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Mapping of Wind Velocity Available in Bangladesh

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Abstract

Utilization of wind energy in Bangladesh has not yet started due to lack of wind data availability. Recent measurement in some places of Bangladesh has shown significant wind energy potentials. In this paper, a wind map is presented which incorporates several microscale features, such as terrain roughness, elevation etc. with a mesoscale model. Several meso-maps were obtained from global database and a suitable model was chosen for a 30-m elevation. Ground data from various sources were collected and modified for height and land condition based on local knowledge and GIS. It was found that, the general wind map and modified ground data resemble. Annual average wind speed at a 30m height along the coastal belt was above 5 m/s. Wind speed in northeastern parts was above 4.5 m/s while island wind speed was around 3.5 m/s for most part of Bangladesh. More measurement and demonstration type wind turbine installation could be made in Chittagong, Cox's Bazar, Sandip, Kutubdia, Comilla, Faridpur, Satkhira, Bhola, Khepupara, Jessore and Ishurdi for harvesting wind energy.

Keywords: Wind energy, Mapping, Meteorological Department, Climatological and Analysis

1. Introduction

In Bangladesh, as in many other countries, wind energy has also been used to provide some motive force to boats with sails of various designs. Unfortunately, not much research has been conducted in these areas, although renewed interests have recently been generated in utilizing the energy of wind for wind pumps and sailing boats.

Bangladesh is one of the highly energy deficient countries in the world. About 73% of the total energy consumption (1999) of Bangladesh come from traditional biomass fuels (wood 65%, crop residue 22.1%, and animal dung 7.8%). Bangladesh Power Development Board (BPDB) and several Independent Power Producers (IPP) are responsible for generating electricity for the national grid (73.08% and 26.92%, respectively). Total installed capacity of BPDP in 1999 was 3603 MW (fossil fuel: 92.45%, hydro: 7.55%).

Only about 18% of the population (25% in urban areas and 10% in villages) is connected to the grid and the demand for electricity is increasing by 300 MW performance year. The need for a huge investment implies that grid-connected electricity supply for the rural areas is not going to happen in the near future and 80% of the population would remain off-grid for the days to come. Considering these facts wind resources may be an alternative source of energy for electricity generation and water pumping. However, it needs to be examined for small-scale oil and gas reserve.

Assessment of wind energy resources and installation of wind energy conversion systems (WECS) in Bangladesh has long been hindered due to lack of reliable wind speed data. There is no reported wind map of Bangladesh that could be relied upon and used for wind energy assessment. Weather data collected by the meteorological offices around the country are considered as low quality data (characterized by low tower height, obstacles around the tower and poor data recording mechanism). Some organizations have recently started wind data measurement activities in various parts of the country. A long-term surface measurement (3–5 year averages) is vital for making a quality wind resource assessment. Before this is done, a wind map proposed in this paper, which is developed with alternative means, could prove to identify suitable sites with higher wind velocity concentration and locate the potential areas to install low speed wind turbines. Thus the objective of this study is to map the wind velocity in difference locations at 30m heights, which could be helpful to install wind turbines at the suitable position for harvesting the maximum wind energy.

2. Methodology

The meteorological department of Bangladesh collects monthly wind speed data with the help of

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vertical axis cup type anemometers at 20 m height. These wind data for different stations were taken manually form the logbook, and monthly and yearly average speeds were computed for all the stations. Then these data and wind data from different sources were compared, analyzed and a new data set is prepared for making corrections with the logarithmic law; and these corrected data were used in mapping of wind velocity.

The wind velocity for different stations are not same due to geographical situation, surface level, crisscrossing land by hundred of rivers, flooding, various crop cultivation and plantation with respect of soil fertility etc; which has several effects on climate. The climate of Bangladesh has two major seasonal variations: mild winter and hot-humid summer. The dry-winter season lasts for about 5 months (November–March) and gentle northeasterly land breeze blows over the terrain during this period. The summer spans from April to October with frequent small-scale storms occurring almost every day. Monsoon rains cause a large quantity of precipitation at June–October. Strong southwesterly sea breeze blows over the land during the summer season.

