate.



Source: Bangladesh Power Development Board (BPDB)

Fig 2.4.1: Sector wise Energy Consumption Pattern in 2005



Source: Bangladesh Power Development Board (BPDB)

Fig 2.4.2: Load Generation Pattern

Table 2.1: Zone Wise Future Electricity Demand in Bangladesh

(MW)*								
Year	**Maximum Demand by Consumption Zone (Net Generation Basis)**							
	National	**Central**	**Dhaka**	**Northern**	**Southern**	**Western**	**East**	**West**
2001	3097	303	1329	415	673	378	2305	792
2002	3339	326	1451	443	721	400	2497	842
2003	3602	351	1584	272	773	425	2706	895
2004	3886	377	1730	503	828	450	2934	952
2005	4195	406	1890	536	887	478	3182	1013
2006	4533	437	2047	580	953	517	2437	1096
2007	4898	470	2218	629	1025	559	3712	1187
2008	5294	506	2403	681	1102	604	4009	1285
2009	5722	544	2603	738	1184	654	4331	1391
2010	6186	586	2820	800	1274	708	5678	1507
2011	6672	528	3044	865	1369	767	5041	1631
2012	7197	674	3287	936	1473	830	5432	1765
2013	7764	723	3549	1012	1584	899	5854	1910
2014	8377	775	3831	1095	1703	974	6308	2068
2015	9039	831	4137	1185	1832	1056	6799	2240

- Excluding Transmission Losses
- Source: Bangladesh Power Development Board (BPDB)

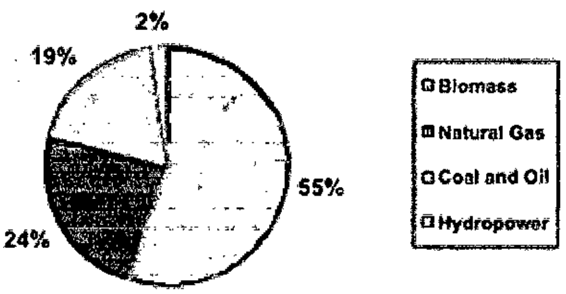


Fig 2.4.3: Energy Sources in Bangladesh in 2004

Wind energy is a very clean and environment friendly renewable energy. Therefore, it is right time to explore and implement the wind energy technology without any further delay, considering the wind speed characteristics, it is believed that wind energy has a bright prospect and significantly towards the solution of energy crisis in Bangladesh.

The preliminary study shows that this technology is suitable in the coastal islands and some remote areas with a great open space.

2.5 Wind Prospect in Bangladesh:

Bangladesh has a 724 km long coastal line alone the Bay of Bengal. There are many islands in the bay, which belongs to Bangladesh. The strong south /south-westerly monsoon wind coming from the Indian Ocean, after traveling a long distance over the water surface, enter into Asia over the coastal area of Bangladesh. This wind blows over Bangladesh from March to September with a monthly average speed 3 m/s to 6 m/s [25]. The wind speed is enhanced when it enters the V- shaped coastal region of the country. According to preliminary studies, (from meteorological department, BCAS, LGED, and BUET) winds are available in Bangladesh mainly during the monsoon and around one to two months before and after the monsoon. During the months starting from late October to February wind speed remains either calm or too low.- The peak wind speeds occurs during the months of June and July [25]. The monthly average wind speeds during these periods are about 6 m/s [25]. This speed is quite enough to operate a 55 kW wind turbine in the coastal areas and islands especially at Kuakata, Patenga, Char fashion etc. Park of wind turbines in these areas, can be incorporated in electricity grid on a substantial basis and could add reliability and consistency to the electricity generated by the Kaptai Hydro-Electric Power Station from March to September, during which load shedding becomes critical than winter season. So, the deficit power could be compensated with the help of wind power plants along the coastal zone. They're many islands along the Bay of Bengal where the wind speed is quite high. For example Kuakata, St. Martin islands are very prospective areas for this type of wind turbines. Most of the people of these islands are fishermen and there are many shrimp-farms in these areas. They can never avail the opportunities to have the electricity from the National Grid line. Therefore, these areas have a great prospect to utilize the wind energy. Besides these, there are a lot of hilly and remote areas with a great open space island where the wind speed remains 2 m/s to 5 m/s in Bangladesh. The recent development of wind rotor aerodynamics makes it feasible to extract energy from wind speed as low as 2.5 m/s.

Bangladesh is an agricultural land. The agriculture needs supply of water at right time for better yielding. Bangladesh Government has already undertaken many irrigation and canal digging projects to supply water. Many power pumps and hand pumps have been distributed to the farmers. A study of Bangladesh Agriculture Development Corporation (BADC) shows that low lift pumps (LLP) of about 40 feet head and two-cusec discharge were in operation. It is claimed that there is surface water potential for 54,700 LLP of two-cusec capacity. Recently man powered (TARA PUMP) water pumps have become very popular for irrigation, and every year its supply is increasing. Considering the terrain of the country about 50% of the pumps require to be operated at a total head of 20 feet or less. Most of these power pumps along with a number of deep and .shallow tube wells are being run in most cases by diesel engines and in other cases by electric motors. The non- availability of electricity and irregular supply of diesel fuel in rural areas the existing schemes of irrigation have been adversely affected. The installation of windmills will be very much convenient for operating the pumps. The application of wind power for operating man powered water pumps will also be very convenient, and it will save energy.

2.6 Energy Supply Options:

The National Energy Policy suggests maximization of the supply of indigenous primary energy resources in meeting future energy demands. For the time horizon under consideration the known reserves of indigenous primary energy resources and their annual supply have been calculated and balanced against the projected demand. These include natural gas, liquid natural gas, coal and hydroelectricity (Table 2.2) [38]. The deficit has to be met by imported fuels as shown in Table 2.3[38].

Table 2.2- Projected Demand for Commercial Energy and Electricity

(Low Economic Growth Scenario)

Items/years	1990	1995	2000	2005	2010	2015	2020
Population (mil.)	107	118	130	141	153	165	177
GNP Growth Rate	4.44%	5.25%	5.24%	5.24%	5.24%	6.65%	6.65%
Per Capita GNP($)	190	220	242	272	317	366	424
Energy Growth Rate	7.19%	7.19%	7.18%	7.18%	7.18%	8.6%	8.6%
Per capita Kg OE	56	68	92	127	157	219	272
Total Fuel(MTOE)	6	8	12	18	24	36	48
Total Energy (PJ)	256	342	512	769	1025	1537	2050
MJ/S GNP	13	14	16	20	21	26	27

Electricity

Percentage of fuel	35%	37%	39%	37%	33%	33%	33%
Total GWH	8207	11584	18315	26063	30994	46491	61988
Per capita kWh	77	98	141	185	203	282	351
Load Factor.	55%	57%	57%	57%	58%	59%	60%
Peak Load MW	1703	2320	3668	5220	6100	8995	11794

Table 2.3 - Projected Demand for Commercial Energy and Electricity

Items/years	1990	1995	2000	2005	2010	2015	2020
Population (mJ)	107	118	130	141	153	165	177
GNP Growth Kate	4.5%	5.4%	6.4%	7.2%	7.7%	8.2%	8.7%
Per Capita GNP($) J	190	220	254	316	416	560	744
Energy Growth Rate	7.3%	7.4%	8.77%	8.86%	8.32%	8.86%	9.4%
Per capita Kg OE	56	72	94	131	194	269	384
Total Fuel(MTOE)	6	8	12	19	31	46	72
Total Energy (MJ)	256	362	531	827	1314	1979	3055
MJ/S GNP	13	14	16	18	20	20	21

Electricity

Percentage of fuel	35%	37%	39%	37%	33%	33%	33%
Total GWh	8207	12280	18971	28060	39750	59858	92402
Per capita kWh	77	104	146	199	260	363	523
Load Factor	55%	57%	57%	57%	58%	59%	60%
Peak Load	1703	2459	3799	5620	7823	11581	17580

2.7 Role of Renewable Energy:

The demand for energy, as projected in the National Energy Policy is quite conservative, nevertheless the import of fuel for meeting even such a demand would have telling effects on the national economy. Moreover, availability and price of different network fuels in the international market on a long-term perspective is subject to serve uncertainties. Logistics of inland transportation and handling of bulk fuels like oil or coal would also pose serious problems. Environmental dimension of such fuels is another serious constraint. Thus, it would be necessary to evolve a judicious, economic and environmental friendly energy mix consisting of components like biomass, commercial fuels and various renewable energy technologies. Improved conversion efficiency of biomass fuel can be one of the key issues in short term prospective, while in mid to long- term perspective, renewable energy technologies will be expected to assume an increasing complementary role to commercial energy. Renewable energy technologies that appear to have good prospects of contributing to the future energy balance of the country may be classified into two broad groups, namely:

I. Technologies which have either been developed locally or adopted with suitable modifications to suit local needs (indigenous/adopted Technologies).

II. Technologies like solar photovoltaic and wind turbines, which will depend on more imported components. Their prospects are described in the following paragraphs.

2.7.1 Solar Photovoltaic Systems:

In conventional sense the application of solar energy in Bangladesh as an alternative to commercial fuels for various forms of end-use, like open air drying of agricultural products, production of salt from sea water, fish drying etc. are very high. However, uses of technologies like Solar Photovoltaic are still insignificant. But proper research and step regard this matter; solar energy can also help in solving energy crisis in Bangladesh.

Programmes on studies of different types of end-use were initiated in the mid-80. Some of the main objectives of the Programme were:

I. To identify specific end-use and geographical areas where solar photovoltaic technology could be used profitably and effectively.

II. To identify components, systems and sub-systems, where gradual replacement of import photo voltaic ponds could be implemented.

III. To study cost-economics and other conditions of social acceptance of different types of end-uses.

IV. To involve the private sector in fabrications of identified components in the balance of systems and also in marketing of identified SPV (Solar Photovoltaic) based technologies

A number of demonstration units were established in different locations in order to study feasibility of various types of end-uses. These demonstration units include solar lighting systems for rural and remote areas, through installing charging station as well as stand alone system. Some solar pumping systems are also installed for irrigation purpose in the remote areas.

2.7.2 Wind Energy:

Bangladesh, like many other developing countries, has a long-standing tradition of using wind energy, especially in sailboats. Considering the large proportion of riverine transportation, contribution of wind energy to the energy balance as replacement of fossil fuel should be quite significant. Today Nordic countries (Denmark, Finland, Iceland, Norway and Sweden), the USA, India and many other developed, as well as , developing countries are erecting increasing numbers of wind turbines. Some of these are even connected to the grid. Efficiency and overall performance of wind turbines depend heavily on average wind speed and seasonal variation. It is generally believed that some coastal areas, which widen over 75 km, are suitable for installing wind turbines. Unfortunately, reliable data on wind speed in different areas of the country are not available. A few organizations are now collecting such data. In parallel to this, demonstration units are also being planned for 4 to 10 prospective locations. It is important to conduct a systematic wind mapping study in the country. Based on such data; stand-alone, grid connected or hybrid systems with wind turbines could be built in selected areas of the country.

2.8 Wind Resource Assessment in Bangladesh:

2.8.1 Early Stage of Wind Monitoring:

The meteorological department at Agargoan, Dhaka has been collecting the wind speed from 35 stations located all over Bangladesh [25]. The wind speed data, temperature, air pressure, and humidity data every three hours has been collected. With the help of monthly average wind speed for 30 years, wind speed maps for every month for Bangladesh have been prepared. From the maps, one can easily observes that a speed zone exists along the Chittagong coast, whereas around Dhaka the wind speed is fairly high from March to September and low wind speeds region over the northern part of Bangladesh. Average wind speed for Amla (1975-80), Joydebpur (1970-75) was also collected from BWDB, BRRI, and Savar Dairy Farm. Wind speed data was collected every three hours, using vertical axis cup anemometers. The output is recorded on special type printers as voltage, which is further converted into wind velocity or is to be read from the velocity charts recorders. Then these data are processed to further analysis in view of wind resource assessment statistics. In 1981 and 1982 Hussain [20] investigated the availability of wind energy for particular locations in Bangladesh, namely, Chittagong and Cox's Bazar. The wind speed in Chittagong is 2.57m/s (5 knots) or above, throughout a day in the month of May and 4000 hours a year and that of the wind speed in Cox's Bazar area is 3.09m/s (6 knots) and 2000 hours a year. A jointly research had studied on the characteristics of wind speed data for ten years recorded at 15 stations of Bangladesh Meteorological Department (1976-1986) and estimated the monthly average wind speed and the energy availability for the 15 stations. It is also found that the wind speed is available for seven months from March to September and the rest period is lean. In 1984-85 a Cretan type windmill was constructed at the Katabon site of Dhaka University [25]. The windmill was mounted on a 25 feet high wooden tower. The rotor was also made of wood and the sails were made of canvas. The windmill was used intermittently for more than two years. It has been found that its durability in the contact of Bangladesh is not satisfactory as it unable to sustain extreme weather conditions like cyclonic storms and heavy rains, which are regular features of our climate. Some under graduate students have taken a .project to study both vertical and horizontal type windmills in BUET campus. It is still now working in this field. Till now there is no adequate wind data is generated to harness wind energy in Bangladesh.

2.8.2 Present Stage of Wind Monitoring:

In Bangladesh some organization are involved in wind monitoring and plays an important role in making the best use of wind. The organizations that are involved in wind energy field in the country are:

i) Bangladesh University of Engineering and Technology (BUET)
ii) Bangladesh Atomic Energy Commission (BAEC)
iii) Local Government Engineering Department (LGED) with Bangladesh Rural Electricity Board (REB).
iv) Bangladesh Centre for Advanced Studies (BCAS) with German Technical Assistance (GTZ).
v) Bangladesh Council of Scientific and Industrial Research (BCSIR).
vi) Grameen Shakti

2.8.3 Present Status of Wind Utilization in Bangladesh:

Several small wind generators have been installed by BRAC and Grameen Shakti (two wind generators of 300 W and 1 kW at its Chakoria Shrimp Farm). These are small DC operation type systems, supplying power to target groups, to improve their quality of life. Their results are not well documented. Grameen Shakti has recently installed 4 small wind generators (3Xl.5kW + 1X10 kW) in Barguna district (south coastal). They are planning to develop these stations into hybrid systems later, first with diesel and then with solar photovoltaic, to maximize the energy output and then study the cost economics. Their final quantitative results would be awaited with great interest.

As for mechanical power from the wind, recently two groups have worked in such projects. The first one, form LGED, has set up a number of 27 ft high windpumps at Tangail, Kushtia, Cox's Bazar and other places. Theoretically, these indigenously made Windpumps have a power of 0.5 hp (385W) at a wind speed of 4m/s. The pump outlet is narrow and the output was found to be 25 liter/minute at wind speed of 3.2 m/sec. No quantitative results are, however, available. The second Group from BCAS installed a windpump designed by the IT (Intermediate Technology) Group of the UK and made in Karachi (Pakistan). The windpump is located in an agricultural field at Patenga (Chittagong). The Tower height is 40 ft and the rotor consisted of 12 blades. Daily water output has been varying and the average water output between November and January was about 8000 liters/day. It appears that suitability designed wind pumps can be extensively used for irrigation of vegetables in winter period in the coastal region of Bangladesh. It should also be possible to draw fresh underground water for drinking purposes in the coastal and remote islands.

Chapter 3

DATA PROCESSING

3.1 Data Analysis:

After getting the raw wind data, it can easily be processed by some computer software. The frequency distribution, velocity duration, determination of energy concentration, availability of wind power and Weibull parameters can be determined to find out the nature of wind for any site. All these analysis are discussed in chapter-4.

3.2 Mathematical Representation of Wind Regimes:

After having drawn a number of velocity duration histograms or velocity frequency histograms and approximating, themes by smooth curves, it is striking to notice that the shape of these curves is quite similar. This is even clearer, if the wind speed values are made dimensionless, by dividing them by the average wind speed of that particular distribution. In this respect much attention has been given to the Weibull function, since it is a good match with the experimental data. In some cases the Raleigh Distribution, a special case of the Weibull Distribution, is preferred. This section deals with the Weibull Function and the method to estimate its parameters from a given distribution.

Three functions are used throughout this section:

i. The cumulative distribution function F(v), indicating the time fraction or probability that the wind speed V is smaller than or equal to a given wind speed V', [26]

$$F(v) = P(V \leq V') \tag{3.1}$$

ii. The probability density function, represented in the present case by the velocity frequency curve[26]:

$$f(v) = \frac{dF(v)}{dv} = (\frac{k}{c})(\frac{v}{c})^{k-1} \times e^{-(\frac{v}{c})^k} \tag{3.2}$$

Or,

$$F(v) = \int_0^v f(v')d(v') \tag{3.3}$$

iii. Velocity duration curve [26] $= S(v) = e^{-(v/c)k}$ (3.4)

The velocity duration, S(v) is the period of time during which the wind speed is available greater than that specific wind speed. The shape of the duration curve follows a negative exponential function. Studying the shape of this duration curve an idea is obtained about the wind regime for that site. The more horizontal shape means longer duration period of that specific wind speed. The steeper the shape duration curve indicates the more irregular

There are several distributions, which are used for analysis; the statistical observed wind data. They are:

i. Rayleigh distribution,
ii. Chi-squared distribution,
iii. Normal distribution,
iv. Gaussian distribution,
v. Binomial distribution,
vi. Poisson distribution and
vii. Weibull distribution.

All these distributions are used to determine the probability of occurrence. The nature of occurrence affects the shape of the probability curve and cumulative curve, in case of wind regime, probability nature mostly fits to Weibull Function. This function has much flexibility. Depending on the 'k' value it falls under

k=l	: Exponential
k = 1.5-3	: Logarithmic Normal Distribution
k = 2.0	: Rayleigh (very close to normal) Distribution
k = 3.1-3.6	: Again Logarithmic Normal Distribution
k >3.6	: Normal Distribution

3.2.1 The Weibull Distribution:

The Weibull distribution is characterized by two parameters: the shape parameter k (dimensionless) and the scale parameter c (m/s.) The cumulative distribution function [26] is given by

$$F(v) = 1 - e^{-(\frac{v}{c})^k} \tag{3.5}$$

And the Weibull density (provability density) function by [26],

$$f(v) = \frac{dF(v)}{dv} = (\frac{k}{c})(\frac{v}{c})^{k-1} \times e^{-(\frac{v}{c})^k} \tag{3.6}$$

With an expression of Gamma function, Γ(x) the average wind speed can be expressed as a function of c and k or vice versa and c is a function of wind speed, v (m/s) and k. The integral found cannot be solved however, but it can be reduced to a standard integral, the so-called gamma function [27].

$$\Gamma(x) = \int_0^{\alpha} y^{x-1} \times e^{-y} dy \tag{3.7}$$

With $y = (v/c)^k$ and $v/c = y^{x-1}$

One obtains x=1+1/k and after a few manipulation,

$$\overline{V} = C \times \Gamma(1 + \frac{1}{k}) = 0.8525 + 0.0135k + e^{-[2.0+3.0(K-1)]} \tag{3.8}$$

This formula can easily be handled by pocket calculators in energy output calculations. The accuracy of the approximation is within 0.5% for $1.6 < k < 3.5$.

3.2.2 Estimation of the Weibull Parameters from Given Data:

The Weibull distribution shows its usefulness when the wind data of one reference station are being used to predict the wind regime in the surrounding of that station. The idea is that only annual or monthly average wind speeds are sufficient to predict the complete frequency distribution of the year or the month. This section deals with the methods to extract the Weibull parameter k and c from a given set of data. There are several methods by which k & c can be determined. Three different methods are described below.

a) Weibull paper,

b) Standard - deviation analysis, and

c) Energy pattern factor analysis,

3.2.2a Weibull Paper Method:

In principle it would be possible to construct the dimensionless velocity frequency curve or the cumulative distribution, to draw these curves and to "guess" the Weibull factor from their position. Comparing curves is a rather awkward business; however, it is preferred to transform them into straight lines for comparison purposes.

The so-called, Weibull paper is constructed in such a way that the cumulative Weibull distribution becomes a straight line, with the shape factor k as its slope, as shown Fig 3.1 in the next page.

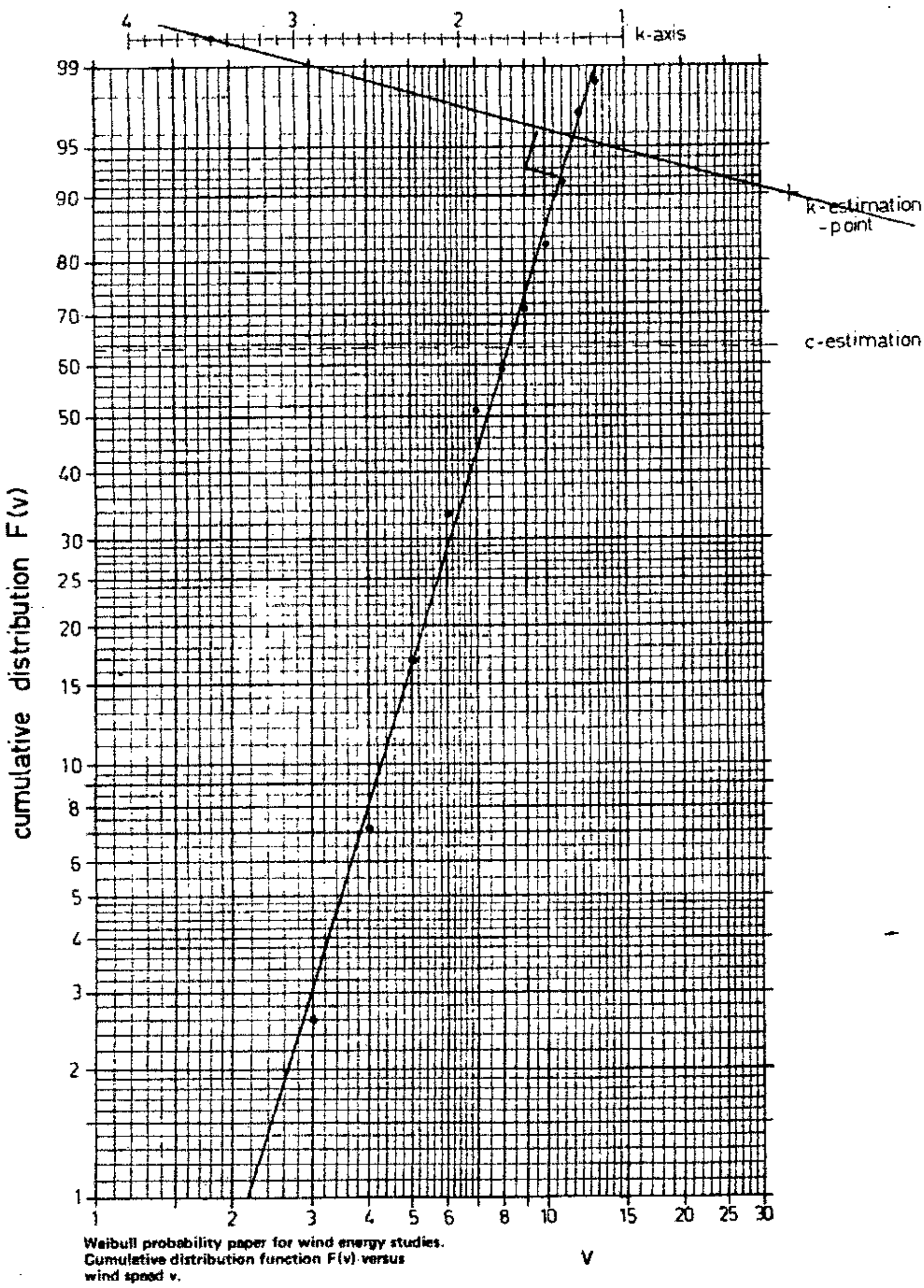


Fig 3.1: Cumulative distribution Vs wind speed graph

Source: Wind Energy Group, Dept. of Physics. University of Tech., Edinburgh, the Netherlands.

Expression (3.5) can be rewritten as:

$$(1 - F(v))^{-1} = e^{(v/c)^k}$$

Taking logarithm in both side,

$\ln [1\text{-F}(v)]^{-1} = k \ln V - k \ln c$

The horizontal axis of the Weibull paper now becomes in V while at the vertical axis in $\ln(1 - F(v))^{-1}$ is placed. The result is a straight line with slope k or V =c one finds: F(c) $=1 - e^{-1}=0.632$ and this gives an estimation for the value of c, by drawing a horizontal line at F (v) = 0.632. The intersection point with the Weibull line gives the value of c. The practical procedure to find the Weibull shape factor from a given set of data starts with establishing the cumulative distribution of the data.

The cumulative distribution refers to the total number of hours during which the wind speed is below the given value. If the number of hours in a specific interval is included in the cumulative number of hours belonging to that interval then it is referred to the upper value of the interval for our calculations. The procedures now consist of plotting the percentages of the cumulative, distribution as a function of the upper boundaries of their respective intervals on the Weibull paper. The result will be a number of dots lying more or less on a straight line. In case the line is straight, the distribution perfectly fits to the Weibull distribution. In many cases, however, the line will be slightly bent. Then the linearization should be focused on the wind speed interval that is most interesting for over wind energy applications, i.e. between 0.7 V and 2 V.

The value of k is found by measuring the slope of the line just drawn. In the Fig 3.1, it is found an angle of 74° with the horizontal, so k = tan74°. To facilitate the angle measurement, as simple geometrical operation can be performed; draw a second line through the '+' marked "k-estimation point", and a perpendicular to the Weibull line. The intersection of this second line with the linear k-axis on top of the paper gives the desired k-value. The c-value, if required, is simply the intersection of the Weibull line with the-dotted line, marked "c-estimation". Preferably this procedure should be applied not to the data of one month only, but to those of a number of months or years.

3.2.2b Standard-Deviation Analysis Method:

By determining the mean wind speed V_{mean} and standard deviation σ of wind data k and c can be obtained by solving the following equations [27].

$$\sigma = \sqrt{[\int_0^{\alpha}(v-\bar{v})\,f(v)dv]} \tag{3.9}$$

And the expression for f (v),

$$f(v) = \frac{dF(v)}{dv} = (\frac{k}{c})(\frac{v}{c})^{k-1} \times e^{-(\frac{v}{c})^k} \tag{3.10}$$

One can find next expression for σ [26],

$$\sigma = c\sqrt{\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]} \tag{3.11}$$

Or with $\bar{v} = c \times \Gamma\left(1+\frac{1}{k}\right)$ (3.12)

$$\frac{\sigma}{\bar{v}} = \frac{\sqrt{\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{3.13}$$

The standard deviation of the distribution is calculated with,

$$\sigma^2 = \frac{\sum (V_n)^2 - \frac{\left(\sum V_n\right)^2}{N}}{N-1} \tag{3.14}$$

Then corresponding k value can be found from fig 3.2

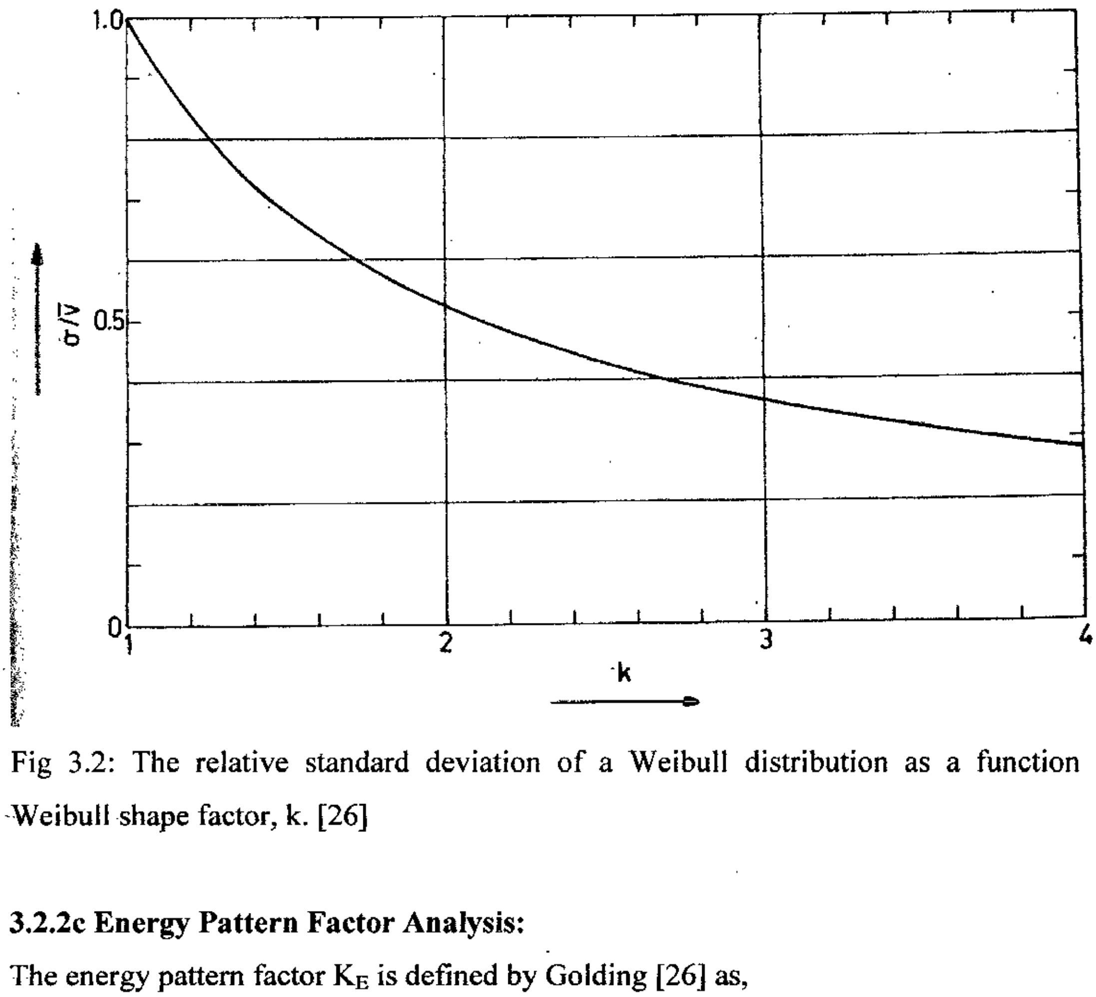


Fig 3.2: The relative standard deviation of a Weibull distribution as a function of Weibull shape factor, k. [26]

3.2.2c Energy Pattern Factor Analysis:

The energy pattern factor K_E is defined by Golding [26] as,

$$K_E = \frac{\text{Total amount of power available in the wind}}{\text{Power calculated by cubing the mean wind speed}}$$

Realizing that the power density of the wind is given by [26],

$$\frac{P(v)}{A} = \frac{1}{3}\rho V^3 \quad [\text{W/m}^2] \qquad (3.15)$$

Then the total amount of energy available in the wind in a period T [26] is equal to

$$\frac{E}{A} = T\int_0^{\alpha}\frac{1}{2}\rho v^3 f(v)dv \quad [\text{J/m}^2] \tag{3.16}$$

Whereas the energy [26] is calculated by cubing the mean wind speed is equal to

$$\frac{E}{A} = \frac{1}{2}\rho V^3 T \tag{3.17}$$

Using Weibull provability density function f(v) in (3.15) results,

$$K_E = \frac{\Gamma(1+\frac{3}{k})}{\Gamma^3(1+\frac{1}{k})} \tag{3.18}$$

The energy pattern factor of a given set of N hourly data V_n can be determined with [26]

$$K_E = \frac{\frac{1}{N}\sum_{n=1}^{N}(V_n)^3}{\left(\frac{1}{N}\sum_{n=1}^{N}V_n\right)^3} \tag{3.19}$$

Using the above expression the Weibull shape parameter k is easily found by following figure.

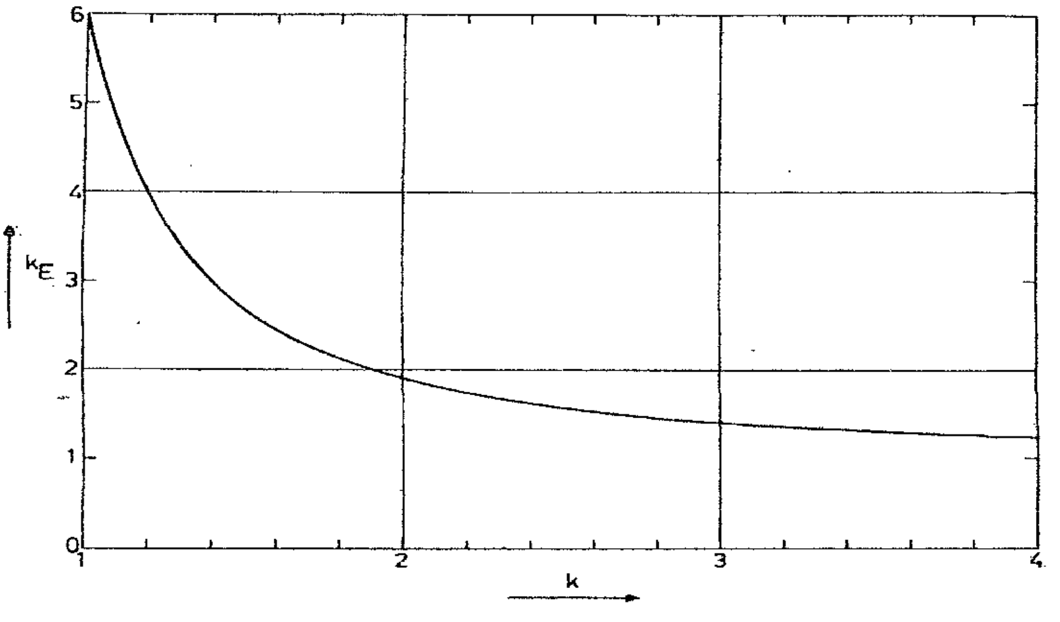


Fig 3.3: The energy pattern factor of a Weibull wind speed distribution as a function of the Weibull shape factor, k [26].

Chapter 4

WIND DATA PROCESSING AND ANALYSIS

4.1 Data Collection and Processing:

From wind data and observations, frequency curves, speed duration curves, means wind speed of month or year, Weibull distribution curve, energy curve may be projected. The drawing of these curves is necessary for any important design.

4.1.1. Frequency Distribution:

It is important to know the number of hours per month or per year during which the given wind speeds occurred, i.e. the frequency distribution of wind speeds. In order to get this frequency distribution, it is necessary to divide the wind speed domain into a number of intervals, mostly of equal width of 1 m/s or 0.5 m/s. Then starting at the first interval of say 0-1 m/s, the number of hours is counted in the period concerned that the wind speed was in this interval. This velocity frequency distribution as relative frequency is obtained from the velocity interval. The velocity intervals are 1 m/s wide such as 0-1, 1-2, 2-3.................m/s. All the velocities above 15 m/s have been considered under 13-14 m/s class interval. One sample is presented here. Rests are shown in the Appendix-E.

Location	: Kutubdia, Cox's Bazar
Duration	: 01/03/2003~31/03/2003
	: 44640 min. (24 x 60x 31 days)
V_{mean} (Monthly average)	: 3.7 m/s
V_{max} (Maximum velocity of the month)	: 8.545 m/s

Velocity frequency as a percentage of relative basis:

Table 4.1: Velocity frequency (hour basis) for Kutubdia, March 2003

Speed (m/s)	Total hours of the month in percentage	Frequency (hrs) Distribution
0-1	3.22	24
1-2	11.42	85
2-3	24.05	179
3-4	22.71	169
4-5	15.72	117
5-6	11.15	83
6-7	5.64	42
7-8	2.55	19
8-9	2.69	20
9-10	0.53	5
10-11	0	0
11-12	0	0
12-13	0.13	1
		Total hours T= 744

4.1.2. Data Processing for Weibull Distribution:

This frequency distribution is further processed for Weibull Distribution to have the shape/form factor (k) and scale factor (c). There are many distributions to analyses any raw data. But for the wind regime Weibull Distribution fits very closely because of its flexibility in nature. Depending on the value of 'k', the Weibull Function becomes Normal Distribution, Raleigh Distribution and exponential one. It is one of the most powerful tools to analyses wind regime for any site. From the graph of relative cumulative frequency versus non-dimensional velocity i.e. class velocity/mean velocity (v/v_{mean}) the shape of the Weibull Function can be obtained practically. How to process this data towards Weibull Function is described in the following.

At first the hourly frequency distribution is added successively to have a cumulative frequency distribution. Then this value of individual velocity class is divided by total time (744 or 720 hrs.). If these values are plotted against velocity classes, the Weibull Function is obtained. One sample table of March 2003 for Kutubdia for this purpose is presented below. Details are given in appendix-E.

Table 4.2: Data processing for Weibull Distribution from the raw data

Interval V	Frequency h_i	Relative Frequency f(v)	Cumulative Frequency F(v)	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity duration	Velocity	Energy (wh/m^2)
m/s	hrs	h_i/T	$\sum h_i$	$\sum(h_i/T)$	T-h_i	1-F(v)	m/s	$E=0.1v^3h_i$
0-1	24	0.032	24	0.032	720	0.968	0.5	0.3
1-2	85	0.114	109	0.146	635	0.853	1.5	28.69
2-3	179	0.241	288	0.387	465	0.625	2.5	279.69
3-4	169	0.227	457	0.614	287	0.386	3.5	724.59
4-5	117	0.157	574	0.771	170	0.228	4.5	1066.16
5-6	83	0.112	657	0.883	87	0.117	5.5	1380.91
6-7	42	0.056	699	0.939	45	0.060	6.5	1153.43
7-8	19	0.026	718	0.965	26	0.035	7.5	801.56
8-9	20	0.027	738	0.992	6	0.008	8.5	1228
9-10	5	0.007	743	0.999	1	0.001	9.5	428.69
10-11	0	0	743	0.999	1	0.001	10.5	0
11-12	0	0	743	0.999	1	0.001	11.5	0
12-13	1	0.001	744	1	0	0.000	12.5	195.31
Total	744							

The frequency distribution will be used to calculate the energy output of windy sites by multiplying the number of hours in each interval with the power output as the equation, presented in Table 4.2,. $E = 0.1\ v^3h$. It is the rule of wind energy equation. Similar tables for each location have been shown in Appendix-A. The data of this processed table is used to analysis the whole system of wind monitoring parameters.

From all the processed data tables, the location wise frequency distribution of wind speeds can be drawn easily. One sample is presented in the following table, rests are hereby indicated in Appendix-A

Table 4.3: Frequency distribution of wind speeds in Teknaf, Cox's Bazar, Bangladesh

Location	Month \ Vel Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	Total Hours
Teknaf, Cox's Bazar 2003	March	140	156	167	98	64	67	21	18	10	3	-	-		744
	April	130	153	184	118	80	41	12	1	1	-	-	-		720
	May	154	165	198	124	56	21	18	4	3	0	1	-		744
	June	15	90	111	130	72	90	66	63	40	21	13	8	1	720
	July	129	156	151	118	76	66	39	8	1	-	-	-	-	744
	August	59	80	107	120	116	112	73	47	21	7	2	-	-	744
	September	72	112	196	97	97	96	28	20	2	-	-	-	-	720
Total															

4.1.3 Some Tables of Mean Wind speeds:

4.1.3a Mean Monthly Wind Speeds (Hour basis)

It is the hourly average of the wind during the whole day. The mean monthly speed for Teknaf, Cox's Bazar is given below, rest are shown in Appendix.-B

Table 4.4: Hourly wind speed in m/s for Teknaf, Cox's Bazar

Location		Month						
	Hours	Mar	Apr	May	Jun	Jul	Aug	Sep
Teknaf, Cox's Bazar, 2003	1	1.81	1.35	1.84	4.52	2.49	3.98	*2.61*
	2	1.64	1.27	1.93	4.24	2.34	3.79	*2.25*
	3	1.87	1.35	1.78	4.21	2.33	3.96	*2.12*
	4	1.93	1.58	1.99	4.35	2.50	4.16	*2.24*
	5	2.22	1.74	2.14	4.49	2.15	3.95	*2.24*
	6	2.18	2.02	2.30	4.17	2.36	3.80	*2.61*
	7	1.85	2.20	2.59	4.22	2.56	4.11	*2.80*
	8	1.74	2.48	2.88	4.37	2.91	4.30	*2.95*
	9	2.04	2.75	3.00	4.69	3.32	4.47	*3.18*
	10	2.67	2.97	3.24	4.84	3.32	4.85	*3.31*
	11	3.33	3.14	3.27	5.05	3.31	4.84	*3.58*
	12	3.89	3.21	3.47	4.89	3.21	4.72	*3.68*
	13	4.37	3.60	3.33	5.16	3.37	4.77	*3.80*
	14	4.51	3.62	3.26	5.21	3.56	4.55	*4.18*
	15	4.96	3.82	2.81	5.47	3.63	4.24	*4.27*
	16	4.98	3.73	2.46	5.37	3.54	4.03	*4.26*
	17	4.67	3.58	2.45	4.98	3.24	4.10	*3.86*
	18	4.35	3.28	2.30	4.83	2.96	4.39	*3.41*
	19	3.59	3.07	1.73	4.69	2.52	4.03	*3.14*
	20	2.80	2.69	1.75	4.82	2.21	3.64	*2.78*
	21	1.94	2.49	1.75	4.81	2.44	3.77	*2.86*
	22	1.72	2.22	1.75	4.79	2.56	3.79	*2.90*
	23	1.61	1.75	1.71	4.49	2.53	3.65	*2.74*
	24	1.63	1.59	1.66	4.29	2.45	3.58	*2.42*
Monthly average (m/s)		2.85	2.56	2.39	4.71	2.83	4.14	3.09

4.1.3b Mean Speeds (Day Basis):

It is the daily average of the wind speeds for each month. This speed for each station is given below: The mean speed (day basis) for Teknaf, Cox's Bazar is given below, rest are shown in Appendix-C.

Table 4.5: Daily speed in m/s for Teknaf, Cox's Bazar

Location	Day	Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Teknaf, Cox's Bazar, 2003	1	3.47	2.95	1.15	1.96	5.14	4.68	4.58
	2	3.21	1.92	2.68	1.90	4.38	4.14	2.76
	3	0.97	1.97	2.68	1.75	3.71	4.04	3.43
	4	2.35	2.65	4.38	2.12	4.53	3.99	4.09
	5	2.87	4.07	4.81	2.29	4.83	4.29	5.40
	6	5.25	3.21	4.41	3.27	4.01	4.92	5.64
	7	5,81	2.37	3.97	3.19	3.25	5.76	2.99
	8	4.71	2.73	2.96	3.22	3.73	5.00	2.60
	9	4.14	2.67	1.43	2.68	5.00	2.78	1.42
	10	3.42	2.02	1.61	2.55	4.46	4.41	1.08
	11	1.66	1.50	1.24	3.57	4.24	7.71	2.31
	12	2.13	2.74	1.20	3.53	3.33	6.21	3.87
	13	3,61	3.38	2.63	2.88	4.49	3.68	4.48
	14	2.08	2.33	1.27	3.79	3.20	2.11	3.20
	15	1.02	2.34	0.41	3.05	2.16	2.92	2.15
	16	2.16	1.48	1.52	4.77	1.90	2.69	2.35
	17	2.31	3.68	2.33	5.63	1.56	3.45	3.87
	18	1.34	3.95	1.95	6.57	2.31	2.32	3.84
	19	2;91	2.77	1.87	6.50	2.28	3.32	4.47
	20	3.92	2.62	2.57	8.96	1.33	1.86	2.78
	21	3.07	1.34	2.46	9.33	1.02	2.97	1.93
	22	3.11	1.76	2.67	6.62	1.25	6.44	2.13
	23	3.31	1.93	2.38	5.21	0.67	4.26	1.94
	24	2.57	3.30	2.62	4.97	1.54	2.02	3.11
	25	2:00	4.13	3.27	6.16	1.70	2.17	2.63
	26	2.31	2.89	2.54	8.04	1.44	4.99	2.63
	27	2.66	1.74	1.77	6.32	0.97	6.24	2.77
	28	3.14	2.49	2.13	7.66	1.08	6.45	2.31
	29	2.19	1.96	2.65	6.40	1.51	5.44	2.49
	30	1.61	1.96	2.80	6.31	0.88	4.19	3.48
	31	2.93	-	1.73	-	5.70	3.07	4.58
Monthly average (m/s)		2.85	2.56	2.39	4.71	2.83	4.15	3.09

4.2: Estimation of the Weibull Parameters from the Processed Data:

The Weibull distribution shows its usefulness when the wind data of reference station are being used to predict the wind regime in the surrounding of that station. The idea is that only annual or monthly average wind speeds are sufficient to predict the complete frequency distribution of the year or the month. This section deals with methods to extract the Weibull parameter k and c from a given set of data. There are several methods by which k and c can be determined. Three different methods are described below.

1. Weibull paper/ Regression analysis
2. Standard - deviation analysis
3. Energy pattern factor analysis.

4.2.1 Weibull Paper:

Weibull paper method is the method where practical relative cumulative data is plotted against the velocity intervals in log-log paper. The Weibull Function is obtained as a straight line on the log-log graph paper and the slope of this line represents the value of k, the shape parameter of the Weibull function. This method is described in Chapter-3; the calculated Weibull parameter k and c by using Weibull paper method are shown in the Appendix-D

4.2.2 Standard Deviation Analysis Method:

By determining the mean wind speed V_{mean} and standard deviation σ of wind data, k and c can be obtained from equation mentioned in chapter-3 as follows,

$$\sigma = \sqrt{[\int_{0}^{\alpha}(v-\bar{v})q\int(v)dv}$$

And the expression for f (v),

$$f(v) = \frac{dF(v)}{dv} = (\frac{k}{c})(\frac{v}{c})^{k-1} \times e^{-(\frac{v}{c})^{k}}$$

One can find next expression for σ,

$$\sigma = c\sqrt{\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]}$$

Or with $\bar{v} = c \times \Gamma\left(1+\frac{1}{k}\right)$

$$\frac{\sigma}{v} = \frac{\sqrt{\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]}}{\Gamma\left(1+\frac{1}{k}\right)}$$

The standard deviation of the distribution is calculated with,

$$\sigma^2 = \frac{\sum (V_n)^2 - \frac{\left(\sum V_n\right)^2}{N}}{N-1}$$

Then corresponding k value can be found from Fig 3.2

This formula can be easily be handled by simple calculators in energy output calculations.

Value of k and c from Standard Deviation method for each station for each month is given in Appendix-D

4.2.3 Energy Pattern Factor Method:

As this method is described in Chapter-3, the energy pattern factor of a given set of N hourly data V_n can be determined with the following equation,

$$K_E = \frac{\frac{1}{N}\sum_{n=1}^{N}(V_n)^3}{\left(\frac{1}{N}\sum_{n=1}^{N}V_n\right)^3}$$

Using the above expression the Weibull shape parameter k is easily found by Fig 3.3.

