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WIND ENERGY POTENTIAL ASSESSMENT IN UTTARA KANNADA DISTRICT OF KARNATAKA, INDIA

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Abstract—Availability of wind energy and its characteristics at Kumta and Sirsi in Uttara Kannada District of Karnataka has been studied based on primary data collected at these sites for a period of 24 months. Wind regimes at Karwar (1952–89), Honnavar (1939–89) and Shirali (1974–89) have also been analysed based on data collected from India Meteorological Department (IMD) of respective meterological observatories. Wind energy conversion systems would be most effective in these taluks during the period May to August. The monthly frequency distributions of wind speed have been analysed for Kumta and Sirsi where hourly wind speed recording is available. It is shown that two parameter Weibull distribution is a good representation of the probability density function for the wind speed. Energy Pattern Factor (EPF) and Power Densities are computed for sites at Kumta and Sirsi. With the knowledge of EPF and mean wind speed, mean power density is computed for Karwar, Honnavar and Shirali. Our analyses show that the coastal taluks such as Karwar and Kumta have good wind potential. This potential, if exploited would help local industries and coconut and areca plantations. Pre-monsoon availability of wind energy would help in irrigating these orchards and makes the wind energy a desirable alternative.

1. INTRODUCTION

Windmills have been used for centuries to grind grain and pump water in rural areas. Winds are caused by the rotation of the earth and the heating of the atmosphere by the sun. The total annual kinetic energy of air movement in the atmosphere is estimated to be about 3×10^5 kWh or about 0.2% of the solar energy reaching the earth. The maximum technically usable potential is estimated to be theoretically 30 trillion kilo watt hours per year, or about 35% of current world total energy consumption [1]. The power in the wind blowing at 25.6 km/h is about 200 W/m^2 of the area swept by the windmill. Approximately 35% of this power can be captured by the windmill and converted to electricity. However, it is important to note that the power output from the windmill varies with the cube of the wind speed. Consequently, only windy locations on the mountains and coasts are suitable for the economic generation of electricity by wind power. Harnessing of wind energy could play a significant role in the energy mix of a region. Wind energy is renewable and environmentally benign. It has the advantage of being harnessed on a local basis for applications in rural areas and remote areas. Water pumping for agriculture and plantations is probably the most important application that contributes to the rural development through multiple cropping. Wind driven electric generators could be utilised as an independent power source and for purposes of augmenting the electricity supply from grids. In coastal densely populated taluks like Karwar, Kumta in Uttara Kannada District, decentralised production of electricity would help local industries, especially seasonal agro processing industries like cashew, etc.

The extent to which wind can be exploited as a resource of energy depends upon the probability density of occurrence of different speeds. To optimise the design of a wind energy device, data on speed range over which the device must operate to maximise energy extractions are required, which requires the knowledge of frequency distribution of the wind speed. Data on mean monthly and annual wind speeds for a long time (30–50 years) are available at meteorological observatories and the data on frequency distribution are available from sites at Sirsi and Kumta where primary data have been collected for the last 24 months. The wind measurements were taken up with the aid of a Cup Anemometer with mechanical counter, fixed to a guyed mast at a height of 5 m at Sirsi and Kumta.

1.1. *Wind energy resource parameters*

Wind cannot be transported and, therefore, wind turbines must be located where the wind resource is present. The energy content of the wind, being related to the cube of the wind speed, varies significantly with only small changes in wind speed. This fact demands the importance of having accurate wind speed data when the wind energy resource is being evaluated. Since wind speed is a continuously varying parameter, it is customary to average the wind speeds during each hour and to use the hourly mean wind speed as the basic parameter in calculations of wind power.

1.2. *Mean wind speed and energy resource*

The annual wind speed at a location is useful as an initial indicator of the value of the wind resource. The relationships between the annual mean wind speed and the potential value of the wind energy resource are listed below:

Annual Mean Wind Speed @ 10m Ht	Indicated value of wind resource
<4.5 m/s	Poor
4.5–5.4 m/s	Marginal
5.4–6.7 m/s	Good to Very Good
>6.7 m/s	Exceptional.

In locations where data are not available, a qualitative indication of a high annual mean wind speed can be inferred from geographical location, topographical features, wind-induced soil erosion, and deformation of vegetation. However, accurate determination of the mean annual wind speed requires anemometer data for at least a 12 month period. Earlier studies have revealed that the mean wind speed for a given year varies from year to year but within $\pm 10\%$ of the long term mean. A $\pm 10\%$ variation in mean wind speed would show a variation in energy content of $\pm 30\%$ or more.

The power P due to the kinetic energy of wind is proportional to (1/2)* [mass × (velocity)^2]. That is the mass of air passing through an area A at velocity V. The mass of air passing through an area A per unit time is ρAV, and the total power available from wind is:

$$P = [(1/2)^*(\rho AV)^*V^2] = [(1/2)^*(\rho AV^3)], \tag{1}$$

where ρ is the mass density, ρAV is the air mass flow rate, and V is the airstream velocity.

1.3. *Adjustment of anemometer height*

Anemometers at different meteorological stations are set at different levels, the measurements, wind speed recorded at each station, prior to any analysis, have to be adjusted to the same height. The standard height according to the World Meterological Organization, is 10 m above the ground level [2]. This height is adopted in our analyses. The horizontal component of the wind velocity can vary a great deal with height under the influence of frictional and impact forces on the ground. The most common model for the variation of horizontal velocity with height is given by the logarithmic wind profile equation as [3]:

$$(V1/V2) = (H1/H2)^{\alpha}, \tag{2}$$

Where $V1$ is a wind speed at height $H1$ of 10m above ground level, $V2$ is a wind speed at height $H2$ above ground level, and α is the roughness factor which is determined by substituting the wind speed data obtained with anemometer height in various wind directions, and found to be 0.30.