Wind has primary, secondary and tertiary classes of origin (Manwell et al. 2002). The primary origin is accounted for pressure differences across the earth's surface, gravitational forces, inertia of the air, the earth's rotation and friction with the surface. In a simpler form, four atmospheric forces: pressure force, Coriolis force, inertial force and frictional forces determine global perspective of wind motion. Secondary sources of wind include hurricanes, monsoon circulation, and cyclones. Thirdly, diurnal variations, thunderstorms, tornadoes etc. determine short-term, small-scale wind variations.

The Tropic of Cancer passes through the middle of Bangladesh and the terrain is subjected to the northeast trade winds (primary origin). During the summer, wind blows from the southwest direction bringing moisture from the Bay of Bengal and causing significant monsoon effect throughout the country (secondary origin). Tropical cyclones are also common at the beginning of the summer season. All the studies such as Wind Energy Study (WEST), Solar and Wind Energy Resource Assessment (SWERA) and Technical Expertise for Renewable Application (TERNA) show that, wind speed is generally lower in the winter and higher in the summer. Wind also exhibits a diurnal cycle, generally having a peak at noon and a dip at evening (tertiary origin).

2.1 Wind map generation using global databases

The first steps for harnessing energy from the wind is to make extensive assessment of wind energy potential and cost analysis for a site of interest. A suitable location could then be identified from several candidate sites. All of these analyses need a reliable and accurate wind map. However, when data is inadequate or inaccurate several other alternatives could also be explored (Landberg et al. 2003).

A microscale wind map considers the effects of near-by obstacle, terrain roughness, orography and thermal flow with a scale of 1–10 km. On the other hand, a mesoscale map has a grid size of the order of 10–100 km (Petersen et al. 1997). Large-scale climatological data is regionalized in order to develope meso-map, where, local effects defined above are not considered. Various software tools, such as WASP, KAMM could be used to model high-resolution wind resource maps. Wind energy mapping requires local knowledge, regional surface measurements, global climatological databases, computational fluid dynamics (CFD) analysis, and correlation analysis. (Landberg et al. 2003). In this paper two aspects (global database and surface measurement correlation) are considered for generating a wind map that essentially incorporates microscale features embedded in a mesoscale map.

2.2 Collection, analysis and modification of surface data

Bangladesh Meteorological Department had been collecting wind speed data for a long period (1961 onward) from many weather stations spread throughout the country. But these were usually meant for weather forecasting and were unsuitable for wind energy assessment purposes owing to three major reasons. Firstly, measurement tower height was too low (5–10 m), whereas wind turbines generally had higher hub heights (10–30 m). Secondly, obstacles such as, near-by buildings, houses and plantation, surround much weather stations. Thirdly, data recording mechanisms in many stations were not automated and were subject to erroneous processing. However, since these were averaged over a very long period (more than 30 years), use of these data with proper adjustments for elevation and terrain conditions are still worth consideration.

Wind data measured in a place surrounded by near-by obstacles such as hills, tall trees, house etc. were characterized by lower magnitude, higher turbulence and lower power concentration. Similar affects were observed when wind measurement was done near-surface locations (Fig. 1a).

The variation of wind speed with elevation could be described with two mathematical models: logarithmic law and power law. The logarithmic law was meant for vertical wind speed variation modeling in a particular terrain condition, here it was used for incorporating both vertical and lateral variations providing means for scaling a data from one elevation and terrain class to another elevation and land condition.

The log law was given by the following equation:

$$Uz = (ln\frac{Z}{Zo}/ln\frac{Zr}{Zor})Ur = Cf_1.Ur \qquad (1)$$

Where Z and Z_o were modified elevation and roughness length of new terrain respectively. *Zr* and *Zor* were similar parameters for reference (measurement) site. The log law correlation/ correction factor *(Cf1)* converts wind speed *(Ur)* form reference area to a new value *(Uz)* that would suit a near-by location. To identify the roughness length of the particular site, a terrain profile index versus roughness length correlation (Fig. 1b) was done using the rule of thumb information (Manwell et al. 2002).

The power low was a similar model that represents vertical wind speed profile. It was given by: (Manwell et al. 2002).

$$U_Z = (\frac{Z}{Z_r})^{\infty} U_r = Cf_p.U_r \qquad (2)$$

Here, Cf_p was the power law correlation/correction factor. The power law exponent α, varies with parameters such as elevation, time of day, season, terrain, temperature, wind etc. A model correlating this exponent to surface roughness was given by: (Manwell et al. 2002).

$$\alpha = 0.0961 log_{10}Z_0 + 0.016(log_{10}Z_0)^2 + 0.24 \qquad (3)$$

The logarithmic law (5) was used for converting reported wind data with specified measurement lower height to a new elevation of 30 m. The measurement (reference) area terrain index was taken from 5.25 to 7, which was attributed to locations with near-by obstacles. Since most of the land was covered with vegetation a terrain profile index from 4 to 6 was chosen for the near-by areas. Since these methods corrects the available data and also correlates others measurements (Table 1), the term correction and correlation were used interchangeably.