Value of k and c by this method for each station for each month is given in Appendix -D

The closest value of k and c are given below:

Table 4.6: Closest values of k and c

Location	Month	k	c
Teknaf	March	1.45	3.14
	April	1.62	2.86
	May	1.55	2.65
	June	1.99	5.47
	July	1.63	3.19
	August	1.97	4.68
	September	1.83	3.48
Kutubdia	March	2.14	4.16
	April	1.12	12.13
	May	1.56	2.60
	June	1.92	5.31
	July	3.17	6.07
	August	2.23	5.37
	September	1.48	3.24
Sandwip	March	[illegible]	[illegible]
	April	1.14	8.73
	May	1.38	2.50
	June	2.1	4.15
	July	2.1	6.14
	August	1.40	4.87
	September	2.17	5.86
Kuakata	March	1.8	3.4
	April	1.21	5.5
	May	2.2	3.49
	June	2.15	4.05
	July	2.70	4.82
	August	1.87	3.81
	September	1.33	2.22
Mongla	March	2.39	3.27
	April	1.85	2.74
	May	2.39	3.47
	June	1.72	4.76
	July	2.63	4.85
	August	1.54	5.31
	September	1.81	2.82

After determining the parameters of Weibull Function, the calculated Weibull density Function f (v), Weibull Function F (v) and Velocity Duration Function S (v) are checked with the observed data. All the observed and calculated f (v), F (v) and S (v) are given in Appendix-E. A graphical comparison between the observed & calculated Weibull Density Function f(v) and that of Weibull Function F(v) are also presented and discussed in discussion Chapter-8 .

4.2.4 Weibull Density Function:

The Weibull Density Function means the relative frequency of wind speeds for the site. Therefore, the shape of wind speeds distribution can be guessed when it is plotted. The equation of Weibull Density Function [27] is given by,

$$f(v) = (\frac{k}{c})(\frac{v}{c})^{k-1} \times e^{-(\frac{v}{c})^k}$$

4.2.5 Weibull Function:

Weibull Function is the integration of Weibull Density Function. It is the cumulative of relative frequency of each velocity interval.

The equation of Weibull Function [26] is given by,

$$F(v) = 1 - e^{-(\frac{v}{c})^k}$$

4.2.6 Velocity Duration Function:

The velocity duration curve directly shows the length individual wind velocity. The more length means the higher the duration of that wind speed. From this curve we can get how much time the turbine will be on running condition when the cut-in speed is identified from Weibull Function. The equation is given below [26]-

$$S(v) = e^{-(\frac{v}{c})^k}$$

4.3.7 Lull Period:

The lull period is the times during which the turbine or windmill will not be on operating condition. This is very low velocity classes. It is normally fall under the speed that is not sufficient to produce output of the turbine. It is generally called unproductive time of wind speeds.

4.3.8 Wind Energy:

The wind energy (Wh/m^2) for every month and year is calculated by the following rule [38]:

$E = 0.1\ v^3 h\ (Wh/m^2)$,

Where,

v = wind speed (m/s),

h = velocity frequency (hrs.)

The velocity frequency and energy histogram are discussed in discussion chapter-8. Here the velocity duration are also calculated which indicates the availability of wind.

Chapter 5

PROSPECT OF WIND ENERGY FOR WATER PUMPING IN BANGLADESH

5.1 Introduction

Wind is available in Bangladesh mainly during the monsoon and around one to two months before and after the monsoon. During the months starting from late October to the middle of February, wind either remains calm or too low to be of any use by a windmill. Except for the above mentioned period of four months, a windmill, if properly designed and located, can supply enough energy.

During the months of June, July and August the peak rainfall occurs in Bangladesh. However, the peak wind speed above average occurs one to two months and in some cases three months before the peak rainfall occurs. So, one of the advantages is that, the above average winds are available during the hottest and the driest months of March, April and May. During this period, windmills may be used for pumping water for irrigation, if it had been previously stored in a reservoir during the monsoon. During the operating seasons, subsoil water from shallow wells can also be pumped up by low lift pumps, run by windmills. Wind power can also be incorporated in electricity grid on a substantial basis and could add reliability and consistency to the electricity generated by the Kaptai hydroelectric Power Station during the dry season. This is due to fact that, during the dry season, required water head becomes rather low for total utilization of all the generators. Thus, power generation has to be curtailed during this period. So, this power could be compensated with the help of wind power plant.

5.2 Analysis of Wind Characteristics and Site Selection

The wind data used for the study was taken from the project work for collecting wind data of the coastal areas of Bangladesh, financed by LGED in year 2003 [1]. The monthly average wind speed of different location in Coastal area of Bangladesh is shown in Table 5.2.1. It can be seen from Table-5.2.1 that the wind speed at different sites are very low except Kutubdia, which are not feasible for electricity generation and water pumping. The causes of poor conditions of the meteorological data are [28]:

- Most of the meteorological stations are situated in the places of roughness class 3 as shown in Table-5.2.2. So, the wind after loosing 70% energy is measured by the meteorological stations and for these reasons meteorological stations show poor wind speeds.
- Few meteorological stations are located several kilometers away from their respective sea coast and the anemometers do not face the winds coming from the sea directly. So in the areas, directly open to the sea, wind speed will be higher than those in the present locations. Experiments carried out by the International Energy Agency (IEA) and the European Community (EC) countries show that this increase in wind speed may range from 5-100%.
- Some of the meteorological stations are surrounded by trees, buildings, hills and hillocks etc. The wind speed becomes weak as it faces obstacles on its way and it results the lower value.
- Generally, meteorological stations measure winds at heights of 5 to 10m. But the normal hub-height of modern wind turbines ranges from 30 to 40 meters. So at these heights wind speeds would be better. A rule is that if the height is doubled in the areas of roughness class-3, wind speed is increased by 20% and in the areas of roughness class-0, wind speed increased by 10 %.
- The anemometers of these stations are not calibrated for long times.

The meteorological data provide little information about the fluctuation in the speed and direction of the wind, which are also necessary to predict the performance of turbine appropriately. For a wind turbine, the main source of fluctuating aerodynamic loads is the wind shear, which is once per revolution.

Table-5.2.1: Average wind speed (m/s) in different coastal location of Bangladesh

Locations	Months							Mean
	March	April	May	June	July	August	September	
Teknaf	2.85	2.56	2.39	4.71	2.83	4.14	3.09	3.22
Kutubdia	3.79	12.02	2.95	4.71	5.73	4.64	2.97	5.17
Sandwip	NA	8.34	2.28	3.64	5.44	4.44	5.18	4.89
Kuakata	3.07	5.26	3.09	3.69	4.28	3.67	2.03	3.58
Mongla	2.95	2.41	2.94	4.23	4.34	4.74	2.48	3.44

Table-5.2.2: Types of Terrain, Roughness Classes and Their Energy Contains.

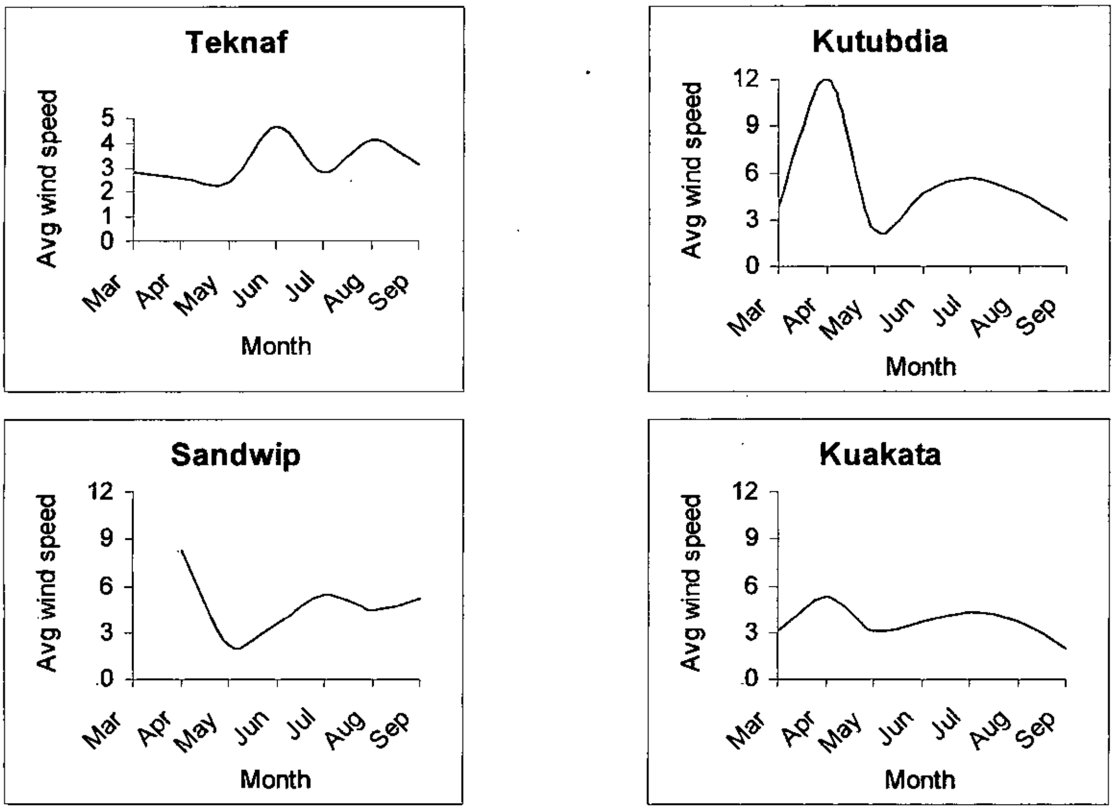
Roughness Class	Terrain Type	Value of α	Energy (%)
0	Water areas, airports, plain lands, etc.	0.17	100
1	Country areas with few bushes, trees and buildings	0.28	70
2	Farmlands with scattered buildings	0.35	60
3	Build-up areas.	0.40	30

Wind velocity changes with height. The rate of increase of velocity with height depends upon the roughness of the terrain. The variation of average wind speed can be determined analytically by using power law expression shown as below [19],

$$\frac{V_Z}{V_{ref}} = \left(\frac{h}{h_{ref}}\right)^{\alpha} \qquad 5.2.1$$

Where, V_Z and V_{ref} are the average speeds at h meter and at the reference height of h=10m above the ground respectively and α varies from 0.1 to 0.4 depending on the nature of the terrain. The value of α for the different terrain has been shown in Table-5.2.2 [29]. A value of 0.17 for α may be used, in general, although this is applicable for the open terrain only. The value of α may be chosen as 0.28 for the terrain with trees and houses like the suburb area. But for the city with tall buildings the value of α should be considered as 0.4. In the present analysis, the average wind speed is determined from the power law expression as in equation (5.2.1), taking the value of power exponent, α

=0.28. The power law description is used for its simplicity. Figures 5.2.1 show the monthly variation of average wind speed for several Coastal regions in Bangladesh. It can be seen that wind speeds are higher from May to August for all places. It is found that a peak wind speed is found in the month of April for Kutubdia, may be the possible cause is that there was a cyclone during the time of data collection. Same situation also found for Sandwip.



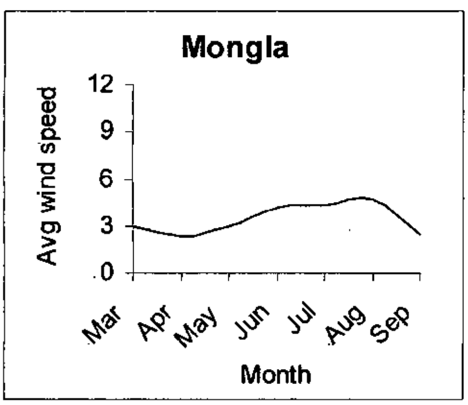


Fig. 5.2.1: Monthly average velocity for different locations.

A wind turbine, if properly designed and located, can supply enough wind energy. The peak rainfall in Bangladesh occurs during the months of June, July and August. But peak wind speeds are available during the hottest and driest months of March, April and May. From September to February the velocities are not at all promising for harnessing power. One point can be noted that there is wide variation of wind speeds in the coastal areas throughout the year.

Extractable wind power of an area determines the size and shape of the rotor appropriate to that location. Wind data shown in Table-5.2.3; give an estimation of available wind power. The wind data analyzed here are the average of the data recorded during the period March 2003 to September 2003. In Figure-5.2.2, the annual average wind velocity in different regions of Bangladesh is presented. The wind power per unit area of approach is proportional to the cube of wind speed [29] and can be expressed as $P/A = 0.6V^3$ (watts), where P/A is in W/m^2 and V is in m/s. The available wind power represents the strength of wind and theoretically 59% of this power is extractable but practically only 30-40% can be extracted.

Table-5.2.3: Theoretical Available Power of Different Locations in Bangladesh

Locations	Months	Average Wind Velocity, V_{av} (m/s)	Theoretical Available Power, $W/m2=0.6V^3_{av}$
Teknaf	March-September	3.22	20.03
Kutubdia	March-September	5.17	82.91
Sandwip	April-September	4.89	70.16
Kuakata	March-September	3.58	27.52
Mongla	March-September	3.44	24.42

Practically, extractable power by any type of windmill can be written approximately as [4], $P_e = 0.1\ AV^3$ (watt), where A is the total swept area of the rotor blades and V is wind speed (m/s).

Extracted power per square meter of swept area for different months for above noted locations in Bangladesh is shown in Figure 5.2.2. From this figure it can be seen that wind energy can be used in the hottest months i.e., March, April and May for irrigation purposes. The wind data at other locations also show similar strength of wind energy. The installation of wind power machines at the coastal and island areas will be useful for lifting water and for generation of electricity.

The wind data presented may be helpful for lifting water, which may solve energy problem in the country to some extent. In most of the areas in Bangladesh, the pumping head is less than 6 m, which is appropriate for using diaphragm pumps and the man-powered pumps. For these pumps, the available wind power in the country can produce good results with a suitable rotor. The use of locally available materials and technology can produce satisfactory wind pumping unit for lifting water.

In coastal areas, island and isolated villages, wind speed is expected to be reasonably sufficient for installing wind plant for electricity generation. In many areas, the transmission of electricity is either expensive or impossible. The installation of wind plant for generating electricity will be very useful for such areas.

Lack of proper analysis of the wind regime often leads to disappointments on the water yields. In Bangladesh, about 30% of total irrigated area is irrigated by hand pumps. So the wind turbine-pumping set may be useful by replacing hand-pumping system for irrigation purposes in rural areas. In some regions of Bangladesh, the wind speed is satisfactory for operating pumps and for generation of electricity. The wind turbine may also be useful to drive hand pumps used for irrigating agricultural land.

Among the above noted location at Kutubdia, wind speed varies from 2.2 to 25 m/s. In Table 5.2.3, it is seen that the average wind speed and theoretical power output per square meter of rotor swept area are 5.17m/s and 82.91 watts, respectively.

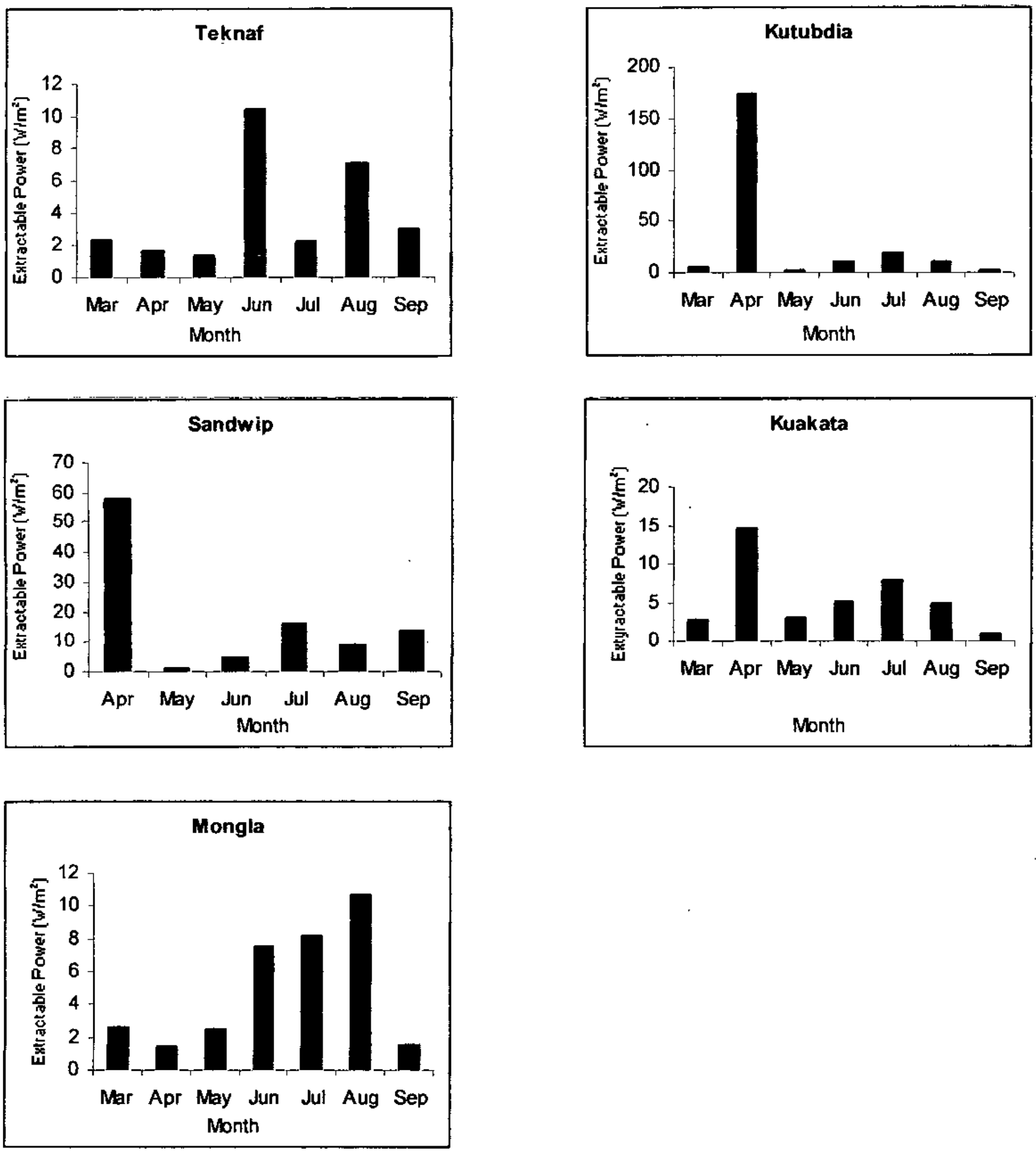


Fig 5.2.2: Monthly Average Extracted Power at Different Coastal Regions (Year 2003)

Chapter 6

DESIGNING OF A HORIZONTAL AXIS WIND TURBINE

6.1 Design of the Rotor:

The design procedures of a horizontal axis wind turbine in which lift forces on airfoils are the driving forces are described in the following sections. The design of a wind rotor consists of two steps:

- The choice of basic parameters such as the number of blades B, the radius of the rotor R, the type of airfoil and the design tip speed ratio λ_d.
- The calculations of the blade twist angle β_T and the chord C at a number of positions along the blade, in order to produce maximum power at a given tip speed ratio by each section of the blade.

The design procedures are described in the following sections:

6.2 Selection of Design Tip Speed Ratio and Number of Blades:

In wind turbine designs, the question arises as to how many blades should be used. In general, as the number of blades increases, the manufacturing cost also increase. Increasing the number of blades results improve performance and lower torque variations due to wind shear. Furthermore, power output increases but with diminishing return. The choice of λ_d and B is more or less related. For the lower design tip speed ratios a higher number of blades are chosen. This is done because the influence of B on power coefficient C_p is larger at lower tip speed ratio. For higher design tip speed ratio lower number of blades is chosen. Because, higher number of blades for a high design tip speed ratio will lead to very small and thin blades, which results in manufacturing problems. Type of load also limits the choice of the design tip speed ratio. If it is a piston pump or some other slow running load, that in most cases will require a high starting torque, the design speed of the rotor will usually be chosen low. If the load is running fast like a generator or a centrifugal pump, then a high design speed will be selected. The following Table 6.2.1 may be used as the guideline [26].

Table 6.2.1: Choice of the Design TSR and Selection of Number of Blades

Design tip speed ratio, λ_d	Number of blades, B
1	6-20
2	4-12
3	3-6
4	2-4
5-8	2-3
8-15	1 -2

To obtain the optimum configuration the blade is divided into a number of radial stations. Four formulas [29] will be used to describe the information about β_T and C:

Local design speed: $\lambda_r = \lambda_d \frac{r}{R}$ 6.2.1

Where, r is the local speed ratio and R is the rotor radius and $\lambda_d = R\Omega/V_\alpha$ is the tip speed ratio at the design point.

Relation for flow angle, $$\lambda_r = \frac{\sin\phi(2\cos\phi - 1)}{(1-\cos\phi)(2\cos\phi + 1)} \quad 6.2.2$$

or, $$\phi = \frac{2}{3}\tan^{-1}\frac{1}{\lambda_r} \quad 6.2.3$$

Here, ϕ is the angle of relative velocity.

Twist angle: $$\beta_T = \phi - \alpha \quad 6.2.4$$

Here, α is the angle of attack

Chord: $$C = \frac{8\pi r(1-\cos\phi)}{BC_{l_d}}$$ 6.2.5

Here C_{l_d} is the design lift coefficient.

The blade starting torque can be calculated by [30],

$$Q_{S_1} = \frac{1}{2}\rho V_\alpha^{\ 2} B \int_r^R C(r)C_l[90^0 - \beta_T(r)]rdr$$ 6.2.6

Here, ρ and V_α are the air density and undistributed wind velocity respectively.

The rotor configuration is determined using the assumption of zero drag and without any tip loss. Each radial element is optimized independently by continuously varying the chord and twist angle to obtain a maximum energy extraction.

6.3 Selection of Airfoil:

Power coefficient of the wind turbine is affected by drag coefficient C_d and lift coefficient C_l, values of the airfoil sections. For a fast running load a high design tip speed ratio is selected and airfoils with a low C_d/C_l, ratio is preferred. But for wind turbines having lower design tip speed ratios the use of more blades compensates the power loss due to drag. So, airfoils having higher C_d/C_l, ratio are selected to reduce the manufacturing costs.

Drag affects the expected power coefficient via the C_d/C_l, ratio. This will influence the size and, even more, the speed ratio of the design. Promising airfoils have minimum C_d/C_l ratio ranges 0.1- 0.01 and the NACA airfoil has the lowest values (Appendix G). A large C_d/C_l , ratio restricts the design tip speed ratio. At lower tip speed ratios the use of more blades compensates the power loss due to drag. In this collection of maximum power coefficients it is seen that for a range of design speeds $1 \leq \lambda_d \leq 10$ the maximum theoretically attainable power coefficients lie between $0.35 \leq (C_P)_{max} \leq 0.5$. Due to deviations, however, of the ideal geometry and hub losses for example, these maximums will lie between 0.3 and 0.4. This result shows that the choice of the design tip speed ratio hardly affects the power output.

For different types of airfoils the sensitivity for surface roughness are also different. Using airfoil data of NACA standard roughness in the calculation of wind turbine performance, results losses in peak value of the order of 10- 15% in comparison with the peak value obtained with usual airfoil data for a smooth surface.

6.4 Calculation Steps for Blade Configuration:

For calculating the blade geometry the following data must be available beforehand:
Design tip speed ratio, λ_d
Amount of power to be extracted, P_e
Design wind velocity, V_d

Type of airfoil section:

The following steps are to be carried out for getting the blade configurations:

1) A certain number of radial stations for which the chord and blade twist are to be assumed.
2) A tangent from the origin to C_l/C_d graph of airfoil section to locate the minimum value of C_d/C_l, are to be drawn. Corresponding to this value find the design angle of attack α_d and design lift coefficient C_{l_d}. This is explained in Appendix-G.
3) Number of blades B corresponding to the design tip speed ratio λ_d is to be selected.
4) A reasonable value of C_p, is to be taken. Estimation of the value of C_p has been explained in Appendix J.
5) Calculation of blade radius is done from the equation, $C_P = \dfrac{P_e}{\frac{1}{2}\rho\pi R^2 V_\alpha{}^3}$
6) A fixed value of hub and tip radius ratio, r_{hub}/R is chosen.

7) Calculation of λ_r for each radial station using the equation, $\lambda_r = \lambda_d, r/R$ is to be done.

8) Determination of ϕ by using the equation $\phi = \frac{2}{3}\tan^{-1}\frac{1}{\lambda_r}$ is to be done.

9) The value of chord for each radial station using the equation, $C = \frac{8\pi r(1-\cos\phi)}{BC_{l_d}}$ is to be found.

10) The value of blade twist is to be calculated using the relation, $\beta_T = \phi - \alpha_d$.

6.5 Selection of Design Parameters:

In chapter 5, at Kutubdia monthly average wind speed varies from 2.92 to 12.02 m/s as shown in Table 5.2.1. In Table 5.2.3, it is seen that the average wind speed and theoretical power output per square meter of rotor swept area are 5.17 m/s and 82.91 watts, respectively. It has been observed that during the day times (8 a.m. to 7 p.m.) wind speeds are about 50 % higher than that of during the night times. Although many factors enter in consideration of the Wind Energy Conversion System (WECS), a rule is that a site with an average wind speed of above 5 m/s will be cost effective with modern wind turbines. So, it can be seen that wind speed in Kutubdia is suitable for extracting wind energy for water pumping and electricity generation. Although in present research the considering duration of wind data are for seven months, but for a stable designing purpose, it is necessary to consider data of some years. In coastal region of Bangladesh there is a normal wind trend of high magnitude are found during the month of April and May during the data collection period.

In Bangladesh, the average power needed for a deep tube-well is around 50 kW. For the design purpose, let us consider the airfoil section of NACA 4418 which is generally used for horizontal axis wind turbine blades [25].

In Appendix-G, it is given that for airfoil section NACA 44XX, ratio of minimum drag coefficient (C_d) to lift coefficient (C_l) equal to $(C_d/C_l)_{min} = 0.01$. Again from Appendix-H, design lift coefficient, $C_{ld} = 1.07$ and design angle of attack, $\alpha_d = 7^\circ$

In Appendix-J, for $(C_d/C_l)_{min}$ = 0.01, maximum power coefficient occurs in the range of design tip speeds ratio, $1 \leq \lambda_d \leq 10$.

For the design purposes, let us consider the design tip speed ratio, $\lambda_d = 6$.

On the basis of $\lambda_d = 6$, from Table 6.2.1, let us consider the number of blades, B = 3.

Considering, $\lambda_d = 6$, B = 3 and $(C_d/C_l)_{min}$ = 0.01, from Appendix-J, choose maximum power coefficient, $(C_p)_{max}$ = 0.5.

For conservative design, Cp= $(Cp)_{max}$x 0.8 = 0.5x0.8 = 0.4

From the section 6.4 and step 5, the equation is rewritten as.

$$\text{Rotor Radius, } R = \sqrt{\frac{2P_e}{\rho\pi V_a^{3} C_p}}$$

Now putting the given values, the rotor radius is obtained as 21.68m. Density of wind is considered as 1.225 kg/m3. Based on these data, model rotor radius is calculated as 220 mm.

6.6 Calculation of Blade Chord and Blade Setting Angles:

For selecting the blade chord and blade setting angles, the design procedure is as follows:

Divide the blade along the radius in 10 cross sections of equal length.

Table 6.6.1 Ideal Blade Sections, Local TSR, Angle of Attack, Blade Setting Angle and Chord

Cross section number	R(mm)	λr	ϕ_o	α°	β_T °	C (mm)
1	22	0.6	39.36	7	32.36	39.07
2	44	1.2	26.54	7	19.54	33.30
3	66	1.8	19.37	7	12.37	28.25
4	88	2.4	15.08	7	8.08	23.73
5	110	3.0	12.29	7	5.30	19.74
6	132	3.6	10.35	7	3.35	16.82
7	154	4.2	8.93	7	1.93	14.62
8	176	4.8	7.85	7	0.85	12.91",
9	198	5.4	6.99	7	-0.01	11.56
10	220	6.0	6.31	7	-0.69	10.43

Each cross section has a distance r from the rotor center. Local speed ratio 'λ_r', flow angle 'ϕ', blade setting angle 'β_T' and chord 'C' for each sections are calculated by using the equations stated in the section 6.4, steps 7, 8, 9 and 10. The values are shown in the Table 6.6.1.

6.7 Deviations from the Ideal Blade Form:

In the previous section it has been discussed how to calculate the ideal blades form. The chords as well as the blade twist vary in a non-linear manner along the blade. Such blades are usually difficult to manufacture and may not have structural integrity. In order to reduce these problems it is possible to linearize the chords and the twist angles. This results in a small loss of power. If the linearization is done properly the loss becomes only a few percent. In considering such linearization, it must be realized that the outer half of the blades extract about 75% of the power that is extracted by the rotor blades from the wind. Because the blade swept area varies with the square of the radius and the efficiency of the blades is less at smaller radii, where the tip speed ratio λ_r is small. On the other hand, at the tip of the blade the efficiency is low due to the tip losses. For the reasons mentioned above it is advised to linearize the chord C and the blade setting angles β_T, between r = 0.5R and r = 0.9R [31]. The equations for linearized chord and twist can be written in the following way,

$$C = C_1 + C_2 \qquad 6.7.1$$

$$\beta_T = C_3 r + C_4 \qquad 6.7.2$$

Where, C_1, C_2, C_3 and C_4 are the constants. With the value of C and β_T at 0.5R and 0.9R from the ideal blade form the values of C_1, C_2, C_3 and C_4 can be obtained. The ultimate expressions for chord and twist of linearized blade can be written as,

$$C = 2.5(C_{90} - C_{50})\frac{r}{R} + 2.25C_{50} - 1.25C_{90} \qquad 6.7.3$$

$$\beta_T = 2.5(\beta_{90} - \beta_{50})\frac{r}{R} + 2.25\beta_{50} - 1.25\beta_{90} \qquad 6.7.4$$

Where,

C_{50} = chord of the ideal blade form at 0.5R

C_{90} = chord of the ideal blade form at 0.9R

β_{50} = twist angle of the ideal blade form at 0.5R

β_{90} = twist angle of the ideal blade form at 0.9R

A further simplification of the blade shape consists of omitting the twist altogether. Introduction of a rotor blade without twist results in a power loss penalty of about 6 to 10% [55]. This might be acceptable for a single production unit but loses its attraction in case of mass production. When the main purpose is the design of a cheap wind turbine, an untwisted blade with a constant chord seems to be a good choice with only limited power losses.

Ideal blade form was linearized by using the equations (6.7.1), (6.7.2), (6.7.3) and (6.7.4) and shown in Table 6.7.1. Figure 6.7.1 and Figure 6.7.2 show the distribution of chord and blade twist angles for two types of blades. From these figures it is found that the changes in chords and twist angles are very small at the outer half of the blade.

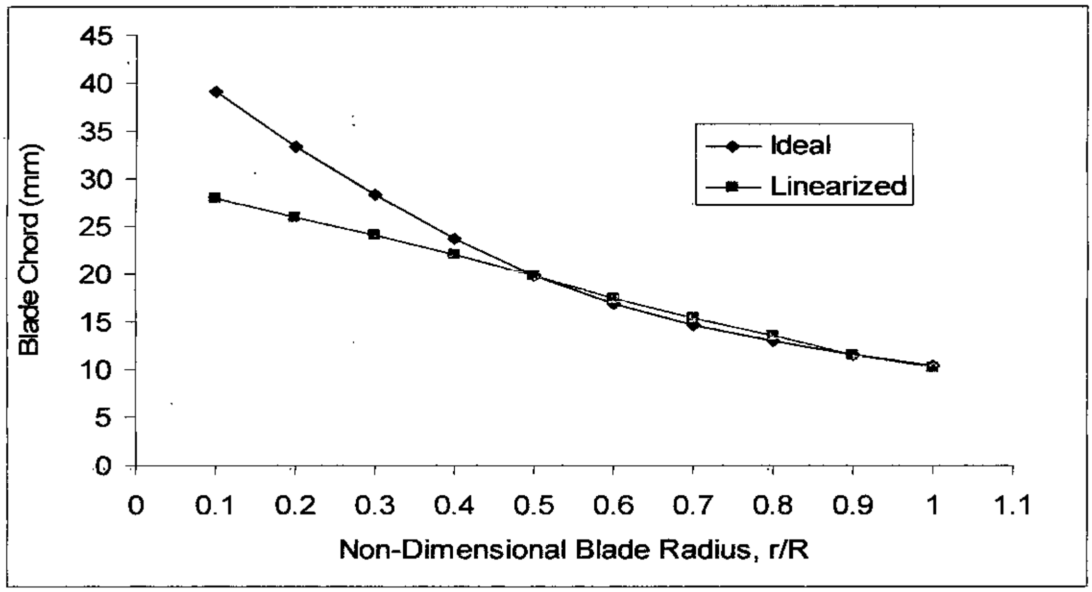


Fig 6.7.1: Optimum and Linearized Blade Chord Distribution

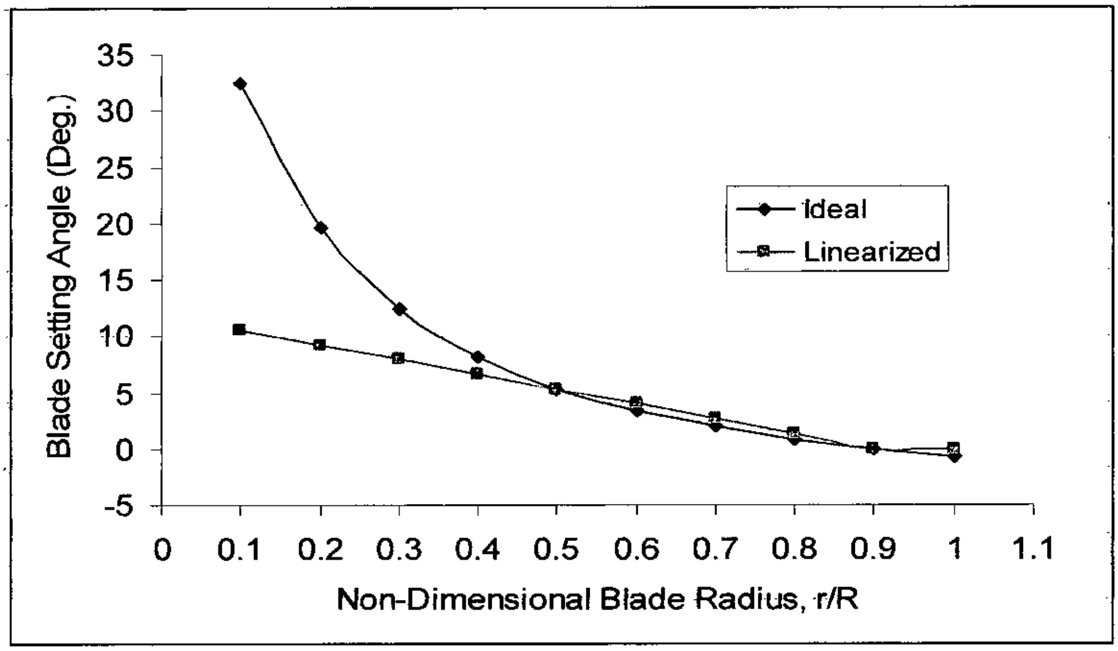


Fig 6.7.2: Optimum and Linearized Blade Twist Distribution

Large variations with the linear chord and twist distributions are found only at the lower radius of the blade.

Table 6.7.1 Linearized Blade Cross Sections, Local TSR, Blade Setting Angle and Chord.

Cross section Number	R(mm)	λr	ϕ o	α°	β_T °	C (mm)
1	22	0.6	17.58	7	10.58	28.00
2	44	1.2	16.26	7	9.26	26.01
3	66	1.8	14.94	7	7.94	24.03
4	88	2.4	13.62	7	6.62	22.05
5	110	3.0	12.30	7	5.30	19.74
6	132	3.6	10.98	7	3.98	18.09
7	154	4.2	9.66	7	2.66	16.11
8	176	4.8	8.34	7	1.34	14.13
9	198	5.4	7	7	0	11.56
10	220	6.0	7	7	0	10.17

Thus, the design values for the model are as follows:

Blade airfoil type	: NACA 4418
Rotor radius	: 220 mm
Root chord length	: 28mm
Tip chord length	: 10.17mm
Root twist angle	: 10.58°
Tip twist angle	: 0°
Hub radius	: 22 mm
Number of Blades	: 2, 3 and 4 were used

The schematic diagram of the rotor is shown in Figure 6.7.3.

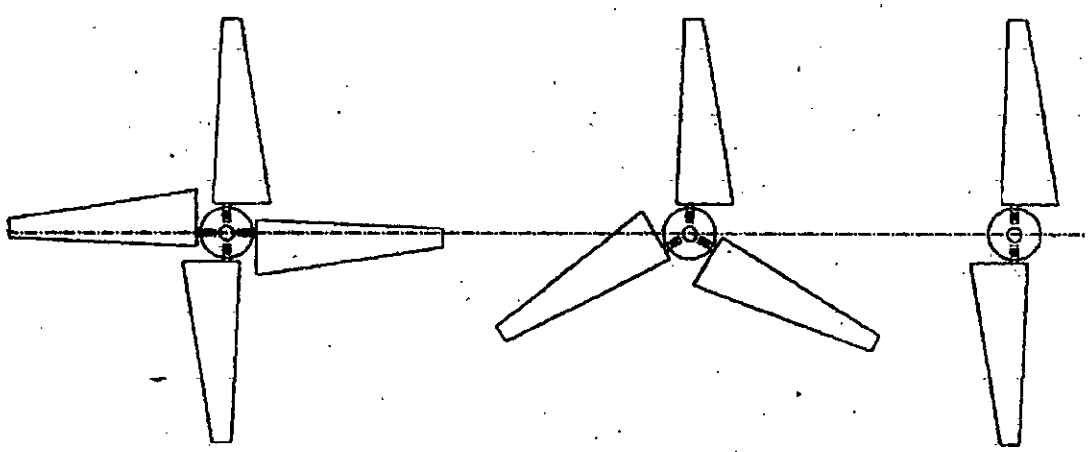


Fig 6.7.3 Schematic Diagram of the Rotors

6.8 Choice of Rotor Blade Material:

Different blade materials can be used for rotor construction. Some have been tested by Peter Garman [33]:

(i) Solid aluminum alloy;

(ii) Laminated hardwood sheathed with glass fiber reinforced plastic (GRP);

(iii) Steel spar with polyurethane foam filled GRP fairing;

(iv) Untreated hardwood;

(v) Ferro cement (a) untreated, (b) painted, (c) sheathed with Al alloy sheet;

(vi) Steel spar, timber fairing sheathed with Al alloy sheet.

Blade surface finish is critical from the performance point of view and any deterioration causes drastic shaft power reduction. So drag produced by the blade surface friction is very important [33]. In this consideration, Aluminum alloy maintains its surface highly finished and hence, high level of performance can be maintained. For this reason, Aluminum alloy is suggested to use for the fabrication of the model.

Chapter 7

WIND PUMPING FOR IRRIGATION IN BANGLADESH

7.1 Introduction:

For people, animals and crop irrigation; water is an essential need in every country. Frequently, this water has to be pumped from under ground; the pumping requires energy. In the rural areas, this energy has traditionally been provided by people operating hand pumps or animal pumps. Where mechanized power is available, it is most commonly an internal combustion engine burning petrol or diesel oil. In the wake of the increasing world energy crisis, it hits the least developed countries most; the interest in alternative energy resources has increased considerably. Recently, there has been a growing interest in the new technology of solar-powered water pumps and a revival of interest in wind pumps.

Windmills have good potentials in many areas of the world, since they are relatively efficient energy converters. Their construction is relatively simple, cheap and can be carried out locally. The ancient Egyptians used wind power 5000 years ago to propel boats [25]. It is estimated that wind power was first used in land to power rotating machinery about 2000 years ago. The Chinese used windmills for low lift paddy irrigation for many centuries.

By the 18^{th} century, windmills were a major form of technology particularly in some European country. They could produce 30-40 kW of power [25]. In the mid 19^{th} century settlers were moving into the great plain from where there was a shortage of fuel and transport was also difficult. With the need for water and the steady, regular wind across the Great Plains, windmills were ideal technology. By the 1880's the familiar all-steel windmills were American multi-bladed farm wind pump had evolved. It looked not much different from many that are still in production [34]. In Bangladesh, farmers need adequate supply of irrigation water at right time and in sufficient quantities for maximum agricultural production. About 50% of irrigation pump operate at a head of 6 m or less, depending on the terrain of the country. For driving these pumps, either diesel engine or electric motors are used. These pumps can be driven with the help of wind turbine [35].

7.1.1 Wind Pumping Technology:

For a considerable length of time, the classical "American" wind pump depicted the basic wind pump technology. Around the 1970s, with the revival of wind energy development, various designs of a new generation of wind pumps came into use. Many such designs were based on grossly oversimplified engineering principles and they rarely went beyond the experimental stage. Some of the more successful designs, such as those have developed by the Consultancy Services for Wind Energy in Developing Countries in Netherlands, Intermediate Technology (IT) Power Ltd. in the United Kingdom and in country projects in China, India and Sri Lanka have reached the maturity for commercial production [35].

7.1.2 Principal Benefits of Wind Pumps:

- Wind pumps are often more economical method of pumping water in the rural areas where the average wind speed in the least windy month is greater than about 3 m/s and no grid power is available.
- There is no fuel requirement for wind pumps, contrary to engine-driven pumps which require expensive fuel that is difficult to obtain in the rural areas. Wind pumping systems represent an environmentally sound technology, though there is some noise, and visual impact.
- They are highly reliable with regular maintenance, and are also less vulnerable to theft or damage than other systems.
- Wind pumps last a long time, typically 20 years for a well-made, regular maintenance machine.

- They can be locally manufactured in most developing countries, creating indigenous skills and reducing foreign exchange requirements for costly diesel fuel and equipment [37]

7.2 Performance of the Wind Pumps:

7.2.1 Matching of Windmill and Wind Pump:

In order to achieve the desire performance of a wind pump, it is necessary to match the windmill to the wind regime as well as with the load. It seems necessary to analyze the load characteristics, in the present analysis, the characteristics of a piston pump and centrifugal pump.

In Figure-7.2.1, the torque of a single acting piston pump is cyclic, because it is only during the upward stroke that the pump gets loaded due to lifting water. During the downward stroke the piston valve opens and the piston merely moves through the water. Once the pump is running, the rotor only feels the average torque demanded by the pump, because the cyclic torque variations get smoothened by the large inertia of the rotor. As the output of a piston pump is independent of the speed and the pumping head, the average torque remains almost constant.

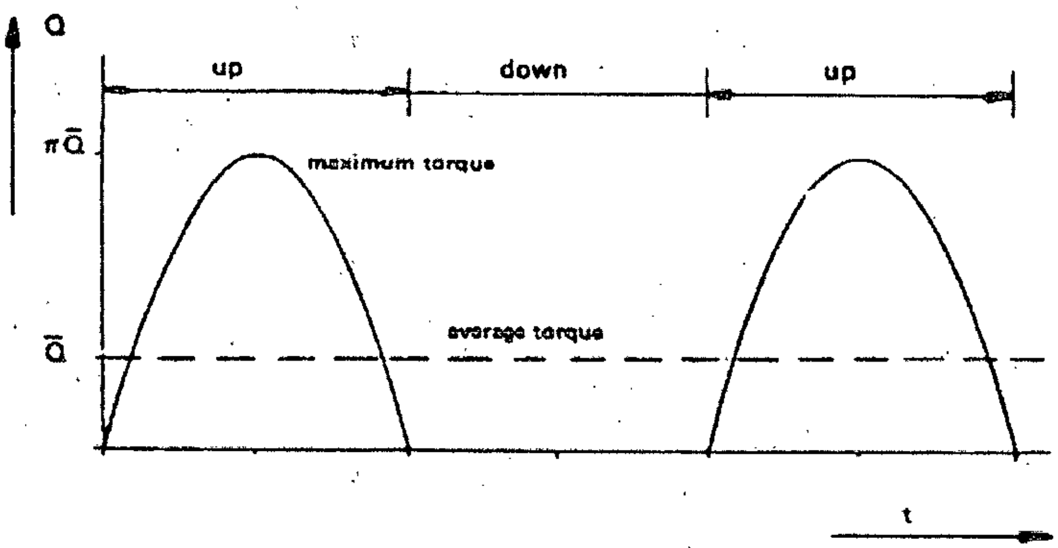


Fig 7.2.1 Torque of a Single Acting Piston Pump [35]

In the Figure 7.2.2a and Figure 7.2.2b, the constant average torque of a piston pump is superimposed on the torque-speed and power-speed curves of a wind rotor for different wind speeds. In the starting region, the pump torque reaches a value that is π times the average torque, as this stage the rotor has to overcome the torque of the pump.

As any other machine, the wind pump system operates at the point where the torque demanded by the load is equal to the torque supplied by the rotor. Thus as the wind speed increases, the point of operation of the system would move to the right along the line of constant pump torque. Corresponding operating points are also shown in the power-speed curve. The dotted line indicates the locus of maximum power of the wind rotor. It is evident from the two sets of curves that it is only at the point D that the system operates. It is also clearly seen that, as the wind speed increase, the point of operation of the system moves away from the line of maximum power thereby shedding much of the available power from the wind. The wind speed corresponding to the point D is referred to as the "design wind speed" and is denoted by V_d. This is also illustrated in the curve depicting the overall performance ($C_{p\eta}$) against the wind speed in Figure 7.2.2c and in the output curve shown in Figure 7.2.2 d.

The matching of a windmill to the wind regime and the pump is essentially a matter of choosing the design wind speed. Up to a point, a higher design wind speed tends to increase the overall system output, but the wind availability may be lower (i.e. the wind pump will often stand still). Selection of lower V_d has an opposite effect. Thus, the selection of the design wind speed V_d is a compromise between the water output and the wind availability. For example, a farmer having a large water tank would prefer to have a large water output with lower availability, as the resulting intermittent nature of output does not influence his irrigation water supply coming from the tank. On the other hand, a wind pump for drinking water supply should be matched with a lower V_d so as to increase the availability thereby, maintaining a regular water output from the wind pump throughout the year.