1.4. *Wind speed frequency distribution*

Because the energy in the wind is proportional to the cube of wind speed, wind speeds above the annual mean will have a disproportionate amount of the wind energy. As a result, two locations with identical mean wind speeds that have differing wind speed distributions could have quite different levels of wind energy resources. Furthermore, the frequency of occurrence of various wind speeds, including the extremes, must be known to determine how well the operating range of a particular wind turbine under consideration matches the wind speed distribution. The wind speed frequency distribution at a given location is either tabulated from wind speed data measured as a function of time or is approximated by a probability distribution function based on measured data or assumed wind resources characteristics. In recent years, much effort has been made to construct an adequate statistical model for describing the wind frequency distribution. Earlier studies have shown that the Weibull distribution gives a good fit to the experimental wind speed data [3,4]. The probability density function $F(\mathrm{v})$ for wind data is given by:

$$F(\mathrm{v}) = (k/c)^*(V/c)^{k-1*}\,\mathrm{Exp}\,[-(V/c)^k]. \tag{3}$$

The cumulative distribution function (CDF) is,

$$M(\mathrm{v}) = 1 - \mathrm{Exp}\,[-(V/c)^k], \tag{4}$$

where k is a dimensionless shape factor, c is a scale factor with units of speed, and $F(\mathrm{v})$ is the probability or percentage of occurrence per unit speed of the wind speed V. The first and second moments of (PDF) in terms of c and k are,

$$\bar{x}_v = c\Gamma(1+1/k) \tag{5}$$

$$\sigma_v^2 = c^2[\Gamma(1+2/k) - \Gamma^2(1+1/k)], \tag{6}$$

where $\bar{x}_v$ is the mean wind speed, σ_v^2 the variance and Γ is the gamma function.

There are several methods for determining the Weibull distribution parameters, such as (a) the method of moment, (b) using the energy pattern factor, (c) the method of maximum likelihood and (d) the method of least squares fit of the cumulative probabilities [5]. The method of least squares fit of the cumulative probabilities is employed in our analyses of Sirsi and Kumta data where hourly wind speed is available.

The CDF of wind speed is $M(\mathrm{v}) = 1 - \mathrm{Exp}\,[-(V/c)^{\mathrm{k}}]$, by taking the natural logarithm to linearise the CDF equation,

$$\ln\{-\ln[1-M(\mathrm{v})\} = K\ln V - K\ln c, \tag{7}$$

which is of the form $y = \mathrm{a}x + \mathrm{b}$, by plotting different values of $\ln\{-\ln[1-M(\mathrm{v})]\}$ vs $\ln V$, a straight line is fitted to the points. The slope of the line is k, and the intercept on the $\ln\{-\ln[1-M(\mathrm{v})]\}$ axis is $[-k\ln(c)]$, giving c.

1.5. *Energy pattern factor (EFP)*

The power density per unit area is given by,

$$P = K_{\mathrm{Em}}{*}[1/2(\rho{*}V\mathrm{m}^3)] \text{ for the month and}$$

$$P = K_{\mathrm{Ea}}{*}[1/2(\rho{*}V\mathrm{a}^3)] \text{ for the year,}$$

where ρ is the density, K_{Em} is the energy pattern factor [EPF] [6]:

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

$$= \frac{\text{Mean power density for the month}}{\text{Mean power density at the monthly mean speed}}$$

$$= \frac{1/2{*}\rho\Sigma V_i^3/\mathrm{Nm}}{1/2{*}\rho{*}V\mathrm{m}^3} = \frac{\Sigma V_i^3/N\mathrm{m}}{V\mathrm{m}^3}, \tag{8}$$

where V_{i} is the hourly speed during the month, Nm is the number of hourly wind speed values during the month and Vm is the monthly mean wind speed $= \Sigma V_i/N\mathrm{m}$.

While the annual energy pattern factor is

$$K_{\mathrm{Ea}} = \frac{\Sigma V_i^3/N\mathrm{a}}{V\mathrm{a}^3}.$$

The mean power density for the month is $= K_{\mathrm{Em}}{*}1/2{*}\rho{*}V\mathrm{m}^3$ and for the year is $= K_{\mathrm{Ea}}{*}1/2{*}\rho{*}V\mathrm{a}^3$.

2. OBJECTIVE

This study is undertaken as part of ongoing research in "Ecologically Sound Integrated Regional Energy Planning" in Uttara Kannada District, Karnataka State, India. Our primary goal in this endeavour is to assess the potential of wind energy that can be exploited to meet the regional energy demand in a decentralised way. Out of 11 taluks in Uttara Kannada District, we have chosen sites to monitor wind velocity at Sirsi and Kumta in the first phase of our study. Availability of infrastructure facilities like a research station with computers, etc. has also played a dominant role in site selection. We intend to carry out the wind potential assessment in other taluks in the next stage of this research.

3. METHODS

This work was carried out in Uttara Kannada District of Karnataka State, India based on:

(a) Data from the meteorological observatories at Karwar (for the period 1952–1989), Honnavar (for the period 1939–1989) and Shirali (for the period 1974–1989) obtained from the Indian Meteorological Department, Government of India, Pune, and daily wind data for the period 1990–1993 for these observatories, from the Indian Meteorology Department, Bangalore.
(b) The primary data obtained by installing a cup counter anemometer with mechanical counter fixed on 5 m tall guyed masts at Sirsi and Kumta. The anemometer readings were noted down every three hours during the day, at the synoptic hour observation, from 05.30 to 20.30 hours. Sites for fixing masts were selected in flat open terrain and where the safety of the instruments is assured. Table 1 gives the location details of these stations.

Cup counter anemometers with hemispherical cups measuring 7.62 cm in diameter were used in Indian Meteorological Department observatories until 1973. During 1973–1979 these anemometers are replaced with 3 cup anemometers with 127 mm diameter conical cups, in conformity with international practice. The wind instruments are at 10 m above ground, over open terrain in all these observatories.

At Sirsi and Kumta, cup counter anemometers with mechanical counters are installed on 5 m tall guyed masts. The readings of the anemometer are recorded every three hours during the day, at the synoptic hour observation from 05.30 to 20.30 IST. These masts are located in flat open terrain. To get synoptic hour wind speed, readings are taken twice at 3 min intervals, that is after 3 min and after 6 min, in order to check the correctness of the readings recorded. At Sirsi initially the anemometers were installed in open play ground (Arts and Science College Campus, Sirsi) at two locations, readings were taken for 36

Table 1. List of stations in Uttara Kannada District

Location	Latitude N	Longitude E	Elevation
Karwar	14°47′	74°08′	4
Honnavar	14°17′	74°27′	26
Shirali	14°05′	74°32′	45
Kumta	14°26′	74°25′	8
Sirsi	14°62′	74°85′	610

months (Tables 2a and 2b) and on a hillock (Huliappa Gudda) at elevation 622 m (Table 3), readings were recorded for 24 months.