To test the validity of this approach wind data from the meteorological office was scaled up for elevation correlation and compared with WERM project data for four separate locations. These were the only sites, where multiple reliable data could be gathered, corrected and compared (Table 1) (LGED, 1997; Shakti, 2005).

To determine the terrain profile index, local knowledge and Geographic Information System (GIS) database of Environment System Research Institute (ESRI) [6] were used. Calculation of the roughness length from the terrain index was done by a curve fitting equation that represents in Fig. 1b. The range of error of estimation method for these locations is –4 to +20% as shown in Table 1.

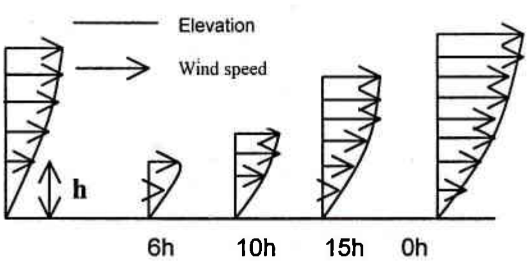
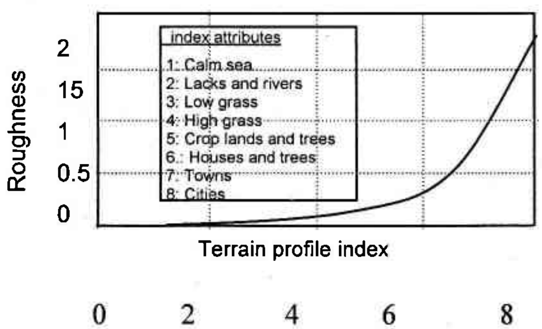


Fig. 1(a). Downstream wind speed variation due to obstacles



1(b). Terrain classification in terms of a terrain profile index.

Table 1. Terrain profile analysis for four test locations

Place	Meteorological office data		WERM wind speed data (m/s) at 25 m.	Estimated wind speed Uz (m/s) at Z=25 m	Error (%)	Estimation method
	Wind speed, U_r (m/s)	Tower height Z_r (m)				
Cox's Bazar	2.42	10	3.34	3.22	-3.61	Terrain profile index: 6.5 Zo=Zor=0.6245 m
Kutubdia	2.16	5	4.18	3.69	-11.77	Terrain profile index: 6.25 Zo=Zor=0..5139 m
Patenga	2.45	5	3.85	4.04	5.12	Terrain profile index: 6 Zo=Zor=0.416 m
Teknaf	2.16	5	2.96	3.33	12.62	Terrain profile index: 5.5 Zo=Zor=0.0.258 m

2.3 The proposed wind map and its validity

The Climate Diagnostic Center (CDC) derived NCEP reanalysis based wind model for Bangladesh, and considered a suitable map compared with other global data based models. However, it also needs some height and terrain modifications to take into account for the land profile and elevations attributed to Bangladesh. The plot of CDC derived NCEP reanalysis was gridded into a 13 x 13 matrix (with 169 data points representing $0{:}5^0$ x $0{:}5^0$ resolution). Then the power law (Eq.2) was used to modify the model to elevate it to 30 m. Necessary height adjustments were introduced to the gridded data for the hilly districts in the southeast and eroded highlands in the north. The value of the power law exponent α, for most parts of the country was found to be 0.15 when Eq. (3) is used with land profile index of 4.5 (Zo = 0.07 m, equivalent to cropland with occasional trees).

3. Result and Discussion

Attempt would be made to give a detailed idea about various kinds of presentation of the wind data at different sites at 30 m and 40m height. This would provide information to make decision whether that site has reasonably potential for the operation of wind machine.