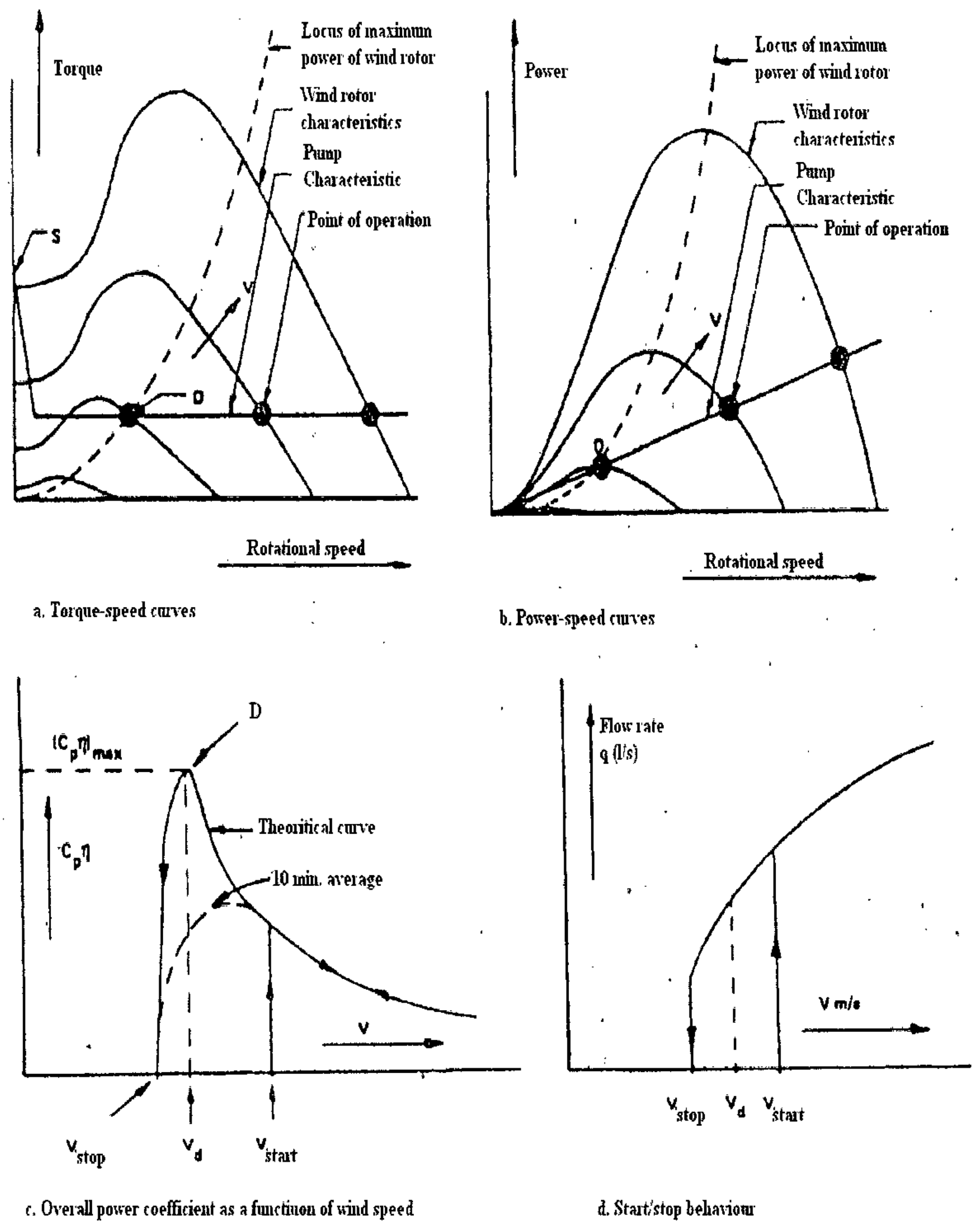


Fig 7.2.2 Matching of Wind Turbine and Piston Pump [36]

The shaft power of a centrifugal pump is superimposed on the same wind turbine characteristics. The centrifugal pump, once delivery has commenced, operates close to the optimum conditions even when wind speeds increases strongly. The power requirement of centrifugal pump fits the characteristics much better as shown Figure-7.2.3 than the case of the piston pump.

In Figure-7.2.4a and Figure-7.2.4b the curves of delivery of the two pump types and their total efficiency are shown as a function of wind speed. It can be seen from the curve of delivery that after delivery begins (V_{beg} = 2.7 m/s) the piston pump initially deliver more water. However, as soon as the wind speed is above 4 m/s the centrifugal pump delivers more water. Above 4 m/s the total efficiency of the wind pump system with centrifugal pump is higher than the wind pump system with piston pump. At higher wind speeds (around 9 m/s) it is nearly twice as efficient [16].

Start and Stop Behavior of the Piston Pump:

Due to the specific torque characteristic of the single acting piston pump, a wind pump exhibits a peculiar behavior in the lower end of the output curve. As shown in Figure 7.2.2d, the wind speed needed to start a wind pump (V_{start}) is higher than the wind speed at which the machine would stop (V_{stop}). The higher V_{start} is necessary to overcome the starting torque of the pump and, once the wind pump starts operating, it experiences only the average pump torque. As the wind speed comes down, the pump speed and output keep on reducing, but due to rotor inertia the machine continues to operate until the wind speed reaches V_{stop}. At this point, if the wind speed starts increasing, the wind pump would not start until V_{start} is reached. It could thus be expected that within the range of wind speeds between V_{stop} and V_{start} the wind pump may or may not be pumping depending on whether the wind speed was decreasing or increasing. This region in the output curve is referred to as the hysteresis region [26]. It is due to this peculiar starting behavior that the 10 min. average values of the $C_{p\eta}$ (Figure 7.2.2c) are very much below the computed value around the design wind speed.

Following are some of the methods, which could mitigate the adverse effects of this starting behavior on the wind pump performance.

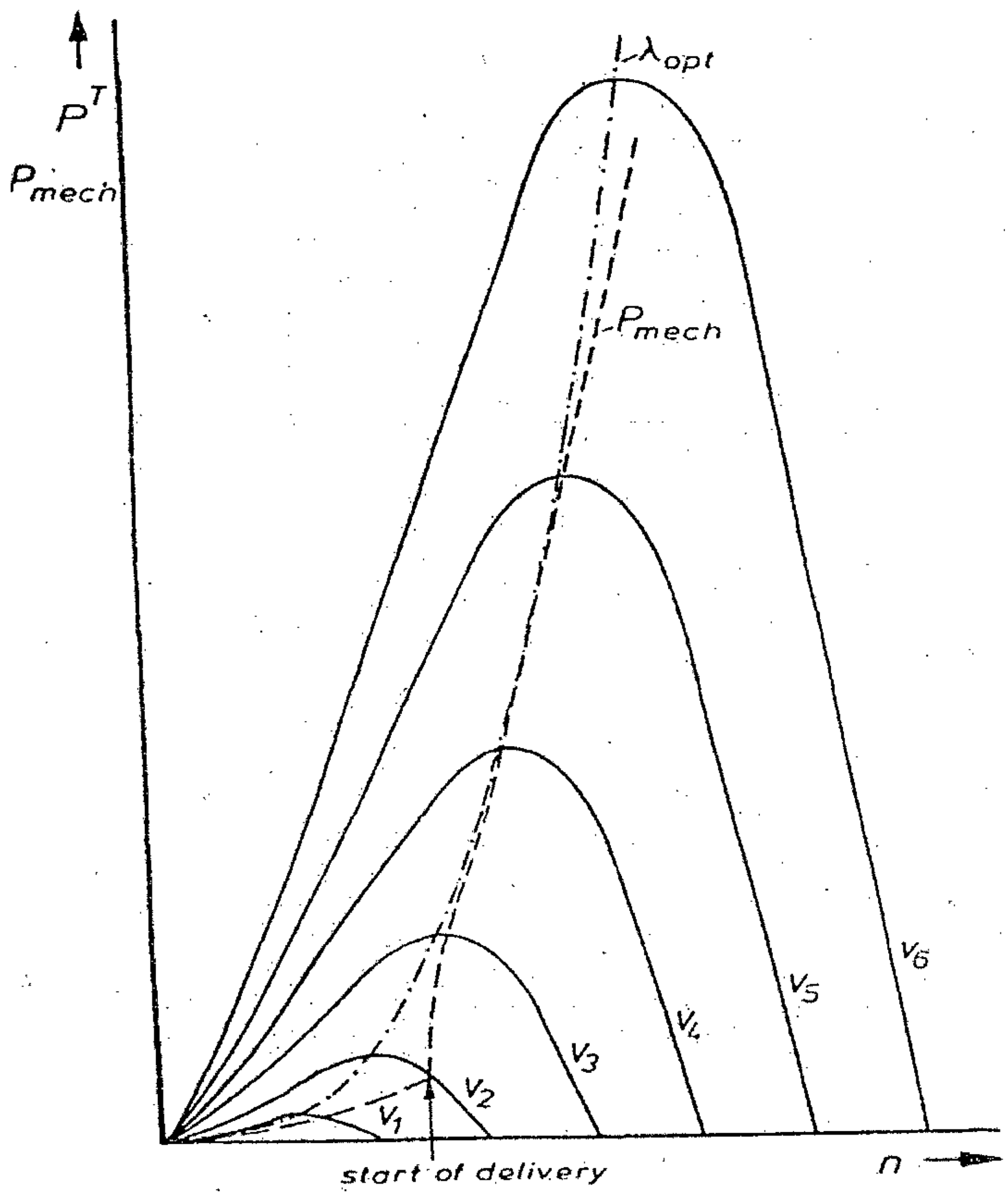


Fig 7.2.3: Operation of a Centrifugal Pump [17]

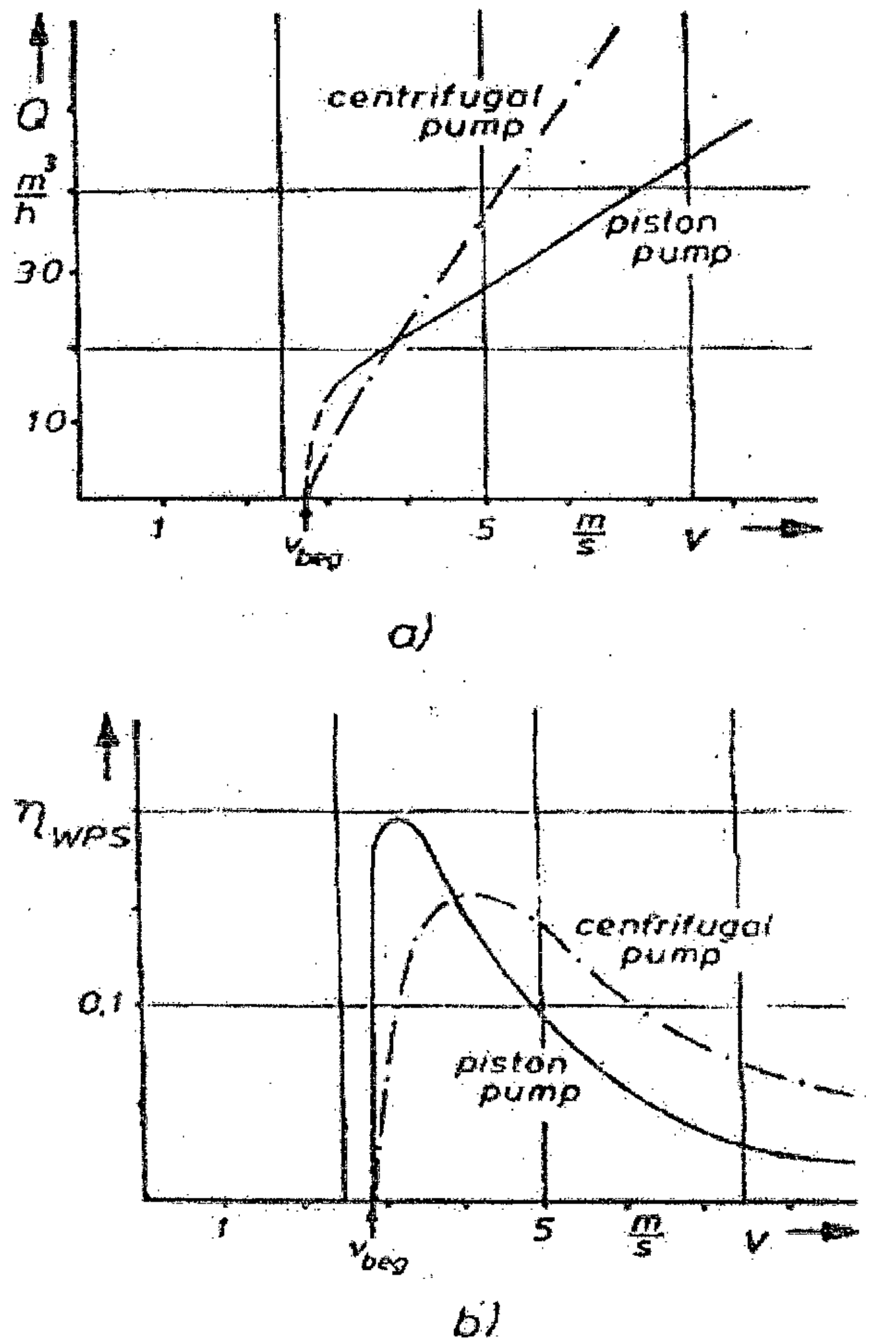


Fig 7.2.4 a) Curve of Delivery of Piston and Centrifugal Pump System

b) Comparison of Total Efficiency [17]

Variable Stroke Transmission: In this design, the pump torque is continuously varied to follow the varying rotor torque (due to change in wind speed) in such a manner that the system would follow the locus of maximum power. Such a design would allow a wind pump to operate close to the theoretical curve, but, as far is known, a practical design of a variable stroke transmission is yet to develop.

Starting Nozzle: In this design, at low wind speeds water leaks through small orifice (of pre-determined diameter) in the piston body, thereby reducing the starting torque. As the wind speed increases, the system starts pumping more and more water, letting only a specified amount of water to leak through the starting nozzle, typically 10 percent of the stroke volume. However, clogging of the nozzle (which is less than 3-4 mm in diameter) by particles in water could easily set the mechanism out of action.

Controlled Valve: The design is incorporated a method of keeping the piston valve open during low wind speeds so that the rotor could start without experiencing the pump starting torque. As the wind speed increases beyond a pre-determined value, the valve closes and the wind pump starts pumping. This principle is now being tried with the aid of a "floating valve" with encouraging results.

7.2.2 Energy Output and Availability:

The performance of a wind pump resulting from the matching of wind machine and pump can be summarized by two characteristic quantities, related to output and availability [27].

Energy production coefficient C_E, defined as the real hydraulic energy output (E) in time period T, divided by the reference energy which would be obtained during the same period, if the wind pump was operating at a constant wind speed equal to the average site wind speed, assuming that the machine is operating at the maximum power coefficient (Cp) and transmission efficiency (η) during the whole period T. This is given by,

$$C_E = \frac{E}{0.5\rho V_{av}^{\ 3} A(C_{p\eta})_{max} T} \qquad 7.2.1$$

Output availability is defined as the percentage of the time during which sufficient wind speed is available to operate the wind pump at more than 10% of its average pumping rate.

Both these quantities depend on the type of pump and the design wind speed. Some typical values of these two quantities for different versions of wind pumps are given in Table 7.2.1. These values are based on what have been found in practice and are supported by the theory. As can be seen in the expression for the energy production coefficient, one also needs to know the maximum overall power coefficient $(C_{P\eta})_{max}$. Typical values of $(C_{P\eta})_{max}$ for different pumping heights are also presented in Table-7.2.1a and Table-7.2.1b. The effect of these three factors may be represented through a "quality factor" defined as:

$$\beta = \frac{P_{av}}{AV_{ac}^3} = 0.5\rho(C_{P\eta})_{max} C_E \qquad 7.2.2$$

The average power referred to above is in fact the hydraulic power output of the system. Values of the quality factor are presented in Table 7.2.1b, taking $\rho = 1.2\ kg/m^3$

Table-7.2.1a: Design and Performance Characteristics for Wind Pumps [35]

Choice of design wind speed Vd, energy production coefficient C_E and output availability			
	V_d/V_{av}	C_E	Availability
Wind machines driving piston pumps			
• Classical deep well	0.6	0.40	60%
• Classical shallow well or deep well with balanced pump rod	0.7	0.55	60%
• Starting nozzle and balanced	1.0	0.90	50%
• Ideal (Future)	1.3	1.20	50%
• Wind machines driving rotating pumps	1.2	0.80	50%

Table-7.2.1b: Peak overall Power Coefficient $(Cp\eta)_{max}$ [35]

Pumping Head	<3m	3 m	10m	>20 m
Wind machines driving piston pumps				
• Classical	0-0.15	0.15	0.20	0.30
• Starting nozzle Wind machine driving rotating pumps	0-0.13	0.13	0.18	0.27
• Mechanical transmission			0.15-0.25	
• Electric transmission			0.05-0.10	
Quality factor: 0.05 - low, 0.10 - medium, 0.15 - high.				

7.3 Design of Wind Pump Systems:

Wind turbines are becoming an attractive proposition for agricultural pumping in the developing countries. For designing a wind pumping system for a particular area, water requirement per day of that area should be known.

7.3.1 Assessment of Water Requirements:

Main applications of wind pumps in rural areas of developing countries are water supply for drinking and irrigation, with other limited end uses such as water pumping in fish breeding centers, salterns, drainage, etc.

Irrigation:

Water requirements for irrigation depend on a number of factors, which need to be carefully analyzed in order to optimize the wind pumping system to the given situation. Factors which have the most direct influence on the assessment of water requirements are;

(i) Cropping system followed by the farmer;

(ii) Crop water requirements under given climatic conditions;

(iii) Type and condition of soil;

(iv) Topography of the area.

The annual cropping system followed by farmers basically reflects the seasonality of the agricultural practices as well as the crop mix during each season. The choice of cropping system would be mainly governed by the market considerations of the produce. Some typical cropping systems followed in Bangladesh are presented in Table-7.3.1. Wind pumping could be used for irrigation only during the cropping season, which coincides with the windy period in the region and also if it happens to be the season of irrigated agriculture. Once the cropping system is identified, the net water supply for irrigation could be estimated from the data on crop water requirements. These are obtained from the Directorate of Agricultural Extension (DAE) in Bangladesh, as shown in Table-7.3.2. The gross water supply, which is also the desired wind pump output, depends on the efficiency of water conveyance through the field, which in turn depends primarily on the field canal network and soil conditions.

Table-7.3.1: Some Typical Medium Highland Cropping Systems followed in Bangladesh

SI. No.	Crop	Season	
1.	Pulses	October	January
	Chilly	February	July
	Soyabean	July	September
2.	Chilly	November	May
	Vegetables	May	October
3.	Mustard	October	February
	Potato	December	February
	Vegetables	June	October
4.	Wheat	November	February
	Chilly	March	September
5.	Onion	October	January
	Vegetables	March	July
	Soyabean	July	September
&	Garlic	September	January
	Chilly	February	May
	Vegetables	June	August
7.	Potato	November	January
	Rice (Boro)	February	May
	Chilly	May	September

Source: Irrigated Crop Production Manual, DAE, Bangladesh

Table 7.3.2: Irrigation Water Requirements of Medium Highland Crops Grown in Bangladesh

Crops	Crop duration (days)	Number of irrigation	Irrigation frequency (days)	Water requirement per irrigation (m^3/ha)	Daily water requirement per irrigation on rotation basis
Chilly	150	19	8	184	23
Onion	95	11	7	273	39
Garlic	90	15	6	200	33
Soybean	110	4	28	750	27
Wheat	120	5	24	700	29
Rice (Boro)	120	5	24	2150	90
Potato	100	10	10	350	35
Mustard	96	4	24	750	31
Vegetables	100	17	6	176	29

Source: Irrigated Crop Production Manual, DAE, Bangladesh

Drinking Water Supply:

In general, drinking water requirements could be estimated as the product of the per capita consumption and the human or animal population as the case may be. Domestic water requirements per capita vary markedly in response to the actual availability of water. If there is home supply, the consumption may be five or more times greater than if water has to be collected from the public water point. Where groundwater is scarce, the per capita allocation of water will be determined more by supply constraints than by the demand. Subject to availability of water, it seems reasonable to assume a consumption rate of 40 litres per capita per day for the purpose of designing village drinking water supply schemes [34]. Typical daily water requirements for a range of livestock are presented in Table 7.3.3.

Table 7.3.3: Typical Daily Water-Requirement of Livestock [34]

Species	Liters of water per day
Camels	40 - 90
Horses	30-40
Cattle	20-40
Milk Cow	70-100
Sheep and Goats	1-5
Swine	3-6
Lactating	25
Poultry	0.2-0.3

For example, population at Kutubdia where water to be supplied by the wind pump is 5500 peoples, 3000 cattle, 5000 goats and 30000 chickens-

Then present daily water demand is:

5000 People	=5000x40L	= 200000 Liters
2000 Cattle	= 2000 x 40 L	= 80000 Liters
5000 Goats	=5000x5L	= 25000 Liters
30000 Chickens	=30000 x 0.1 L	= 3000 Liters
Total Demand		= 308000 Liters
		= $308m^3$

7.3.2 Hydraulic Power Requirements:

Once the water requirements are established, the hydraulic power requirements could be estimated using the following equation [36]:

$$P_{hyd} = 0.1134qH \text{ (Watt)} \qquad 7.3.1$$

Where,

P_{hyd} - Average hydraulic power (W)

q - Pumping rate (m^3/day)

H - Total pumping head (m)

The total pumping head includes the static head, draw down in the well (the lowering of the water level due to pumping), and the head losses in pipes and fittings. Data for a hypothetical water supply scheme in Bangladesh are presented as a design example in Table 7.3.4.

Table 7.3.4: Hydraulic Power Requirements in the Design Example

Total static pumping head: 20 m				System head loss: 10%	
Month	Required water output (m^3/day)	Static head (m)	Head loss (m)	Total head (m)	Average hydraulic power required (W)
January	308	20.0	2.0	22.0	768.4
February	308	20.0	2.0	22.0	768.4
March	308	20.0	2.0	22.0	768.4
April	308	20.0	2.0	22.0	768.4
May	308	20.0	2.0	22.0	768.4
June	308	20.0	2.0	22.0	768.4
July	308	20.0	2.0	22.0	768.4
August	308	20.0	2.0	22.0	768.4
September	308	20.0	2.0	22.0	768.4
October	308	20.0	2.0	22.0	768.4
November	308	20.0	2.0	22.0	768.4
December	308	20.0	2.0	22.0	768.4
Total annual water requirement :112420 m^3/year					

7.3.3 Available Wind Power Resources:

Once the demand considerations are specified, the next step of the design process is to ascertain the availability of wind power resources to meet the hydraulic power demanded by the system. As wind speed is very often a seasonal phenomenon, it is necessary to evaluate the availability of wind power resources on a monthly basis. Wind speed data required for such an analysis would have to be obtained from the nearest wind measuring station such as the local meteorological station. The process of designing a wind pump system for a given location required a further step in estimating the site wind speeds using the station potential wind speeds.

For the example considered here, wind speed data are taken from the wind measuring station at Kutubdia, Cox's Bazar. Both potential wind speeds and the estimated site wind speeds are presented in Table 7.3.5. Specific wind power at the site could be calculated as the available wind power divided by the rotor area (P_{wind}/A_{rotor}).

Table 7.3.5: Wind Power Resources in the Design Example

Kutubdia, Cox's Bazar			Assumed wind pump hub height: 20 m	
Month	Average potential wind speed at 10 m height (m/s)	Average potential wind speed at 20 m height (m/s)	Density of air (kg/m^3)	Specific wind power (w/m^2)
March	3.79	4.92	1.2	72.95
April	12.02	15.63	1.2	2338.75
May	2.95	3.92	1.2	36.9
June	4.71	6.12	1.2	140.6
July	5.73	7.45	1.2	253.26
August	4.64	6.03	1.2	134.3
September	2.98	3.97	1.2	38.32

7.3.4. Determining the Design Month:

There are two options for operating wind pump: either as a stand alone system providing water throughout the year or a fuel saver operated during the windy months to reduce the fuel consumption of the water supply system equipped with an engine-driven water pump set.

The sizing methodology for a wind pump in the fuel saver mode is an iterative process, going from sizing to economic analysis, and back to sizing, until the most cost effective combination of the engine-pump set and wind pump is established. For the example considered in this chapter, a storage tank of three days capacity or 120 m^3 is chosen. In the case of a stand alone wind pumping system, the requirement is that the system should provide output during the entire year without any back-up system. Therefore, the wind pump size is chosen on the basis of the "design month", which is the month during which the ratio of the hydraulic power to the specific wind power is highest. If the hydraulic power demand is constant throughout the year (e.g. in drinking water supply schemes), then the design month is essentially the month having the lowest wind power potential. This ratio has the dimension of an area and will be referred as the "reference area". It is related to the rotor area needed to capture sufficient power from the wind to meet the demand. Results of this computation as applied to the design example are presented in Table-7.3.6, and the design month is May.

Table 7.3.6: Calculation of the Design Month for Wind Pump Sizing in the Design Example.

Month	Average hydraulic power, P_{hyd} (W)	Average wind speed at hub height (m/s)	Specific wind power, P_{wind} (W/m2)	Reference Area P_{hyd}/P_{wind} (m2)	Design months
March	768.4	4.92	72.95	10.53	
April	768.4	15.63	2338.75	0.33	
May	768.4	3.92	36.9	20.8	√
June	768.4	6.12	140.6	5.46	
July	768.4	7.45	253.26	3.03	
August	768.4	6.03	134.3	5.72	
September	768.4	3.97	38.32	20.0	

7.3.5 Sizing the Wind Pump:

Prior to determine the size of the wind pump, it is necessary to outline the system demand characteristics in relation to output i.e. high output or high availability. Equally important is the choice of the technology, modern light weight designs with high maintenance duty or classical wind pumps offering greater reliability and prolonged unattended operation.

Experience so far indicates that most modern designs have yet to prove their ability to withstand the conditions of deep well pumping [25]. According to available experience, most modern wind pumps are suitable for low head pumping, where structural loads are manageable and frequent maintenance is more easily carried out, than in deep well pumping. Therefore, it is advisable to consider classical wind pumps when a choice is made on the technology for deep well wind pumping. Accordingly, classical type of a wind pump is chosen for the case in the example. Sizing of the wind pump is basically the determination of the required diameter of the rotor. This could be done using equation 7.2.2, or more easily from the Nomogram given in Figure 7.3.1 by carrying out the following procedure.

Step-1: Locate the reference area along the X-axis on the graph on the right side. In the case of the example, the reference area is taken as $20.8 \approx 20\ m^2$.

Step-2: Move upwards to intercept the line conforming to the chosen energy production coefficient C_E (values could be chosen by referring to Table-7.2.1). Chose 0.4 for classical wind pump for deep well application: H=20 m.

Step-3: Move horizontally to intercept the lines of peak overall power coefficient on the Fig. 7.3.1 on the left-hand side. Chose $(C_{P\eta})_{\max} = 0.3$.

Step-4: Move downwards to intercept the X-axis referring to the rotor diameter. This results in $D_{rotor} = 9m$

When selecting a 9 m wind pump from available commercial, designs, it might become necessary to alter the hub height to conform to standard designs. When selecting the appropriate pump for the chosen machine, it is necessary to evaluate the design wind speed V_d. Choosing $V_d/V_{av} = 0.6$ from Table 7.2.1 and the average wind speed during the design month equal to 3.92 m/s, the design wind speed works out to 2.4 m/s. Referring to the nomogram in Figure 7.3.2, the following steps should be taken for selection of the pump size.

Step-1: Locate the rotor diameter on the X-axis on the Fig. 7.3.2 on the right side.

Step-2: Move upwards to intercept the lines of design wind speeds. The lowest design wind speed marked is 2.5 m/s, which is close enough to the value of 2.4m/s in the example.

Step-3: Move to the left to intercept the speed of operation represented by the product of TSR(tip-speed ratio) x gear ratio(i). Choose TSR of classical wind pumps as unity and gear ratio of back-geared transmission as 0.3. Substituting for the chosen $(C_{P\eta})_{max}$ of 0.3, the result is 0.25.

Step-4: Move downwards to lines of total pumping head, which is 22 in this case, and moving horizontally to the right gives the design stroke volume of approximately 27.50 liters. This might have to be increased by dividing by the volumetric efficiency, which is typically 0.9. The resulting geometrical stroke volume would then be 30.6 liters.

The diameter of the pump could be established from the supplier's catalogues, depending on the stroke adjustment scale and standard pump diameters.

7.3.6 Sizing the Wind Pump for Kutubdia, Bangladesh:

Empirical equation developed for wind pump rotor sizing for Bangladesh is given below

$$HQ=C \times D^2 \times V^3 \qquad (7.3.1)$$

Where,

C = Constant (here, 8.47)

HQ = Volume-Head product (m^4/day)

Q = Water requirement per day (m^3/ day)

H = Water tank height (m)

D = Diameter of the rotor (m)

V = Average wind velocity (m/s)

When the water requirement per day for a particular region is known, then the following steps could easily do rotor sizing.

Sizing of the wind pump for Kutubdia, Bangladesh could be carried out using equation 7.3.1, the results is D = 3.98 m.

When selecting a 3.98 m wind pump from available commercial designs, it might, become necessary to alter the hub height to conform to standard designs. Another way, sizing of the wind pump for Patenga, Bangladesh could be carried out using equation 7.3.1, when selecting a wind pump from available commercial designs, it might become necessary to alter the hub height to conform to standard designs. The diameter of the pump could be established from the supplier's catalogues, depending on the stroke adjustment scale and standard pump diameters.

7.3.7 Sizing of Storage Tank:

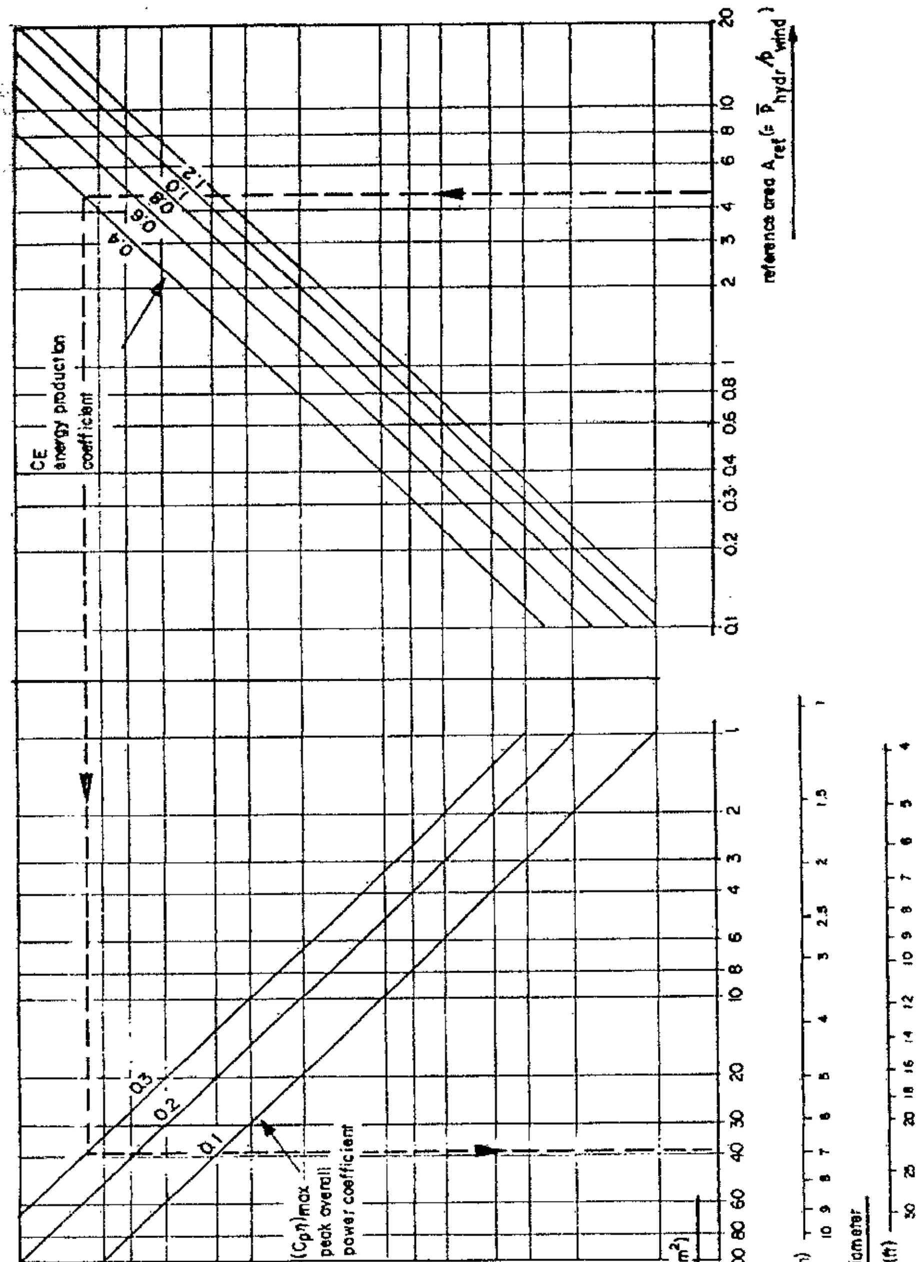
In wind-powered water supply systems, there is a need for storage of water for two basic reasons: to maintain supply during windless periods (Lull periods) and to store water that is pumped during the period of low consumption. For example, in irrigation system water is used for irrigation only during the day time, whereas pumping may go on throughout the night. Thus, storage of water during the night would enhance the command area of the cultivation. For this purpose, a storage tank of about half the typical daily output would be sufficient. But, if it is necessary to guarantee the supply of water during intermittent windless days as well, then the storage tank capacity would have to be considerably higher and would depend on the probability of occurrence of such events. In most locations, it is very rare for the wind to be too low to operate the pump more than three days, so a tank sized for three days would normally be adequate.
In practice, however, for example, the use of large water storage tanks to account for windless day is rare among the farmers. Although water scarcity could seriously hamper the farming operations, most farmers are unable to afford the high cost of tank construction. Instead, farmers often use an engine pump, either his own or taken on rent, to meet the water deficit during windless days. Thus, the final choice of the storage tank or an alternative power source depends very much on the cost involved and other factors such as the availability of alternative pumping systems within close proximity of the users.

In the case of wind pumping for drinking water supply, a storage tank is an indispensable item, at least from the view point of design of the distribution piping system. Such systems are always designed for a given range of supply head variations and any fast fluctuating outputs (such as the direct output from a wind pump) could cause considerable technical problems.

On the user side, there is also the possibility of having periods of peak demand, when the demand may exceed the supply and a storage tank of a pre-determined size would be essential to meet such situations. The tank could then store water pumped during the periods of low consumption as well as during the times of strong winds to meet such situations. The sizing of the tank may also take into account the supply of water during windless days. Although it might involve a high cost, such expenditures are well within the capacity of community drinking water supply projects. The storage capacity is calculated as follows:

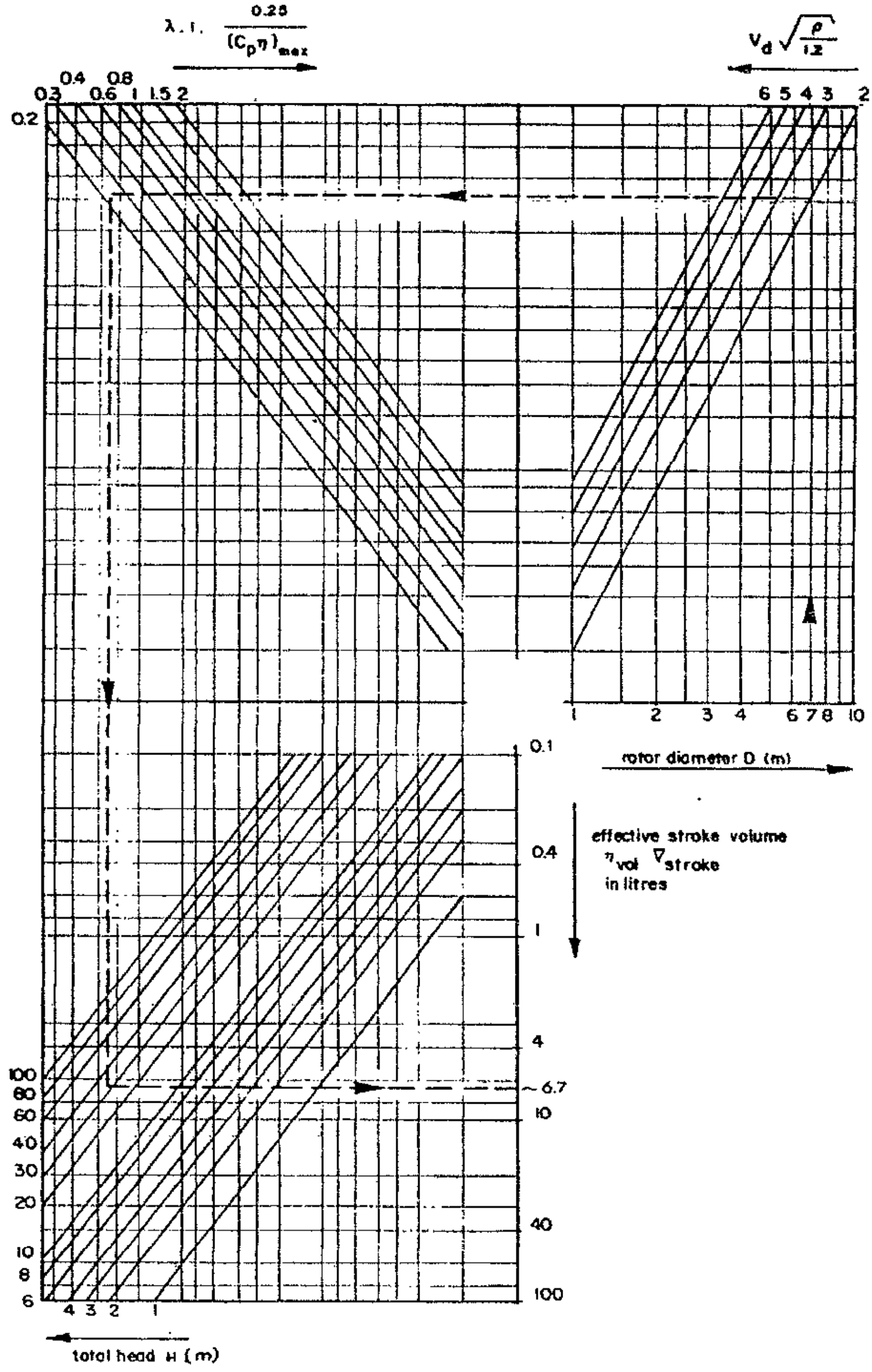
Storage capacity = Daily water requirement x Longest lull Period x Safety factor

A safety factor of two is recommended. The example considered in this text, a storage tank of three days capacity or 960 m^3 is chosen [25].



Source: van Meel and Smulders, 1987

Fig 7.3.1: Nomogram to determine the rotor size of a wind pump



Source: van Meel and Smulders, 1987

Fig 7.3.2: Nomogram to determine the size of a pump

Chapter 8

DISCUSSION

Probability density function is an important parameter that indicates the wind speed distribution for a given time. Now considering the Weibull density function f(v) and Weibull function F(v) for all the location. Figures 8.1a show the Weibull density functions for Teknaf.

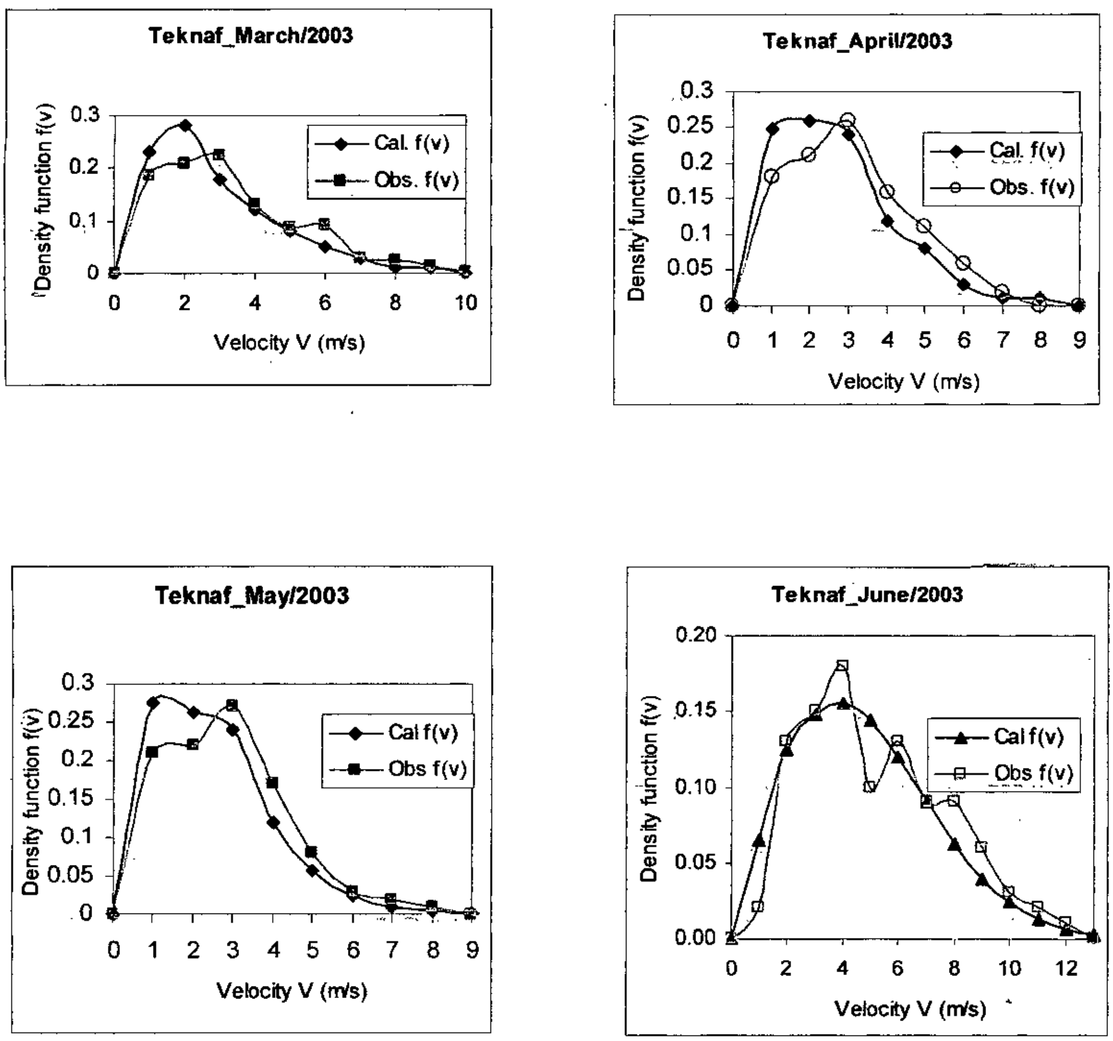


Fig. 8.1a: Weibull density function for Teknaf.................Contd.

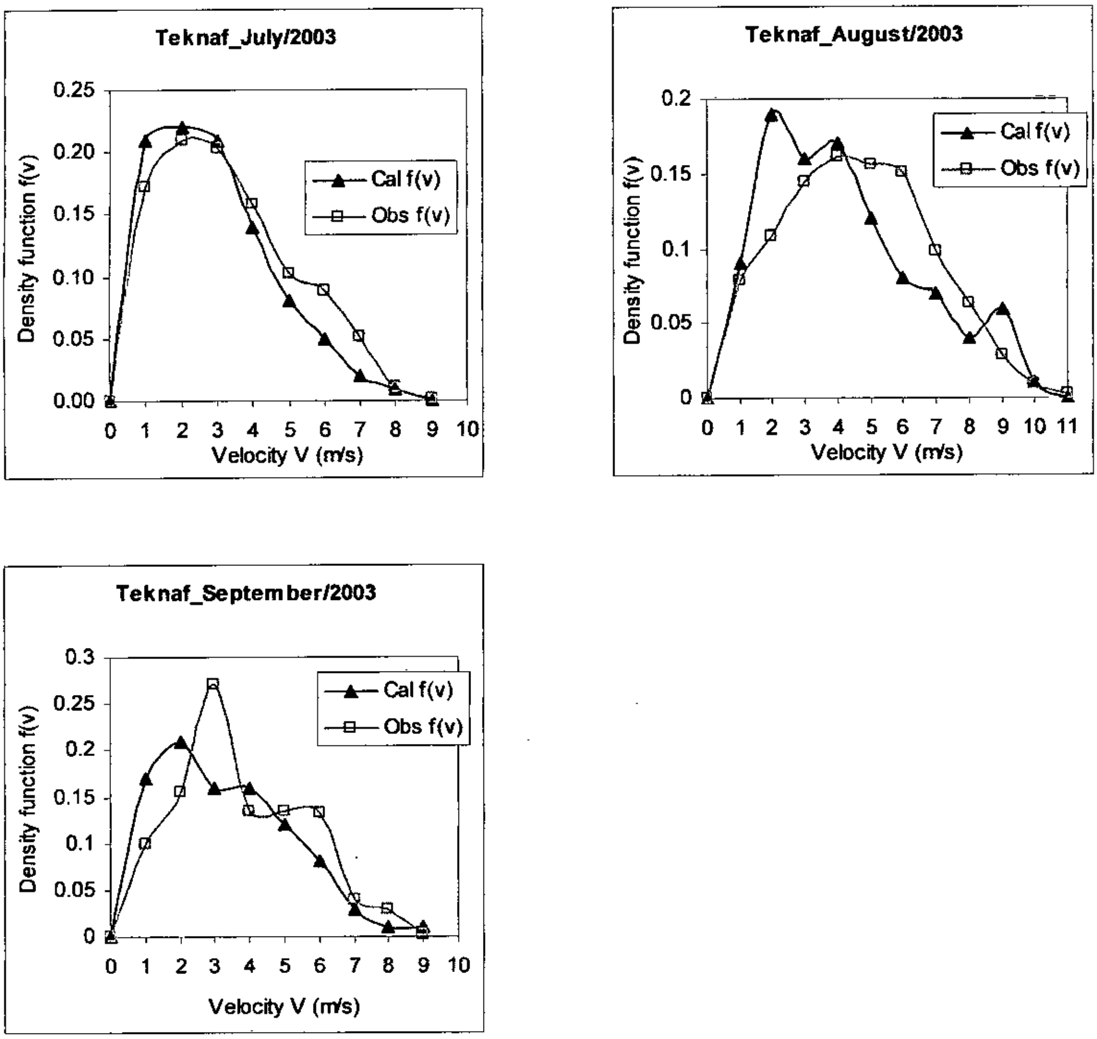


Fig.8.1a: Weibull density function for Teknaf

From above all figures of Weibull density function, it is found that for April and May the peak of calculated and observed f(v) is same and rest are varies from 0.15 to 0.28. Maximum peak variation is found in September. Here the peak is obtained at approx. wind speed of 2.5 m/s to 5 m/s.

Now considering the Weibull function for this location and it is presented in Figures 8.1b.

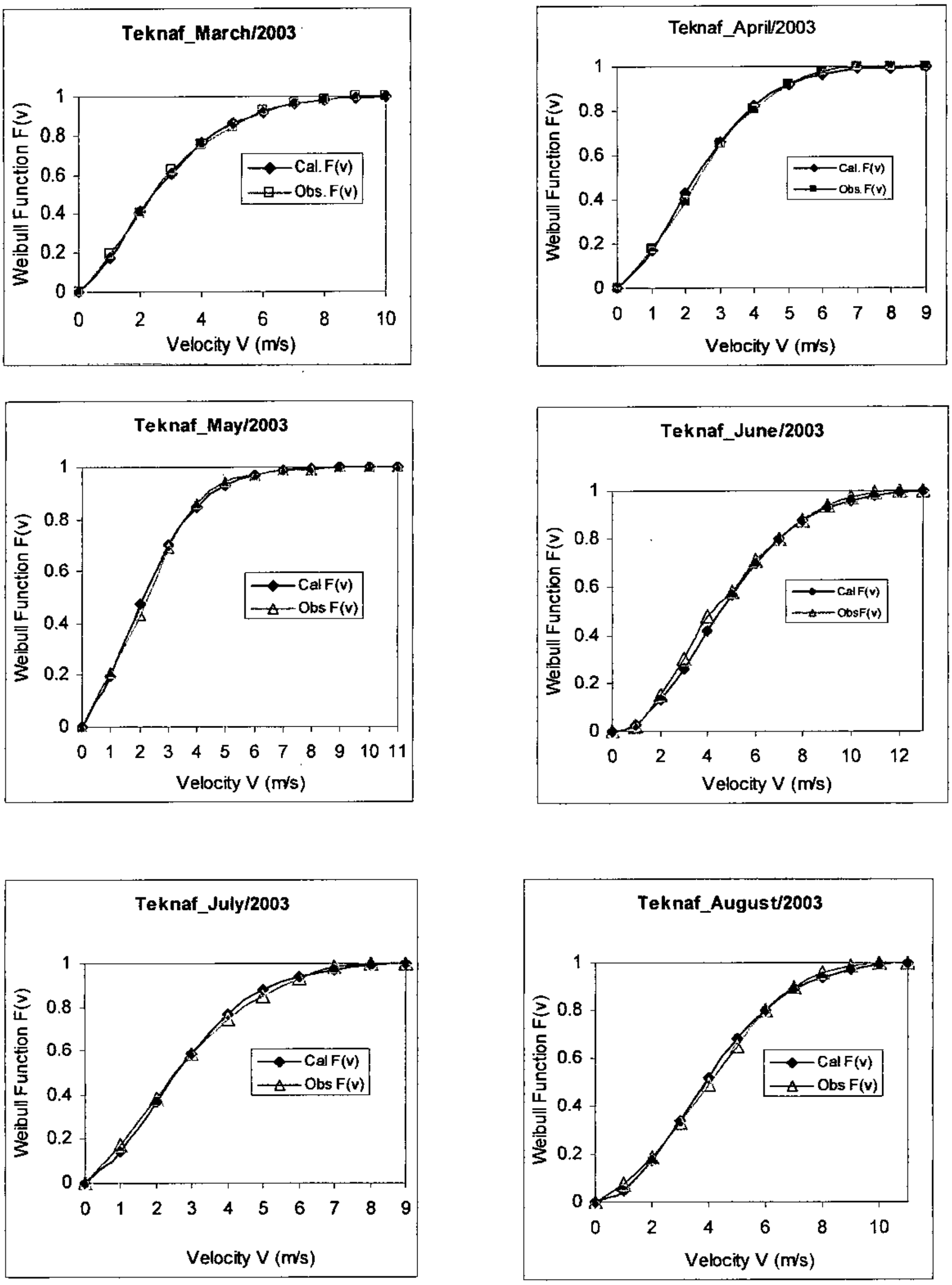


Fig. 8.1b: Weibull Function for Teknaf................Contd.