4. WIND DATA PRESENTATION, DISCUSSION AND ANALYSES

The annual and monthly means of wind speed (w) for 24 h ending at 08.30 IST, the mean wind speed ($w1$) for the period 08.30 to 17.30 and the mean wind speed ($w2$) for the period 17.30 to 08.30, as well as the wind speeds at the six synoptic hours of observation are listed in Tables 2a and 2b for Sirsi sites. Figure 1 is the pictorial representation of monthwise mean daily wind speed in km/h. It is noticed that at Sirsi, wind speed is high during the period May to August. It ranges from 13.1 km/h during May and reaches a peak of 15.2 km/h in the month of July. While at site 2 in Sirsi it ranges from 10.5 in the month of May and reaches a peak in the months of July and August at 15.4 km/h. Figure 2a gives a diurnal variation of mean wind speed in a day. It is seen that the day is windy between 08.30 and

Table 2a. Mean wind speed (km/h) at Sirsi (at 610 m elevation)

Hours	05.30	08.30	11.30	14.30	17.30	20.30	w	$w1$	$w2$
Jan	3.6	8.1	12.2	11.4	7.7	4.5	7.7	11.8	5.3
Feb	2.6	7.6	10.4	10.2	9.8	4.3	7.3	11.3	4.8
Mar	2.1	5.4	8.8	11.6	11.8	6.3	7.3	10.6	5.3
Apr	3.5	7.0	9.5	12.1	13.2	9.4	8.6	11.0	7.2
May	3.8	9.6	11.2	13.4	12.8	9.6	10.0	13.1	8.2
June	5.8	11.7	13.5	14.3	11.9	7.9	10.7	14.2	8.6
July	6.3	9.6	13.5	14.3	12.8	8.7	11.9	15.2	10.0
Aug	6.4	9.5	13.5	14.9	12.4	8.7	11.0	13.9	9.1
Sept	2.3	6.7	10.0	12.1	10.4	6.2	8.0	11.2	6.1
Oct	1.9	7.3	9.9	9.6	7.2	4.5	6.3	9.4	4.5
Nov	4.9	10.4	13.1	11.2	5.8	4.7	8.4	12.1	6.1
Dec	5.7	11.4	12.6	10.2	6.4	5.2	9.4	12.7	7.4
Annual	4.1	8.2	11.5	12.1	10.2	6.6	8.9	12.2	6.9

Table 2b. Mean wind speed (km/h) at Sirsi (at 622 m elevation)

Hours	05.30	08.30	11.30	14.30	17.30	20.30	w	$w1$	$w2$
Jan	5.3	8.0	13.0	11.0	7.0	4.9	7.9	11.6	5.6
Feb	3.2	7.7	12.2	10.2	10.4	5.3	7.6	11.8	5.0
Mar	3.0	5.8	8.0	11.5	12.4	6.2	7.2	10.1	5.5
Apr	4.3	7.9	10.2	11.4	13.2	9.3	8.7	11.1	7.3
May	5.1	9.3	12.0	13.3	12.6	9.6	10.5	13.3	8.8
June	6.6	11.0	12.4	14.1	11.8	8.2	10.4	13.6	8.7
July	6.6	10.5	13.2	16.4	13.7	10.8	11.8	14.7	9.9
Aug	7.0	11.0	15.6	16.8	13.7	9.0	11.9	15.4	9.8
Sept	2.0	6.0	8.8	10.1	9.88	5.7	7.2	10.4	5.3
Oct	1.2	6.0	8.6	9.6	9.1	5.1	5.5	8.3	3.9
Nov	6.5	13.0	15.6	13.9	5.6	5.9	9.8	14.1	7.2
Dec	6.2	11.4	12.5	8.6	7.14	5.2	9.3	11.8	7.6
Annual	4.8	9.0	11.8	12.2	10.4	7.1	9.0	12.2	7.1

Table 3. Mean wind speed (km/h) at Sirsi II (elevation 622 m, location Huliappa Gudda) and at Kumta (elevation 8 m)

Month	Sirsi Avg.	Sirsi Sd.	Kumta Avg.	Kumta Sd.
January	6.92	3.25	5.95	3.12
February	6.88	2.68	7.76	4.16
March	7.20	3.74	9.09	1.64
April	8.38	5.57	9.42	2.55
May	9.09	5.48	9.87	3.15
June	11.19	7.59	11.83	2.79
July	18.17	7.61	13.03	2.38
August	14.19	7.15	11.54	5.45
September	11.14	7.74	6.71	4.49
October	8.39	6.66	6.59	3.62
November	7.72	6.50	6.29	2.29
December	8.42	6.88	7.73	3.27