From monthly average wind speed data (1990-2000) it was found that wind speeds were higher from March to September for all places. A wind turbine, if properly designed and located, can supply enough wind velocity. 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. During this period wind turbine may be used for water pumping for irrigation, if the water is previously stored in a reservoir during the monsoon season. In these operating seasons, subsoil water from shallow wells can be pumped by low lift pump (LLP) run by wind turbine. From October to February the velocities are not at all promising for harnessing power. One point can be noted that there is wide variation of wind velocity in the coastal areas throughout the year. Patenga, Chittagong, Thakurgaon, Jessore, Khepupara and Satkhira are relatively prospective site of wind velocity for extraction of wind energy.

Yearly wind speeds from 1981 to 2000 are also graphically presented for difference division with respect of difference station in Fig. 2 (a, b, c & d). From figure 2(a) the maximum wind speed was 4.47 knots (1 Knot = 1.85 km/hr) at station Faridpur in 1988 and the minimum wind speed was 0.44 knots at the Srimangal in 1994. It is also clear that speed fluctuation was the maximum in the Faridpur stations. The maximum speed was 4.47 knots and the minimum speed was 1.27 knots. Speed variation is linear at station Sylhet, Bhola etc. Similarly the maximum speed was 7.79 knots and the minimum speed was 1.33 knots at chittagong division. In the khulna division the maximum speed was 8.22 knots at satkhira and the minimum speed was 0.85 knots at the Bhola.

From these graph the maximum speed was 8.27 knots at Satkhira and the minimum speed was 0.44 knots at Srimangal. It is also noted that the Chittagong, Cox Bazar, Sandip, Kutubdia, Comilla, Faridpur, Tangail, Dhaka, Sylhet, Satkhira, Bhola, Khepupara, Jessore and Rajshahi were prospective site of wind velocity for extraction of wind energy.

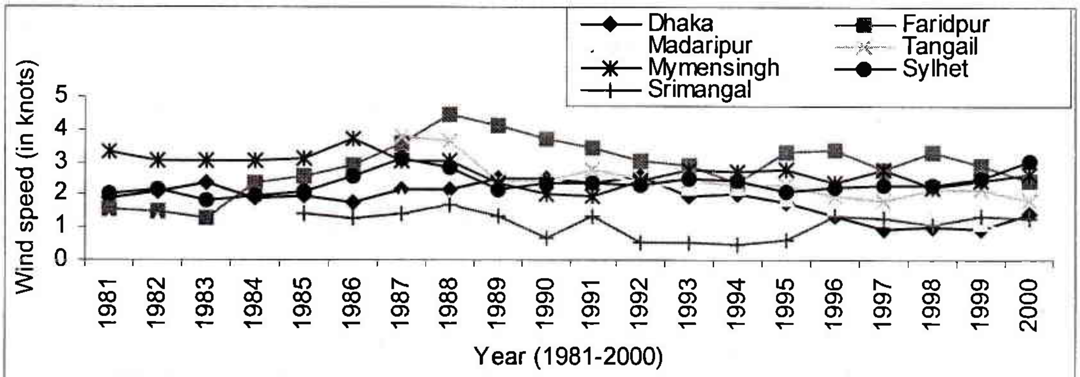
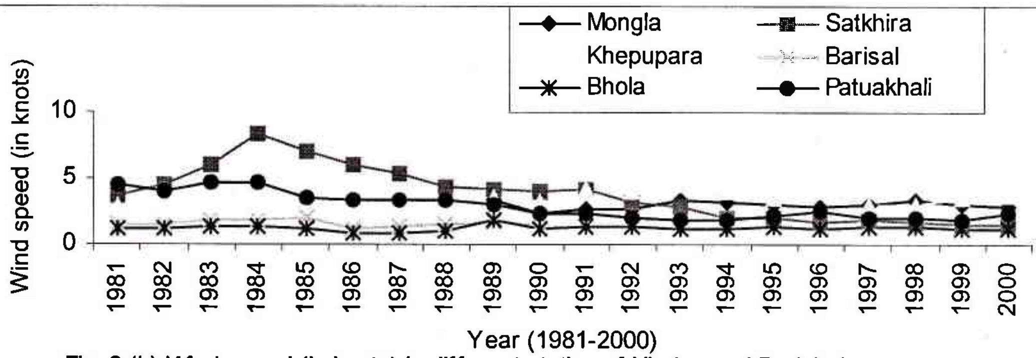


Fig. 2 (a) Wind speed (in knots) in different district of Dhaka and Sylhet Division