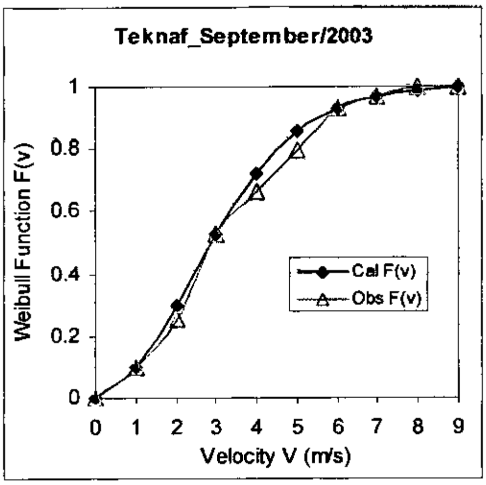
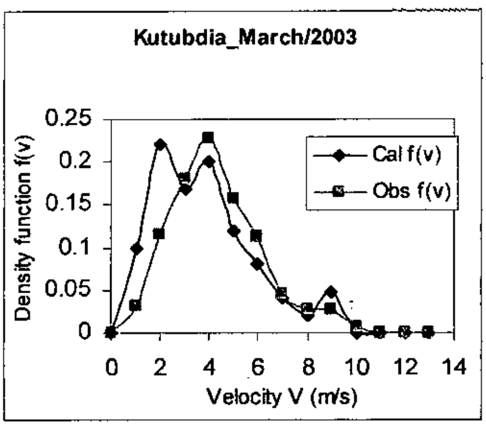


Fig. 8.1b: Weibull Function for Teknaf

From all the Weibull function graph of Teknaf, it is found that the observed and calculated Weibull functions are closely fitted with each other.

The following Fig. 8.2a shows the Weibull density function for Kutubdia.



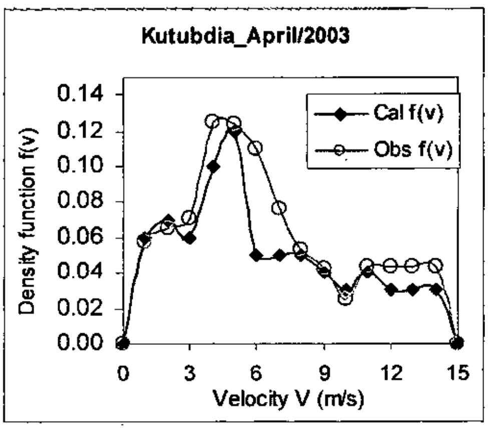
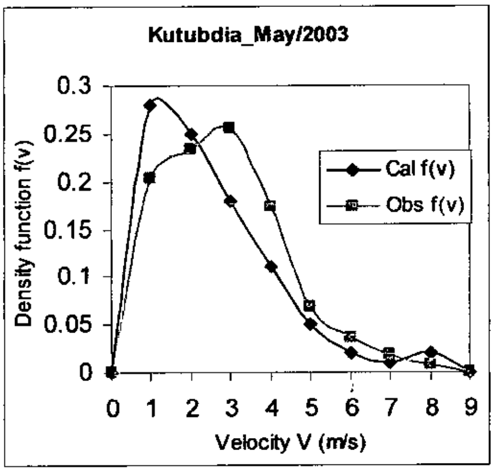
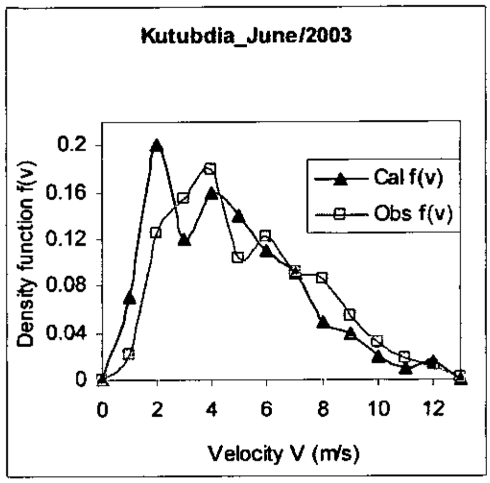
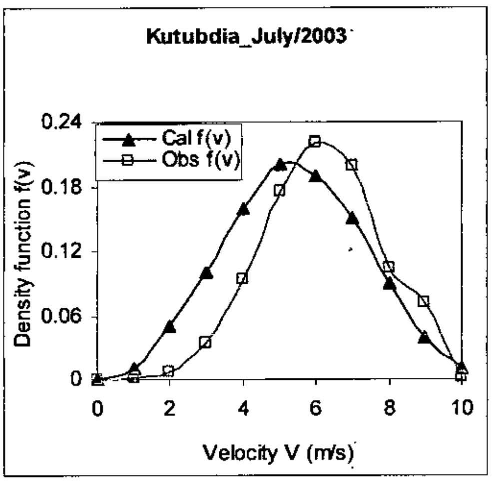
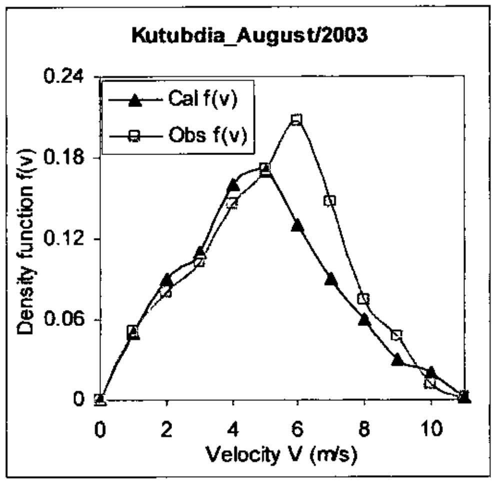


Fig. 8.2a: Weibull density function for Kutubdia...................Contd.









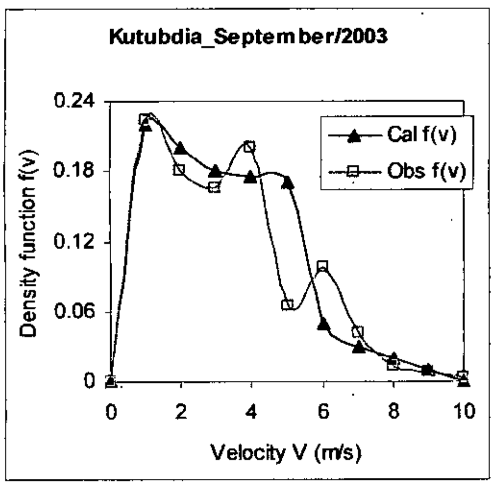


Fig. 8.2a: Weibull density function for Kutubdia

From the above figures of Weibull density function for Kutubdia, it is found that although the calculated and observed data roughly varied with wind speed but their peak is closely to each other except July and August.

Fig. 8.2b shows the Weibull function for Kutubdia.

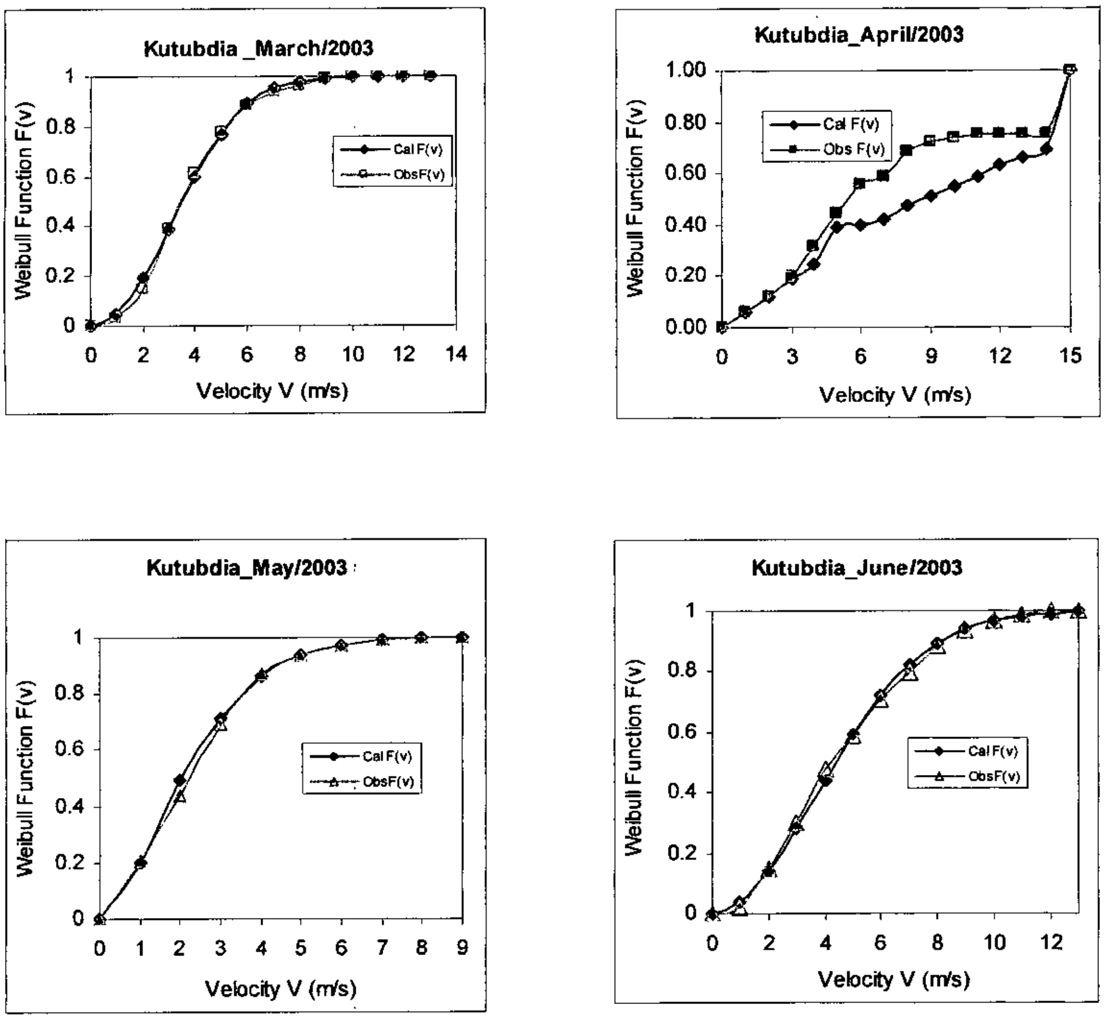


Fig. 8.2b: Weibull Function for Kutubdia.............Contd.

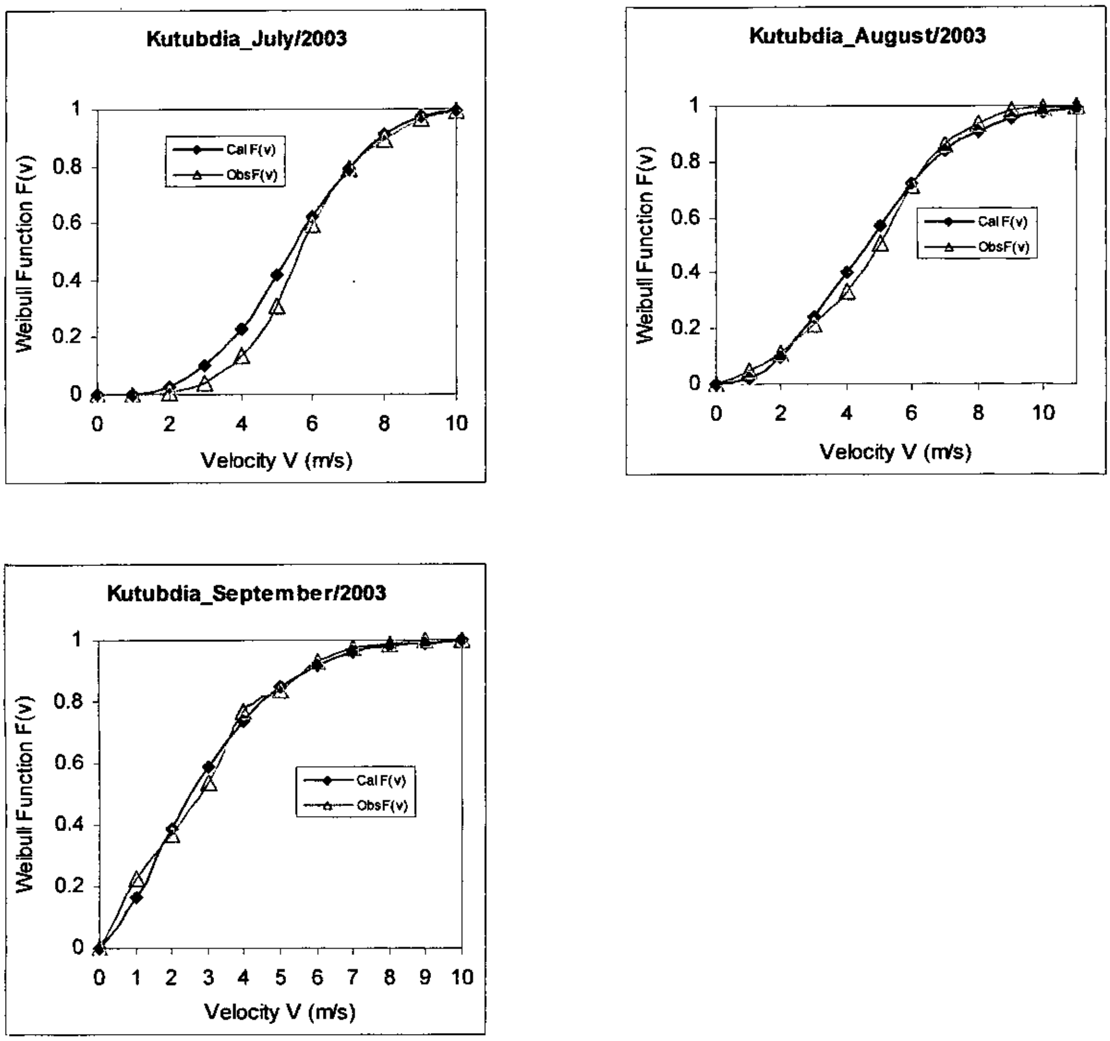


Fig. 8.2b: Weibull Function for Kutubdia

All figures of Weibull function for Kutubdia show that the observed and calculated data are closely fitted with each other except only little deflection in April. The Weibull density function for Sandwip is presented in the following Fig. 8.3a.

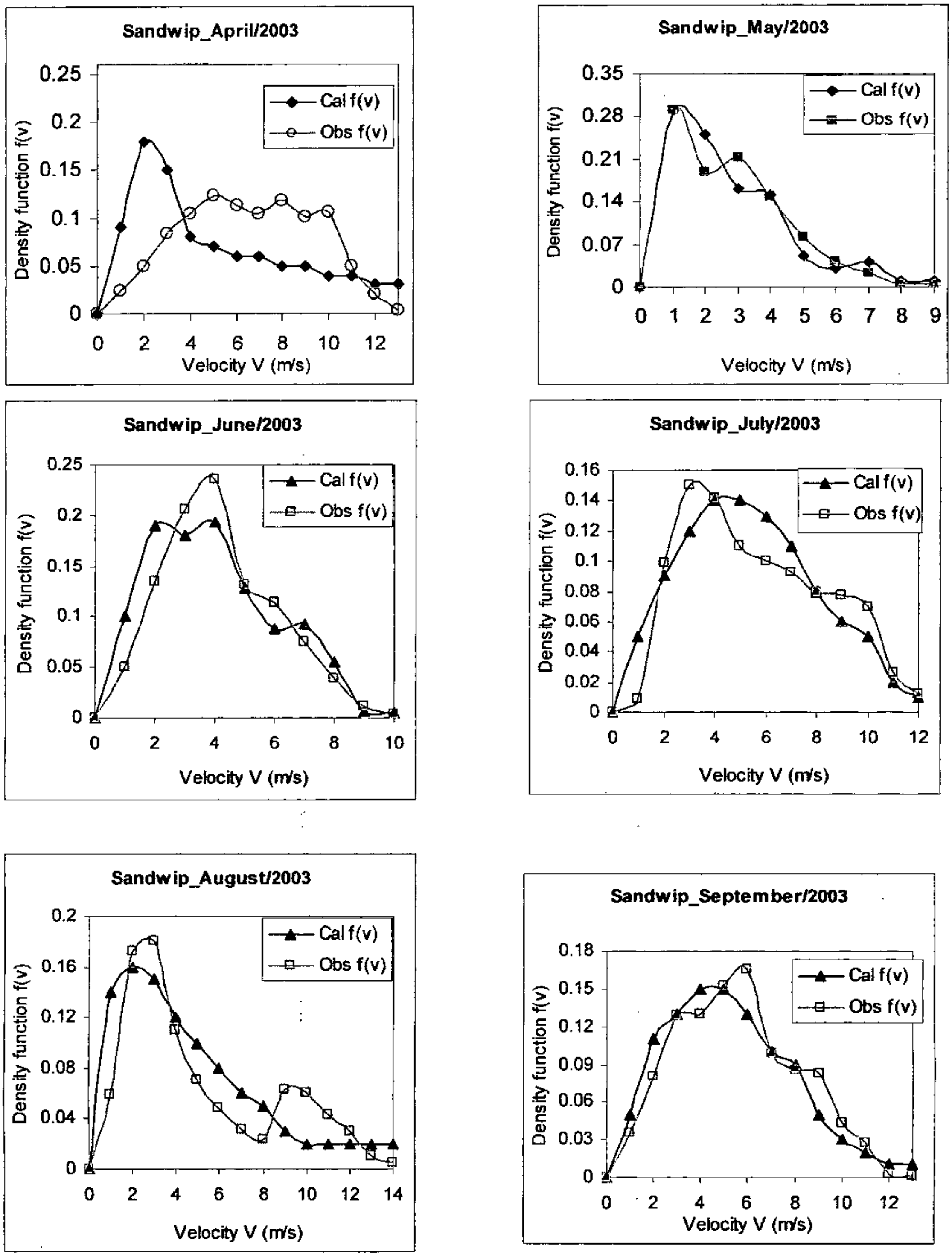


Fig. 8.3a: Weibull Density Function for Sandwip

the Weibull density function it is found that except April, both data are almost closely fitted with each other. Maximum peak is obtained in June for observed data and that of calculated obtained in April. Fig. 8.3b shows the Weibull function for the same location.

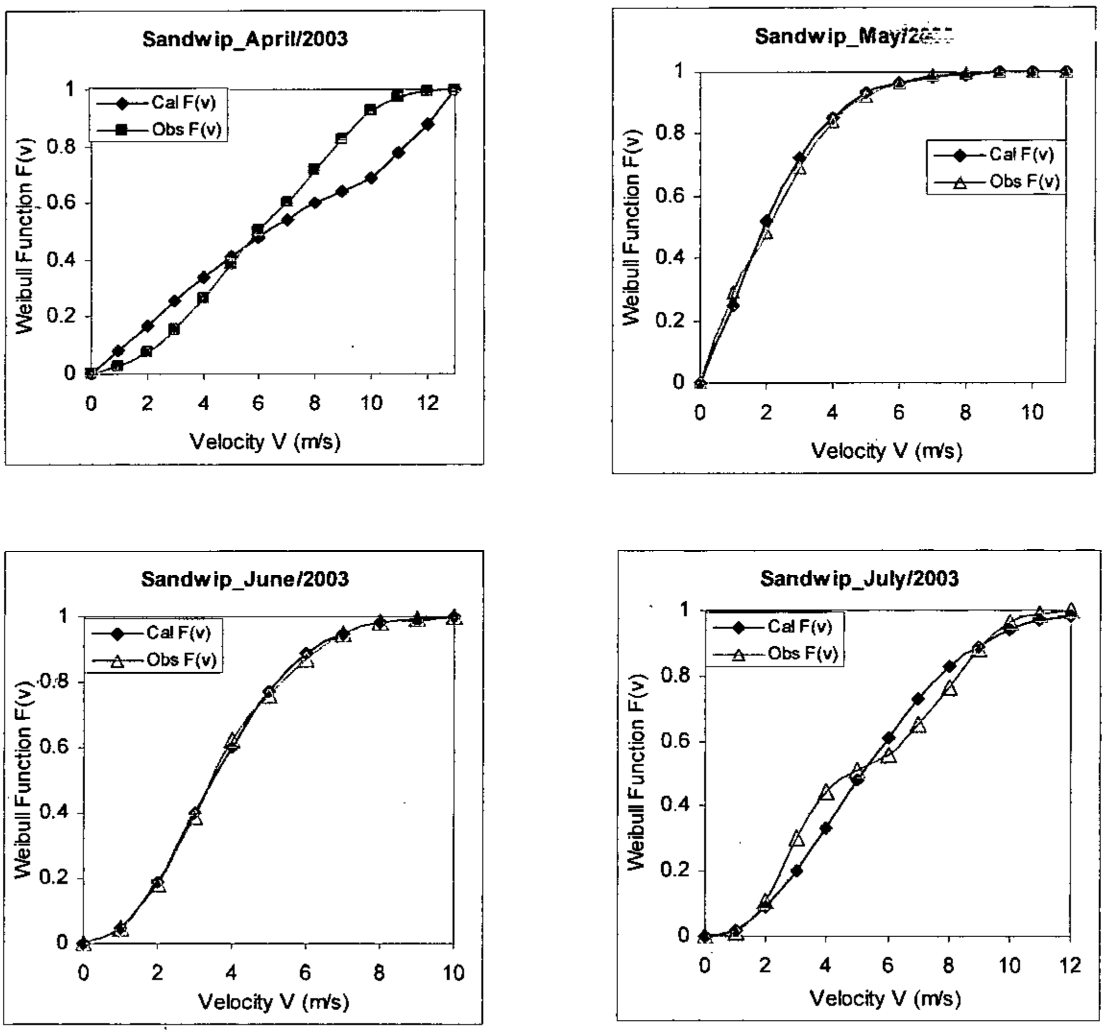


Fig. 8.3b: Weibull Function for Sandwip...........contd.

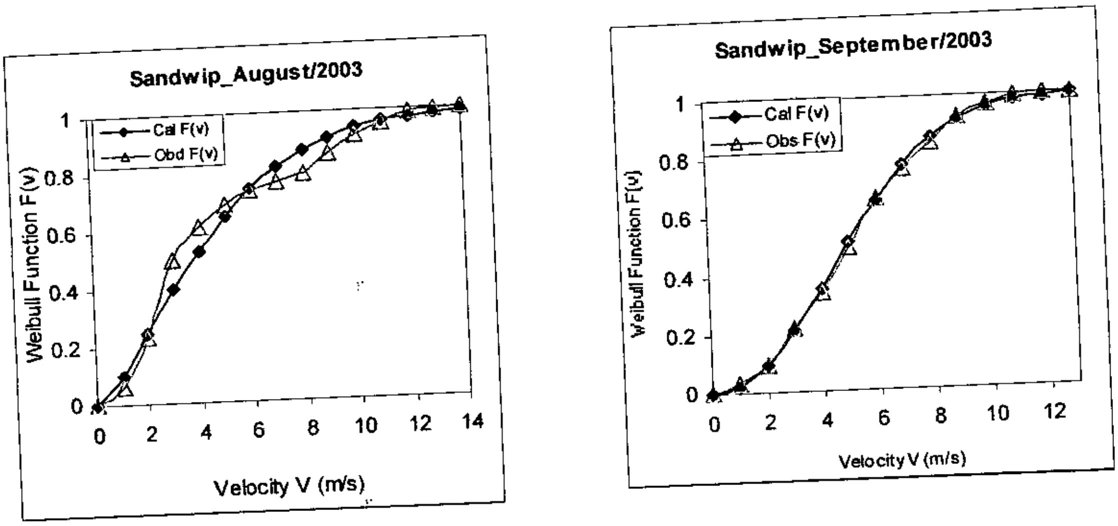


Fig. 8.3b: Weibull Function for Sandwip

Here from the above figures it is clear that except April, rest both calculated and observed data are closely fitted. Fig. 8.4a shows the Weibull Density Function for Kuakata for year 2003.

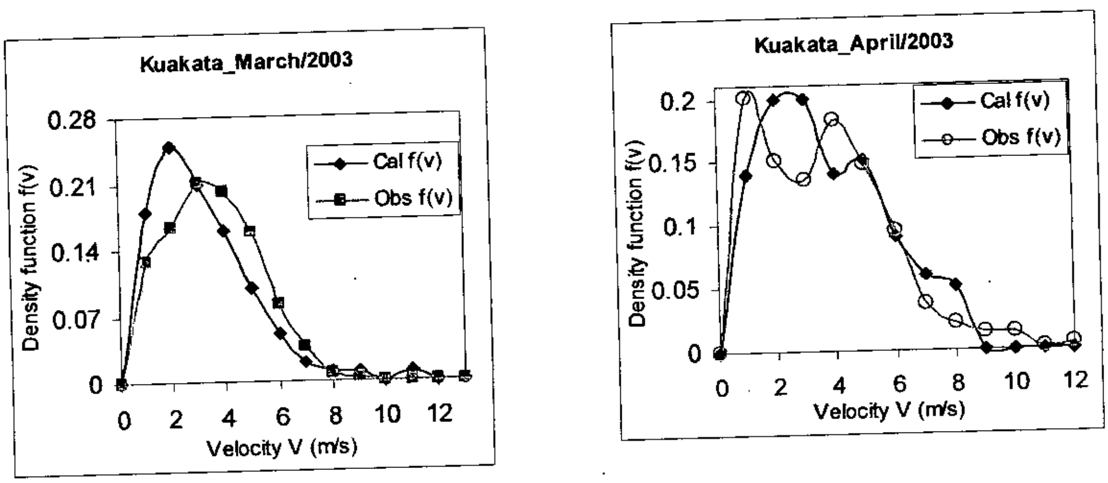
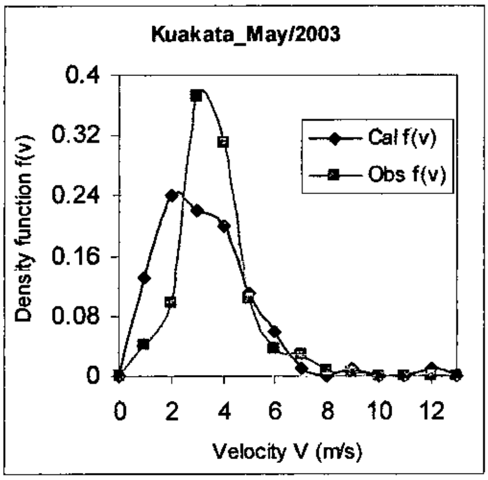
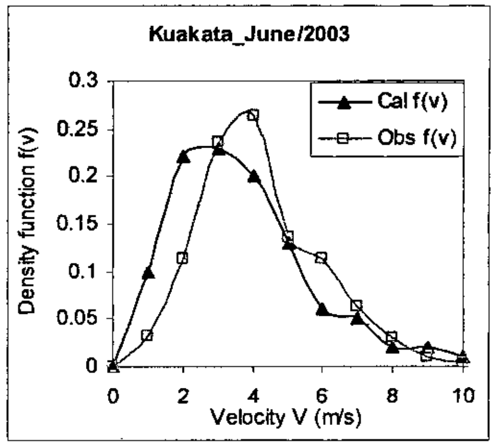
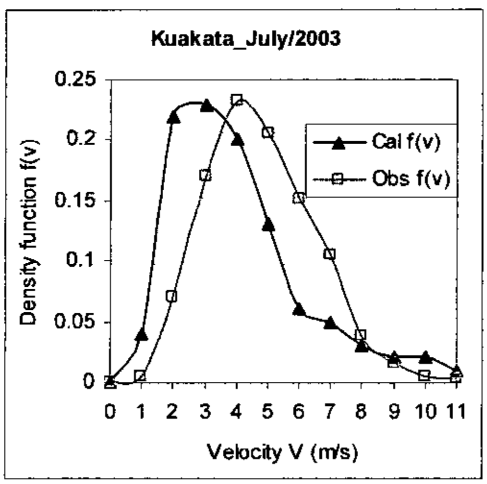
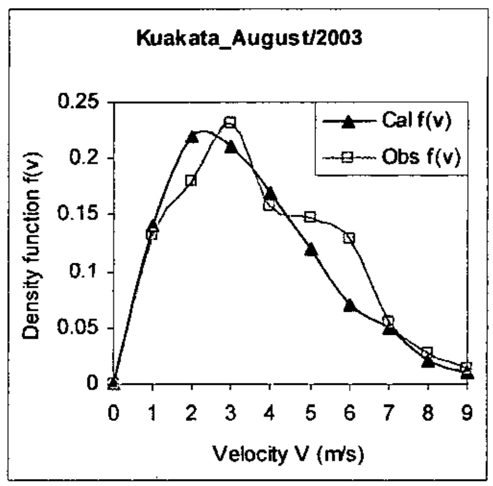


Fig. 8.4a: Weibull Density Function for Kuakata ……..contd.









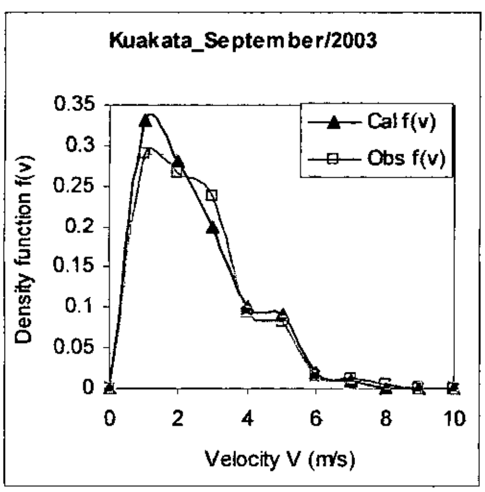


Fig. 8.4a: Weibull Density Function for Kuakata

From above figures, it is found that except March, May and June, the peaks of the rest month are too closer. The maximum peak variation is obtained in May which is 0.24 and 0.38. Average peak is obtained in wind speed range of 3 to 5m/s. Now the following Fig. 8.4b shows the Weibull Function for the same location.

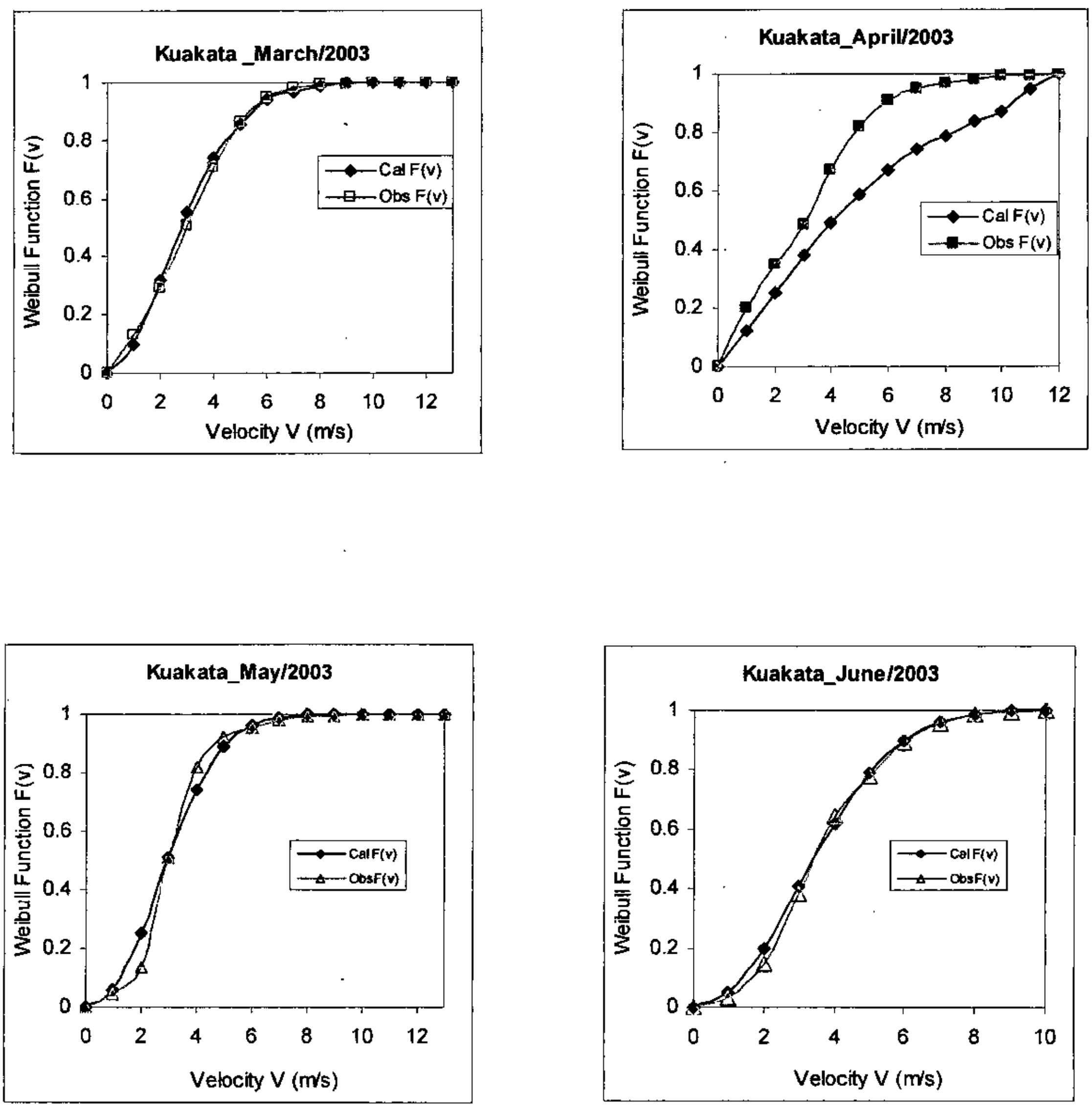


Fig. 8.4b: Weibull Function for Kuakata...................contd.

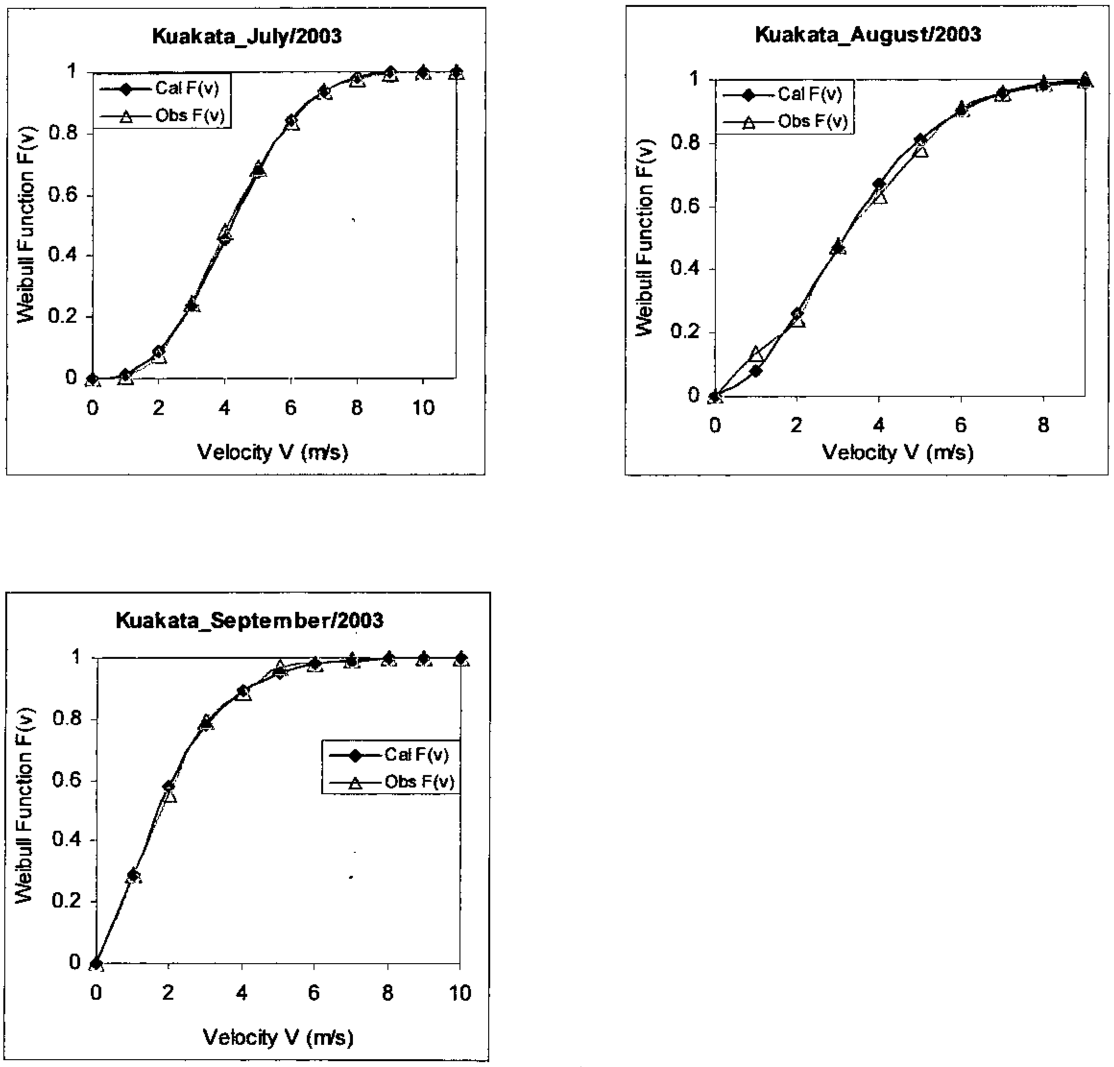


Fig. 8.4b: Weibull Function for Kuakata

Here the entire Fig shown above for Kuakata, it is observed that both the data of calculated and observed are fitted with each other except only a little variation is found in April. The data are too smooth in both July and September. Now Weibull Density Function for Mongla are presented in Fig. 8.5a.

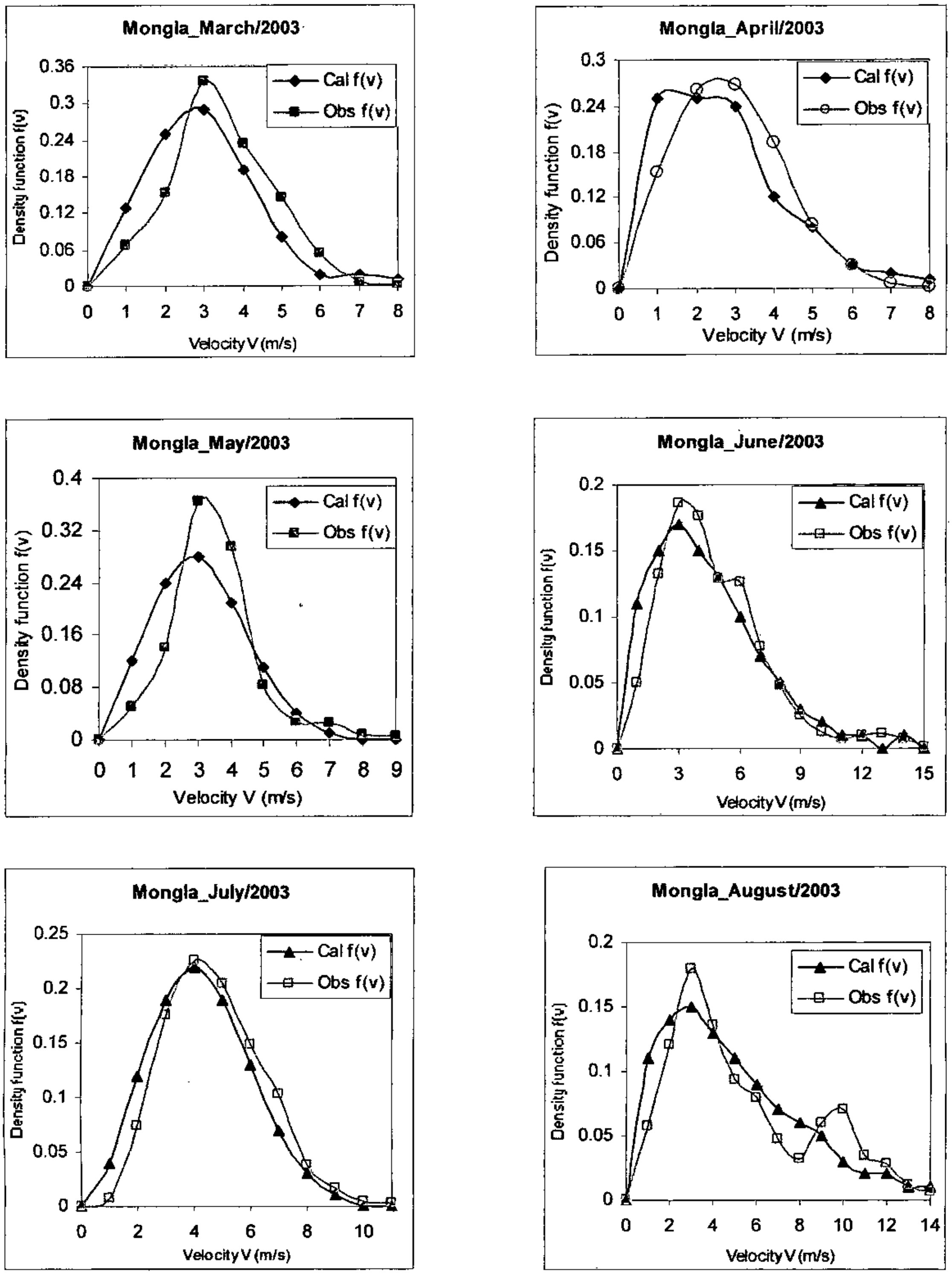


Fig. 8.5a: Weibull Density Function for Mongla........contd.

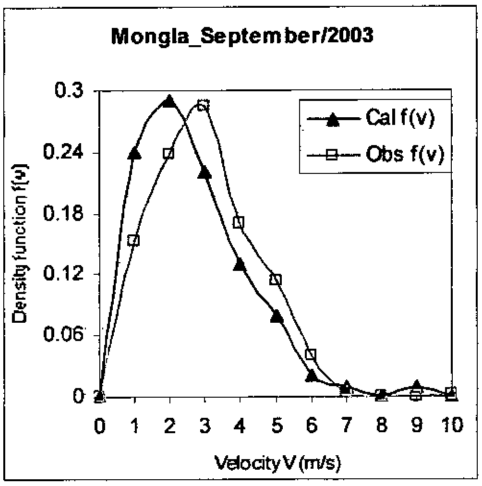
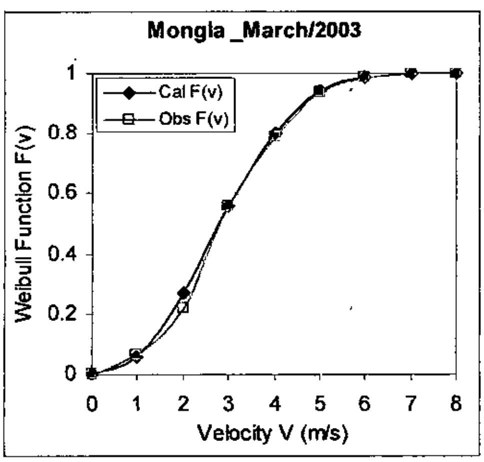


Fig. 8.5a: Weibull Density Function for Mongla

From Fig 8.5a, except July and September the peak variation between observed and calculated data is found. Max. Peak of observed data is found in Mongla which is 0.36 and that of calculated data is found in March and September (in both case the peak is 0.29). Fig. 8.5b shows the Weibull Function for Mongla.



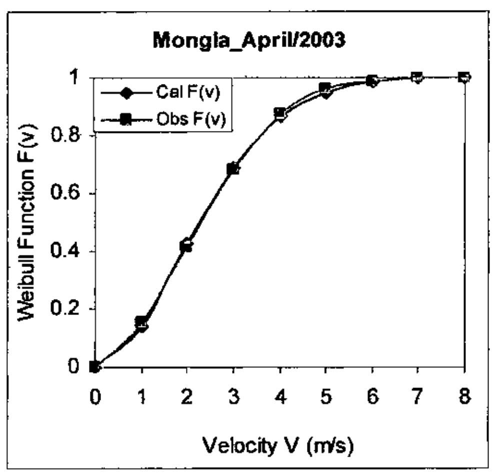


Fig. 8.5b: Weibull Function for Mongla.......................contd.