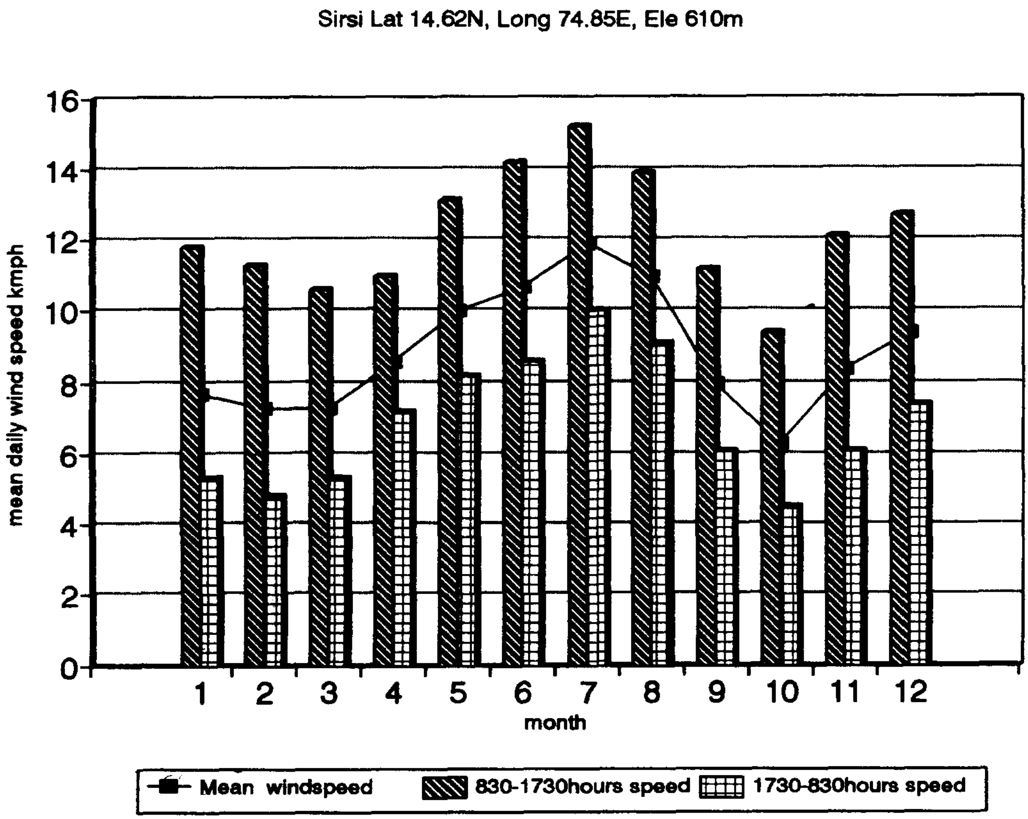


Fig. 1. Mean daily wind speed at Sirsi.

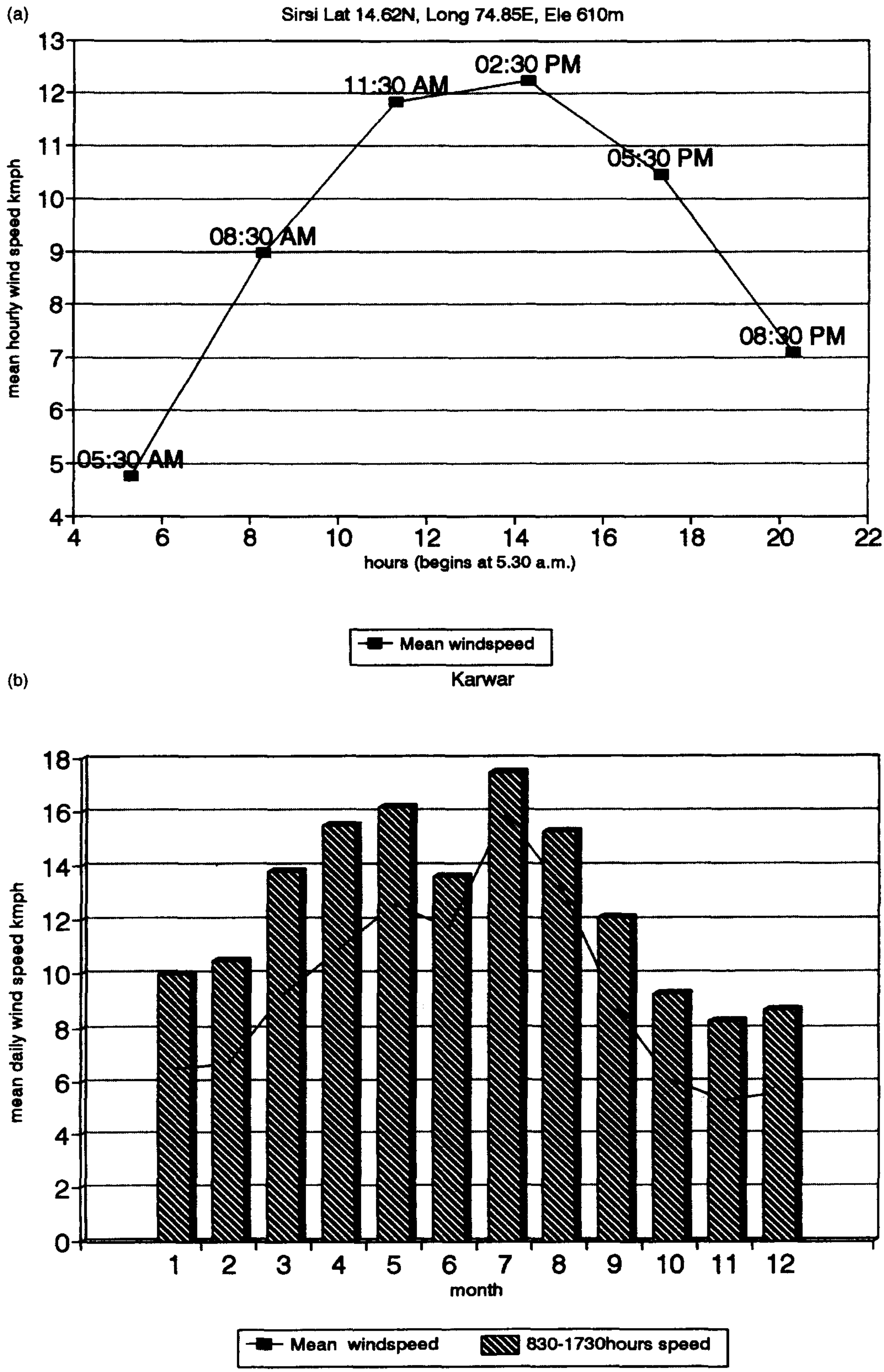


Fig. 2. (a) Mean hourly wind speed (year) at Sirsi; (b) mean daily wind speed (Karwar); (c) mean daily wind speed (Honnavar).

(c)