Fig, 2 (b) Wind speed (in knots) in different station of Khulna and Barishal

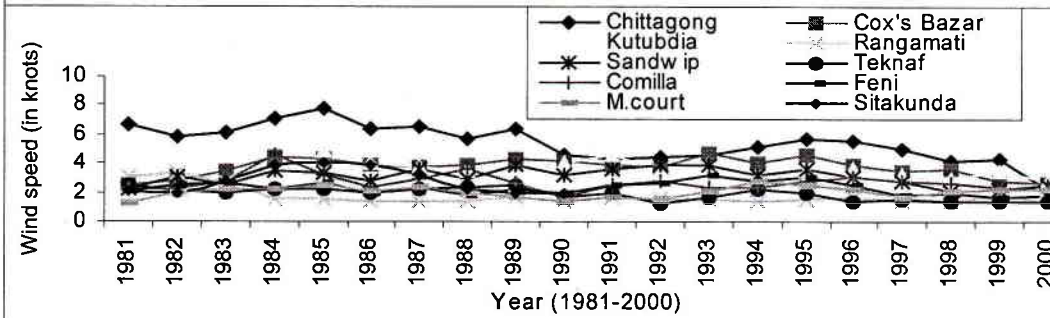


Fig. 2(c) Wind speed (in knots) in different station of Chittagong Division

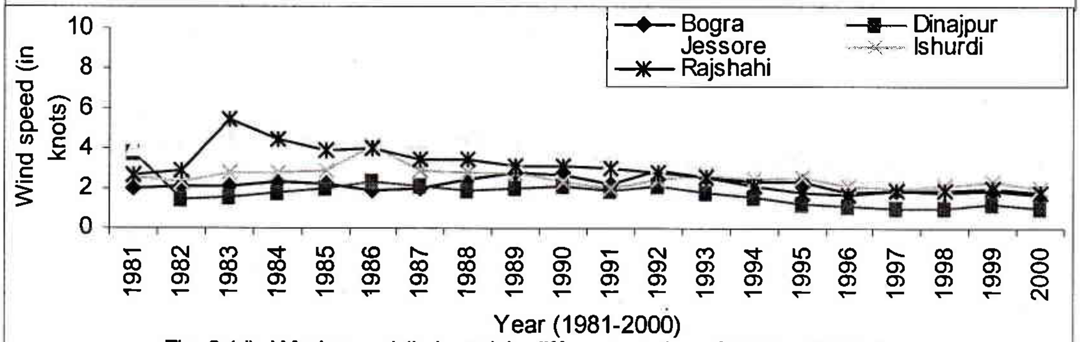


Fig. 2 (d) Wind speed (in knots) in different station of Rajshahi Division

The modified CDC derived NCEP reanalysis data was plotted in Matlab. Fig. 3 shows the developed wind map at a 30m elevation. The wind map effectively incorporates with the surface roughness in a micro-scale condition. This model highly correlates with the corrected surface data of Table 2, as seen in Fig. 4. Deviations in the northeastern part was not analyzed further as there was only one measurement available in that region. However, most of the values in the coastal region show a close match with the wind speed outlined in Fig. 2. The widely accepted notion that, wind speed in Bangladesh was higher than others studies. As predicted, the coastal and northeastern regions were found to be higher-wind areas compared to the mainland and the wind map is shown in Fig. 5 with respect to all observations. Where as acceptable wind velocity stations means velocity is more then 4.5 m/sec at 30m height. Similarly wind velocities are 4 to 4.5 m/sec and less then 4 m/sec at 30m height in probable and low probable wind velocity stations.