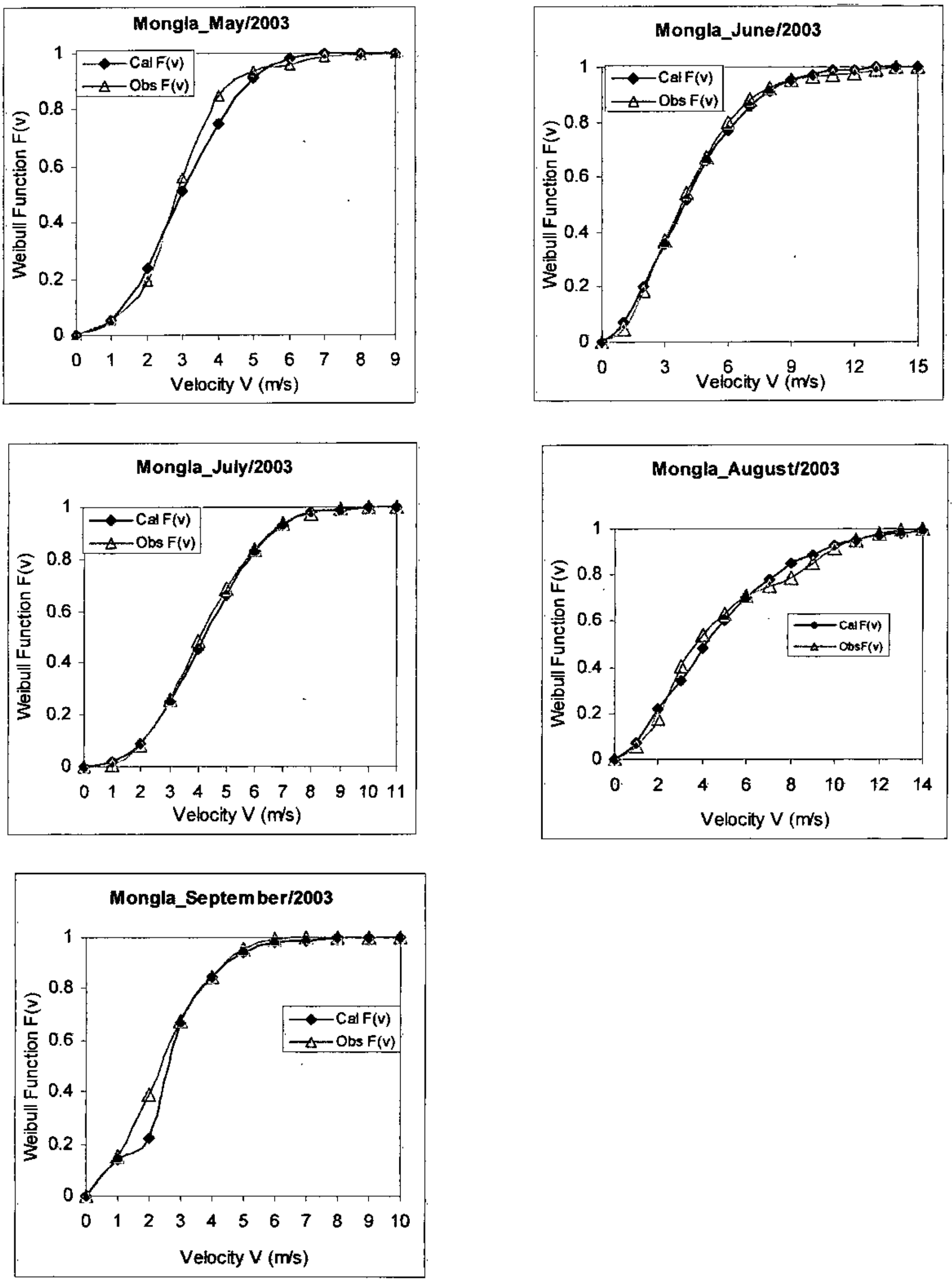


Fig. 8.5b: Weibull Function for Mongla

The Weibull function for Mongla as shown in Fig. 8.5b, it is found that both the calculated and observed data are all about closely fitted with each other. The following fig as shown below represent the frequency occurs and energy histogram, Velocity Duration Curves for each locations.

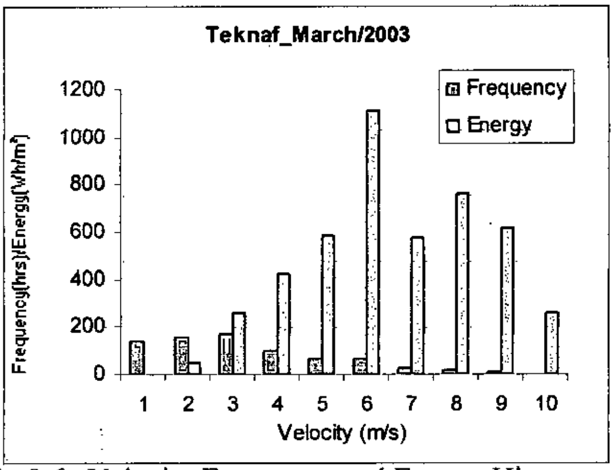


Fig 8.6a Velocity Frequency and Energy Histogram

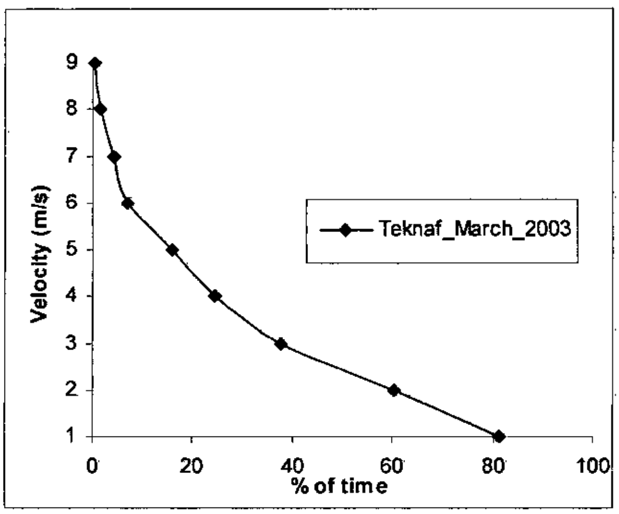


Fig. 8.6b: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 37.77% of total time (744 hrs) above V= 3m/s

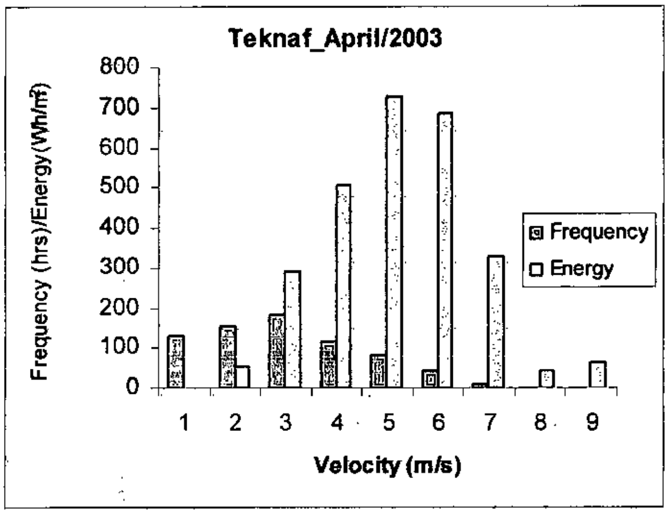


Fig. 8.6c: Velocity Frequency and Energy Histogram

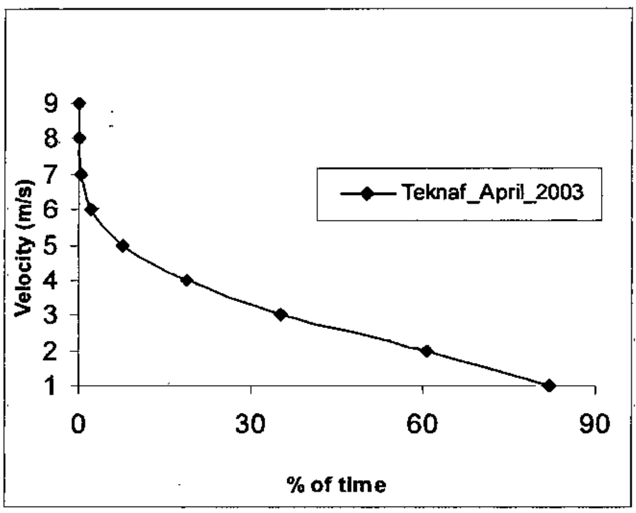


Fig. 8.6d: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=5m/s

And velocity duration is 35.14% of total time (720 hrs) above V= 3m/s

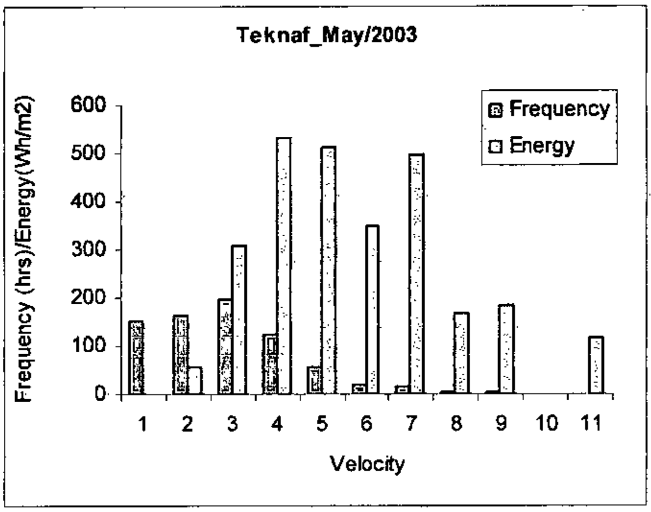


Fig. 8.6e: Velocity Frequency and Energy Histogram

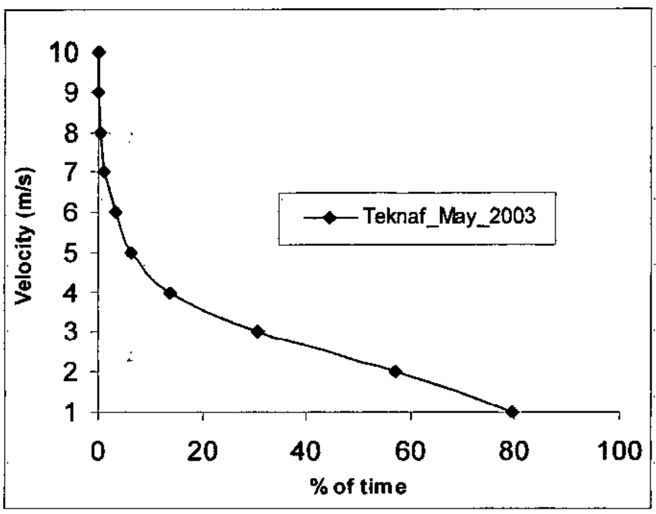


Fig. 8.6f: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=4m/s

And velocity duration is 30.51% of total time (744 hrs) above V= 3m/s

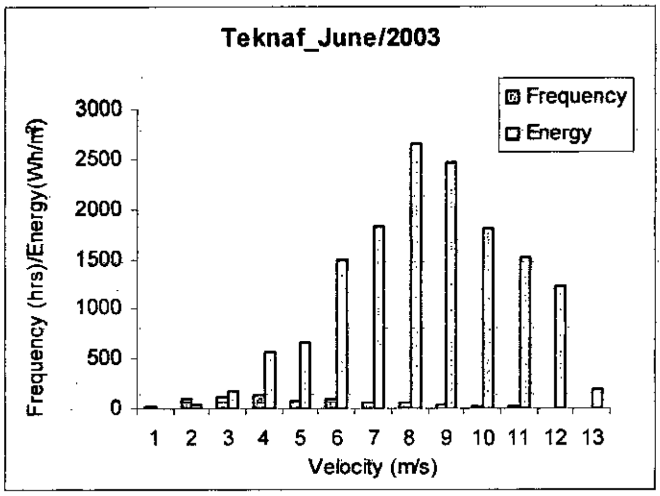


Fig. 8.6g: Velocity Frequency and Energy Histogram

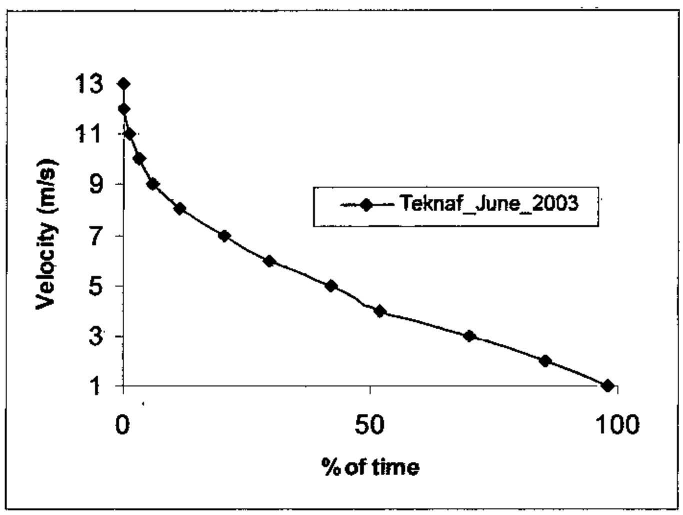


Fig. 8.6h: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=8m/s

And velocity duration is 51.94% of total time (720 hrs) above V= 3m/s

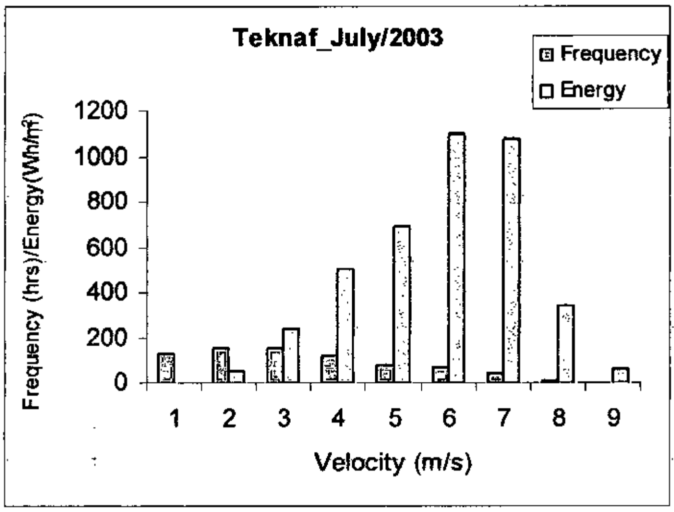


Fig. 8.6i: Velocity Frequency and Energy Histogram

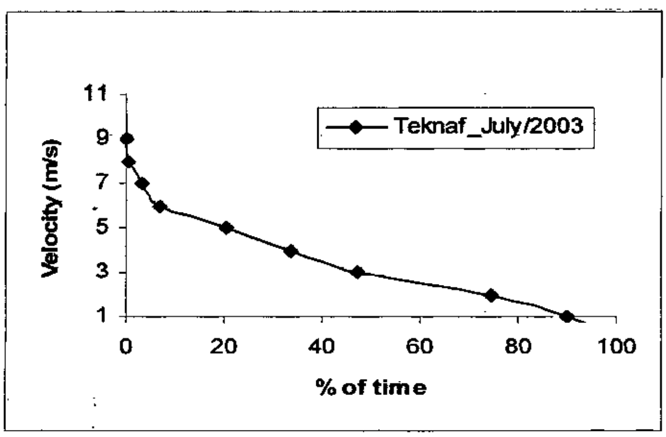


Fig8.6j: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 2m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 61.69% of total time (744 hrs) above V= 2m/s

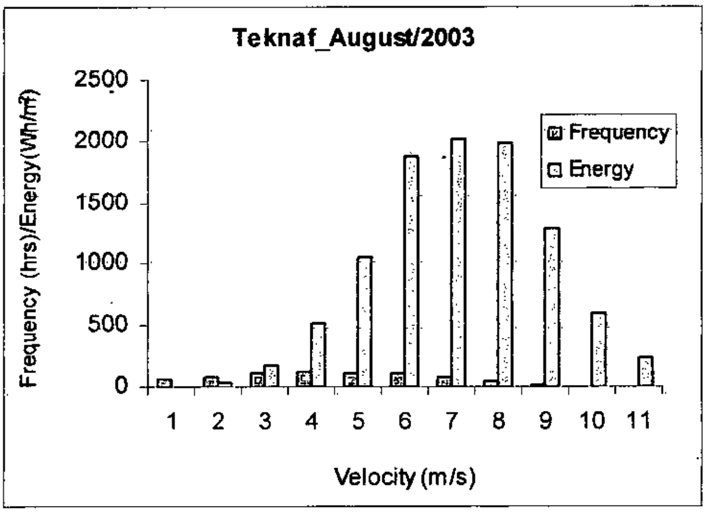


Fig. 8.6k: Velocity Frequency and Energy Histogram

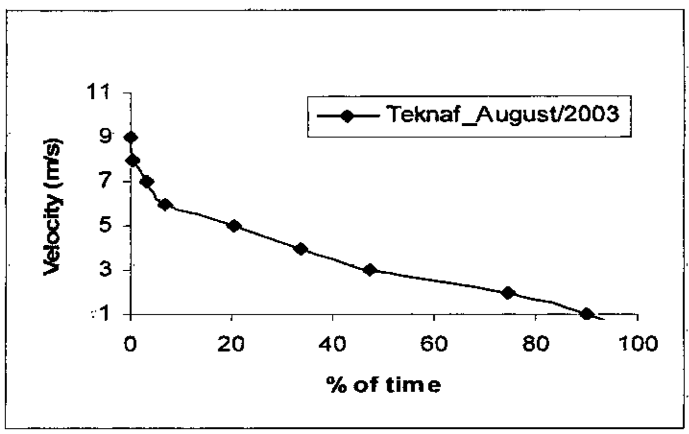


Fig. 8.6l: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=7m/s

And velocity duration is 50.81% of total time (744 hrs) above V= 4m/s

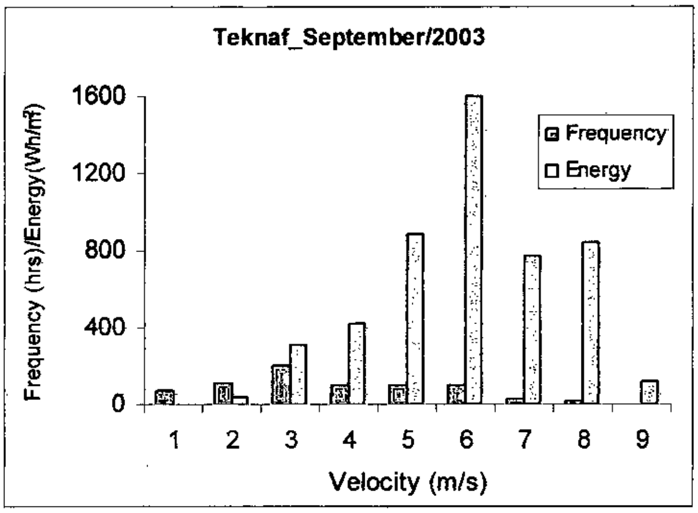


Fig. 8.6m: Velocity Frequency and Energy Histogram

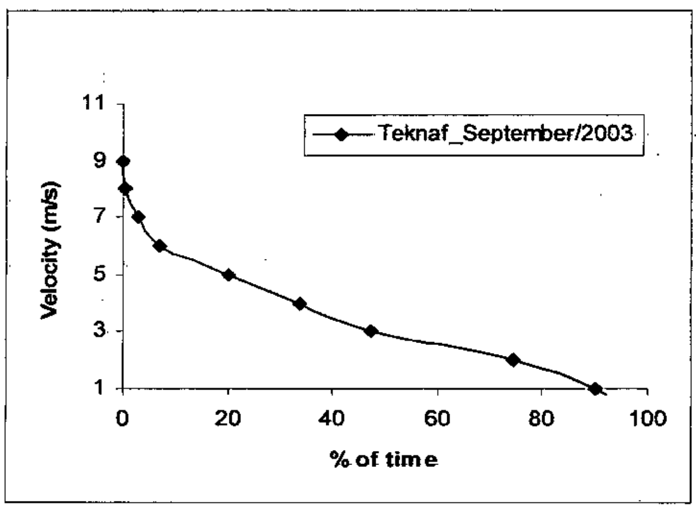


Fig. 8.6n: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 47.22% of total time (720 hrs) above V= 3m/s

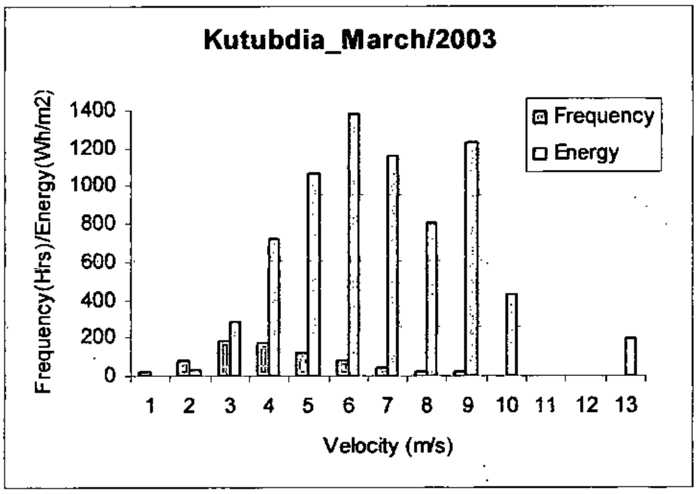


Fig. 8.7a: Velocity Frequency and Energy Histogram

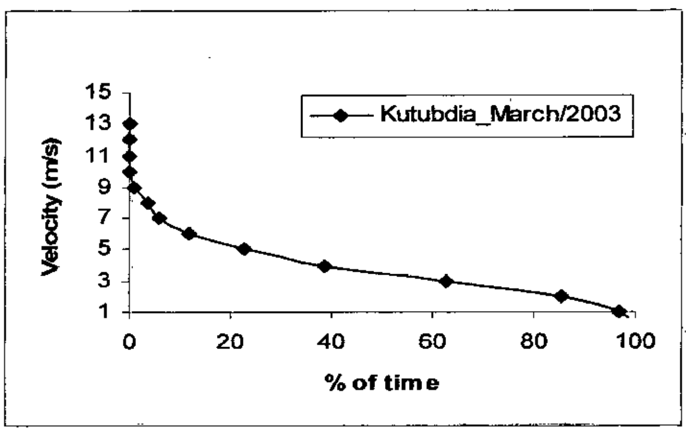


Fig. 8.7b: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 62.50% of total time (744 hrs) above V= 3m/s

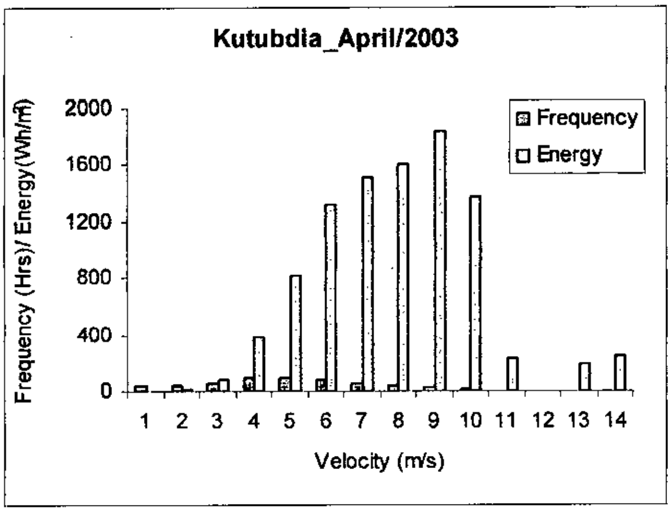


Fig. 8.7c: Velocity Frequency and Energy Histogram

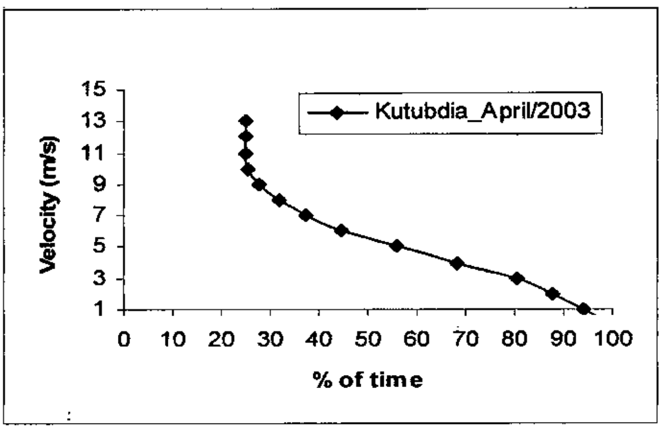


Fig. 8.7d: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=9m/s

And velocity duration is 80.56% of total time (720 hrs) above V= 4m/s

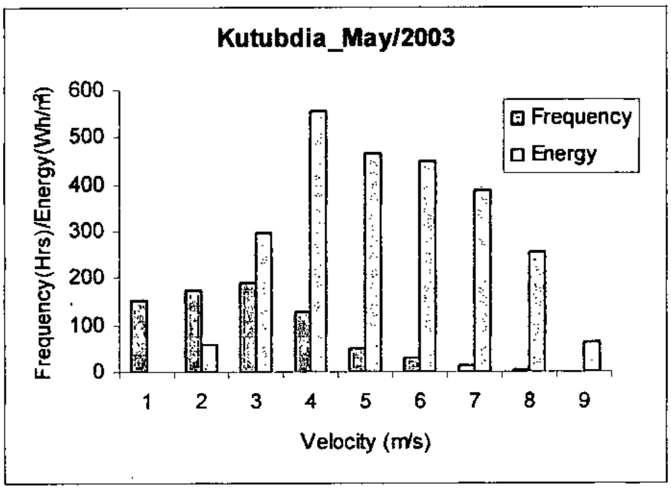


Fig. 8.7e: Velocity Frequency and Energy Histogram

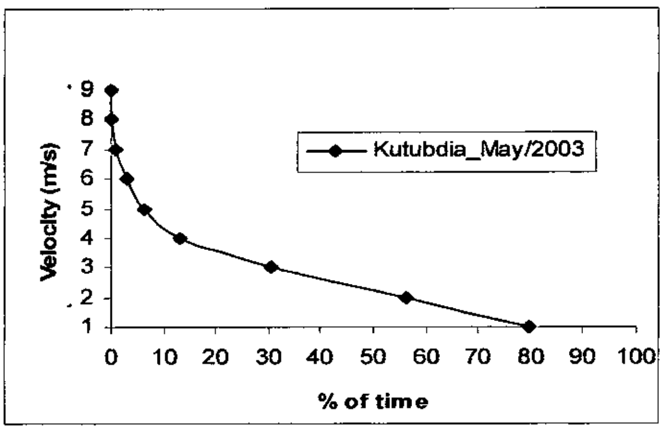


Fig. 8.7f: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=4m/s

And velocity duration is 30.65% of total time (744 hrs) above V= 3m/s

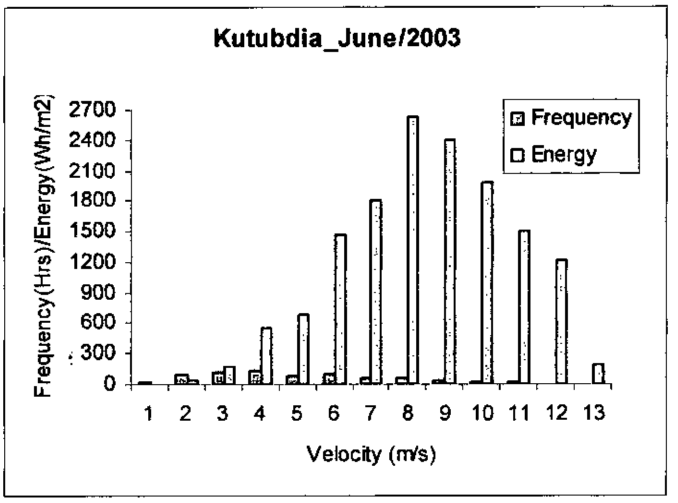


Fig. 8.7g: Velocity Frequency and Energy Histogram

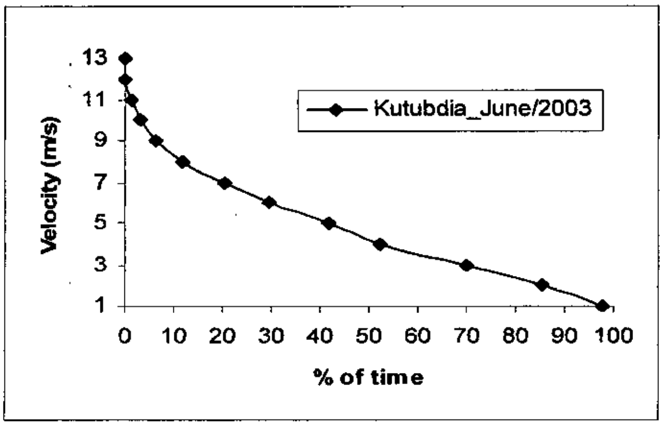


Fig. 8.7h: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=8m/s

And velocity duration is 52.08% of total time (744 hrs) above V= 4m/s

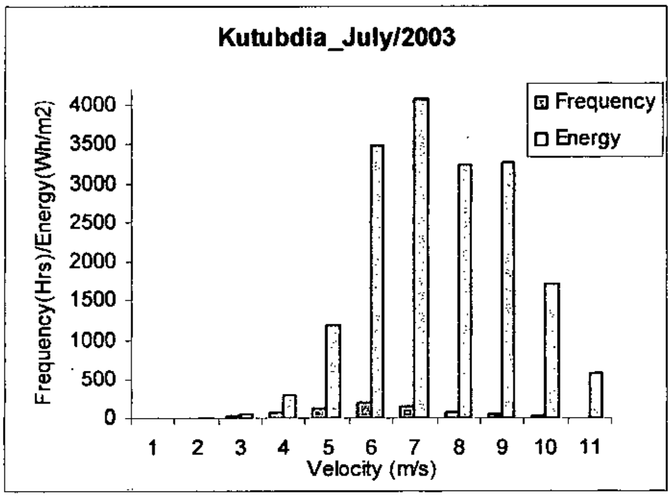


Fig. 8.7i: Velocity Frequency and Energy Histogram

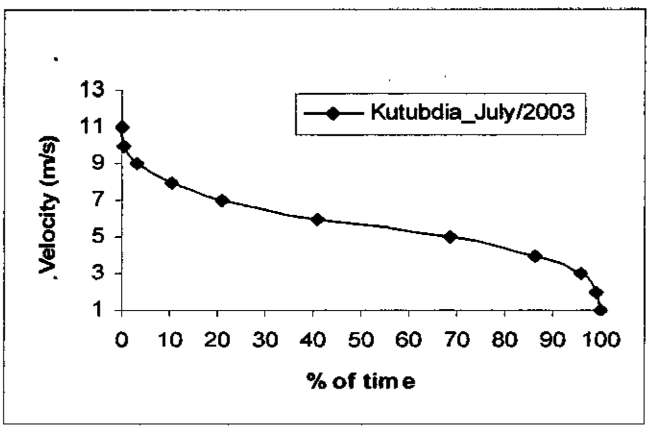


Fig. 8.7j: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 6m/s and

Max. Energy occurs at V=7m/s

And velocity duration is 40.73% of total time (744 hrs) above V= 6m/s

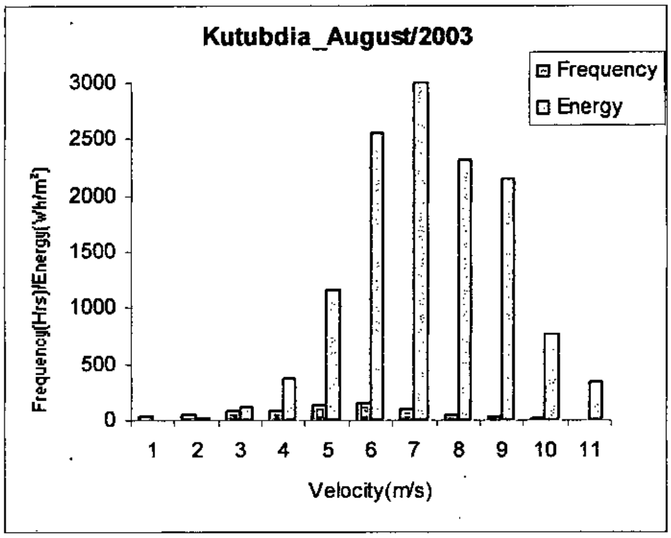


Fig. 8.7k: Velocity Frequency and Energy Histogram

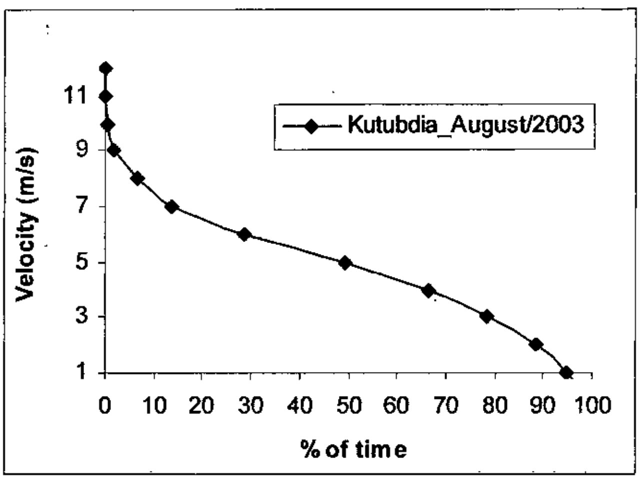


Fig. 8.7l: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 6m/s and

Max. Energy occurs at V=7m/s

And velocity duration is 28.49% of total time (744 hrs) above V= 6m/s

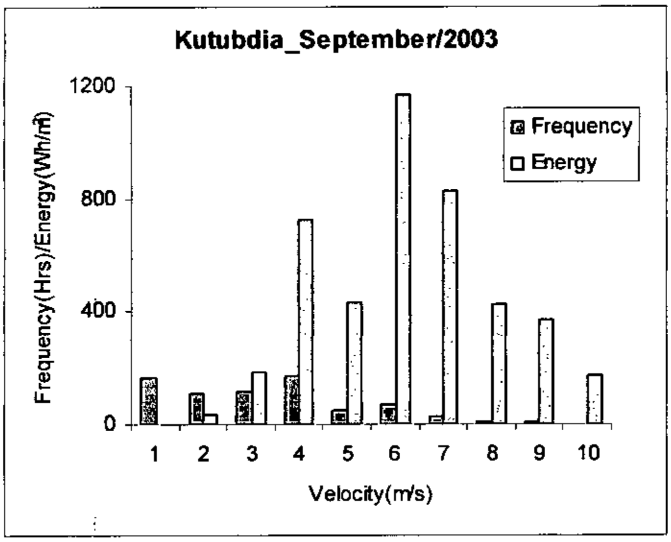


Fig. 8.7m: Velocity Frequency and Energy Histogram

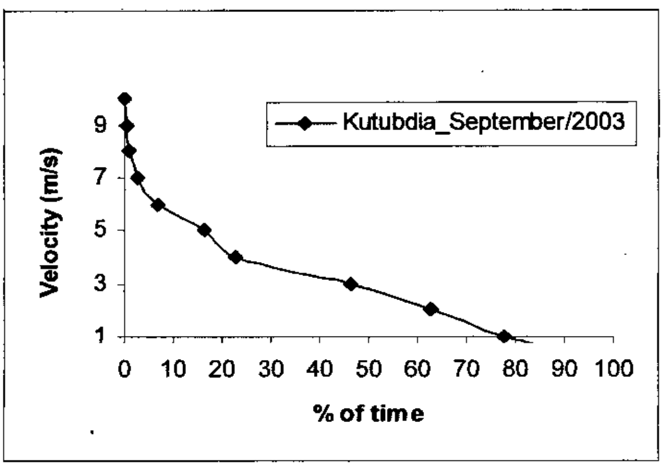


Fig. 8.7n: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 22.92% of total time (720 hrs) above V= 4m/s

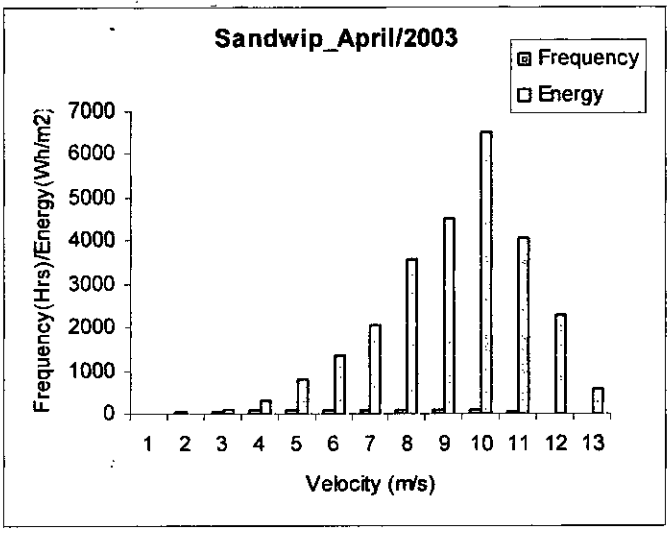


Fig. 8.8a: Velocity Frequency and Energy Histogram

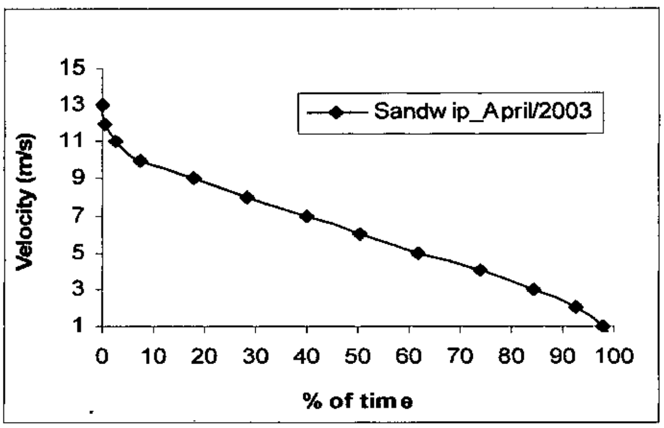


Fig. 8.8b: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 5m/s and

Max. Energy occurs at V=10m/s

And velocity duration is 61.53% of total time (720 hrs) above V= 5m/s

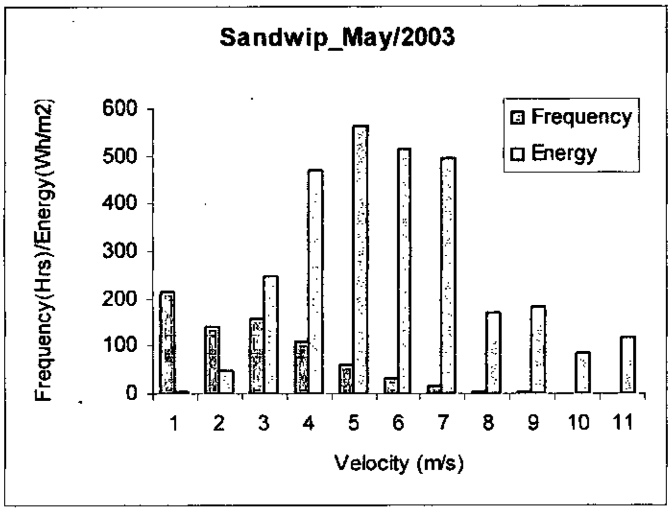


Fig. 8.8c: Velocity Frequency and Energy Histogram

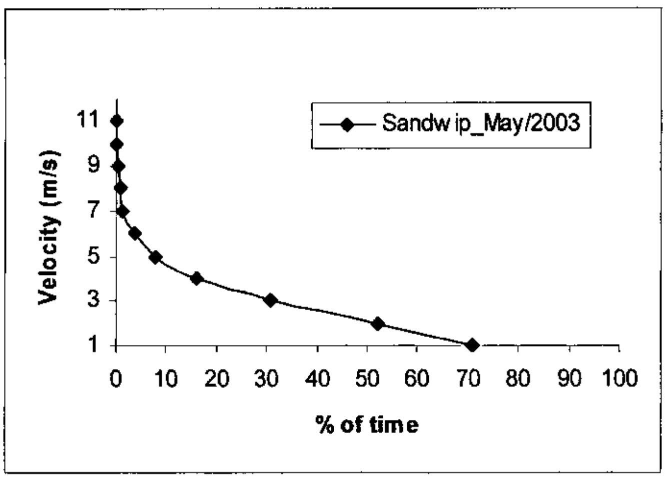


Fig. 8.8d: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 1m/s and

Max. Energy occurs at V=5m/s

And velocity duration is 70.97% of total time (744 hrs) above V= 5m/s

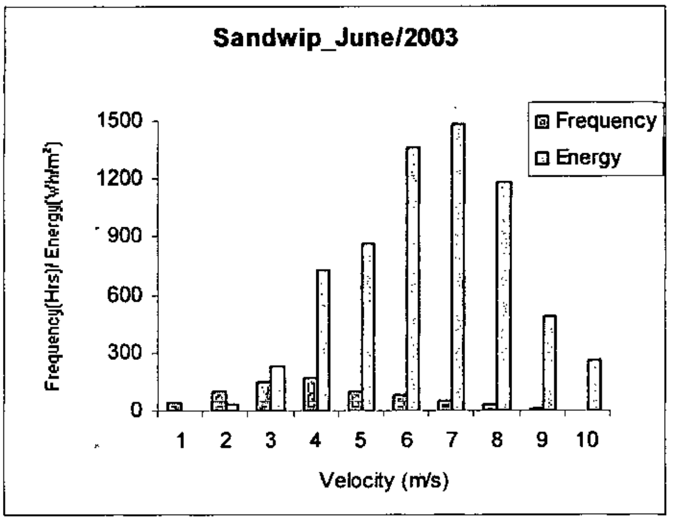


Fig. 8.8e: Velocity Frequency and Energy Histogram

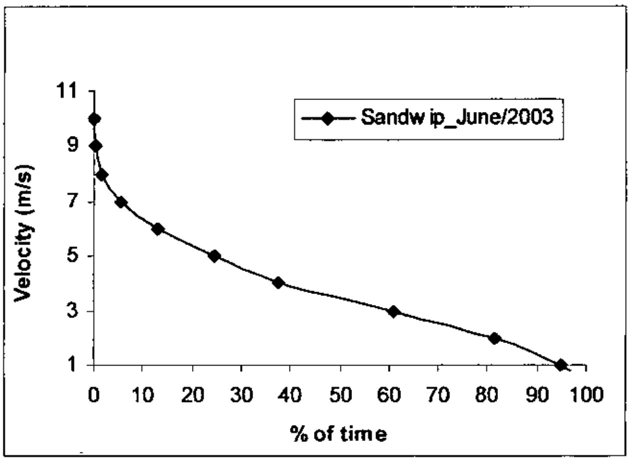


Fig. 8.8f: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=7m/s

And velocity duration is 37.50% of total time (720 hrs) above V= 4m/s

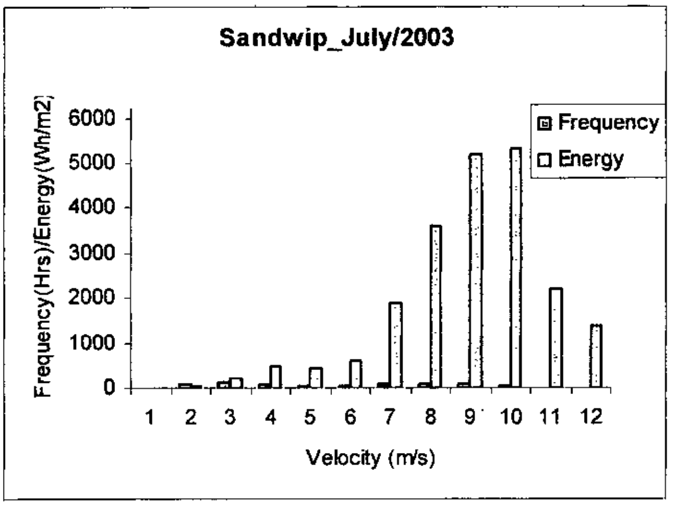


Fig. 8.8g: Velocity Frequency and Energy Histogram

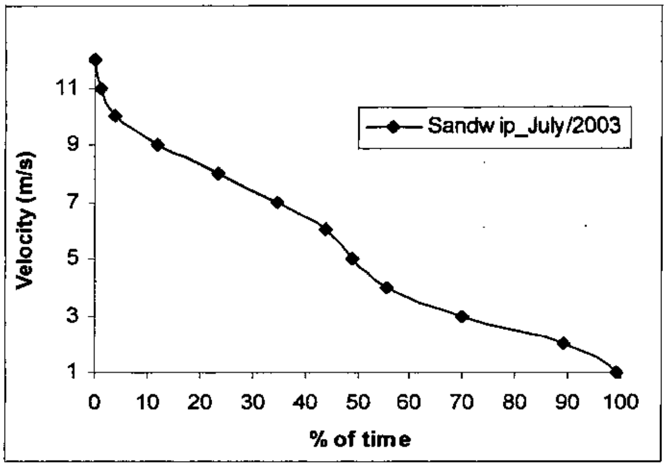


Fig. 8.8h: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=10m/s

And velocity duration is 69.76% of total time (744 hrs) above V= 3m/s

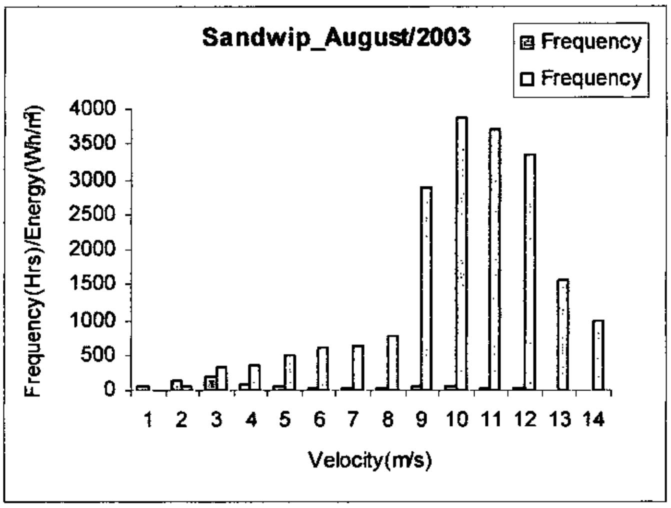


Fig. 8.8i: Velocity Frequency and Energy Histogram

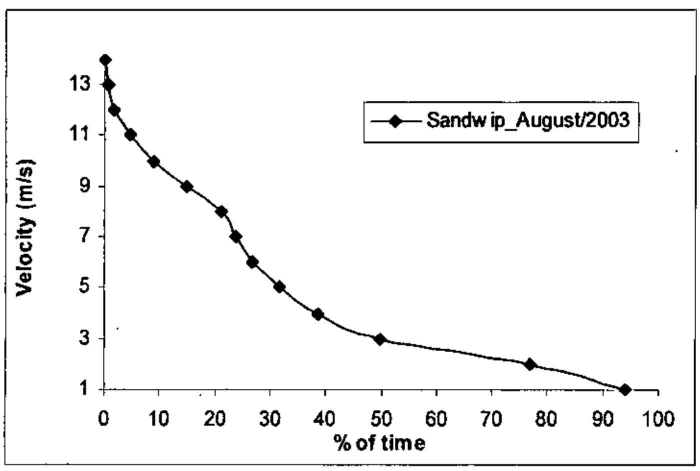


Fig. 8.8j: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=10m/s

And velocity duration is 49.73% of total time (744 hrs) above V= 3m/s

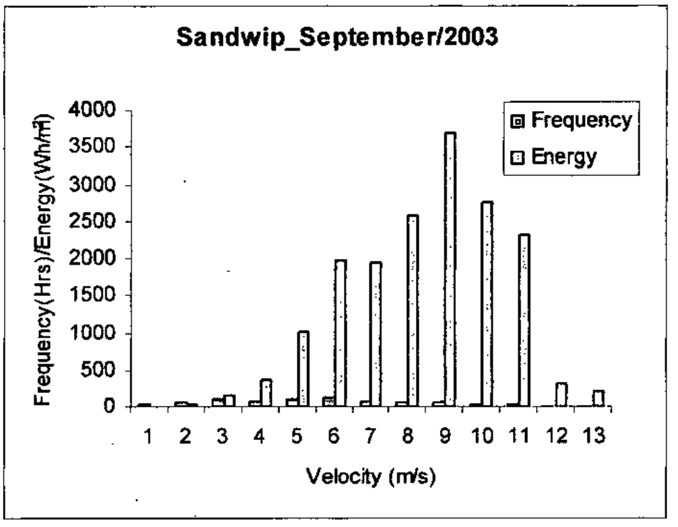


Fig. 8.8k: Velocity Frequency and Energy Histogram

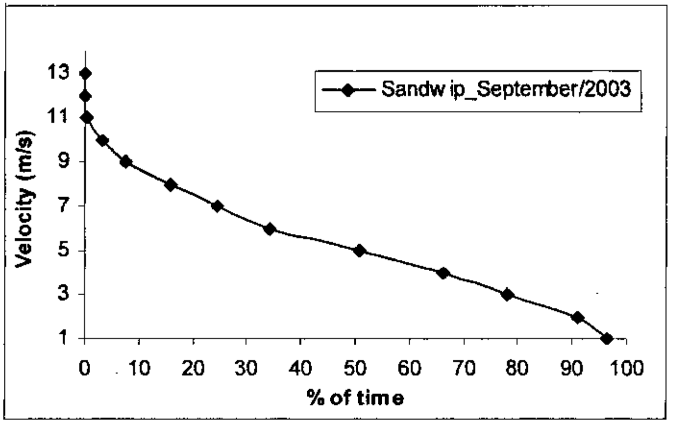


Fig. 8.8l: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 6m/s and

Max. Energy occurs at V=9m/s

And velocity duration is 34.31% of total time (720 hrs) above V= 6m/s

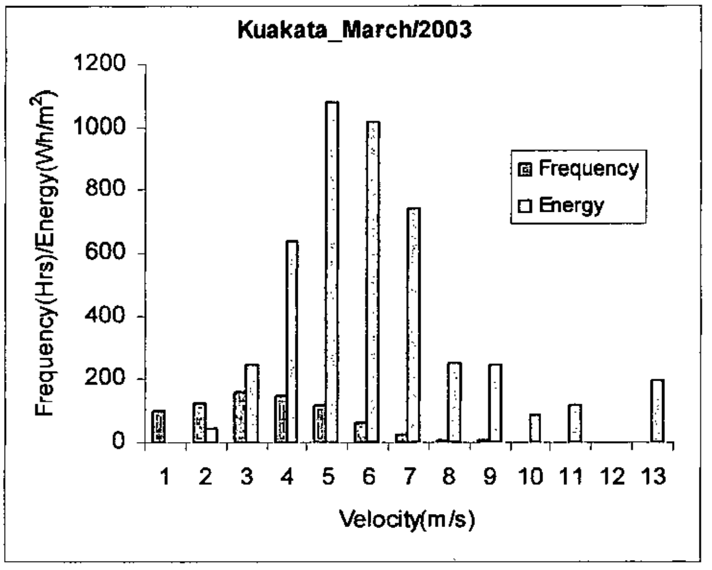


Fig. 8.9a: Velocity Frequency and Energy Histogram

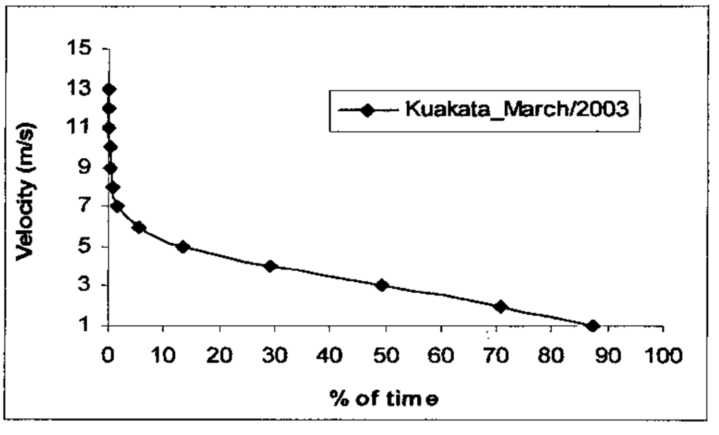


Fig. 8.9b: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=5m/s

And velocity duration is 49.46% of total time (744 hrs) above V= 3m/s

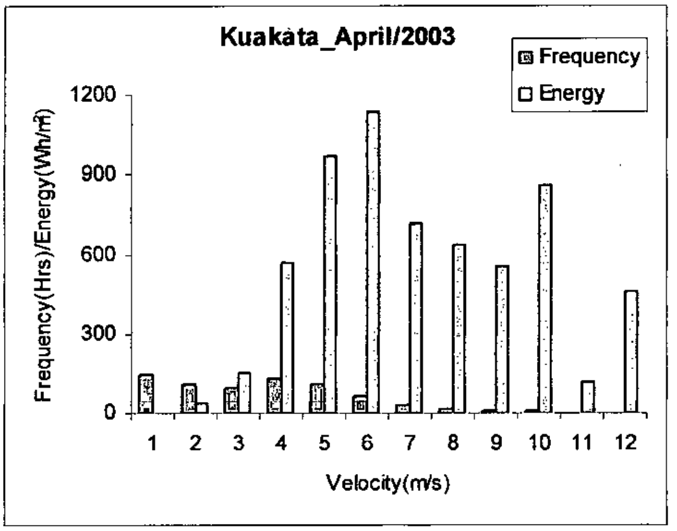


Fig. 8.9c: Velocity Frequency and Energy Histogram

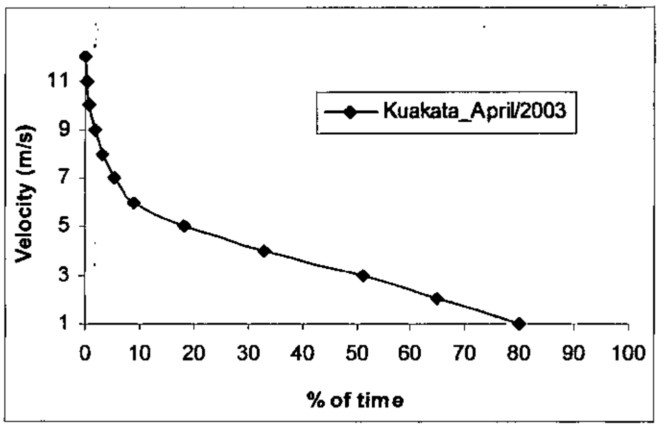


Fig. 8.9d: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 1m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 79.86% of total time (720 hrs) above V= 1m/s