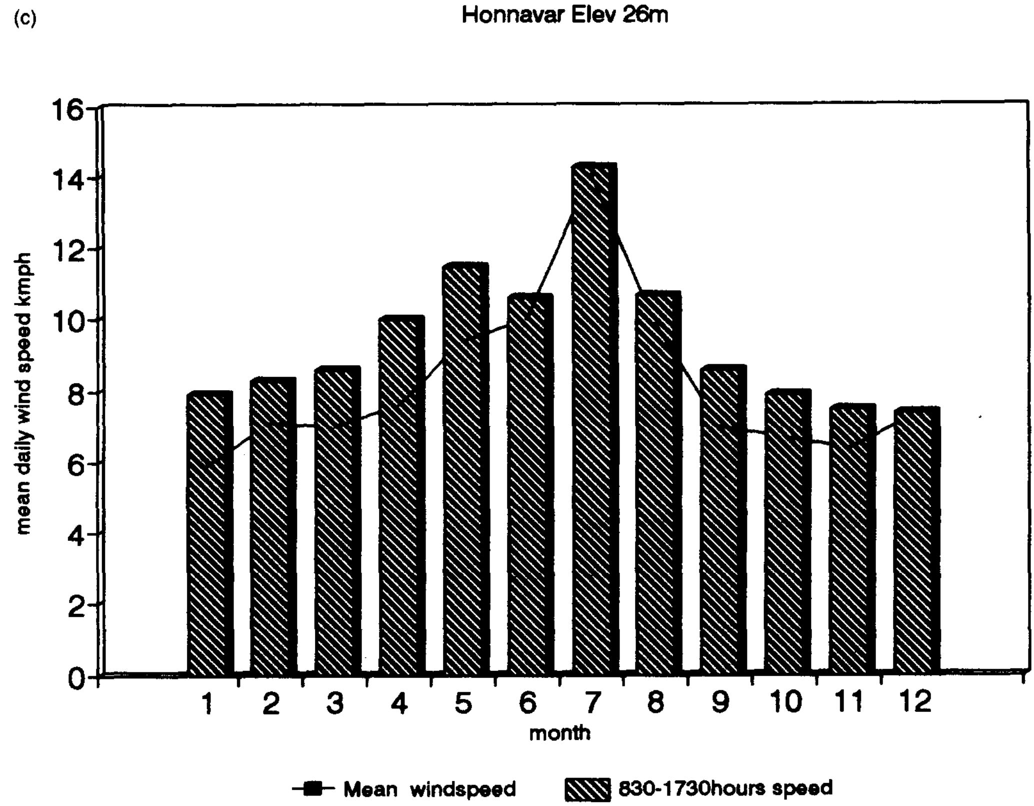


Fig. 2.—*Continued.*

17.30, the maximum occurs during the day around 14.30. Figure 2b and 2c gives, pictorially, variation in mean daily wind speed (monthwise) for Honnavar and Karwar. Figure 3 gives monthwise hourly wind speed which substantiates the earlier result. The May to August period is windy during the year and variation is most pronounced during this period. The diurnal variation is least during the monsoon season for all sites studied.

Table 3 gives the monthly mean speed and standard deviation at sites located at Sirsi (622 m) and Kumta (elevation 8 m). At site II at Sirsi, the wind speed varies from a minimum of 6.88 ± 2.68 (for February) km/h to the maximum of 18.17 ± 7.61 (for July). Table 4a gives the mean wind speed, standard deviation, maximum and minimum wind speed is based on daily wind data at meteorological observatories at Karwar, Honnavar and Shirali for the period 1990–1994, collected from Indian Meteorological Department at Bangalore. Wind speed is maximum during July in all these stations. It ranges from 15.2 km/h for Karwar to 8.5 for Shirali and 7.7 km/h for Honnavar. The same is shown by bar graphs in Figs 4–6.

Table 4b gives the monthly mean wind speed for the period 08.30–17.30 and for the period 17.30–08.30 at Honnavar based on data for the period 1939–1989 and at Karwar (Table 4c) based on data for the period 1952–1989. Variation in monthly wind speed is quite evident in the graph shown in Fig. 7. Among the coastal taluks, Karwar seems to have the better wind regime, followed by Kumta and Shirali.

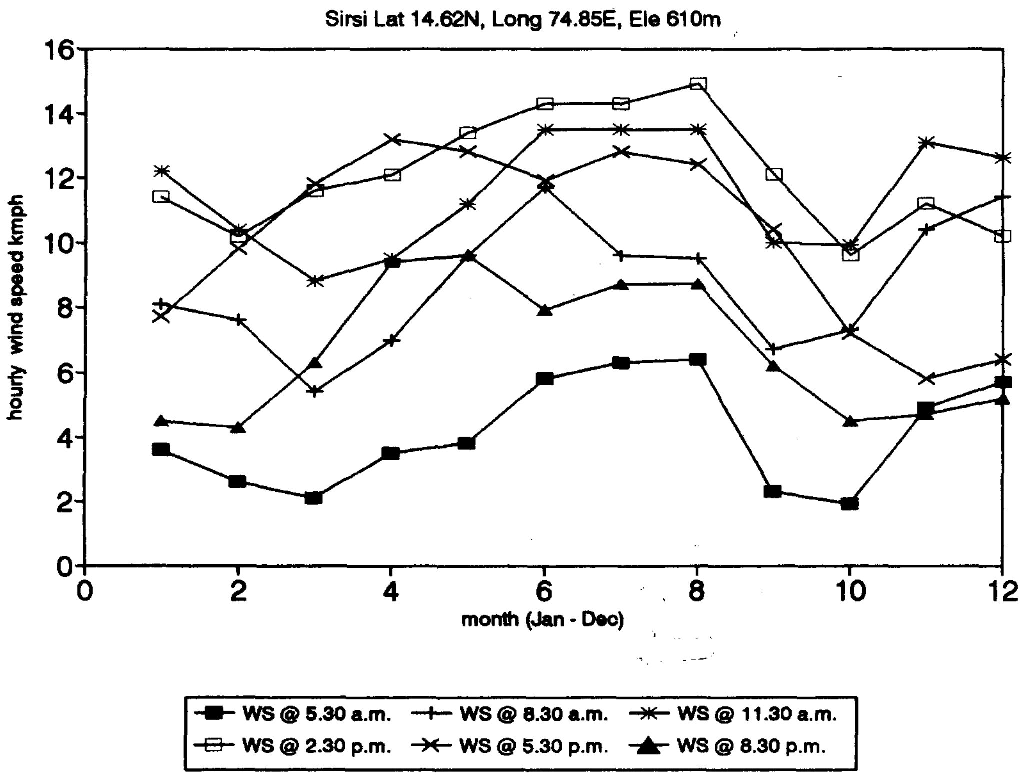


Fig. 3. Hourly wind speed at Sirsi.