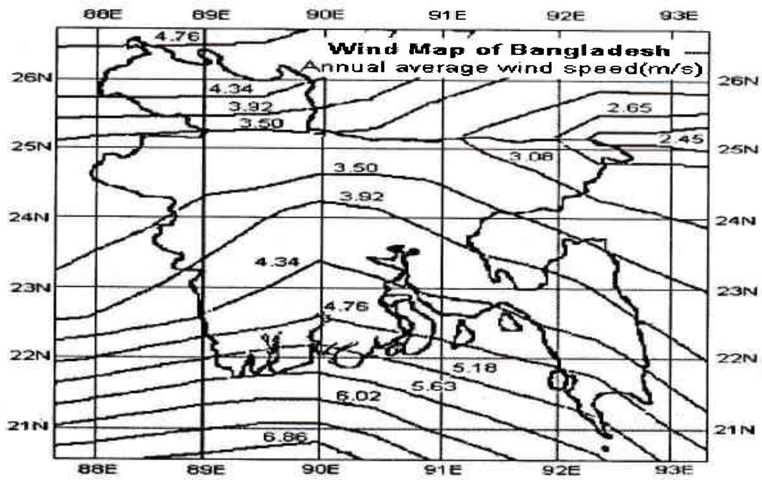


Fig.3. Wind map of Bangladesh at 30-m elevation

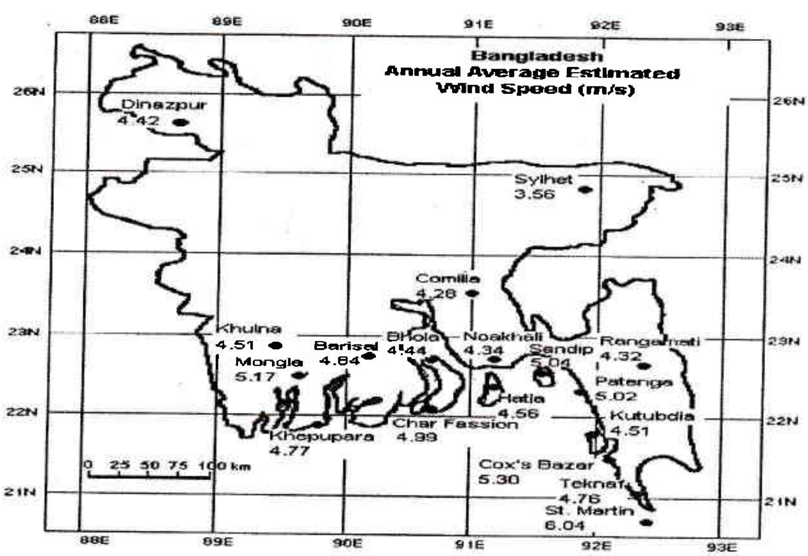


Fig.4. Comparison with corrected surface data (Table 3)

Table 2. Corrected wind speed (m/s) data set for 30 m elevation and typical countryside errain of Bangladesh using the logarithmic law

Place	Ref. wind speed U_r (m/s)	Tower height Zr (m)	Reference area terrain profile index	Reference area roughness length Zor (m)	Near-by area terrain profile index	Near-by area roughness length Zo (m)	Correction factor, Cf1	Estimated wind speed at Z=30m
Barisal	2.66	7[a]	6.25	0.5139	5.5	0.2586	1.8203	4.8419
Bhola Island	2.44	7	6.25	0.5139	5.5	0.2586	1.8203	4.4414
Char Fassion	4.07	25	6	0.4166	5.25	0.1963	1.2284	4.9994
Comilla	2.21	6	6.25	0.5139	6	0.2586	1.9349	4.2751
Cox's Bazar	3.34	25	6.5	0.6245	4.65	0.0862	1.5862	5.2977
Dinajpur	2.83	7[a]	6	0.4166	5.85	0.3642	1.5634	4.4243
Hatia Island	2.08	6	5.5	0.2586	4.15	0.0307	2.1897	4.5546
Khepupara	2.36	10	5.75	0.3318	4.15	0.0307	2.0215	4.7708
Khulna	2.89	7[a]	5.5	0.2586	5.15	0.1742	1.5610	4.5112
Kuakata	4.54	25	5.5	0.2586	5	0.1440	1.1679	5.3024
Kutubdia	4.18	25	6.25	0.5139	5.25	0.1963	1.2947	5.4120
Mongla	2.20	7[a]	6	0.4166	4.25	0.0359	2.3507	5.1716
Noakhali	2.96	25	6.25	0.5139	4.75	0.1000	1.4658	4.3387
Patenga	3.85	25	6	0.4166	5	0.1440	1.3040	5.0203
Rangamati	2.15	7[a]	7	0.8888	6.15	0.4734	2.0108	4.3222
Sandip	2.76	7[a]	6	0.4166	5.15	0.1742	1.8248	5.0365
St. Martin	4.79	25	5.25	0.1963	4.5	0.0664	1.2611	6.0418
Sylhet	2.38	7[a]	5.25	0.1963	5	0.1440	1.4938	3.5562
Teknaf	2.96	25	5.5	0.2586	4	0.0194	1.6064	4.7550
Chittagong	4.49	20	5.75	0.5139	5	0.2154	1.8125	5.8301
Kishorgonj	2.54	25	5	0.4165	4.75	0.1965	1.254	4.1522
Pakshey	2.27	20	5.25	0.2648	4.4.85	0.1452	1.452	4.1051