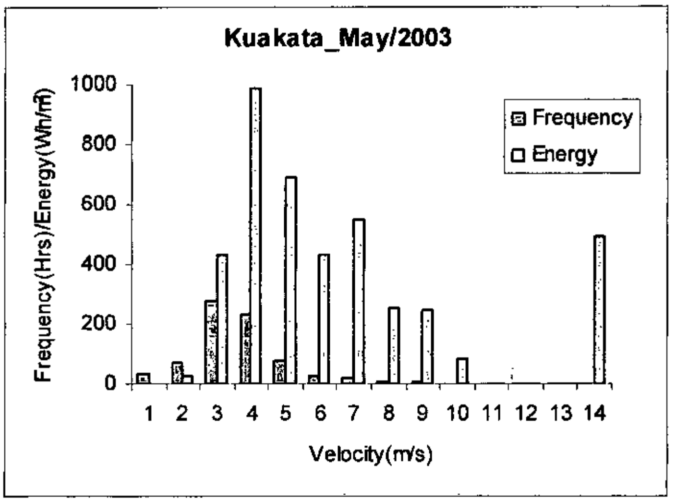


Fig. 8.9e: Velocity Frequency and Energy Histogram

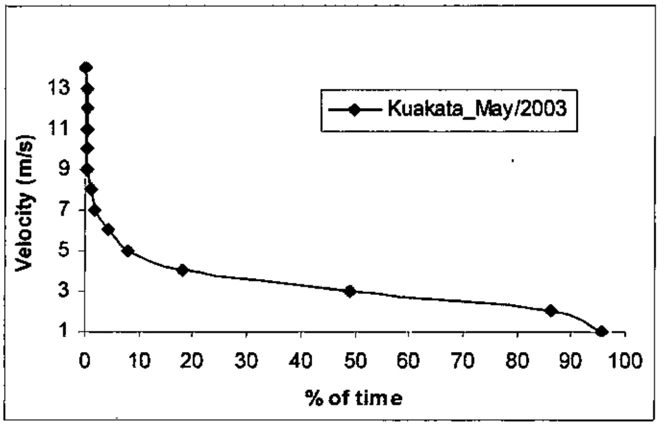


Fig. 8.8f: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=4m/s

And velocity duration is 49.06% of total time (744 hrs) above V= 3m/s

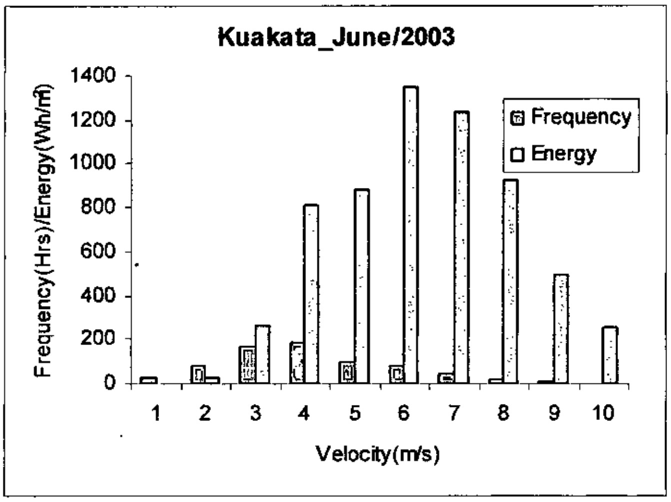


Fig. 8.9g: Velocity Frequency and Energy Histogram

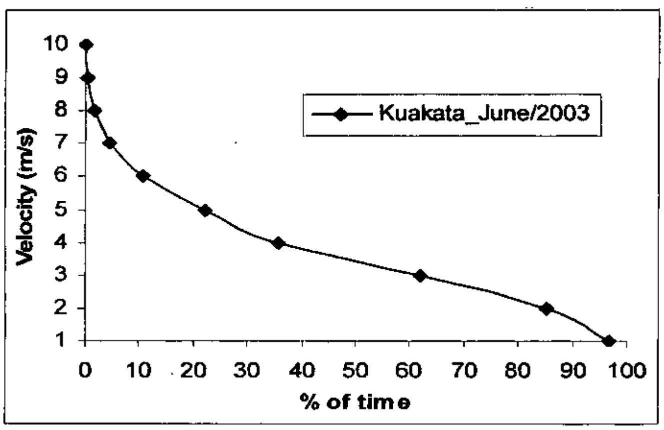


Fig. 8.9h: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 35.56% of total time (720hrs) above V= 4m/s

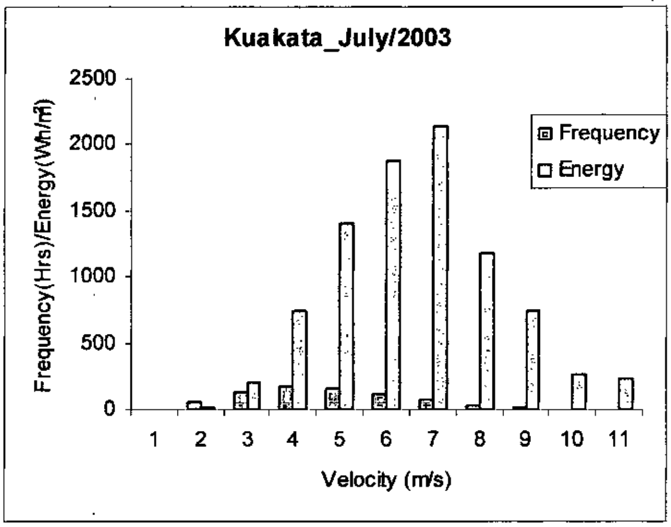


Fig. 8.9i: Velocity Frequency and Energy Histogram

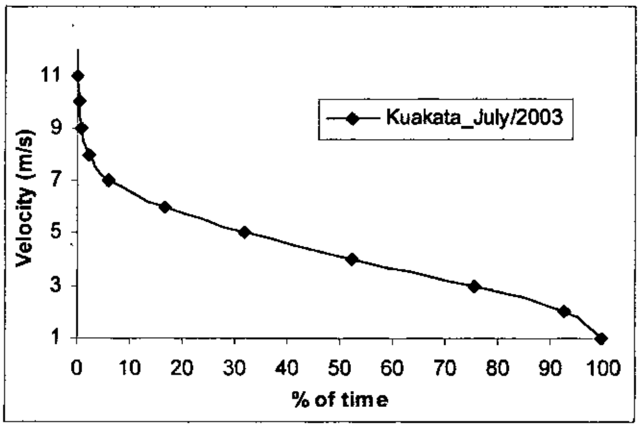


Fig. 8.9j: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=7m/s

And velocity duration is 52.28% of total time (744hrs) above V= 4m/s

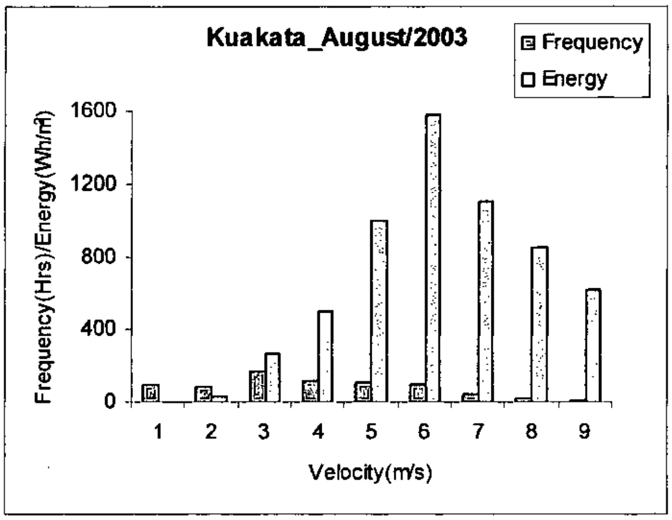


Fig. 8.9k: Velocity Frequency and Energy Histogram

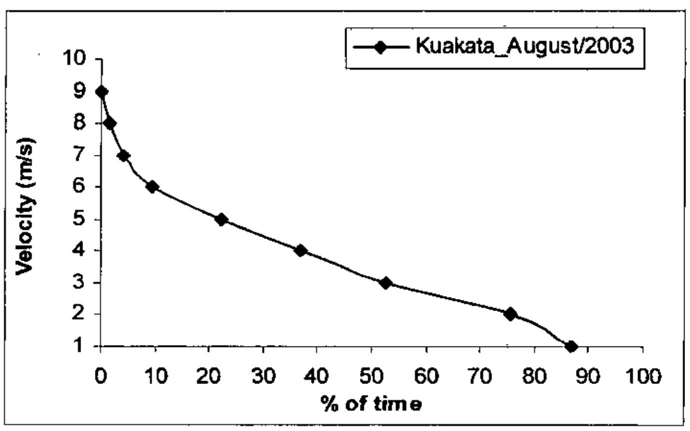


Fig. 8.9l: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 52.55% of total time (744hrs) above V= 3m/s

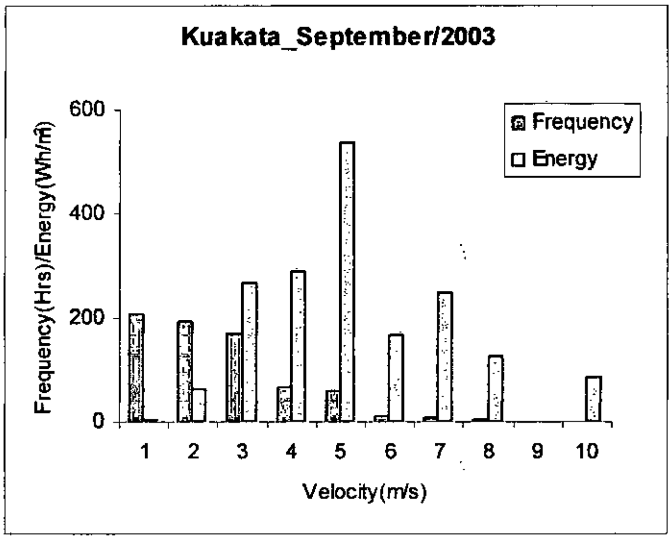


Fig. 8.9m: Velocity Frequency and Energy Histogram

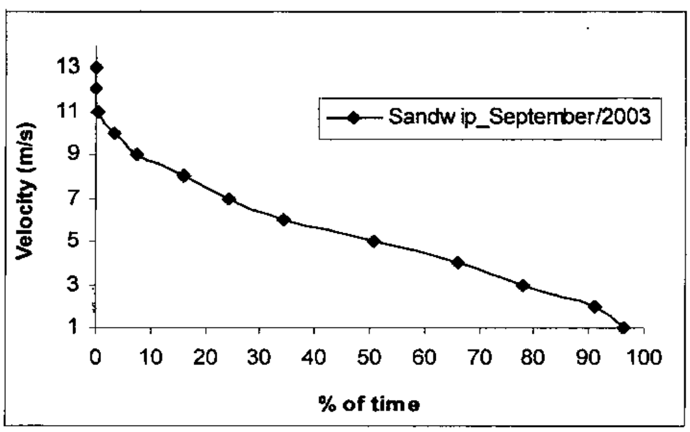


Fig. 8.9n: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 1m/s and

Max. Energy occurs at V=5m/s

And velocity duration is 70.97% of total time (720hrs) above V= 1m/s

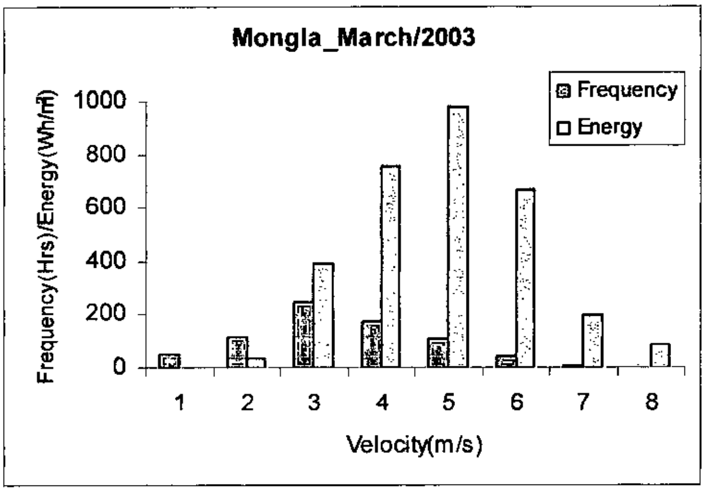


Fig. 8.10a: Velocity Frequency and Energy Histogram

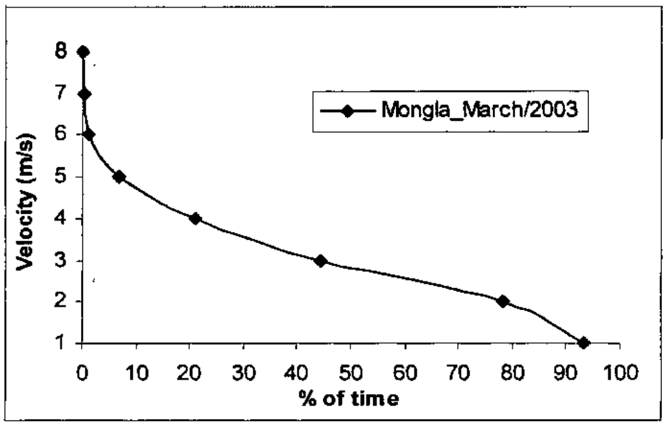


Fig. 8.10b: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=5m/s

And velocity duration is 44.49% of total time (744hrs) above V= 3m/s

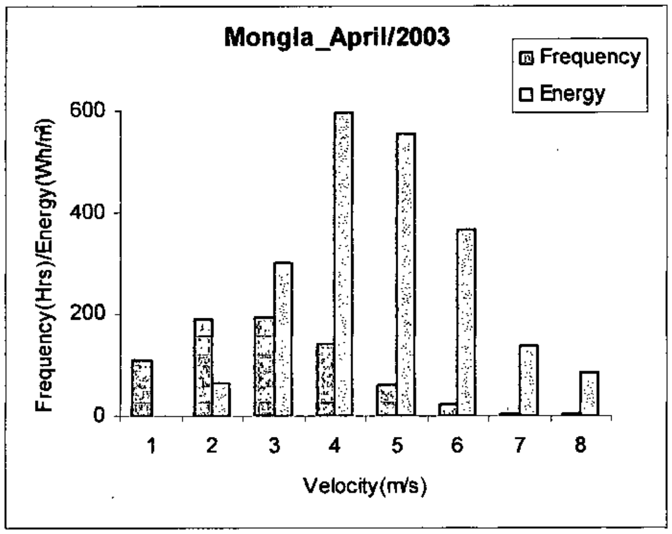


Fig. 8.10c: Velocity Frequency and Energy Histogram

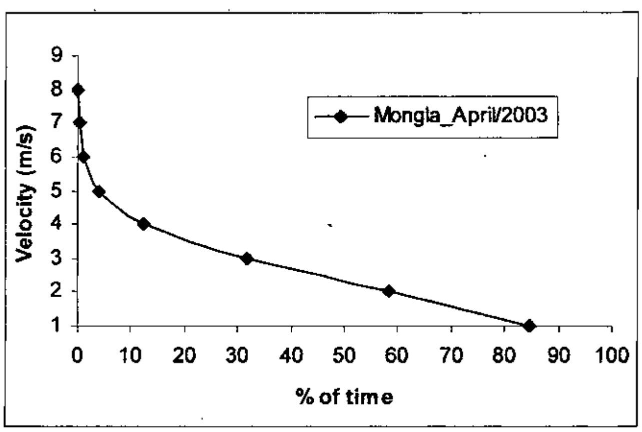


Fig. 8.10d: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=4m/s

And velocity duration is 31.81% of total time (720hrs) above V= 3m/s

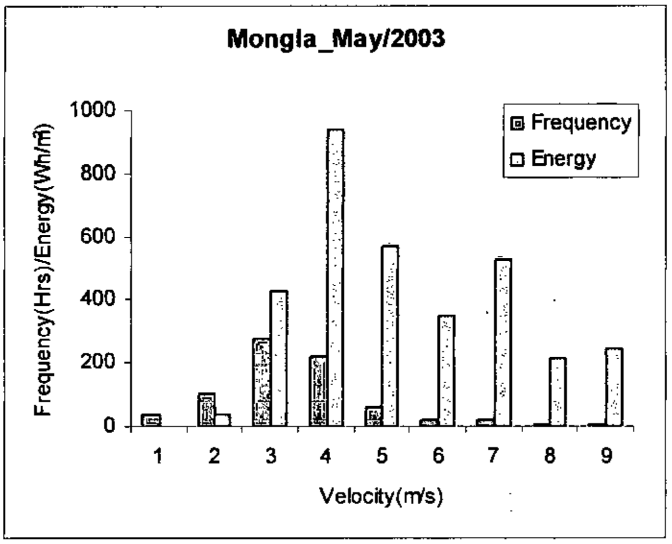


Fig. 8.10e: Velocity Frequency and Energy Histogram

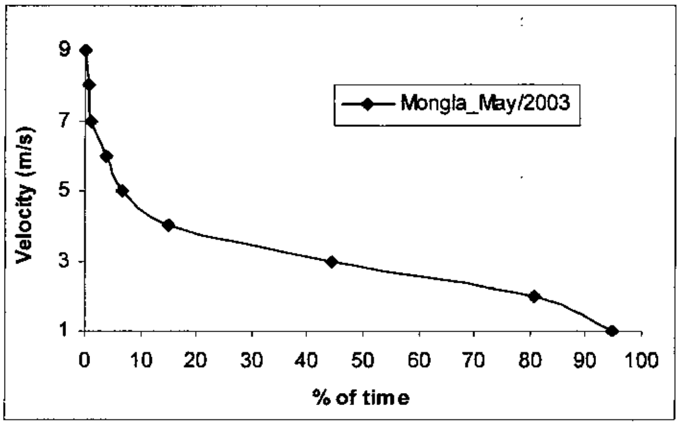


Fig. 8.10f: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=4m/s

And velocity duration is 44.35% of total time (744hrs) above V= 3m/s

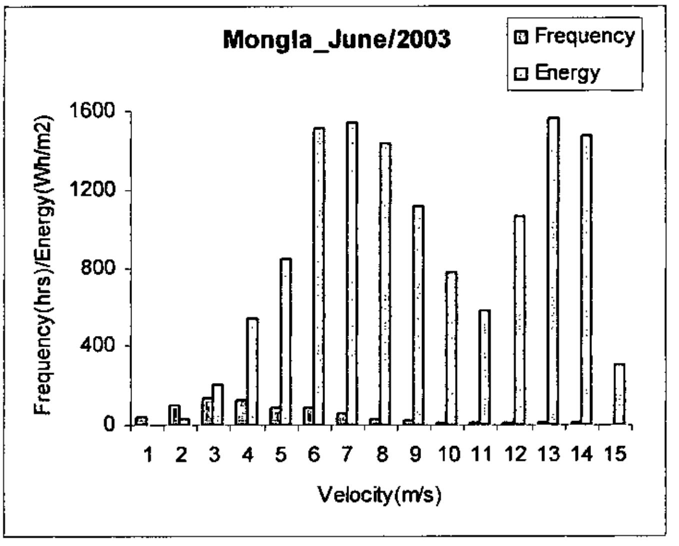


Fig. 8.10g: Velocity Frequency and Energy Histogram

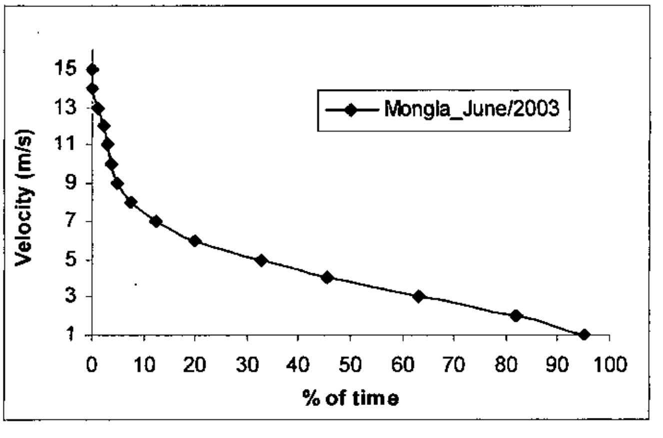


Fig. 8.10h: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=6m/s

And velocity duration is 63.19% of total time (720hrs) above V= 3m/s

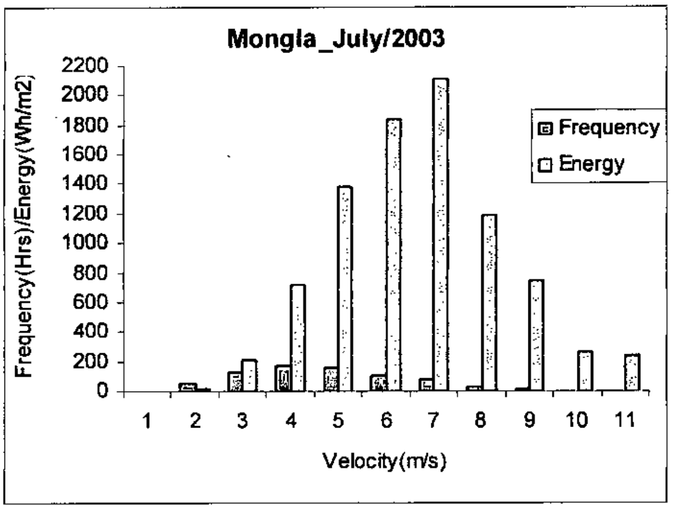


Fig. 8.10i: Velocity Frequency and Energy Histogram

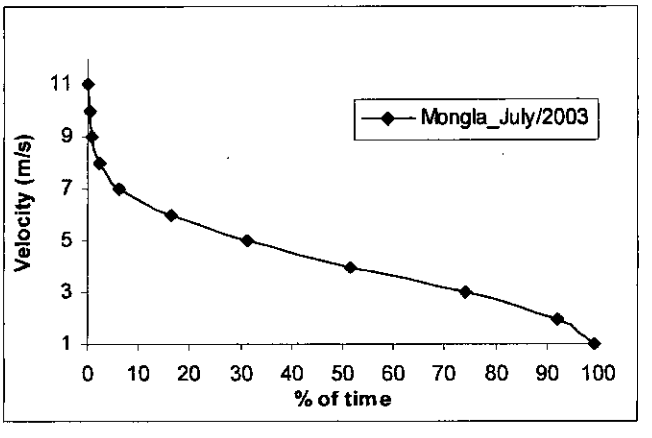


Fig. 8.10j: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 4m/s and

Max. Energy occurs at V=7m/s

And velocity duration is 51.61% of total time (744hrs) above V= 4m/s

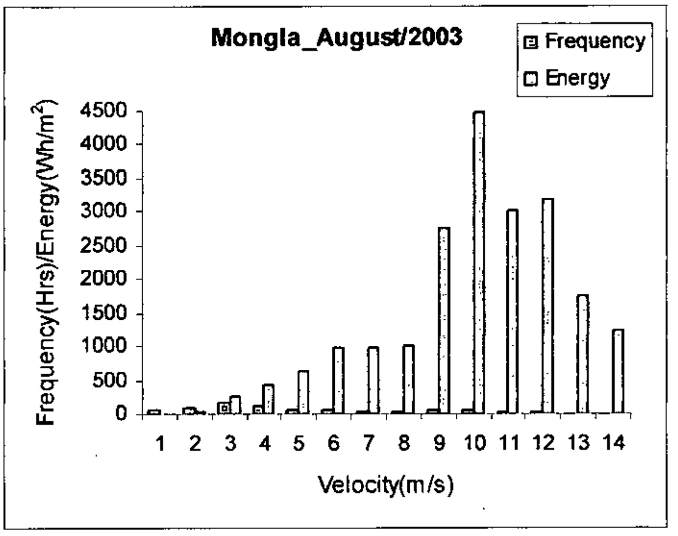


Fig. 8.10k: Velocity Frequency and Energy Histogram

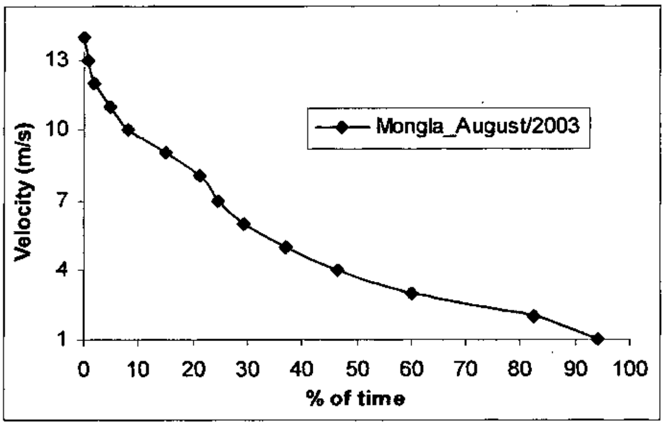


Fig. 8.10l: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=10m/s

And velocity duration is 59.95% of total time (744hrs) above V= 3m/s

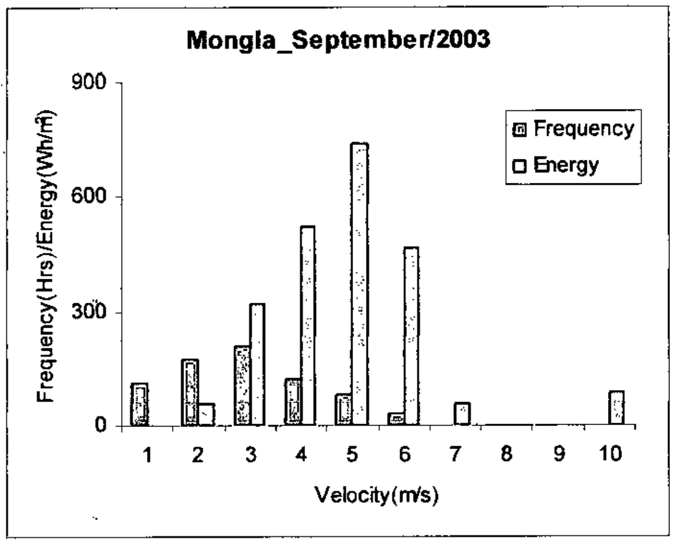


Fig. 8.10m: Velocity Frequency and Energy Histogram

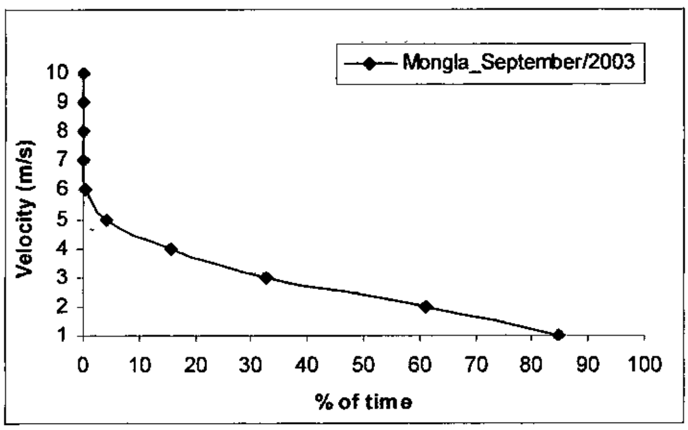


Fig. 8.10n: Velocity Duration Curve

From above two figures, it is seen that,

Max. Velocity frequency occurs at V= 3m/s and

Max. Energy occurs at V=5m/s

And velocity duration is 32.50% of total time (720hrs) above V= 3m/s

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions:

In regard to the present statistical analysis and design analysis of the horizontal axis wind turbines the following conclusions are drawn:

(i) Winds are available in Bangladesh during the monsoon and one to two months before and after the monsoon in general. However, in some regions at 20 meters height, the wind speed is satisfactory for pumping water and generating electricity.

(ii) At Kutubdia of Bangladesh wind speed available in the range of about 2.2 to 25 m/s almost throughout the study period, which is prospective for extraction of power.

(iii) A nomogram and an empirical relation to design the rotor size of a horizontal axis wind turbine and pump size have been developed for a particular region Kutubdia, Bangladesh. The same design procedure can be applied for any prospective wind regime.

(iv) The shape factor (k) and scale factor (c) are determined for each month. It is found that the value of k remains in between 1.1 to 3.5 and that of c remains between 2.5 to 5.5. The most of the Weibull functions follow very close to the Raleigh function (k=2) for the selected sites.

(v) The mean wind speed (v_{mean}) for each station remains 2.5 to 5.17 m/s and among them Kutubdia has the highest 5.17m/s.

(vi) The maximum velocity frequency is at 2 -6 m/s and maximum energy yield is at 3 to10 m/s

9.2 Recommendations:

The following recommendations are given for the future work:

(i) In this study, the wind data of only seven months (March to October) have been considered here, but for preparing a stable analysis and wind pattern, it is necessary to consider data more than one year. Here wind pump is designed for the site Kutubdia only. If the wind speed data is considered for a whole year, then another location also come in the range for designing the water pumping and electricity generation.

(ii) Estimation of the rotor blades loading and stresses developed in the deformed blade due to blade flexibility may also be studied.

(iii) For actual design the flapping and lagging mode shapes with frequencies may be taken into consideration for study of standard analysis.

(iv) Cost-benefit ratio of wind pumping system with the other existing system can be studied.

(v) Prospect of different types of drag type and lift type wind turbine can be carried out.

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Appendix-A

Frequency Distribution for Each Station

Frequency distribution of wind speeds in Kutubdia, Cox's Bazar, Bangladesh

Location	Month \ Vel Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	Total Hours
Kutubdia, Cox's Bazar 2003	Mar	24	85	179	169	117	83	42	19	20	5	0	0	1	-	-	744
	April	42	47	51	90	89	79	55	38	30	16	2	0	1	1	179	720
	May	152	174	190	129	51	27	14	6	1	-	-	-	-	-	-	744
	June	15	90	111	129	75	88	66	62	39	23	13	8	1	-	-	720
	July	1	6	25	70	130	209	148	77	53	20	5	-	-	-	-	744
	Aug	38	46	77	89	128	154	109	55	35	9	3	1	-	-	-	744
	Sep	161	106	119	169	47	70	30	10	6	2	-	-	-	-	-	720
Total																	

Frequency distribution of wind speeds in Sandwip, Chittagong, Bangladesh

Location	Month \ Vel Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	Total Hours
Sandwip, Chittagong 2003	April	17	36	60	75	89	81	75	85	73	76	35	15	3	-	720
	May	216	141	157	110	62	31	18	4	3	1	1	-	-	-	744
	June	36	97	148	169	95	82	54	28	8	3	-	-	-	-	720
	July	7	74	144	105	49	37	69	85	84	62	19	9	-	-	744
	Aug	44	128	202	82	53	36	23	18	47	45	32	22	8	4	744
	Sep	26	39	93	86	110	119	71	61	60	32	20	2	1	-	720
Total																

Frequency distribution of wind speeds in Kuakata, Patuakhali, Bangladesh

Location	Month \ Vel Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	Total Hours
Kuakata, Patuakhali 2003	Mar	95	123	158	149	118	61	27	6	4	1	1	0	1	-	744
	April	145	108	97	132	106	68	26	15	9	10	1	3	-	-	720
	May	31	72	276	230	76	26	20	6	4	1	0	0	0	2	744
	June	24	81	170	189	97	81	45	22	8	3	-	-	-	-	720
	July	3	52	127	173	153	113	78	28	12	3	2	-	-	-	744
	Aug	98	83	172	117	109	95	40	20	10	-	-	-	-	-	744
	Sep	209	191	171	67	59	10	9	3	0	1	-	-	-	-	720
Total																

Frequency distribution of wind speeds in Mongla, Bagherhat, Bangladesh

Location	Month \ Vel Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	Total Hours
Kutubdia, Cox's Bazar 2003	March	50	113	250	175	107	40	7	2	-	-	-	-	-	-	744
	April	111	188	192	139	61	22	5	2	-	-	-	-	-	-	720
	May	38	104	272	219	62	21	19	5	4	-	-	-	-	-	744
	June	36	95	134	127	93	91	56	34	18	9	5	7	8	7	720
	July	5	56	131	168	152	110	77	28	12	3	2	-	-	-	744
	August	43	89	166	101	69	59	35	24	45	52	26	21	9	5	744
	September	110	171	205	122	81	28	2	0	0	1	-	-	-	-	720
Total																

Appendix-B

Mean Monthly at an Hour Speed for Each Location

(All Wind speeds are in m/s)

Hourly wind speed for Kutubdia, Cox's Bazar

Location	Hours	Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Kutubdia, Cox's Bazar, 2003	1	2.61	10.91	1.79	4.52	4.91	4.58	2.71
	2	2.25	11.52	1.91	4.24	4.97	4.74	2.67
	3	3.13	11.64	1.53	4.21	4.95	4.65	2.78
	4	3.11	11.91	1.65	4.35	4.92	4.47	2.62
	5	3.24	11.64	2.02	4.49	4.86	4.47	2.39
	6	3.25	12.13	2.01	4.17	4.71	4.41	2.67
	7	3.16	11.78	2.20	4.22	5.03	4.65	2.62
	8	3.29	11.44	2.44	4.37	5.25	4.66	2.90
	9	3.45	11.59	2.52	4.69	5.49	4.96	3.05
	10	3.10	12.75	2.70	4.84	5.79	5.21	3.16
	11	3.18	12.81	2.90	5.05	5.75	5.23	3.27
	12	3.75	13.15	2.97	4.89	5.95	5.14	3.40
	13	4.10	13.29	3.16	5.16	6.27	4.92	3.43
	14	4.48	13.57	3.33	5.21	7.05	5.12	3.41
	15	4.86	12.48	3.37	5.47	7.15	5.29	3.62
	16	5.19	13.36	3.34	5.37	7.23	5.25	3.70
	17	5.05	13.24	3.21	4.98	7.10	5.22	3.27
	18	4.77	12.43	2.73	4.83	6.72	5.08	2.91
	19	4.67	13.29	2.04	4.69	6.40	4.88	2.54
	20	4.37	11.43	1.82	4.82	5.91	4.68	2.43
	21	4.08	11.01	1.95	4.81	5.68	4.62	2.62
	22	3.75	10.35	1.81	4.79	5.15	4.50	2.56
	23	3.19	10.08	1.71	4.49	5.11	4.33	2.65
	24	3.11	10.75	1.80	4.28	5.24	4.23	2.57
Monthly average		3.71	12.02	2.37	4.71	5.73	4.80	2.92

Hourly wind speed for Sandwip, Cox's Bazar

Location	Hours	Month					
		Apr	May	Jun	Jul	Aug	Sep
Sandwip, Cox's Bazar, 2003	1	8.27	1.85	3.83	5.65	4.12	5.37
	2	8.13	2.10	3.61	5.56	4.17	5.26
	3	6.63	2.08	3.32	5.41	4.00	5.03
	4	7.58	2.06	3.79	5.23	4.14	5.12
	5	7.29	2.24	3.72	5.16	3.90	5.02
	6	7.00	2.45	3.52	5.16	4.20	4.86
	7	7.32	2.79	3.65	5.21	4.03	4.74
	8	7.52	2.99	3.57	5.18	4.01	4.72
	9	7.50	2.94	3.70	5.17	4.41	4.84
	10	7.53	3.04	3.55	5.09	4.38	4.85
	11	7.71	3.01	3.96	5.27	4.55	4.71
	12	8.91	3.11	3.89	5.09	4.21	4.78
	13	8.20	3.26	4.34	5.19	4.39	5.02
	14	8.48	2.92	4.06	5.40	4.54	5.37
	15	8.45	2.46	4.28	5.77	4.72	5.50
	16	8.61	2.07	4.34	6.05	4.50	5.60
	17	9.31	1.88	4.07	5.77	4.62	5.60
	18	9.03	1.92	3.96	5.64	4.73	5.67
	19	9.28	1.57	4.23	5.64	5.12	5.50
	20	9.66	1.57	4.12	5.72	5.20	5.26
	21	9.95	1.60	4.12	5.72	4.97	5.21
	22	9.53	1.65	4.01	5.48	4.69	5.38
	23	9.02	1.55	4.13	5.54	4.61	5.44
	24	9.20	1.61	4.45	5.42	4.46	5.41
Monthly average		8.34	2.28	3.93	5.44	4.44	5.18

Hourly wind speed for Kuakata, Patuakhali

Location	Hours	Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Kuakata, Patuakhali, 2003	1	2.73	5.95	2.80	3.65	3.90	2.92	1.87
	2	3.08	5.77	2.81	3.76	3.58	3.12	1.46
	3	2.98	4.21	2.72	3.44	3.24	3.01	1.37
	4	3.28	4.64	2.75	3.80	3.36	2.91	1.43
	5	3.19	4.59	2.80	3.82	3.34	2.71	1.38
	6	3.44	4.86	3.00	3.71	3.29	2.80	1.27
	7	3.54	4.66	3.16	3.64	3.49	2.94	1.04
	8	3.31	4.98	3.48	3.48	3.74	3.27	1.14
	9	3.46	5.21	3.40	3.68	4.24	3.80	1.67
	10	3.45	5.10	3.25	3.44	4.57	3.96	2.21
	11	3.39	4.66	3.26	3.59	4.85	4.05	2.66
	12	3.35	5.68	3.34	3.63	4.77	4.27	2.69
	13	3.40	4.93	3.68	3.74	4.82	4.41	2.69
	14	3.56	5.12	3.30	3.69	5.11	3.98	2.94
	15	3.05	5.05	3.55	3.99	5.32	4.12	3.16
	16	2.90	5.44	3.68	4.09	5.20	4.03	3.30
	17	2.93	5.85	3.06	3.77	5.27	3.68	2.85
	18	2.48	6.18	2.90	3.62	5.18	3.37	2.52
	19	2.49	6.12	2.95	3.75	4.89	3.01	2.22
	20	2.37	5.68	2.89	3.66	4.55	2.91	1.95
	21	2.61	5.39	3.01	3.66	4.14	3.10	1.85
	22	2.82	5.42	2.75	3.49	3.82	2.98	1.80
	23	2.87	5.24	2.89	3.60	4.03	2.86	1.69
	24	2.96	5.55	2.79	3.91	3.96	2.68	1.65
Monthly average		3.07	5.26	3.09	3.69	4.28	3.37	2.03

Hourly wind speed for Mongla, Bagherhat

Location	Hours	Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Mongla, Bagherhat, 2003	1	3.14	2.24	2.83	4.46	3.95	4.37	2.20
	2	2.94	1.94	2.88	4.21	3.68	4.44	2.06
	3	2.90	2.06	2.72	3.95	3.30	4.12	2.21
	4	2.75	2.18	2.86	4.10	3.40	4.40	2.10
	5	2.65	2.18	2.67	4.11	3.37	4.23	2.07
	6	2.73	2.33	2.77	4.11	3.39	4.34	2.11
	7	2.93	2.71	2.64	4.01	3.52	4.25	1.86
	8	3.37	2.78	2.77	3.72	3.83	4.23	1.99
	9	3.78	2.66	2.77	3.83	4.34	4.72	2.46
	10	3.34	2.67	2.85	3.81	4.60	4.74	2.77
	11	3.21	2.62	2.83	3.98	4.85	4.93	2.81
	12	3.04	2.27	2.95	4.02	4.74	4.80	2.90
	13	2.84	2.29	3.30	4.11	4.70	5.07	2.84
	14	3.06	2.32	3.24	4.11	5.05	5.14	2.88
	15	2.93	2.47	3.55	4.36	5.31	5.24	3.17
	16	2.70	2.73	3.42	4.57	5.28	4.90	3.27
	17	2.83	2.52	2.93	4.43	5.31	4.91	3.20
	18	2.56	2.55	2.73	4.28	5.26	5.09	2.98
	19	2.99	2.56	2.87	4.51	5.03	5.25	2.59
	20	2.77	2.49	2.91	4.47	4.74	5.24	2.25
	21	2.60	2.38	3.13	4.54	4.33	5.14	2.18
	22	3.02	2.34	2.95	4.67	4.15	4.91	2.13
	23	2.91	2.34	2.92	4.46	4.18	4.73	2.26
	24	2.86	2.24	2.94	4.70	3.84	4.62	2.27
Monthly average		2.95	2.41	2.93	4.23	4.34	4.74	2.48

Appendix-C

Hourly Average Wind Speeds for Each Location

(All Wind speeds are in m/s)