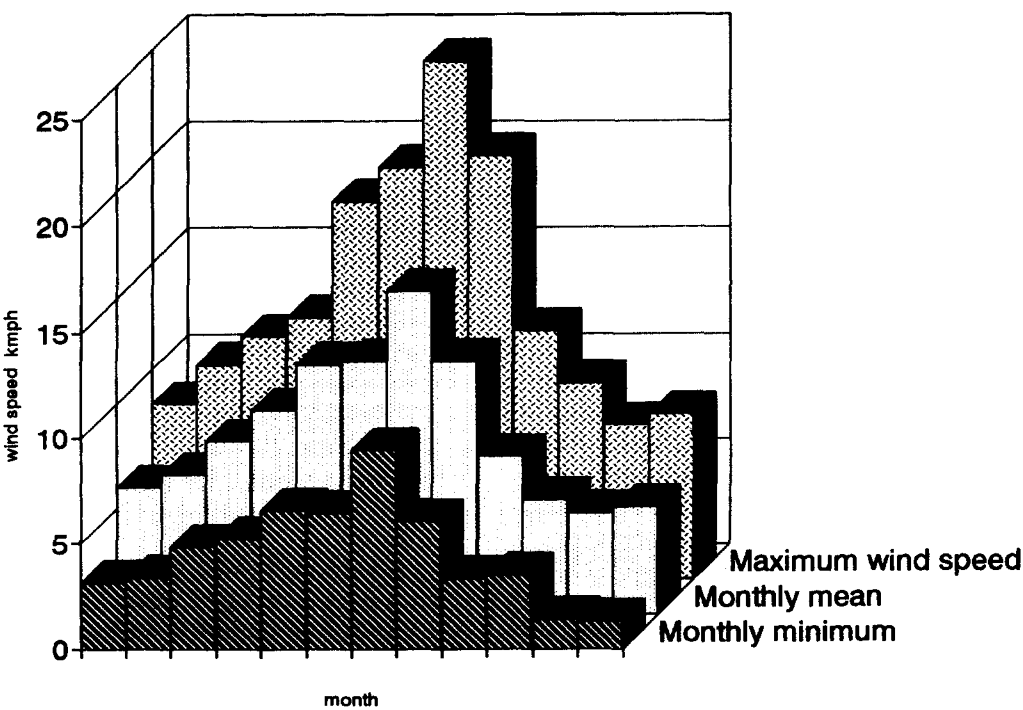


Fig. 4. Monthly wind speed at Karwar.

The frequency distribution of wind speed for each month at Sirsi and Kumta is given in Tables 5a and 5b. The speed range over which a windmill should be designed to operate and the maximum wind its structure has to withstand depends on frequency distribution of the wind speed. We have attempted to fit simple distributions to the Observed Frequency Distributions. Analysis is carried out for the sites at Sirsi and Kumta where primary data

Table 4a. Monthly mean wind speed, Sd, Max, Min

	Avg	Sd	Max	Min
Place. Karwar				
Jan	5.96	1.43	8.30	3.10
Feb	6.55	2.03	10.20	3.40
Mar	8.15	1.99	11.50	4.80
Apr	9.65	2.17	12.40	5.20
May	11.82	2.73	17.80	6.50
June	12.01	3.09	19.40	6.40
July	15.27	4.03	24.40	9.40
Aug	11.98	3.95	20.00	6.00
Sept	7.44	2.53	11.80	3.30
Oct	5.41	1.62	9.30	3.50
Nov	4.75	1.56	7.30	1.40
Dec	5.04	1.63	7.80	1.30
Place. Honnavar				
Jan	5.95	1.93	9.60	2.40
Feb	6.00	2.04	9.60	2.20
Mar	6.10	1.98	9.70	2.50
Apr	6.20	2.03	10.00	2.30
May	7.21	2.39	12.70	3.20
June	7.50	2.64	13.30	3.10
July	7.72	3.30	15.50	1.70
Aug	6.66	2.81	12.90	1.10
Sept	4.87	2.05	9.50	1.00
Oct	4.55	2.02	7.90	1.10
Nov	5.04	1.79	8.60	1.80
Dec	6.00	2.23	10.50	2.00
Place. Shirali				
Jan	6.78	1.10	8.60	4.70
Feb	6.87	0.72	7.80	5.60
Mar	7.03	0.83	8.20	5.20
Apr	7.25	1.06	9.00	5.30
May	7.84	1.59	10.60	5.40
June	8.30	1.66	11.20	5.60
July	8.50	1.78	11.70	6.50
Aug	7.64	0.90	8.90	5.70
Sept	5.56	0.67	6.80	4.40
Oct	5.42	0.50	6.30	4.50
Nov	6.76	1.07	9.40	5.60
Dec	9.51	2.35	13.60	5.90

Computed for data of meteorological observatories located at Karwar, Honnavar, Shirali. (Based on data for the period 1990–1993.)

Table 4b. Mean wind speed (Honnavar, elevation 26 m), based on data for the period 1939–1989

	Mean wind speed (km/h)			
Hours	08.30	17.30	08.30–17.30	17.30–20.30
Jan	4.8	6.3	5.9	7.9
Feb	4.5	6.7	7.1	8.3
Mar	3.8	7.7	7	8.6
Apr	3.2	7.8	7.6	10
May	4.2	9.2	9.4	11.5
June	4.5	7.2	10	10.6
July	6.8	9.1	14.1	14.3
Aug	4.9	6.7	9.9	10.7
Sept	3	6	7	8.6
Oct	3.2	5.7	6.7	7.9
Nov	4.2	4.8	6.4	7.5
Dec	5	5.2	7.3	7.4
Annual	4.34	6.87	8.20	9.44

Table 4c. Mean wind speed at Karwar based on data for the period 1952–1989

	Mean wind speed (km/h)			
	08.30	17.30	08.30–17.30	17.30–20.30
Jan	4.4	8.9	6.5	10
Feb	3.5	11.9	6.7	10.5
Mar	3.9	15.8	9.3	13.8
Apr	3.9	16.7	10.9	15.5
May	6.9	14.4	12.6	16.2
June	8.6	13.1	11.7	13.6
July	13.3	15.9	15.9	17.5
Aug	11.1	14.6	13.4	15.3
Sept	5.3	12.1	9	12.1
Oct	4.3	8.7	6.1	9.3
Nov	5.1	6	5.3	8.3
Dec	5	6.8	5.6	8.7
Annual	6.28	12.08	9.42	12.5

have been collected for the last 24 months. Tables 5a and 5b list the number of occurrence, cumulative Frequency Distributions of wind speeds in the range 0–4, 4–8, 8–12, 12–16, 16–20, 20–24 and >24 km/h. It is seen that the percentage occurrence of wind in the class interval 0–8 km/h is greater during January–April (>50%) and September–December (44 to 60%). While 8–12 km/h wind is predominant during May–August period (25 to 40%). This is illustrated in Fig. 8a (Sirsi) and Fig. 8b (Kumta). The observed cumulative distribution for the months January–June, July–December at stations located at Sirsi and Kumta are shown in Figs 9a, 9b, 9c and 9d, respectively. It is seen that the Weibull fit is good for both these stations. The goodness of fit is tested using the chi square test. The parameters of the Weibull distribution obtained (c and k) are given in Table 6.