Conclusion

The following conclusions are made based on results mentioned in the studies:

i. Analysis of wind data shows that electricity generation in the different locations is possible and future research must be conducted to develop low cost wind powered electricity generation system for using in the rural areas of Bangladesh where national grid system is not possible to connect.

ii. Wind turbine performance curves must be developed before their installation in a place.

iii. The performance of wind turbine can be characterized by three main indicators such as power, torque and thrust, which vary with wind speed.

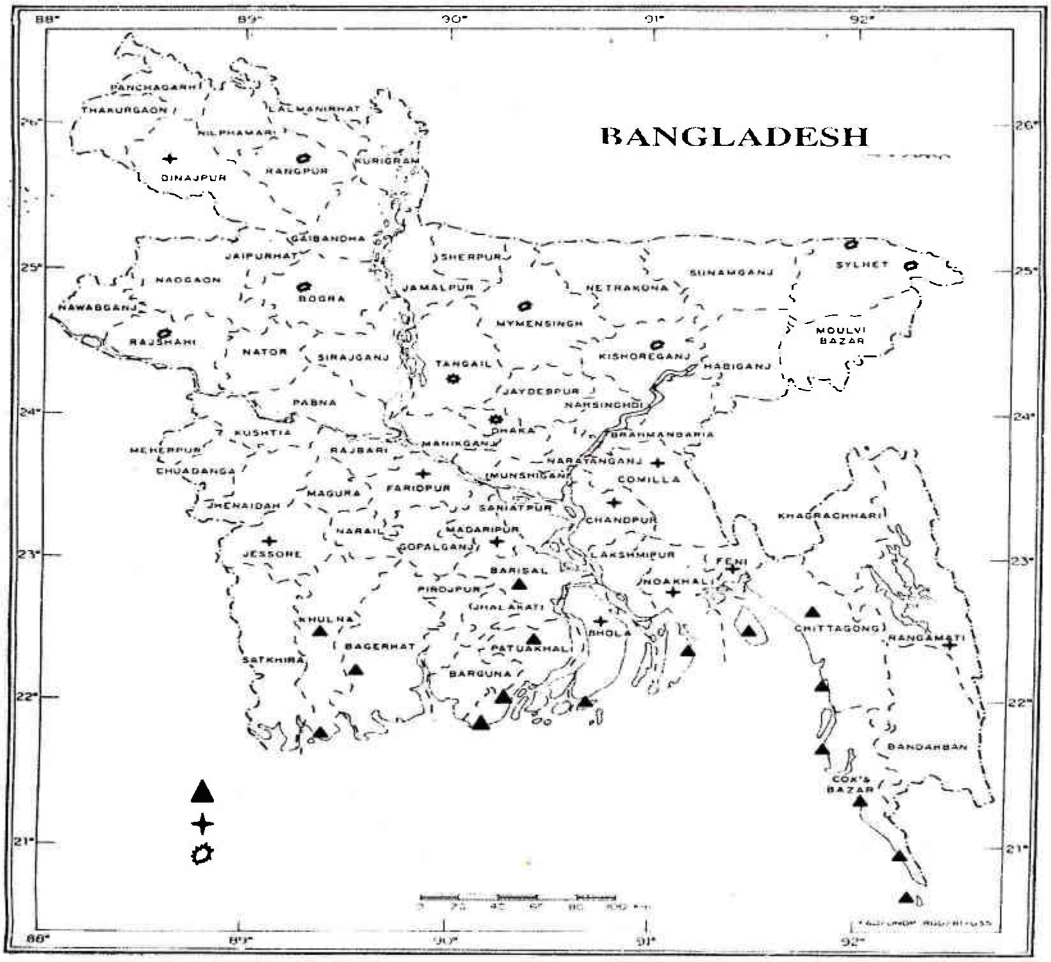


Fig. 5. Makeof wind veloeity in Bangladesh.Fig. 5. Makeof wind veloeity in Bangladesh.

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