Daily speed for Kutubdia, Cox's Bazar

Location	Day	Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Kutubdia, Cox's Bazar, 2003	1	3.85	4.94	2.50	1.96	6.12	6.65	6.50
	2	2.26	4.86	3.20	1.90	6.22	6.39	5.70
	3	3.62	5.06	4.53	1.74	4.64	5.03	4.65
	4	4.79	4.52	4.70	2.12	5.13	3.45	5.36
	5	5.88	4.86	4.42	2.29	4.88	3.61	5.54
	6	6.88	3.91	3.94	3.27	5.30	4.40	6.27
	7	5.62	3.45	3.04	3.19	4.91	5.92	5.58
	8	4.59	3.05	1.50	3.22	5.71	5.21	5.58
	9	4.31	2.55	1.68	2.68	6.28	4.96	3.37
	10	3.76	2.69	1.33	2.55	6.08	5.24	1.50
	11	2.70	3.92	1.22	3.57	5.89	5.28	2.31
	12	3.63	6.45	1.43	3.53	5.79	5.32	3.87
	13	4.59	6.74	1.33	2.88	5.82	3.67	4.49
	14	2.69	5.18	0.43	3.79	5.83	2.18	3.20
	15	3.40	3.27	1.00	3.05	6.41	2.84	2.16
	16	3.85	3.79	1.52	4.77	6.59	2.77	1.90
	17	4.32	7.00	2.33	5.63	5.07	3.86	1.56
	18	1.93	7.31	1.95	6.57	4.68	4.54	2.31
	19	3.19	5.56	1.87	6.50	5.68	4.08	2.28
	20	3.02	17.11	2.57	8.96	5.50	2.66	1.33
	21	3.65	23.99	2.46	9.33	5.24	2.25	1.02
	22	3.36	32.03	2.67	6.62	4.82	7.11	1.25
	23	2.81	32.28	2.38	5.21	3.01	6.38	0.67
	24	2.40	35.22	2.62	4.97	3.67	4.51	1.54
	25	2.62	33.79	3.27	6.16	7.42	3.24	1.70
	26	3.32	36.73	2.54	8.04	8.60	5.11	1.44
	27	3.91	32.87	1.77	6.32	8.15	7.94	0.97
	28	4.52	24.58	2.13	7.66	6.58	7.31	1.08
	29	3.25	1.83	2.65	6.40	5.72	5.96	1.51
	30	2.96	1.18	2.80	6.31	5.61	5.91	0.88
	31	5.65	-	1.73	-	6.37	5.13	-
Monthly average		3.71	12.02	2.37	4.71	5.73	4.80	2.92

Daily speed for Sandwip, Cox's Bazar

Location	Day	Month					
		Apr	May	Jun	Jul	Aug	Sep
Sandwip, Cox's Bazar, 2003	1	7.88	1.15	1.96	8.43	3.20	9.77
	2	7.71	2.68	1.90	7.25	2.89	8.67
	3	7.69	3.35	1.75	6.28	2.82	6.99
	4	5.61	4.38	2.12	5.68	2.79	7.02
	5	3.92	4.81	2.29	5.81	2.28	7.10
	6	3.42	4.41	3.27	7.16	2.94	8.79
	7	3.58	3.97	3.19	7.60	3.15	8.79
	8	3.36	2.96	3.22	8.21	2.32	6.59
	9	3.14	1.43	2.68	8.79	2.50	4.52
	10	3.23	1.61	2.55	8.78	2.76	2.82
	11	5.52	1.24	3.57	8.81	3.19	4.52
	12	9.38	1.20	3.53	9.23	2.62	4.52
	13	9.91	2.63	2.88	8.49	3.53	5.99
	14	7.19	1.27	5.05	7.91	2.34	6.83
	15	4.95	0.41	4.94	8.25	1.79	5.47
	16	4.73	1.08	2.89	7.72	1.96	5.08
	17	9.46	1.45	2.37	5.14	1.77	5.43
	18	10.03	2.41	5.12	2.36	2.15	6.71
	19	7.08	1.59	5.88	2.82	1.59	5.87
	20	8.08	1.36	7.77	2.43	2.82	3.71
	21	7.22	2.62	4.69	2.04	3.59	2.88
	22	5.12	2.43	4.08	2.76	10.67	2.85
	23	5.05	3.64	3.60	2.48	9.03	2.66
	24	3.97	2.56	4.29	1.91	5.65	3.80
	25	14.77	2.39	4.65	3.24	3.97	3.60
	26	32.97	1.46	4.62	3.68	5.62	3.27
	27	32.42	1.22	3.75	3.53	10.43	2.98
	28	8.42	1.79	3.87	2.96	10.75	2.73
	29	9.38	2.64	3.75	3.06	9.26	2.33
	30	4.95	2.82	4.24	2.87	9.03	3.05
	31	-	1.73	-	2.87	8.39	
Monthly average		8.34	2.28	3.68	5.44	4.44	5.18

: Daily speed for Kuakata, Patuakhali

Location	Day	Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Kuakata, Patuakhali, 2003	1	2.38	4.10	3.44	2.32	5.09	4.68	3.68
	2	2.36	6.38	4.04	2.53	4.44	4.07	3.37
	3	3.86	5.26	4.58	2.22	3.73	4.04	2.84
	4	4.13	3.71	5.00	2.41	4.46	3.99	1.91
	5	4.85	1.93	4.44	2.90	4.88	4.26	3.07
	6	1.95	1.19	4.10	3.27	3.97	5.00	3.12
	7	1.92	2.52	3.34	2.97	3.29	5.76	4.68
	8	2.14	2.02	2.71	2.96	3.74	4.98	5.03
	9	3.26	3.25	2.96	2.68	4.93	3.01	1.75
	10	1.27	3.31	2.52	2.55	4.42	2.76	3.00
	11	3.68	5.13	2.60	3.57	4.30	3.19	2.54
	12	4.05	2.60	2.66	3.53	3.33	3.05	1.09
	13	4.45	0.90	2.87	2.90	3.80	3.70	1.75
	14	3.36	0.72	2.52	4.71	4.92	2.10	1.64
	15	4.19	0.74	2.41	4.94	5.61	2.94	1.18
	16	1.72	1.00	1.09	2.89	4.60	2.65	1.55
	17	3.38	1.67	1.45	2.37	3.84	3.94	1.94
	18	2.64	2.84	3.29	5.14	3.10	4.52	2.15
	19	3.09	1.62	2.56	5.84	3.22	1.61	2.10
	20	2.90	0.71	4.49	6.54	3.70	1.63	1.41
	21	3.20	5.96	3.10	4.69	2.80	1.05	1.13
	22	2.52	5.09	3.18	4.08	3.35	4.11	1.10
	23	1.76	4.99	2.41	3.60	2.21	3.08	1.14
	24	1.73	3.97	2.42	4.29	5.28	2.03	1.18
	25	2.07	14.79	2.41	4.65	6.47	1.48	0.94
	26	3.90	32.96	3.28	4.62	7.79	2.06	1.12
	27	3.56	27.43	3.16	3.75	6.15	4.33	1.26
	28	2.07	4.21	3.02	3.87	3.68	4.04	0.91
	29	1.62	3.39	3.56	3.75	2.47	4.04	1.49
	30	4.19	3.45	3.11	4.24	4.19	2.95	0.92
	31	5.71	-	3.11	-	4.86	3.41	-
Monthly average		3.03	5.26	3.09	3.69	4.28	3.37	2.03

Daily speed for Mongla, Bagherhat

Location	Day	Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Mongla, Bagherhat , 2003	1	2.93	3.80	3.43	1.96	5.09	4.68	3.77
	2	3.15	4.01	4.06	1.90	4.44	4.14	3.37
	3	2.91	3.25	4.55	1.70	3.73	4.04	2.84
	4	2.90	2.97	5.04	2.41	4.46	3.99	1.91
	5	3.91	2.10	4.44	3.69	4.88	4.29	3.07
	6	2.50	2.48	4.10	3.40	3.97	5.06	3.12
	7	2.49	2.39	3.34	2.73	3.29	3.14	3.12
	8	2.96	2.69	2.70	2.96	3.74	2.32	3.25
	9	3.66	2.55	2.96	2.68	4.93	2.50	1.75
	10	3.16	1.68	2.54	2.55	4.53	2.78	3.00
	11	2.85	3.11	2.60	5.36	4.46	3.19	2.54
	12	2.85	2.11	2.67	7.91	3.67	2.61	1.09
	13	3.64	0.94	2.87	10.59	3.74	3.55	1.75
	14	2.53	1.96	2.75	7.79	4.92	2.34	1.64
	15	2.97	1.88	3.13	4.94	5.61	1.80	2.16
	16	2.55	2.42	2.94	2.89	4.60	1.91	1.90
	17	2.33	2.37	3.44	2.37	3.84	1.82	1.56
	18	2.27	1.49	2.80	5.14	3.10	2.14	2.31
	19	2.06	1.17	1.82	5.84	3.22	1.59	2.28
	20	2.24	1.98	2.03	6.54	3.70	2.80	1.33
	21	3.32	1.83	2.48	4.69	2.80	3.55	1.02
	22	2.71	0.68	2.78	4.08	3.35	10.66	1.26
	23	2.96	1.97	1.73	3.60	2.21	9.05	2.66
	24	2.15	3.28	1.97	4.29	5.28	5.67	3.80
	25	2.36	4.11	2.12	4.65	7.79	3.97	3.60
	26	3.32	2.91	2.82	4.62	7.79	5.57	3.27
	27	3.69	1.75	2.90	3.75	6.15	10.43	2.98
	28	2.33	2.50	2.80	3.87	3.68	10.75	2.73
	29	2.42	2.60	2.65	3.75	2.47	9.26	2.33
	30	4.19	3.44	2.80	4.24	4.19	9.05	3.05
	31	4.52	-	1.73	-	4.86	8.36	-
Monthly average		2.93	2.41	2.93	4.23	4.34	4.74	2.48

Appendix-D

Value of k and c by Various Methods

(k is a dimensionless number and c in m/s)

Weibull paper

Location	Month	K	C
Teknaf	March	1.47	3.2
	April	1.6	2.8
	May	1.69	2.68
	June	2	5.8
	July	1.9	3.3
	August	2.1	4.88
	September	1.7	3.8
Kutubdia	March	2.1	4.1
	April	1.12	12.09
	May	1.8	2.6
	June	1.84	5.2
	July	3.2	5.4
	August	2.6	5.3
	September	1.8	3.3
Sandwip	March		
	April	1.89	6.5
	May	1.6	3.3
	June	2.3	4.2
	July	2.4	6.8
	August	1.4	5.3
	September	2.2	5.89
Kuakata	March	1.98	3.3
	April	1.34	3.5
	May	1.65	3
	June	2.1	3.8
	July	2.7	4.84
	August	1.92	3.84
	September	1.45	2.3
Mongla	March	2.4	3.2
	April	1.98	2.8
	May	2.4	3.6
	June	1.8	4.8
	July	2.5	4.8
	August	1.6	5.4
	September	1.9	2.9

Standard Deviation Analysis

Location	Month	K	C
Teknaf	March	1.45	3.14
	April	1.65	2.86
	May	1.45	2.63
	June	1.98	5.3
	July	1.5	3.13
	August	1.88	4.68
	September	1.87	3.48
Kutubdia	March	2.18	4.19
	April	1.14	12.06
	May	1.4	2.6
	June	1.97	5.31
	July	3.2	6.4
	August	1.98	5.4
	September	1.48	3.2
Sandwip	March	[illegible]	[illegible]
	April	1.15	8.76
	May	1.38	2.50
	June	2.1	4.15
	July	2.1	6.14
	August	1.39	4.87
	September	2.17	5.85
Kuakata	March	1.8	3.4
	April	1.1	5.45
	May	2.2	3.49
	June	2.17	4.17
	July	2.7	4.81
	August	1.8	3.78
	September	1.3	2.19
Mongla	March	2.4	3.3
	April	1.7	2.7
	May	2.4	3.3
	June	1.7	4.74
	July	2.7	4.88
	August	1.5	5.25
	September	1.75	2.78

Energy Pattern Method

Location	Month	K	C
Teknaf	March	1.45	3.14
	April	1.62	2.86
	May	1.5	2.64
	June	2	5.31
	July	1.48	3.13
	August	1.92	4.68
	September	1.91	3.48
Kutubdia	March	2.15	4.19
	April	1.1	12.23
	May	1.47	2.61
	June	1.95	5.31
	July	3.1	6.4
	August	2.1	5.42
	September	1.47	3.23
Sandwip	March		
	April	1.12	8.69
	May	1.38	2.50
	June	2.12	4.16
	July	2.1	6.14
	August	1.4	4.87
	September	2.15	5.85
Kuakata	March	1.81	3.41
	April	1.2	5.45
	May	2.1	3.49
	June	2.19	4.17
	July	2.7	4.81
	August	1.9	3.80
	September	1.25	2.18
Mongla	March	2.38	3.31
	April	1.87	2.71
	May	2.38	3.52
	June	1.65	4.73
	July	2.68	4.88
	August	1.53	5.27
	September	1.79	2.79

Appendix-E

Data Analysis of Different Location

Data analysis of wind speed March, 2003 at Teknaf, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	140	0.19	140	0.19	604	0.81	0.5	1.75
1-2	156	0.21	296	0.40	448	0.60	1.5	52.65
2-3	167	0.22	463	0.62	281	0.38	2.5	260.94
3-4	98	0.13	561	0.75	183	0.25	3.5	420.18
4-5	64	0.09	625	0.84	119	0.16	4.5	583.20
5-6	67	0.09	692	0.93	52	0.07	5.5	1114.71
6-7	21	0.03	713	0.96	31	0.04	6.5	576.71
7-8	18	0.02	731	0.98	13	0.02	7.5	759.38
8-9	10	0.01	741	1.00	3	0.00	8.5	614.13
9-10	3	0.00		1.00	744	0.00	9.5	257.21
Total (H)	744							4640.85

Calculated data: K=1.45 C=3.14

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.23	0.17	0.83	170	129	615	2.12
2	0.25	0.41	0.59	186	302	442	62.78
3	0.18	0.61	0.39	135	452	292	211.58
4	0.16	0.76	0.24	119	564	180	510.38
5	0.08	0.86	0.14	59	640	104	541.97
6	0.05	0.92	0.08	36	686	58	593.00
7	0.03	0.96	0.04	20	714	30	552.92
8	0.01	0.98	0.02	11	729	15	455.53
9	0.01	0.99	0.01	6	737	7	339.40
10	0.00	1.00	0.00	3	744	3	232.38
							3502.05

Data analysis of wind speed April, 2003 at Teknaf, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	130	0.18	130	0.18	590	0.82	0.5	1.63
1-2	153	0.21	283	0.39	437	0.61	1.5	51.64
2-3	184	0.26	467	0.65	253	0.35	2.5	287.50
3-4	118	0.16	585	0.81	135	0.19	3.5	505.93
4-5	80	0.11	665	0.92	55	0.08	4.5	729.00
5-6	41	0.06	706	0.98	14	0.02	5.5	682.14
6-7	12	0.02	718	1.00	2	0.00	6.5	329.55
7-8	1	0.00	719	1.00	1	0.00	7.5	42.19
8-9	1	0.00	720	1.00	0	0.00	8.5	61.41
Total (H)	720							2690.98

Calculated data: K=1.62 C=2.86

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.25	0.17	0.83	177	120	600	2.21
2	0.26	0.43	0.57	187	309	411	62.97
3	0.24	0.66	0.34	173	476	244	270.00
4	0.12	0.82	0.18	90	591	129	384.75
5	0.08	0.92	0.08	55	659	61	498.64
6	0.03	0.96	0.04	23	694	26	387.89
7	0.01	0.99	0.01	10	710	10	274.60
8	0.01	0.99	0.01	4	716	4	163.67
9	0.00	1.00	0.00	1	719	1	84.24
							2128.97

Data analysis of wind speed May, 2003 at Teknaf, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	154	0.21	154	0.21	590	0.79	0.5	1.93
1-2	165	0.22	319	0.43	425	0.57	1.5	55.69
2-3	198	0.27	517	0.69	227	0.31	2.5	309.38
3-4	124	0.17	641	0.86	103	0.14	3.5	531.65
4-5	56	0.08	697	0.94	47	0.06	4.5	510.30
5-6	21	0.03	718	0.97	26	0.03	5.5	349.39
6-7	18	0.02	736	0.99	8	0.01	6.5	494.33
7-8	4	0.01	740	0.99	4	0.01	7.5	168.75
8-9	3	0.00	743	1.00	1	0.00	8.5	184.24
9-10	0	0.00	743	1.00	1	0.00	9.5	0.00
10-11	1	0.00	744	1.00	0	0.00	10.5	115.76
Total (H)	744							2721.40

Calculated data: K=1.55 C=2.65

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.274	0.198	0.802	204	147	597	2.55
2	0.262	0.476	0.524	195	354	390	65.91
3	0.240	0.702	0.298	179	523	221	279.00
4	0.121	0.849	0.151	90	632	112	385.98
5	0.057	0.931	0.069	43	693	51	387.33
6	0.026	0.971	0.029	20	723	21	326.32
7	0.011	0.989	0.011	8	736	8	224.97
8	0.004	0.996	0.004	3	741	3	131.94
9	0.003	0.999	0.001	2	743	1	137.07
10	0.000	1.000	0.000	0	744	0	30.68
11	0.000	1.000	0.000	0	744	0	12.54
							1984.30

Data analysis of wind speed June, 2003 at Teknaf, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	15	0.02	15	0.02	705	0.98	0.5	0.19
1-2	90	0.13	105	0.15	615	0.85	1.5	30.38
2-3	111	0.15	216	0.30	504	0.70	2.5	173.44
3-4	130	0.18	346	0.48	374	0.52	3.5	557.38
4-5	72	0.10	418	0.58	302	0.42	4.5	656.10
5-6	90	0.13	508	0.71	212	0.29	5.5	1497.38
6-7	66	0.09	574	0.80	146	0.20	6.5	1812.53
7-8	63	0.09	637	0.88	83	0.12	7.5	2657.81
8-9	40	0.06	677	0.94	43	0.06	8.5	2456.50
9-10	21	0.03	698	0.97	22	0.03	9.5	1800.49
10-11	13	0.02	711	0.99	9	0.01	10.5	1504.91
11-12	8	0.01	719	1.00	1	0.00	11.5	1216.70
12-13	1	0.00	720	1.00	0	0.00	12.5	195.31
Total (H)	720							14559.10

Calculated data: K=1.99 C=5.47

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.065	0.03	0.97	47	24	696	0.59
2	0.125	0.13	0.87	90	91	629	30.38
3	0.148	0.26	0.74	107	188	532	167.19
4	0.156	0.42	0.58	112	299	421	480.20
5	0.144	0.57	0.43	104	408	312	947.70
6	0.120	0.70	0.30	86	504	216	1430.83
7	0.091	0.80	0.20	65	579	141	1785.06
8	0.063	0.88	0.12	45	635	85	1898.44
9	0.040	0.93	0.07	29	671	49	1780.96
10	0.024	0.96	0.04	17	694	26	1457.54
11	0.013	0.98	0.02	9	707	13	1041.86
12	0.007	0.99	0.01	5	714	6.08	760.44
13	0.003	1.00	0.00	2	720	2.66	390.63
Total							12171.80

Data analysis of wind speed July, 2003 at Teknaf, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	129	0.173	129	0.173	615	0.827	0.5	1.61
1-2	156	0.210	285	0.383	459	0.617	1.5	52.65
2-3	151	0.203	436	0.586	308	0.414	2.5	235.94
3-4	118	0.159	554	0.745	190	0.255	3.5	505.93
4-5	76	0.102	630	0.847	114	0.153	4.5	692.55
5-6	66	0.089	696	0.935	48	0.065	5.5	1098.08
6-7	39	0.052	735	0.988	9	0.012	6.5	1071.04
7-8	8	0.011	743	0.999	1	0.001	7.5	337.50
8-9	1	0.001	744	1.000	0	0.000	8.5	61.41
Total (H)	744							4056.70

Calculated data: K=1.63 C=3.19

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.21	0.14	0.86	156	101	643	*1.95*
2	0.22	0.37	0.63	164	275	469	*55.24*
3	0.21	0.59	0.41	153	442	302	*238.31*
4	0.14	0.77	0.23	105	571	173	*449.44*
5	0.08	0.88	0.12	63	654	90	*576.22*
6	0.05	0.94	0.06	34	701	43	*563.15*
7	0.02	0.97	0.03	16	725	19	*447.74*
8	0.01	0.99	0.01	7	737	7	*300.95*
9	0.00	1.00	0.00	45	744	3	*2741.45*
Total							5374.45

Data analysis of wind speed August, 2003 at Teknaf, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	59	0.079	59	0.079	685	0.921	0.5	0.74
1-2	80	0.108	139	0.187	605	0.813	1.5	27.00
2-3	107	0.144	246	0.331	498	0.669	2.5	167.19
3-4	120	0.161	366	0.492	378	0.508	3.5	514.50
4-5	116	0.156	482	0.648	262	0.352	4.5	1057.05
5-6	112	0.151	594	0.798	150	0.202	5.5	1863.40
6-7	73	0.098	667	0.897	77	0.103	6.5	2004.76
7-8	47	0.063	714	0.960	30	0.040	7.5	1982.81
8-9	21	0.028	735	0.988	9	0.012	8.5	1289.66
9-10	7	0.009	742	0.997	2	0.003	9.5	600.16
10-11	2	0.003	744	1.000	0	0.000	10.5	231.53
Total (H)	744							9738.80

Calculated data: K=1.97 C=4.68

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.09	0.05	0.95	67	35	709	*0.84*
2	0.19	0.17	0.83	141	127	617	*47.71*
3	0.16	0.34	0.66	119	253	491	*186.00*
4	0.17	0.52	0.48	129	387	357	*553.48*
5	0.12	0.68	0.32	89	506	238	*813.56*
6	0.08	0.80	0.20	60	598	146	*990.26*
7	0.07	0.89	0.11	51	662	82	*1393.81*
8	0.04	0.94	0.06	30	702	42	*1253.29*
9	0.06	0.97	0.03	45	724	20	*2741.45*
10	0.01	0.99	0.01	8	735	9	*646.58*
11	0.00	1.00	0.00	3	744	0	*380.93*
Total							9007.94

Data analysis of wind speed September, 2003 at Teknaf, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	72	0.100	72	0.100	648	0.900	0.5	0.90
1-2	112	0.156	184	0.256	536	0.744	1.5	37.80
2-3	196	0.272	380	0.528	340	0.472	2.5	306.25
3-4	97	0.135	477	0.663	243	0.338	3.5	415.89
4-5	97	0.135	574	0.797	146	0.203	4.5	883.91
5-6	96	0.133	670	0.931	50	0.069	5.5	1597.20
6-7	28	0.039	698	0.969	22	0.031	6.5	768.95
7-8	20	0.028	718	0.997	2	0.003	7.5	843.75
8-9	2	0.003	720	1.000	0	0.000	8.5	122.83
Total (H)	720							4977.48

Calculated data: K=1.83 C=3.48

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.17	0.10	0.90	121	70	650	1.52
2	0.21	0.30	0.70	151	219	501	51.03
3	0.16	0.53	0.47	115	384	336	180.00
4	0.16	0.72	0.28	117	522	198	501.48
5	0.12	0.86	0.14	86	617	103	787.32
6	0.08	0.93	0.07	58	672	48	958.32
7	0.03	0.97	0.03	19	700	20	511.10
8	0.01	0.99	0.01	8	713	7	324.47
9	0.01	1.00	0.00	43	718	2	2653.02
Total							5968.25

Data analysis of wind speed March, 2003 at Kutubdia, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocit y Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	24	0.032	24	0.032	720	0.968	0.5	0.30
1-2	85	0.114	109	0.147	635	0.853	1.5	28.69
2-3	179	0.241	288	0.387	456	0.613	2.5	279.69
3-4	169	0.227	457	0.614	287	0.386	3.5	724.59
4-5	117	0.157	574	0.772	170	0.228	4.5	1066.16
5-6	83	0.112	657	0.883	87	0.117	5.5	1380.91
6-7	42	0.056	699	0.940	45	0.060	6.5	1153.43
7-8	19	0.026	718	0.965	26	0.035	7.5	801.56
8-9	20	0.027	738	0.992	6	0.008	8.5	1228.25
9-10	5	0.007	743	0.999	1	0.001	9.5	428.69
10-11	0	0.000	743	0.999	1	0.001	10.5	0.00
11-12	0	0.000	743	0.999	1	0.001	11.5	0.00
12-13	1	0.001	744	1.000	0	0.000	12.5	195.31
Total (H)	744							7287.58

Calculated data: K=2.14 C=4.16

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.10	0.05	0.95	72	34	710	0.90
2	0.22	0.19	0.81	164	140	604	55.24
3	0.16	0.39	0.61	119	291	453	186.00
4	0.20	0.60	0.40	146	447	297	625.67
5	0.12	0.77	0.23	89	575	169	813.56
6	0.08	0.89	0.11	60	661	83	990.26
7	0.04	0.95	0.05	33	709	35	905.03
8	0.02	0.98	0.02	14	731	13	591.20
9	0.06	0.99	0.01	45	740	4	2741.45
10	0.00	1.00	0.00	2	743	1	129.68
11	0.00	1.00	0.00	0	744	0	44.51
12	0.00	1.00	0.00	0	744	0	12.53
13	0.00	1.00	0.00	0	744	0	2.90
Total							7098.95

Data analysis of wind speed April, 2003 at Kutubdia, Cox's Bazar

Observed data

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v3hi$
0-1	42	0.058	42	0.058	678	0.942	0.5	0.53
1-2	47	0.065	89	0.124	631	0.876	1.5	15.86
2-3	51	0.071	140	0.194	580	0.806	2.5	79.69
3-4	90	0.125	230	0.319	490	0.681	3.5	385.88
4-5	89	0.124	319	0.443	401	0.557	4.5	811.01
5-6	79	0.110	398	0.553	322	0.447	5.5	1314.36
6-7	55	0.076	453	0.629	267	0.371	6.5	1510.44
7-8	38	0.053	491	0.682	229	0.318	7.5	1603.13
8-9	30	0.042	521	0.724	199	0.276	8.5	1842.38
9-10	16	0.022	537	0.746	183	0.254	9.5	1371.80
10-11	2	0.003	539	0.749	181	0.251	10.5	231.53
11-12	0	0.000	539	0.749	181	0.251	11.5	0.00
12-13	1	0.001	540	0.750	180	0.250	12.5	195.31
13-14	1	0.001	541	0.751	179	0.249	13.5	246.04
14-15	179	0.249	720	1.000	720	0.000	14.5	54570.39
Total								64178.33

Table A-10b: Calculated data: K=1.12 C=12.13

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.06	0.06	0.94	46	43	677	0.58
2	0.07	0.12	0.88	144	90	630	48.60
3	0.06	0.19	0.81	130	136	584	202.50
4	0.06	0.25	0.75	44	181	539	186.95
5	0.06	0.31	0.69	41	223	497	376.00
6	0.05	0.37	0.63	39	263	457	645.17
7	0.05	0.42	0.58	36	301	419	995.76
8	0.05	0.47	0.53	72	336	384	3037.50
9	0.04	0.51	0.49	31	368	352	1925.30
10	0.04	0.55	0.45	29	398	322	2488.65
11	0.04	0.59	0.41	27	426	294	3103.98
12	0.03	0.63	0.37	36	452	268	5475.15
13	0.03	0.66	0.34	23	476	244	4443.26
14	0.03	0.69	0.31	21	497	223	5143.01
15	0.03	0.72	0.28	19	518	202.50	5847.22
Total							24430.82

Data analysis of wind speed May, 2003 at Kutubdia, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	152	0.204	152	0.204	592	0.796	0.5	1.90
1-2	174	0.234	326	0.438	418	0.562	1.5	58.73
2-3	190	0.255	516	0.694	228	0.306	2.5	296.88
3-4	129	0.173	645	0.867	99	0.133	3.5	553.09
4-5	51	0.069	696	0.935	48	0.065	4.5	464.74
5-6	27	0.036	723	0.972	21	0.028	5.5	449.21
6-7	14	0.019	737	0.991	7	0.009	6.5	384.48
7-8	6	0.008	743	0.999	1	0.001	7.5	253.13
8-9	1	0.001	744	1.000	0	0.000	8.5	61.41
Total (H)	744							2523.55

Calculated data: K=1.56 C=2.60

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.28	0.20	0.80	209	150	594	2.61
2	0.25	0.49	0.51	186	361	383	62.78
3	0.18	0.71	0.29	134	531	213	209.25
4	0.11	0.86	0.14	80	639	105	343.77
5	0.05	0.94	0.06	40	698	46	366.32
6	0.02	0.97	0.03	18	725	19	297.42
7	0.01	0.99	0.01	7	737	7	196.48
8	0.09	1.00	0.00	67	742	2	2824.88
9	0.00	1.00	0.00	1	743	1	53.29
Total							4356.80

Data analysis of wind speed June, 2003 at Kutubdia, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocit y Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	15	0.021	15	0.021	705	0.979	0.5	0.19
1-2	90	0.125	105	0.146	615	0.854	1.5	30.38
2-3	111	0.154	216	0.300	504	0.700	2.5	173.44
3-4	129	0.179	345	0.479	375	0.521	3.5	553.09
4-5	75	0.104	420	0.583	300	0.417	4.5	683.44
5-6	88	0.122	508	0.706	212	0.294	5.5	1464.10
6-7	66	0.092	574	0.797	146	0.203	6.5	1812.53
7-8	62	0.086	636	0.883	84	0.117	7.5	2615.63
8-9	39	0.054	675	0.938	45	0.062	8.5	2395.09
9-10	23	0.032	698	0.969	22	0.031	9.5	1971.96
10-11	13	0.018	711	0.988	9	0.012	10.5	1504.91
11-12	8	0.011	719	0.999	1	0.001	11.5	1216.70
12-13	1	0.001	720	1.000	0	0.000	12.5	195.31
Total (H)	720							14616.75

Calculated data: K=1.92 C=5.31

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.07	0.04	0.96	54	29	691	0.67
2	0.20	0.14	0.86	144	102	618	48.60
3	0.09	0.28	0.72	63	204	516	99.00
4	0.16	0.44	0.56	112	317	403	481.35
5	0.14	0.59	0.41	101	425	295	920.91
6	0.11	0.72	0.28	82	517	203	1368.79
7	0.09	0.82	0.18	61	588	132	1684.43
8	0.05	0.89	0.11	36	640	80	1518.75
9	0.04	0.94	0.06	27	674	46	1654.11
10	0.02	0.97	0.03	16	695	25	1372.19
11	0.01	0.98	0.02	9	707	13	1027.70
12	0.05	0.99	0.01	36	714	6	5475.15
13	0.00	1.00	0.00	2	717	3	437.42
Total							16089.08

Data analysis of wind speed July, 2003 at Kutubdia, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocit y Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	1	0.001	1	0.001	743	0.999	0.5	0.01
1-2	6	0.008	7	0.009	737	0.991	1.5	2.03
2-3	25	0.034	32	0.043	712	0.957	2.5	39.06
3-4	70	0.094	102	0.137	642	0.863	3.5	300.13
4-5	130	0.175	232	0.312	512	0.688	4.5	1184.63
5-6	209	0.281	441	0.593	303	0.407	5.5	3477.24
6-7	148	0.199	589	0.792	155	0.208	6.5	4064.45
7-8	77	0.103	666	0.895	78	0.105	7.5	3248.44
8-9	53	0.071	719	0.966	25	0.034	8.5	3254.86
9-10	20	0.027	739	0.993	5	0.007	9.5	1714.75
10-11	5	0.007	744	1.000	0	0.000	10.5	578.81
Total (H)	744							17864.40

Calculated data: K=3.17 C=6.07

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.01	0.00	1.00	8	2	742	0.10
2	0.05	0.03	0.97	34	22	722	11.44
3	0.10	0.10	0.90	76	76	668	118.19
4	0.16	0.23	0.77	120	174	570	516.21
5	0.20	0.42	0.58	149	311	433	1353.52
6	0.19	0.62	0.38	145	460	284	2404.28
7	0.15	0.79	0.21	110	589	155	3020.86
8	0.09	0.91	0.09	64	676	68	2708.97
9	0.04	0.97	0.03	28	721	23	1718.85
10	0.01	0.99	0.01	9	738	6	757.24
11	0.00	1.00	0.00	2	743	1	225.84
Total							12835.51

Data analysis of wind speed August, 2003 at Kutubdia, Cox's Bazar

: Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	38	0.051	38	0.051	706	0.949	0.5	0.48
1-2	46	0.062	84	0.113	660	0.887	1.5	15.53
2-3	77	0.103	161	0.216	583	0.784	2.5	120.31
3-4	89	0.120	250	0.336	494	0.664	3.5	381.59
4-5	128	0.172	378	0.508	366	0.492	4.5	1166.40
5-6	154	0.207	532	0.715	212	0.285	5.5	2562.18
6-7	109	0.147	641	0.862	103	0.138	6.5	2993.41
7-8	55	0.074	696	0.935	48	0.065	7.5	2320.31
8-9	35	0.047	731	0.983	13	0.017	8.5	2149.44
9-10	9	0.012	740	0.995	4	0.005	9.5	771.64
10-11	3	0.004	744	0.999	1	0.001	10.5	347.29
Total (H)								12828.56

Calculated data: K=2.23 C=5.37

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.05	0.02	0.98	38	17	727	0.48
2	0.12	0.10	0.90	89	78	666	30.13
3	0.15	0.24	0.76	115	178	566	179.54
4	0.16	0.40	0.60	119	301	443	510.38
5	0.17	0.57	0.43	126	427	317	1145.77
6	0.13	0.72	0.28	98	537	207	1637.06
7	0.09	0.84	0.16	70	622	122	1931.50
8	0.06	0.91	0.09	44	679	65	1869.00
9	0.03	0.96	0.04	25	713	31	1514.53
10	0.02	0.98	0.02	12	730	14	1041.45
11	0.01	0.99	0.01	5	739	5	613.00
Total							10472.85

Data analysis of wind speed September, 2003 at Kutubdia, Cox's Bazar

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	161	0.224	161	0.224	559	0.776	0.5	2.01
1-2	106	0.147	267	0.371	453	0.629	1.5	35.78
2-3	119	0.165	386	0.536	334	0.464	2.5	185.94
3-4	169	0.235	555	0.771	165	0.229	3.5	724.59
4-5	47	0.065	602	0.836	118	0.164	4.5	428.29
5-6	70	0.097	672	0.933	48	0.067	5.5	1164.63
6-7	30	0.042	702	0.975	18	0.025	6.5	823.88
7-8	10	0.014	712	0.989	8	0.011	7.5	421.88
8-9	6	0.008	718	0.997	2	0.003	8.5	368.48
9-10	2	0.003	720	1.000	0	0.000	9.5	171.48
Total (H)	720							4326.93

Calculated data: K=1.48 C=3.24

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.22	0.16	0.84	157	116	604	1.96
2	0.20	0.39	0.61	143	279	441	48.11
3	0.18	0.59	0.41	130	425	295	202.90
4	0.16	0.74	0.26	115	536	184	493.92
5	0.17	0.85	0.15	122	612	108	1108.81
6	0.05	0.92	0.08	37	660	60	610.31
7	0.03	0.96	0.04	21	688	32	573.20
8	0.02	0.98	0.02	11	704	16	474.06
9	0.01	0.99	0.01	6	712	8	353.45
10	0.00	1.00	0.00	3	716	4	241.42
Total							4108.14

Data analysis of wind speed April, 2003 at Sandwip, Chittagong

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	17	0.024	17	0.024	703	0.976	0.5	0.21
1-2	36	0.050	53	0.074	667	0.926	1.5	12.15
2-3	60	0.083	113	0.157	607	0.843	2.5	93.75
3-4	75	0.104	188	0.261	532	0.739	3.5	321.56
4-5	89	0.124	277	0.385	443	0.615	4.5	811.01
5-6	81	0.113	358	0.497	362	0.503	5.5	1347.64
6-7	75	0.104	433	0.601	287	0.399	6.5	2059.69
7-8	85	0.118	518	0.719	202	0.281	7.5	3585.94
8-9	73	0.101	591	0.821	129	0.179	8.5	4483.11
9-10	76	0.106	667	0.926	53	0.074	9.5	6516.05
10-11	35	0.049	702	0.975	18	0.025	10.5	4051.69
11-12	15	0.021	717	0.996	3	0.004	11.5	2281.31
12-13	3	0.004	720	1.000	0	0.000	12.5	585.94
Total (H)	720							26150.05

Calculated data: K=1.14 C=8.73

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.09	0.08	0.92	64	58	662	0.80
2	0.25	0.17	0.83	180	122	598	60.75
3	0.15	0.26	0.74	108	184	536	168.75
4	0.08	0.34	0.66	56	243	477	239.65
5	0.07	0.41	0.59	51	296	424	466.56
6	0.06	0.48	0.52	46	345	375	773.20
7	0.06	0.54	0.46	42	389	331	1150.55
8	0.05	0.60	0.40	38	429	291	1584.73
9	0.05	0.64	0.36	34	464	256	2059.17
10	0.04	0.69	0.31	30	496	224	2556.40
11	0.04	0.73	0.27	26	524	196	3059.33
12	0.03	0.76	0.24	23	549	171	3552.24
13	0.03	0.79	0.21	21	571	149	4021.35
Total							19693.45

Data analysis of wind speed May, 2003 at Sandwip, Chittagong

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	216	0.290	216	0.290	528	0.710	0.5	2.70
1-2	141	0.190	357	0.480	387	0.520	1.5	47.59
2-3	157	0.211	514	0.691	230	0.309	2.5	245.31
3-4	110	0.148	624	0.839	120	0.161	3.5	471.63
4-5	62	0.083	686	0.922	58	0.078	4.5	564.98
5-6	31	0.042	717	0.964	27	0.036	5.5	515.76
6-7	18	0.024	735	0.988	9	0.012	6.5	494.33
7-8	4	0.005	739	0.993	5	0.007	7.5	168.75
8-9	3	0.004	742	0.997	2	0.003	8.5	184.24
9-10	1	0.001	743	0.999	1	0.001	9.5	85.74
10-11	1	0.001	744	1.000	0	0.000	10.5	115.76
Total (H)								2896.78

Calculated data: K=1.38 C=2.50

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.29	0.25	0.75	219	183	561	2.73
2	0.25	0.52	0.48	186	387	357	62.78
3	0.16	0.72	0.28	119	538	206	186.00
4	0.15	0.85	0.15	112	634	110	478.49
5	0.05	0.93	0.07	40	689	55	360.75
6	0.03	0.96	0.04	20	718	26	335.26
7	0.04	0.98	0.02	30	732	12	817.28
8	0.01	0.99	0.01	4	739	5	185.56
9	0.01	1.00	0.00	7	742	2	456.91
10	0.00	1.00	0.00	0	743	1	0.00
11	0.00	1.00	0.00	0	744	0	0.00
Total							2885.75

Data analysis of wind speed June, 2003 at Sandwip, Chittagong

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocit y Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	36	0.050	36	0.050	684	0.950	0.5	0.45
1-2	97	0.135	133	0.185	587	0.815	1.5	32.74
2-3	148	0.206	281	0.390	439	0.610	2.5	231.25
3-4	169	0.235	450	0.625	270	0.375	3.5	724.59
4-5	95	0.132	545	0.757	175	0.243	4.5	865.69
5-6	82	0.114	627	0.871	93	0.129	5.5	1364.28
6-7	54	0.075	681	0.946	39	0.054	6.5	1482.98
7-8	28	0.039	709	0.985	11	0.015	7.5	1181.25
8-9	8	0.011	717	0.996	3	0.004	8.5	491.30
9-10	3	0.004	720	1.000	0	0.000	9.5	257.21
Total (H)								6631.73

Calculated data: K=2.1 C=4.15

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.101	0.05	0.95	72	35	685	0.90
2	0.190	0.19	0.81	137	140	580	46.24
3	0.140	0.40	0.60	101	286	434	157.81
4	0.193	0.60	0.40	139	435	285	595.96
5	0.129	0.77	0.23	93	556	164	847.46
6	0.087	0.89	0.11	62	638	82	1031.53
7	0.093	0.95	0.05	67	684	36	1839.99
8	0.056	0.98	0.02	40	706	14	1687.50
9	0.007	0.99	0.01	5	716	4	307.06
10	0.005	1.00	0.00	4	720	1	342.95
Total							6857.40

Data analysis of wind speed July, 2003 at Sandwip, Chittagong

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	7	0.009	7	0.009	737	0.991	0.5	0.09
1-2	74	0.099	81	0.109	663	0.891	1.5	24.98
2-3	144	0.194	225	0.302	519	0.698	2.5	225.00
3-4	105	0.141	330	0.444	414	0.556	3.5	450.19
4-5	49	0.066	379	0.509	365	0.491	4.5	446.51
5-6	37	0.050	416	0.559	328	0.441	5.5	615.59
6-7	69	0.093	485	0.652	259	0.348	6.5	1894.91
7-8	85	0.114	570	0.766	174	0.234	7.5	3585.94
8-9	84	0.113	654	0.879	90	0.121	8.5	5158.65
9-10	62	0.083	716	0.962	28	0.038	9.5	5315.73
10-11	19	0.026	735	0.988	9	0.012	10.5	2199.49
11-12	9	0.012	744	1.000	0	0.000	11.5	1368.79
Total (H)								21285.85

Calculated data: K=2.1 C=6.14

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.05	0.02	0.98	34	16	728	0.42
2	0.09	0.09	0.91	67	67	677	22.60
3	0.12	0.20	0.80	93	148	596	144.80
4	0.14	0.33	0.67	106	249	495	453.44
5	0.14	0.48	0.52	106	355	389	966.05
6	0.13	0.61	0.39	96	457	287	1591.96
7	0.11	0.73	0.27	79	545	199	2163.04
8	0.08	0.83	0.17	60	614	130	2512.93
9	0.06	0.89	0.11	42	664	80	2553.17
10	0.05	0.94	0.06	37	698	46	3189.44
11	0.02	0.97	0.03	16	719	25	1862.70
12	0.01	0.98	0.02	9	731	13	1361.46
Total							16822.30

Data analysis of wind speed August, 2003 at Sandwip, Chittagong

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	44	0.059	44	0.059	700	0.941	0.5	0.55
1-2	128	0.172	172	0.231	572	0.769	1.5	43.20
2-3	202	0.272	374	0.503	370	0.497	2.5	315.63
3-4	82	0.110	456	0.613	288	0.387	3.5	351.58
4-5	53	0.071	509	0.684	235	0.316	4.5	482.96
5-6	36	0.048	545	0.733	199	0.267	5.5	598.95
6-7	23	0.031	568	0.763	176	0.237	6.5	631.64
7-8	18	0.024	586	0.788	158	0.212	7.5	759.38
8-9	47	0.063	633	0.851	111	0.149	8.5	2886.39
9-10	45	0.060	678	0.911	66	0.089	9.5	3858.19
10-11	32	0.043	710	0.954	34	0.046	10.5	3704.40
11-12	22	0.030	732	0.984	12	0.016	11.5	3345.93
12-13	8	0.011	740	0.995	4	0.005	12.5	1562.50
13-14	4	0.005	744	1.000	0	0.000	13.5	984.15
Total (H)								19525.43

Calculated data: K=1.4 C=4.87

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.14	0.10	0.90	102	77	667	1.27
2	0.16	0.25	0.75	119	186	558	40.18
3	0.15	0.40	0.60	111	296	448	173.21
4	0.12	0.53	0.47	93	396	348	396.72
5	0.10	0.65	0.35	77	480	264	697.87
6	0.08	0.74	0.26	61	549	195	1013.60
7	0.06	0.81	0.19	47	603	141	1288.84
8	0.05	0.87	0.13	35	644	100	1484.15
9	0.03	0.91	0.09	26	674	70	1581.35
10	0.02	0.94	0.06	18	696	48	1581.84
11	0.02	0.96	0.04	13	711	33	1500.95
12	0.02	0.97	0.03	14	722	22	2149.91
13	0.02	0.98	0.02	14	730	14	2760.94
14	0.02	0.99	0.01	14	735	9	3477.99
Total							18148.82

Data analysis of wind speed September, 2003 at Sandwip, Chittagong

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^3hi
0-1	26	0.036	26	0.036	694	0.964	0.5	0.33
1-2	39	0.054	65	0.090	655	0.910	1.5	13.16
2-3	93	0.129	158	0.219	562	0.781	2.5	145.31
3-4	86	0.119	244	0.339	476	0.661	3.5	368.73
4-5	110	0.153	354	0.492	366	0.508	4.5	1002.38
5-6	119	0.165	473	0.657	247	0.343	5.5	1979.86
6-7	71	0.099	544	0.756	176	0.244	6.5	1949.84
7-8	61	0.085	605	0.840	115	0.160	7.5	2573.44
8-9	60	0.083	665	0.924	55	0.076	8.5	3684.75
9-10	32	0.044	697	0.968	23	0.032	9.5	2743.60
10-11	20	0.028	717	0.996	3	0.004	10.5	2315.25
11-12	2	0.003	719	0.999	1	0.001	11.5	304.18
12-13	1	0.001	720	1.000	0	0.000	12.5	195.31
Total (H)	720							17276.13

Calculated data: K=2.17 C=5.86

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^3hi
1	0.05	0.02	0.98	33	15	705	0.41
2	0.11	0.09	0.91	79	67	653	26.73
3	0.13	0.21	0.79	96	150	570	150.64
4	0.15	0.35	0.65	110	255	465	472.54
5	0.15	0.51	0.49	109	366	354	993.41
6	0.13	0.65	0.35	96	469	251	1591.68
7	0.10	0.77	0.23	75	555	165	2071.29
8	0.09	0.86	0.14	65	619	101	2733.75
9	0.05	0.92	0.08	35	663	57	2139.18
10	0.03	0.96	0.04	21	690	30	1760.50
11	0.02	0.98	0.02	11	706	14	1277.14
12	0.01	0.99	0.01	5	714	6	822.28
13	0.01	1.00	0.00	7	717	3	1406.25
Total							15444.80

Data analysis of wind speed March, 2003 at Kuakata, Patuakhali

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	95	0.128	95	0.128	649	0.872	0.5	1.19
1-2	123	0.165	218	0.293	526	0.707	1.5	41.51
2-3	158	0.212	376	0.505	368	0.495	2.5	246.88
3-4	149	0.200	525	0.706	219	0.294	3.5	638.84
4-5	118	0.159	643	0.864	101	0.136	4.5	1075.28
5-6	61	0.082	704	0.946	40	0.054	5.5	1014.89
6-7	27	0.036	731	0.983	13	0.017	6.5	741.49
7-8	6	0.008	737	0.991	7	0.009	7.5	253.13
8-9	4	0.005	741	0.996	3	0.004	8.5	245.65
9-10	1	0.001	742	0.997	2	0.003	9.5	85.74
10-11	1	0.001	743	0.999	1	0.001	10.5	115.76
11-12	0	0.000	743	0.999	1	0.001	11.5	0.00
12-13	1	0.001	744	1.000	0	0.000	12.5	195.31
Total (H)								4655.65

Calculated data: K=1.8 C=3.4

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.18	0.10	0.90	132	78	666	1.66
2	0.25	0.32	0.68	186	238	506	62.78
3	0.21	0.55	0.45	156	409	335	244.13
4	0.16	0.74	0.26	117	549	195	503.69
5	0.10	0.86	0.14	72	644	100	659.93
6	0.05	0.94	0.06	39	698	46	640.55
7	0.02	0.97	0.03	18	725	19	491.70
8	0.01	0.99	0.01	7	737	7	310.19
9	0.01	1.00	0.00	7	742	2	411.22
10	0.00	1.00	0.00	1	743	1	75.09
11	0.01	1.00	0.00	7	744	0	775.15
12	0.00	1.00	0.00	0	744	0	10.27
13	0.00	1.00	0.00	0	744	0	3.14
Total							4189.48