The monthly mean wind Energy Pattern Factor for the sites at Sirsi and Kumta is listed in Table 7. The concept of EPF is useful in calculating the available energy in the wind, along with the knowledge of the annual mean speed. It is also useful while choosing a

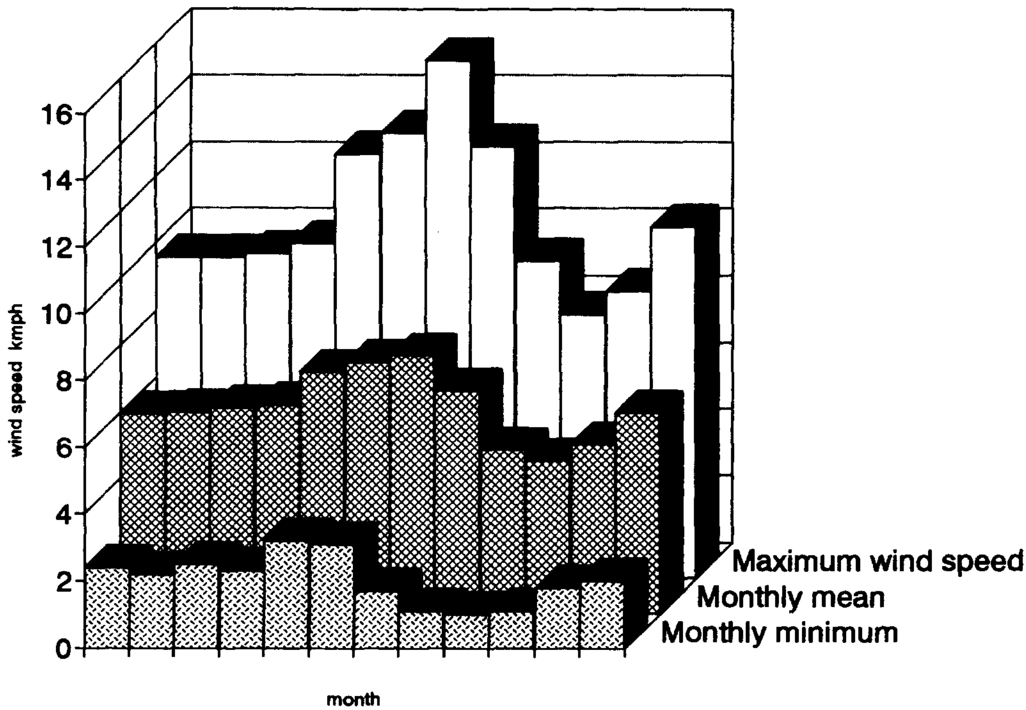


Fig. 5. Monthly wind speed at Honnavar.

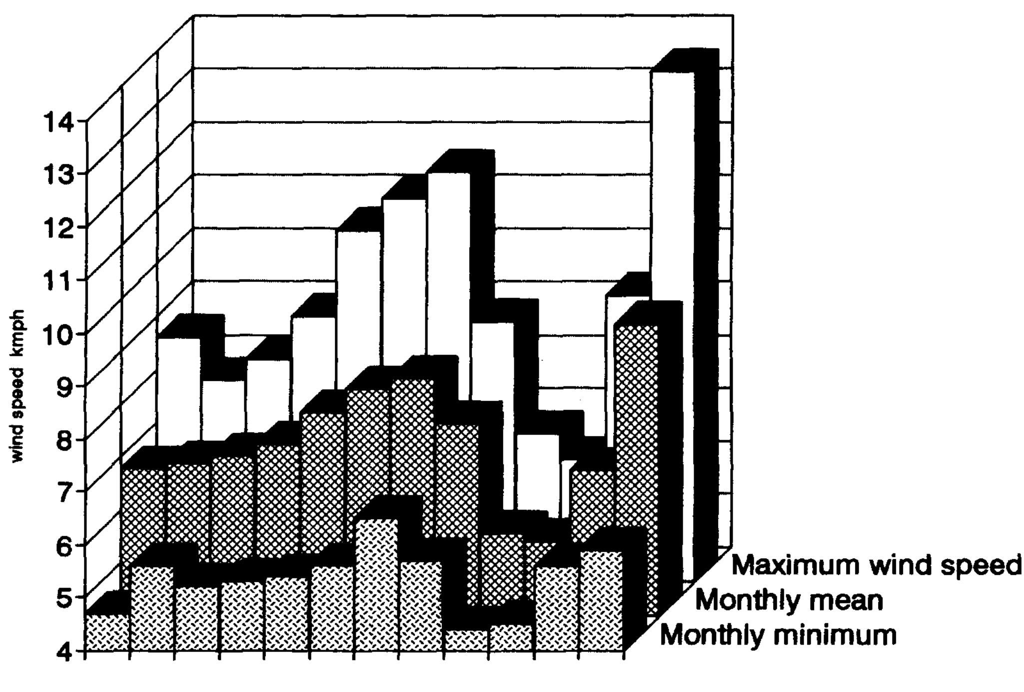


Fig. 6. Monthly wind speed at Shirali.