Data analysis of wind speed April, 2003 at Kuakata, Patuakhali

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	145	0.201	145	0.201	575	0.799	0.5	1.81
1-2	108	0.150	253	0.351	467	0.649	1.5	36.45
2-3	97	0.135	350	0.486	370	0.514	2.5	151.56
3-4	132	0.183	482	0.669	238	0.331	3.5	565.95
4-5	106	0.147	588	0.817	132	0.183	4.5	965.93
5-6	68	0.094	656	0.911	64	0.089	5.5	1131.35
6-7	26	0.036	682	0.947	38	0.053	6.5	714.03
7-8	15	0.021	697	0.968	23	0.032	7.5	632.81
8-9	9	0.013	706	0.981	14	0.019	8.5	552.71
9-10	10	0.014	716	0.994	4	0.006	9.5	857.38
10-11	1	0.001	717	0.996	3	0.004	10.5	115.76
11-12	3	0.004	720	1.000	0	0.000	11.5	456.26
Total (H)								6182.0

Calculated data: K=1.21 C=5.5

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.14	0.12	0.88	98	86	634	1.22
2	0.20	0.25	0.75	144	183	537	48.60
3	0.20	0.38	0.62	144	275	445	225.00
4	0.14	0.49	0.51	101	355	365	432.18
5	0.15	0.59	0.41	108	425	295	984.15
6	0.09	0.67	0.33	65	483	237	1078.11
7	0.06	0.74	0.26	44	531	189	1199.60
8	0.05	0.79	0.21	36	571	149	1498.64
9	0.00	0.84	0.16	1	603	117	44.22
10	0.00	0.87	0.13	1	628	92	61.73
11	0.00	0.90	0.10	1	649	71	83.35
12	0.00	0.92	0.08	0	665	55	0.00
Total							5659.94

Data analysis of wind speed May, 2003 at Kuakata, Patuakhali

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	31	0.042	31	0.042	713	0.958	0.5	0.39
1-2	72	0.097	103	0.138	641	0.862	1.5	24.30
2-3	276	0.371	379	0.509	365	0.491	2.5	431.25
3-4	230	0.309	609	0.819	135	0.181	3.5	986.13
4-5	76	0.102	685	0.921	59	0.079	4.5	692.55
5-6	26	0.035	711	0.956	33	0.044	5.5	432.58
6-7	20	0.027	731	0.983	13	0.017	6.5	549.25
7-8	6	0.008	737	0.991	7	0.009	7.5	253.13
8-9	4	0.005	741	0.996	3	0.004	8.5	245.65
9-10	1	0.001	742	0.997	2	0.003	9.5	85.74
10-11	0	0.000	742	0.997	2	0.003	10.5	0.00
11-12	0	0.000	742	0.997	2	0.003	11.5	0.00
12-13	0	0.000	742	0.997	2	0.003	12.5	0.00
13-14	2	0.003	744	1.000	0	0.000	13.5	492.08
Total (H)								4193.03

Calculated data: K=2.2 C=3.49

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.13	0.06	0.94	98	46	698	1.23
2	0.24	0.25	0.75	179	189	555	60.26
3	0.22	0.51	0.49	164	381	363	255.75
4	0.20	0.74	0.26	149	551	193	637.98
5	0.11	0.89	0.11	80	662	82	724.97
6	0.06	0.96	0.04	45	716	28	742.70
7	0.01	0.99	0.01	11	737	7	291.44
8	0.00	1.00	0.00	3	742	2	108.36
9	0.01	1.00	0.00	7	744	0	456.91
10	0.00	1.00	0.00	0	744	0	5.65
11	0.00	1.00	0.00	0	744	0	0.80
12	0.01	1.00	0.00	7	744	0	1018.38
13	0.00	1.00	0.00	0	744	0	0.01
14	0.00	1.00	0.00	0	744	0	0.00
Total							4304.43

Data analysis of wind speed June, 2003 at Kuakata, Patuakhali

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	24	0.033	24	0.033	696	0.967	0.5	0.30
1-2	81	0.113	105	0.146	615	0.854	1.5	27.34
2-3	170	0.236	275	0.382	445	0.618	2.5	265.63
3-4	189	0.263	464	0.644	256	0.356	3.5	810.34
4-5	97	0.135	561	0.779	159	0.221	4.5	883.91
5-6	81	0.113	642	0.892	78	0.108	5.5	1347.64
6-7	45	0.063	687	0.954	33	0.046	6.5	1235.81
7-8	22	0.031	709	0.985	11	0.015	7.5	928.13
8-9	8	0.011	717	0.996	3	0.004	8.5	491.30
9-10	3	0.004	720	1.000	0	0.000	9.5	257.21
Total (H)								6247.60

Calculated data: K=2.15 C=4.05

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.10	0.05	0.95	73	35	685	0.91
2	0.22	0.20	0.80	158	142	578	53.46
3	0.23	0.41	0.59	166	294	426	258.75
4	0.20	0.62	0.38	143	448	272	614.31
5	0.13	0.79	0.21	94	571	149	852.93
6	0.06	0.90	0.10	43	650	70	718.74
7	0.05	0.96	0.04	36	692	28	988.65
8	0.02	0.99	0.01	11	710	10	468.55
9	0.02	1.00	0.00	14	717	3	840.12
10	0.01	1.00	0.00	6	719	1	555.58
Total							5352.01

Data analysis of wind speed July, 2003 at Kuakata, Patuakhali

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum hi$	$\sum(hi/T)$	T-$\sum$ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	3	0.004	3	0.004	741	0.996	0.5	0.04
1-2	52	0.070	55	0.074	689	0.926	1.5	17.55
2-3	127	0.171	182	0.245	562	0.755	2.5	198.44
3-4	173	0.233	355	0.477	389	0.523	3.5	741.74
4-5	153	0.206	508	0.683	236	0.317	4.5	1394.21
5-6	113	0.152	621	0.835	123	0.165	5.5	1880.04
6-7	78	0.105	699	0.940	45	0.060	6.5	2142.08
7-8	28	0.038	727	0.977	17	0.023	7.5	1181.25
8-9	12	0.016	739	0.993	5	0.007	8.5	736.95
9-10	3	0.004	742	0.997	2	0.003	9.5	257.21
10-11	2	0.003	744	1.000	0	0.000	10.5	231.53
Total (H)								8781.03

Calculated data: K=2.7 C=4.82

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum(hi/T)$	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.04	0.01	0.99	28	11	733	0.35
2	0.22	0.09	0.91	164	66	678	55.24
3	0.23	0.24	0.76	171	181	563	267.38
4	0.20	0.45	0.55	148	337	407	634.79
5	0.13	0.67	0.33	97	497	247	881.36
6	0.06	0.84	0.16	45	622	122	742.70
7	0.05	0.94	0.06	37	696	48	1021.61
8	0.03	0.98	0.02	19	729	15	819.32
9	0.02	1.00	0.00	14	741	3	868.13
10	0.02	1.00	0.00	14	743	1	1211.99
11	0.01	1.00	0.00	7	744	0	775.15
Total							7278.01

Data analysis of wind speed August, 2003 at Kuakata, Patuakhali

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocit y Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	98	0.132	98	0.132	646	0.868	0.5	1.23
1-2	83	0.112	181	0.243	563	0.757	1.5	28.01
2-3	172	0.231	353	0.474	391	0.526	2.5	268.75
3-4	117	0.157	470	0.632	274	0.368	3.5	501.64
4-5	109	0.147	579	0.778	165	0.222	4.5	993.26
5-6	95	0.128	674	0.906	70	0.094	5.5	1580.56
6-7	40	0.054	714	0.960	30	0.040	6.5	1098.50
7-8	20	0.027	734	0.987	10	0.013	7.5	843.75
8-9	10	0.013	744	1.000	0	0.000	8.5	614.13
Total (H)								5929.83

Calculated data: K=1.87 C= 3.81

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.14	0.08	0.92	105	59	685	1.31
2	0.22	0.26	0.74	164	193	551	55.24
3	0.21	0.47	0.53	156	352	392	244.48
4	0.17	0.67	0.33	127	495	249	546.27
5	0.12	0.81	0.19	88	603	141	799.54
6	0.07	0.90	0.10	52	672	72	870.68
7	0.05	0.96	0.04	33	711	33	919.44
8	0.02	0.98	0.02	13	730	14	536.07
9	0.01	0.99	0.01	5	739	5	322.39
Total							4295.44

Data analysis of wind speed September, 2003 at Kuakata, Patuakhali

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	209	0.290	209	0.290	511	0.710	0.5	2.61
1-2	191	0.265	400	0.556	320	0.444	1.5	64.46
2-3	171	0.238	571	0.793	149	0.207	2.5	267.19
3-4	67	0.093	638	0.886	82	0.114	3.5	287.26
4-5	59	0.082	697	0.968	23	0.032	4.5	537.64
5-6	10	0.014	707	0.982	13	0.018	5.5	166.38
6-7	9	0.013	716	0.994	4	0.006	6.5	247.16
7-8	3	0.004	719	0.999	1	0.001	7.5	126.56
8-9	0	0.000	719	0.999	1	0.001	8.5	0.00
9-10	1	0.001	720	1.000	0	0.000	9.5	85.74
Total (H)								1785

Calculated data: K=1.33 C=2.22

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.33	0.29	0.71	235	211	509	2.93
2	0.28	0.58	0.42	202	418	302	68.04
3	0.20	0.78	0.22	144	558	162	225.00
4	0.10	0.89	0.11	72	639	81	308.70
5	0.09	0.95	0.05	64	682	38	583.93
6	0.02	0.98	0.02	14	703	17	233.79
7	0.01	0.99	0.01	6	713	7	172.89
8	0.00	1.00	0.00	3	717	3	113.39
9	0.00	1.00	0.00	1	719	1	67.51
10	0.00	1.00	0.00	0	720	0	37.07
Total							1813.25

Data analysis of wind speed March, 2003 at Mongla, Bagherhat

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	50	0.067	50	0.067	694	0.933	0.5	0.63
1-2	113	0.152	163	0.219	581	0.781	1.5	38.14
2-3	250	0.336	413	0.555	331	0.445	2.5	390.63
3-4	175	0.235	588	0.790	156	0.210	3.5	750.31
4-5	107	0.144	695	0.934	49	0.066	4.5	975.04
5-6	40	0.054	735	0.988	9	0.012	5.5	665.50
6-7	7	0.009	742	0.997	2	0.003	6.5	192.24
7-8	2	0.003	744	1.000	0	0.000	7.5	84.38
Total (H)								3096.85

Calculated data: K=2.39 C=3.27

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.13	0.06	0.94	99	43	701	1.23
2	0.25	0.27	0.73	186	198	546	62.78
3	0.29	0.56	0.44	214	414	330	334.01
4	0.19	0.80	0.20	143	597	147	611.36
5	0.08	0.94	0.06	62	697	47	566.42
6	0.02	0.99	0.01	18	734	10	297.08
7	0.02	1.00	0.00	18	742	2	490.37
8	0.01	1.00	0.00	4	744	0	156.94
Total							2520.19

Data analysis of wind speed April, 2003 at Mongla, Bagherhat

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	111	0.154	111	0.154	609	0.846	0.5	1.39
1-2	188	0.261	299	0.415	421	0.585	1.5	63.45
2-3	192	0.267	491	0.682	229	0.318	2.5	300.00
3-4	139	0.193	630	0.875	90	0.125	3.5	595.96
4-5	61	0.085	691	0.960	29	0.040	4.5	555.86
5-6	22	0.031	713	0.990	7	0.010	5.5	366.03
6-7	5	0.007	718	0.997	2	0.003	6.5	137.31
7-8	2	0.003	720	1.000	0	0.000	7.5	84.38
Total (H)								2104.38

Calculated data: K=1.85 C=2.74

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.25	0.14	0.86	177	103	617	2.21
2	0.25	0.43	0.57	180	308	412	60.75
3	0.24	0.69	0.31	173	499	221	270.00
4	0.12	0.87	0.13	90	624	96	383.82
5	0.08	0.95	0.05	58	686	34	524.88
6	0.03	0.99	0.01	22	710	10	359.37
7	0.02	1.00	0.00	17	718	2	474.55
8	0.01	1.00	0.00	4	720	1	151.88
Total							2227.46

Data analysis of wind speed May, 2003 at Mongla, Bagherhat

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	38	0.051	38	0.051	706	0.949	0.5	0.48
1-2	104	0.140	142	0.191	602	0.809	1.5	35.10
2-3	272	0.366	414	0.556	330	0.444	2.5	425.00
3-4	219	0.294	633	0.851	111	0.149	3.5	938.96
4-5	62	0.083	695	0.934	49	0.066	4.5	564.98
5-6	21	0.028	716	0.962	28	0.038	5.5	349.39
6-7	19	0.026	735	0.988	9	0.012	6.5	521.79
7-8	5	0.007	740	0.995	4	0.005	7.5	210.94
8-9	4	0.005	744	1.000	0	0.000	8.5	245.65
Total (H)								3292.28

Calculated data: K=2.39 C=3.47

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.12	0.05	0.95	86	37	707	1.08
2	0.24	0.24	0.76	182	175	569	61.51
3	0.28	0.51	0.49	207	377	367	322.78
4	0.21	0.75	0.25	153	561	183	657.15
5	0.11	0.91	0.09	80	676	68	732.21
6	0.04	0.98	0.02	27	726	18	450.51
7	0.01	1.00	0.00	6	740	4	177.13
8	0.00	1.00	0.00	1	744	0	43.83
9	0.00	1.00	0.00	1	744	0	45.23
Total							2491.42

Data analysis of wind speed June, 2003 at Mongla, Bagherhat

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	36	0.050	36	0.050	684	0.950	0.5	0.45
1-2	95	0.132	131	0.182	589	0.818	1.5	32.06
2-3	134	0.186	265	0.368	455	0.632	2.5	209.38
3-4	127	0.176	392	0.544	328	0.456	3.5	544.51
4-5	93	0.129	485	0.674	235	0.326	4.5	847.46
5-6	91	0.126	576	0.800	144	0.200	5.5	1514.01
6-7	56	0.078	632	0.878	88	0.122	6.5	1537.90
7-8	34	0.047	666	0.925	54	0.075	7.5	1434.38
8-9	18	0.025	684	0.950	36	0.050	8.5	1105.43
9-10	9	0.013	693	0.963	27	0.038	9.5	771.64
1011	5	0.007	698	0.969	22	0.031	10.5	578.81
11-12	7	0.010	705	0.979	15	0.021	11.5	1064.61
12-13	8	0.011	713	0.990	7	0.010	12.5	1562.50
13-14	6	0.008	719	0.999	1	0.001	13.5	1476.23
14-15	1	0.001	720	1.000	0	0.000	14.5	304.86
Total (H)								12984.23

Calculated data: K=1.72 C=4.76

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	elocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.11	0.07	0.93	79	48	672	0.99
2	0.15	0.20	0.80	112	145	575	37.64
3	0.17	0.36	0.64	122	262	458	191.25
4	0.15	0.52	0.48	109	377	343	468.89
5	0.13	0.66	0.34	91	478	242	827.25
6	0.10	0.77	0.23	69	558	162	1153.47
7	0.07	0.86	0.14	49	617	103	1353.65
8	0.05	0.91	0.09	33	657	63	1386.85
9	0.03	0.95	0.05	21	684	36	1269.76
10	0.02	0.97	0.03	15	700	20	1290.18
11	0.01	0.99	0.01	7	709	11	806.01
12	0.01	0.99	0.01	4	715	5	570.07
13	0.00	1.00	0.00	2	717	3	375.94
14	0.01	1.00	0.00	6	719	1	1594.32
15	0.00	1.00	0.00	0	719	0.54	135.18
Total							11461.47

Data analysis of wind speed July, 2003 at Mongla, Bagherhat

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m²)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	$E=0.1v^3hi$
0-1	5	0.007	5	0.007	739	0.993	0.5	0.06
1-2	56	0.075	61	0.082	683	0.918	1.5	18.90
2-3	131	0.176	192	0.258	552	0.742	2.5	204.69
3-4	168	0.226	360	0.484	384	0.516	3.5	720.30
4-5	152	0.204	512	0.688	232	0.312	4.5	1385.10
5-6	110	0.148	622	0.836	122	0.164	5.5	1830.13
6-7	77	0.103	699	0.940	45	0.060	6.5	2114.61
7-8	28	0.038	727	0.977	17	0.023	7.5	1181.25
8-9	12	0.016	739	0.993	5	0.007	8.5	736.95
9-10	3	0.004	742	0.997	2	0.003	9.5	257.21
10-11	2	0.003	744	1.000	0	0.000	10.5	231.53
Total (H)								7680.73

Calculated data: K=2.63 C=4.85

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m²)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	$E=0.1v^3hi$
1	0.04	0.02	0.98	30	12	732	0.38
2	0.12	0.09	0.91	86	69	675	29.16
3	0.19	0.25	0.75	139	183	561	217.16
4	0.22	0.45	0.55	161	337	407	691.75
5	0.19	0.66	0.34	143	492	252	1307.59
6	0.13	0.83	0.17	99	615	129	1650.02
7	0.07	0.93	0.07	53	690	54	1459.87
8	0.03	0.98	0.02	22	726	18	923.93
9	0.01	0.99	0.01	7	739	5	420.72
10	0.00	1.00	0.00	2	743	1	137.59
11	0.00	1.00	0.00	0	744	0	32.11
Total							6870.27

Data analysis of wind speed August, 2003 at Mongla, Bagherhat

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	∑ hi	∑(hi/T)	T-∑ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	43	0.058	43	0.058	701	0.942	0.5	0.54
1-2	89	0.120	132	0.177	612	0.823	1.5	30.04
2-3	166	0.223	298	0.401	446	0.599	2.5	259.38
3-4	101	0.136	399	0.536	345	0.464	3.5	433.04
4-5	69	0.093	468	0.629	276	0.371	4.5	628.76
5-6	59	0.079	527	0.708	217	0.292	5.5	981.61
6-7	35	0.047	562	0.755	182	0.245	6.5	961.19
7-8	24	0.032	586	0.788	158	0.212	7.5	1012.50
8-9	45	0.060	631	0.848	113	0.152	8.5	2763.56
9-10	52	0.070	683	0.918	61	0.082	9.5	4458.35
10-11	26	0.035	709	0.953	35	0.047	10.5	3009.83
11-12	21	0.028	730	0.981	14	0.019	11.5	3193.84
12-13	9	0.012	739	0.993	5	0.007	12.5	1757.81
13-14	5	0.007	744	1.000	0	0.000	13.5	1230.19
Total (H)								20720.63

Calculated data: K=1.54 C=5.31

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	∑(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.11	0.07	0.93	81	55	689	1.01
2	0.14	0.22	0.78	103	164	580	34.90
3	0.15	0.34	0.66	112	253	491	174.38
4	0.13	0.48	0.52	97	354	390	415.93
5	0.11	0.60	0.40	84	445	299	765.00
6	0.09	0.70	0.30	69	521	223	1146.95
7	0.07	0.78	0.22	54	583	161	1489.00
8	0.06	0.85	0.15	41	630	114	1733.45
9	0.05	0.89	0.11	37	666	78	2284.55
10	0.03	0.93	0.07	21	691	53	1838.45
11	0.02	0.95	0.05	15	709	35	1718.72
12	0.02	0.97	0.03	15	722	22	2263.06
13	0.01	0.98	0.02	7	730	14	1289.47
14	0.01	0.99	0.01	7	735	9	1647.47
Total							16802.33

Data analysis of wind speed September, 2003 at Mongla, Bagherhat

Observed data:

Interval V	Frequency hi	Relative Frequency f(v)	Cumulative Frequency	Relative Cumulative Frequency F(v)	Velocity Duration	Relative velocity Duration S(v)	Velocity	Energy (wh/m^2)
m/s	hrs	hi/T	$\sum$ hi	$\sum$(hi/T)	T-$\sum$ hi	1-F(v)	m/s	E=0.1v^{3}hi
0-1	110	0.153	110	0.153	610	0.847	0.5	1.38
1-2	171	0.238	281	0.390	439	0.610	1.5	57.71
2-3	205	0.285	486	0.675	234	0.325	2.5	320.31
3-4	122	0.169	608	0.844	112	0.156	3.5	523.08
4-5	81	0.113	689	0.957	31	0.043	4.5	738.11
5-6	28	0.039	717	0.996	3	0.004	5.5	465.85
6-7	2	0.003	719	0.999	1	0.001	6.5	54.93
7-8	0	0.000	719	0.999	1	0.001	7.5	0.00
8-9	0	0.000	719	0.999	1	0.001	8.5	0.00
9-10	1	0.001	720	1.000	0	0.000	9.5	85.74
Total (H)								2247.10

Calculated data: K=1.81 C=2.82

Velocity	Calculated f(v)	Calculated F(v)	Calculated S(v)	Velocity frequency (Hrs)	Cumul. Veloc. freq	Velocity Duration	Energy (wh/m^2)
m/s	hi/T	$\sum$(hi/T)	1-F(v)	h=f(v) x H	F(v)x H	S(v) x H	E=0.1v^{3}hi
1	0.24	0.14	0.86	171	102	618	2.14
2	0.29	0.22	0.78	208	158	562	70.23
3	0.22	0.67	0.33	159	485	235	248.08
4	0.13	0.85	0.15	93	610	110	400.21
5	0.08	0.94	0.06	58	677	43	524.88
6	0.02	0.98	0.02	17	706	14	280.65
7	0.01	0.99	0.01	5	716	4	148.55
8	0.00	1.00	0.00	1	719	1	61.62
9	0.01	1.00	0.00	7	720	0	442.17
10	0.00	1.00	0.00	0	720	0	5.62
Total							2184.16

Appendix-F

Data Table of Velocity Duration and Energy in Each Location

Station: Teknaf_March_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	140	1.75
2	156	52.65
3	167	260.94
4	98	420.18
5	64	583.20
6	67	1114.71
7	21	576.71
8	18	759.38
9	10	614.13
10	3	257.21
Total (H)	744	4640.85

Table: Velocity duration

Velocity	% of time
1	81.18
2	60.22
3	37.77
4	24.60
5	15.99
6	6.99
7	4.17
8	1.75
9	0.40
10	0.00

Station: Teknaf_April_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	130	1.63
2	153	51.64
3	184	287.50
4	118	505.93
5	80	729.00
6	41	682.14
7	12	329.55
8	1	42.19
9	1	61.41
Total (H)	720	2690.98

Table: Velocity duration

Velocity	% of time
1	81.94
2	60.69
3	35.14
4	18.75
5	7.64
6	1.94
7	0.28
8	0.14
9	0.00

Station: Teknaf_May_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	154	1.93
2	165	55.69
3	198	309.38
4	124	531.65
5	56	510.30
6	21	349.39
7	18	494.33
8	4	168.75
9	3	184.24
10	0	0.00
11	1	115.76
Total (H)	744	2721.40

Table: Velocity duration

Velocity	% of time
1	79.30
2	57.12
3	30.51
4	13.84
5	6.32
6	3.49
7	1.08
8	0.54
9	0.13
10	0.13
11	0.00

Station: Teknaf_June_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	E=0.1v3hi
1	15	0.19
2	90	30.38
3	111	173.44
4	130	557.38
5	72	656.10
6	90	1497.38
7	66	1812.53
8	63	2657.81
9	40	2456.50
10	21	1800.49
11	13	1504.91
12	8	1216.70
13	1	195.31
Total (H)	720	14559.10

Table: Velocity duration

Velocity	% of time
1	97.92
2	85.42
3	70.00
4	51.94
5	41.94
6	29.44
7	20.28
8	11.53
9	5.97
10	3.06
11	1.25
12	0.14
13	0.00

Station: Teknaf_July_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	129	1.61
2	156	52.65
3	151	235.94
4	118	505.93
5	76	692.55
6	66	1098.08
7	39	1071.04
8	8	337.50
9	1	61.41
Total (H)	744	4056.70

Table: Velocity duration

Velocity	% of time
1	82.66
2	61.69
3	41.40
4	25.54
5	15.32
6	6.45
7	1.21
8	0.13
9	0.00

Station: Teknaf_August_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m²)
m/s	hrs	$E=0.1v^3hi$
1	59	0.74
2	80	27.00
3	107	167.19
4	120	514.50
5	116	1057.05
6	112	1863.40
7	73	2004.76
8	47	1982.81
9	21	1289.66
10	7	600.16
11	2	231.53
Total (H)	744	9738.80

Table: Velocity duration

Velocity	% of time
1	92.07
2	81.32
3	66.94
4	50.81
5	35.22
6	20.16
7	10.35
8	4.03
9	1.21
10	0.27
11	0.00

Station: Teknaf_September_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	72	0.90
2	112	37.80
3	196	306.25
4	97	415.89
5	97	883.91
6	96	1597.20
7	28	768.95
8	20	843.75
9	2	122.83
Total (H)	720	4977.48

Table: Velocity duration

Velocity	% of time
1	90.00
2	74.44
3	47.22
4	33.75
5	20.28
6	6.94
7	3.06
8	0.28
9	0.00

Station: Kutubdia_March_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m²)
m/s	hrs	$E=0.1v^3hi$
1	24	0.30
2	85	28.69
3	179	279.69
4	169	724.59
5	117	1066.16
6	83	1380.91
7	42	1153.43
8	19	801.56
9	20	1228.25
10	5	428.69
11	0	0.00
12	0	0.00
13	1	195.31
Total (H)	744	7287.58

Table: Velocity duration

Velocity	% of time
1	96.77
2	85.35
3	62.50
4	38.58
5	22.85
6	11.69
7	6.05
8	3.49
9	0.81
10	0.13
11	0.13
12	0.13
13	0.00

Station: Kutubdia_April_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	42	0.53
2	47	15.86
3	51	79.69
4	90	385.88
5	89	811.01
6	79	1314.36
7	55	1510.44
8	38	1603.13
9	30	1842.38
10	16	1371.80
11	2	231.53
12	0	0.00
13	1	195.31
14	1	246.04

Table: Velocity duration

Velocity	% of time
1	94.17
2	87.64
3	80.56
4	68.06
5	55.69
6	44.72
7	37.08
8	31.81
9	27.64
10	25.42
11	25.14
12	25.14
13	25.00
14	24.86
15	24.72

Station: Kutubdia_May_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	152	1.90
2	174	58.73
3	190	296.88
4	129	553.09
5	51	464.74
6	27	449.21
7	14	384.48
8	6	253.13
9	1	61.41
Total (H)	744	2523.55

Table: Velocity duration

Velocity	% of time
1	79.57
2	56.18
3	30.65
4	13.31
5	6.45
6	2.82
7	0.94
8	0.13
9	0.00

Station: Kutubdia_June_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m²)
m/s	hrs	$E=0.1v^3hi$
1	15	0.19
2	90	30.38
3	111	173.44
4	129	553.09
5	75	683.44
6	88	1464.10
7	66	1812.53
8	62	2615.63
9	39	2395.09
10	23	1971.96
11	13	1504.91
12	8	1216.70
13	1	195.31
Total (H)	720	14616.75

Table: Velocity duration

Velocity	% of time
1	97.92
2	85.42
3	70.00
4	52.08
5	41.67
6	29.44
7	20.28
8	11.67
9	6.25
10	3.06
11	1.25
12	0.14
13	0.00

Station: Kutubdia_july_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	1	0.01
2	6	2.03
3	25	39.06
4	70	300.13
5	130	1184.63
6	209	3477.24
7	148	4064.45
8	77	3248.44
9	53	3254.86
10	20	1714.75
11	5	578.81
Total (H)	744	17864.40

Table: Velocity duration

Velocity	% of time
1	99.87
2	99.06
3	95.70
4	86.29
5	68.82
6	40.73
7	20.83
8	10.48
9	3.36
10	0.67
11	0.00

Station: Kutubdia_August_2003

Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	38	0.48
2	46	15.53
3	77	120.31
4	89	381.59
5	128	1166.40
6	154	2562.18
7	109	2993.41
8	55	2320.31
9	35	2149.44
10	9	771.64
11	3	347.29
Total (H)	744	12828.56

Table: Velocity duration

Velocity	% of time
1	94.89
2	88.71
3	78.36
4	66.40
5	49.19
6	28.49
7	13.84
8	6.45
9	1.75
10	0.54
12	0.13
13	0.00

Station: Kutubdia_September_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	161	2.01
2	106	35.78
3	119	185.94
4	169	724.59
5	47	428.29
6	70	1164.63
7	30	823.88
8	10	421.88
9	6	368.48
10	2	171.48
Total (H)	720	4326.93

Table: Velocity duration

Velocity	% of time
1	77.64
2	62.92
3	46.39
4	22.92
5	16.39
6	6.67
7	2.50
8	1.11
9	0.28
10	0.00

Station: Sandwip_April_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	17	0.21
2	36	12.15
3	60	93.75
4	75	321.56
5	89	811.01
6	81	1347.64
7	75	2059.69
8	85	3585.94
9	73	4483.11
10	76	6516.05
11	35	4051.69
12	15	2281.31
13	3	585.94
Total (H)	720	26150.05

Table: Velocity duration

Velocity	% of time
1	97.64
2	92.64
3	84.31
4	73.89
5	61.53
6	50.28
7	39.86
8	28.06
9	17.92
10	7.36
11	2.50
12	0.42
13	0.00

Station: Sandwip_May_2003

Table: Velocity frequency and energy

Velocity	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	216	2.70
2	141	47.59
3	157	245.31
4	110	471.63
5	62	564.98
6	31	515.76
7	18	494.33
8	4	168.75
9	3	184.24
10	1	85.74
11	1	115.76
Total (H)		2896.78

Table: Velocity duration

Velocity	% of time
1	70.97
2	52.02
3	30.91
4	16.13
5	7.80
6	3.63
7	1.21
8	0.67
9	0.27
10	0.13
11	0.00

Station: Sandwip_june_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	36	0.45
2	97	32.74
3	148	231.25
4	169	724.59
5	95	865.69
6	82	1364.28
7	54	1482.98
8	28	1181.25
9	8	491.30
10	3	257.21
Total (H)		6631.73

Table: Velocity duration

Velocity	% of time
1	95.00
2	81.53
3	60.97
4	37.50
5	24.31
6	12.92
7	5.42
8	1.53
9	0.42
10	0.00

Station: Sandwip_July_2003

Table: Velocity frequency and energy

Velocity	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	7	0.09
2	74	24.98
3	144	225.00
4	105	450.19
5	49	446.51
6	37	615.59
7	69	1894.91
8	85	3585.94
9	84	5158.65
10	62	5315.73
11	19	2199.49
12	9	1368.79
Total (H)		21285.85

Table: Velocity duration

Velocity	% of time
1	99.06
2	89.11
3	69.76
4	55.65
5	49.06
6	44.09
7	34.81
8	23.39
9	12.10
10	3.76
11	1.21
12	0.00

Station: Sandwip_August_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m²)
m/s	hrs	$E=0.1v^3hi$
1	44	0.55
2	128	43.20
3	202	315.63
4	82	351.58
5	53	482.96
6	36	598.95
7	23	631.64
8	18	759.38
9	47	2886.39
10	45	3858.19
11	32	3704.40
12	22	3345.93
13	8	1562.50
14	4	984.15
Total (H)		19525.43

Table: Velocity duration

Velocity	% of time
1	94.09
2	76.88
3	49.73
4	38.71
5	31.59
6	26.75
7	23.66
8	21.24
9	14.92
10	8.87
11	4.57
12	1.61
13	0.54
14	0.00

Station: Sandwip_September_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	26	0.33
2	39	13.16
3	93	145.31
4	86	368.73
5	110	1002.38
6	119	1979.86
7	71	1949.84
8	61	2573.44
9	60	3684.75
10	32	2743.60
11	20	2315.25
12	2	304.18
13	1	195.31
Total (H)	720	17276.13

Table: Velocity duration

Velocity	% of time
1	96.39
2	90.97
3	78.06
4	66.11
5	50.83
6	34.31
7	24.44
8	15.97
9	7.64
10	3.19
11	0.42
12	0.14
13	0.00

Station: Kuakata_March_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	95	1.19
2	123	41.51
3	158	246.88
4	149	638.84
5	118	1075.28
6	61	1014.89
7	27	741.49
8	6	253.13
9	4	245.65
10	1	85.74
11	1	115.76
12	0	0.00
13	1	195.31
Total (H)		4655.65

Table: Velocity duration

Velocity	% of time
1	87.23
2	70.70
3	49.46
4	29.44
5	13.58
6	5.38
7	1.75
8	0.94
9	0.40
10	0.27
11	0.13
12	0.13
13	0.00

Station: Kuakata_April_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	145	1.81
2	108	36.45
3	97	151.56
4	132	565.95
5	106	965.93
6	68	1131.35
7	26	714.03
8	15	632.81
9	9	552.71
10	10	857.38
11	1	115.76
12	3	456.26
Total (H)		6182.0

Table: Velocity duration

Velocity	% of time
1	79.86
2	64.86
3	51.39
4	33.06
5	18.33
6	8.89
7	5.28
8	3.19
9	1.94
10	0.56
11	0.42
12	0.00

Station: Kuakata_May_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	31	0.39
2	72	24.30
3	276	431.25
4	230	986.13
5	76	692.55
6	26	432.58
7	20	549.25
8	6	253.13
9	4	245.65
10	1	85.74
11	0	0.00
12	0	0.00
13	0	0.00
14	2	492.08
Total (H)		4193.03

Table: Velocity duration

Velocity	% of time
1	95.83
2	86.16
3	49.06
4	18.15
5	7.93
6	4.44
7	1.75
8	0.94
9	0.40
10	0.27
11	0.27
12	0.27
13	0.27
14	0.00

Station: Kuakata_June_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	24	0.30
2	81	27.34
3	170	265.63
4	189	810.34
5	97	883.91
6	81	1347.64
7	45	1235.81
8	22	928.13
9	8	491.30
10	3	257.21
Total (H)		6247.60

Table: Velocity duration

Velocity	% of time
1	96.67
2	85.42
3	61.81
4	35.56
5	22.08
6	10.83
7	4.58
8	1.53
9	0.42
10	0.00

Station: Kuakata_July_2003

Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	3	0.04
2	52	17.55
3	127	198.44
4	173	741.74
5	153	1394.21
6	113	1880.04
7	78	2142.08
8	28	1181.25
9	12	736.95
10	3	257.21
11	2	231.53
Total (H)		8781.03

Table: Velocity duration

Velocity	% of time
1	99.60
2	92.61
3	75.54
4	52.28
5	31.72
6	16.53
7	6.05
8	2.28
9	0.67
10	0.27
11	0.00

Station: Kuakata_August_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	98	1.23
2	83	28.01
3	172	268.75
4	117	501.64
5	109	993.26
6	95	1580.56
7	40	1098.50
8	20	843.75
9	10	614.13
Total (H)		5929.83

Table: Velocity duration

Velocity	% of time
1	86.83
2	75.67
3	52.55
4	36.83
5	22.18
6	9.41
7	4.03
8	1.34
9	0.00

Station: Kuakata_September_2003

Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	209	2.61
2	191	64.46
3	171	267.19
4	67	287.26
5	59	537.64
6	10	166.38
7	9	247.16
8	3	126.56
9	0	0.00
10	1	85.74
Total (H)		1785

Table: Velocity duration

Velocity	% of time
1	70.97
2	44.44
3	20.69
4	11.39
5	3.19
6	1.81
7	0.56
8	0.14
9	0.14
10	0.00

Station: Mongla_March_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	50	0.63
2	113	38.14
3	250	390.63
4	175	750.31
5	107	975.04
6	40	665.50
7	7	192.24
8	2	84.38
Total (H)		3096.85

Table: Velocity duration

Velocity	% of time
1	93.28
2	78.09
3	44.49
4	20.97
5	6.59
6	1.21
7	0.27
8	0.00

Station: Mongla_April_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	111	1.39
2	188	63.45
3	192	300.00
4	139	595.96
5	61	555.86
6	22	366.03
7	5	137.31
8	2	84.38
Total (H)		2104.38

Table: Velocity duration

Velocity	% of time
1	84.58
2	58.47
3	31.81
4	12.50
5	4.03
6	0.97
7	0.28
8	0.00

Station: Mongla_May_2003

Table: Velocity frequency and energy

Velocity V	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	38	0.48
2	104	35.10
3	272	425.00
4	219	938.96
5	62	564.98
6	21	349.39
7	19	521.79
8	5	210.94
9	4	245.65
Total (H)		3292.28

Table: Velocity duration

Velocity	% of time
1	94.89
2	80.91
3	44.35
4	14.92
5	6.59
6	3.76
7	1.21
8	0.54
9	0.00

Station: Mongla_June_2003

Table: Velocity frequency and energy

Velocity	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	36	0.45
2	95	32.06
3	134	209.38
4	127	544.51
5	93	847.46
6	91	1514.01
7	56	1537.90
8	34	1434.38
9	18	1105.43
10	9	771.64
11	5	578.81
12	7	1064.61
13	8	1562.50
14	6	1476.23
15	1	304.86
Total (H)		12984.23

Table: Velocity duration

Velocity	% of time
1	95.00
2	81.81
3	63.19
4	45.56
5	32.64
6	20.00
7	12.22
8	7.50
9	5.00
10	3.75
11	3.06
12	2.08
13	0.97
14	0.14
15	0.00

Station: Mongla_July_2003

Table: Velocity frequency and energy

Velocity	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	5	0.06
2	56	18.90
3	131	204.69
4	168	720.30
5	152	1385.10
6	110	1830.13
7	77	2114.61
8	28	1181.25
9	12	736.95
10	3	257.21
11	2	231.53
Total (H)		7680.73

Table: Velocity duration

Velocity	% of time
1	99.33
2	91.80
3	74.19
4	51.61
5	31.18
6	16.40
7	6.05
8	2.28
9	0.67
10	0.27
11	0.00

Station: Mongla_August_2003

Velocity frequency and energy

Velocity	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	43	0.54
2	89	30.04
3	166	259.38
4	101	433.04
5	69	628.76
6	59	981.61
7	35	961.19
8	24	1012.50
9	45	2763.56
10	52	4458.35
11	26	3009.83
12	21	3193.84
13	9	1757.81
14	5	1230.19
Total (H)		20720.63

Table: Velocity duration

Velocity	% of time
1	94.22
2	82.26
3	59.95
4	46.37
5	37.10
6	29.17
7	24.46
8	21.24
9	15.19
10	8.20
11	4.70
12	1.88
13	0.67
14	0.00

Station: Mongla_September_2003

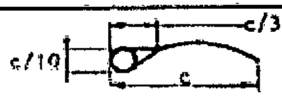
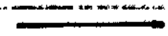
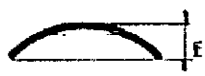
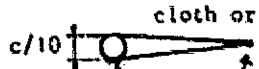
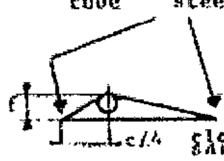
Table: Velocity frequency and energy

Velocity	Frequency hi	Energy (wh/m^2)
m/s	hrs	$E=0.1v^3hi$
1	110	1.38
2	171	57.71
3	205	320.31
4	122	523.08
5	81	738.11
6	28	465.85
7	2	54.93
8	0	0.00
9	0	0.00
10	1	85.74
Total (H)		2247.10

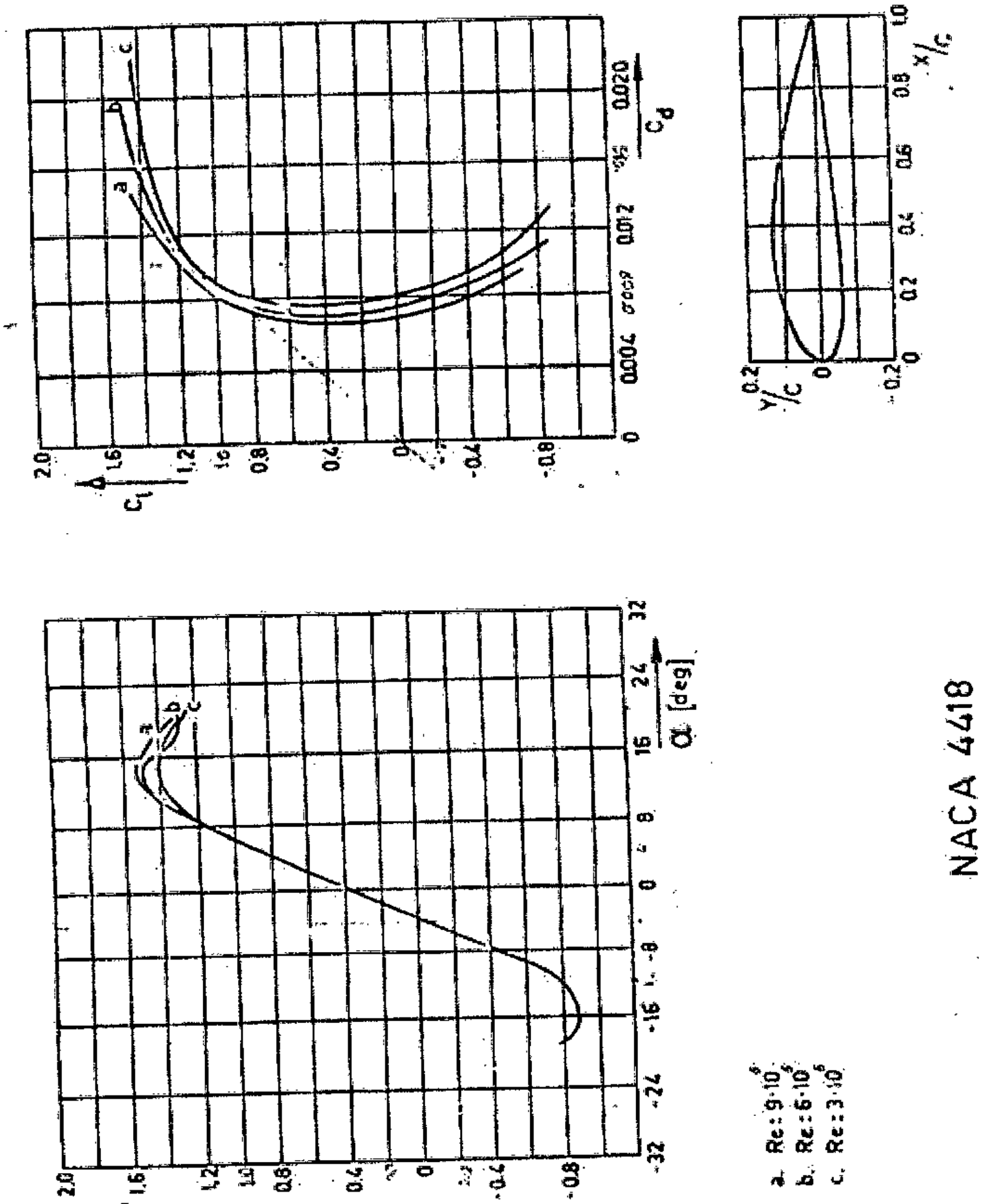
Table: Velocity duration

Velocity	% of time
1	84.72
2	60.97
3	32.50
4	15.56
5	4.31
6	0.42
7	0.14
8	0.14
9	0.14
10	0.00

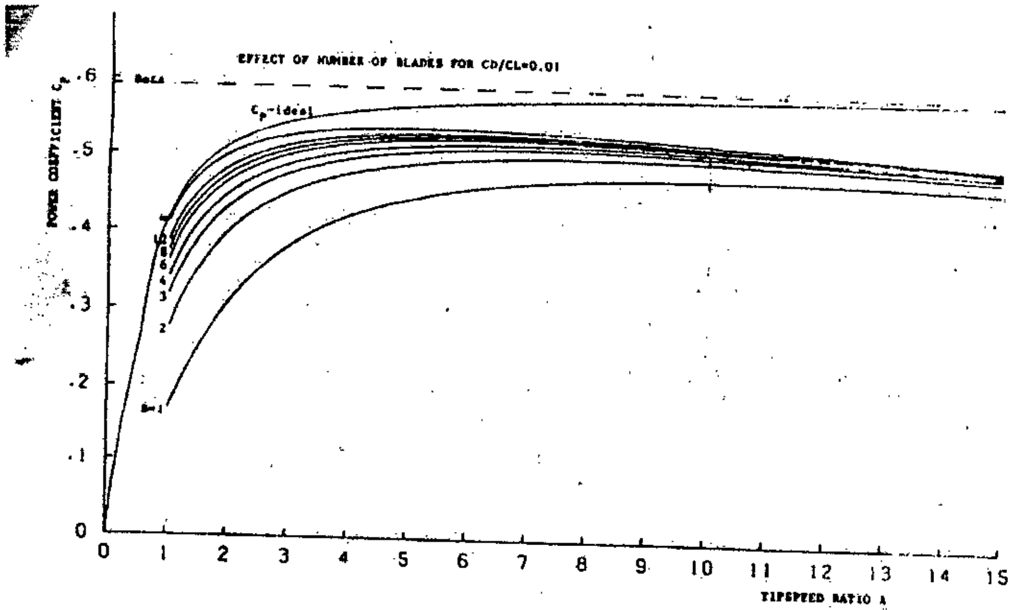
Appendix-G
Determination of Minimum C_d/C_l Ratio

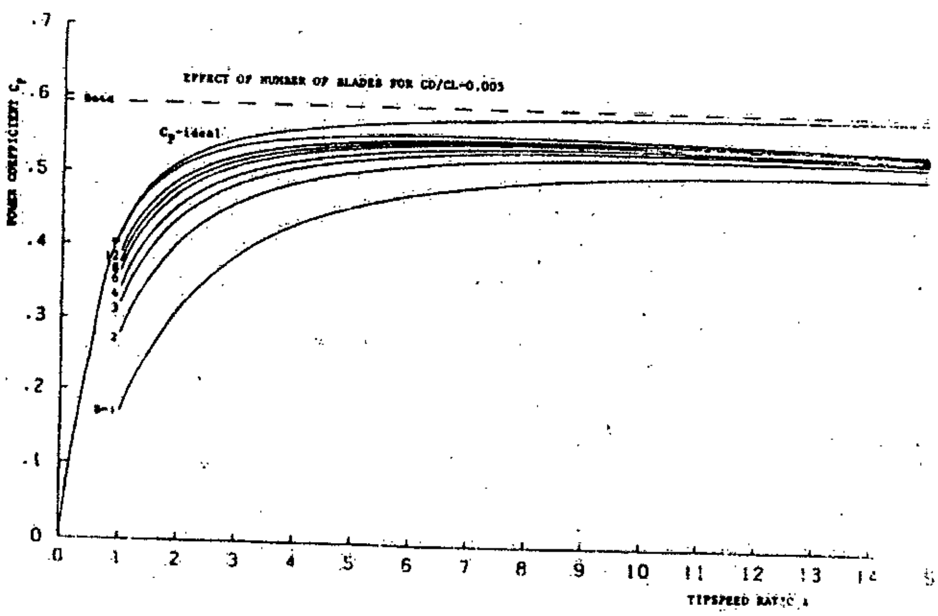
airfoil name	geometrical description	$(C_d/C_l)_{min}$	α^o	C_l
sail and pole		0.1	5	0.8
flat steel plate		0.1	4	0.4
arched steel plate	 f/c=0.07	0.02	4	0.9
	f/c=0.1	0.02	3	1.25
arched steel plate with tube on concave side	 f/c=0.07	0.05	5	0.9
	f/c=0.1	0.05	4	1.1
arched steel plate with tube on convex side	 f/c=0.1	0.2	14	1.25
sail wing		0.05	2	1.0
sail trouser f/c=0.1 d_{tube}=0.6f		0.1	4	1.0
NACA 4412	see appendix H	0.01	4	0.8
NACA 23015	see Lit(1) in appendix I	0.01	4	0.8

Appendix-H
Determination of Design Lift Coefficient and Design Angle of Attack



Appendix-I
Determination of Design Power Coefficient (C_P)





Appendix-J

Determination of Maximum Power Coefficient (C_P)