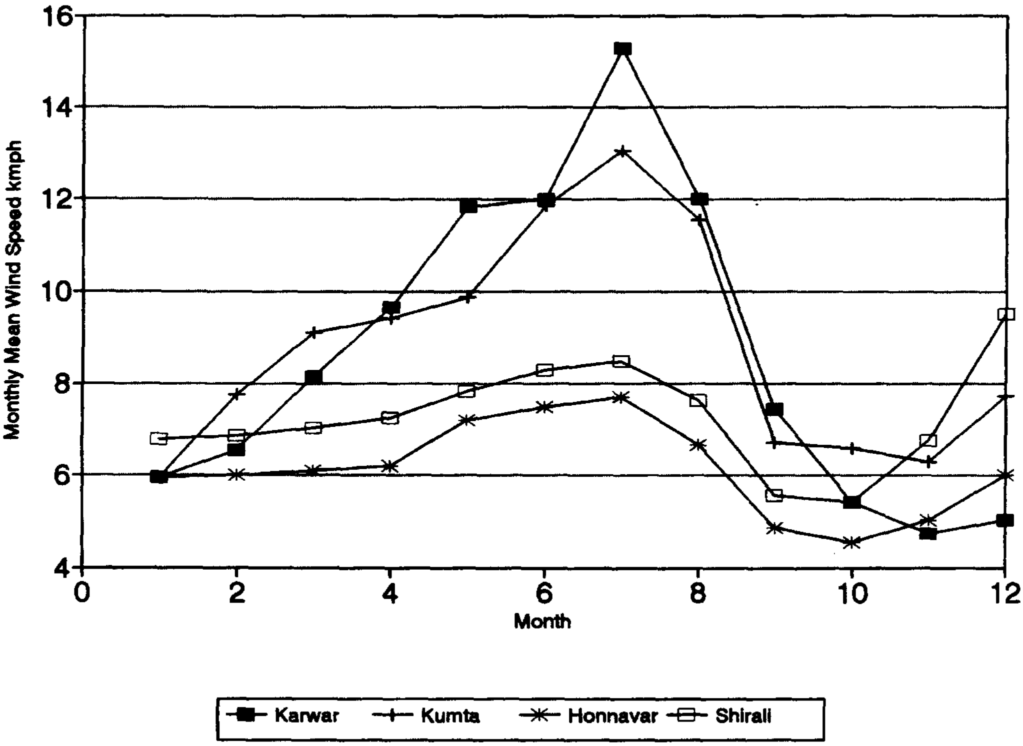


Fig. 7. Monthly mean wind speed (Karwar, Kumta, Honnavar and Shirali).

location with limited wind data, because long term data from neighbouring sites can be correlated with on-site short time measurements.

The monthly average hourly wind speed with monthly average power density (W/m^2) is given in Table 8. Monthly average hourly wind speed is maximum in the month of July for Kumta (13.03 km/h) and Sirsi (18.17 km/h). The mean annual wind speed at Kumta is 8.82 km/h. Corresponding power density at Kumta is 26.49 W/m^2. Similarly at Sirsi, annual mean wind speed is 9.81 km/h and corresponding power density is 45.18 W/m^2.

Hourly wind speed data are not available for Karwar, Honnavar or Shirali. All these are located along the coastal belt of Uttara Kannada District. However, primary hourly wind speed data are available for Kumta, which is also located in the coastal belt. Therefore, EPF is computed for Kumta with hourly wind speed data. EPF computed for Kumta is used to compute mean power density at Karwar, Honnavar and Shirali, listed in Table 9. The mean annual wind speed at Karwar is 8.67 km/h and the power density at Karwar is 30.64 W/m^2. The variation in monthly mean power density for Karwar, Kumta, Honnavar and Shirali is illustrated in Fig. 10.

With this background, we have tried to assess the potential along the coastal tract of Uttara Kannada District. For this purpose we divide the coastal tract along the seashore into three zones. Zone A consists of land space about 5 km wide along the coastal tract, parallel to the sea. Zones B and C correspond to 7.5 km and 10 km width along the coastal tract. Villages in these zones were compiled from village maps. Corresponding wastelands available in these villages are according to a 1991 census. We assume that 1% of wastelands

Table 5a. Frequency distribution (no. of occurence of hours) at Sirsi

Month	Data available	0–4 (km/h)	0–8 (km/h)	8–12 (km/h)	12–16 (km/h)	16–20 (km/h)	20–24 (km/h)	>24 (km/h)
Jan	744	269	134	212	85	34	10	0
Feb	672	254	129	172	84	26	7	2
Mar	744	310	155	162	101	12	4	0
Apr	720	247	124	195	120	22	12	0
May	744	142	71	293	156	60	22	0
June	720	128	66	271	190	42	23	2
July	745	97	58	256	176	98	60	43
Aug	743	89	46	270	206	76	56	2
Sept	720	319	159	154	81	5	2	2
Oct	744	383	191	139	27	2	2	0
Nov	720	234	116	165	111	64	30	3
Dec	744	232	118	214	100	45	35	2

Cumulative frequency distribution

Month	0–4 (km/h)	0–8 (km/h)	8–12 (km/h)	12–16 (km/h)	16–20 (km/h)	20–24 (km/h)	>24 (km/h)
Jan	0.36	0.54	0.83	0.94	0.94	0.99	1
Feb	0.38	0.57	0.83	0.95	0.95	0.99	1
Mar	0.42	0.63	0.84	0.98	0.98	0.99	1
Apr	0.34	0.52	0.79	0.95	0.95	0.98	1
May	0.19	0.29	0.68	0.89	0.89	0.97	1
June	0.18	0.27	0.65	0.91	0.91	0.97	1
July	0.13	0.21	0.55	0.79	0.79	0.92	1
Aug	0.12	0.18	0.55	0.82	0.82	0.92	1
Sept	0.44	0.66	0.88	0.99	0.99	1.00	1
Oct	0.51	0.77	0.96	0.99	0.99	1.00	1
Nov	0.33	0.49	0.72	0.87	0.87	0.96	1
Dec	0.31	0.47	0.76	0.89	0.89	0.95	1

Table 5b. Frequency distribution (no. of occurrence of hours) at Kumta

Month	Data available	0–4 (km/h)	4–8 (km/h)	8–12 (km/h)	12–16 (km/h)	16–20 (km/h)	20–24 (km/h	>24 (km/h)
Jan	752	129	257	224	94	32	16	
Feb	738	133	261	190	100	40	14	2
Mar	801	152	303	187	134	14	11	
Apr	752	131	259	195	127	20	20	2
May	748	65	126	304	176	40	37	2
June	799	69	120	288	216	66	40	8
July	760	24	57	305	232	82	60	34
Aug	760	52	80	290	202	74	62	12
Sept	777	131	259	202	142	22	21	2
Oct	706	121	237	190	124	18	16	3
Nov	734	123	240	188	119	44	20	3
Dec	769	116	228	224	121	36	44	2

Table 5b. *Continued.* Cumulative frequency distribution, Kumta

Month	0–4 (km/h)	4–8 (km/h)	8–12 (km/h)	12–16 (km/h)	16–20 (km/h)	20–24 (km/h)	>24 (km/h)
Jan	0.17	0.51	0.81	0.94	0.94	0.98	1
Feb	0.18	0.53	0.79	0.93	0.93	0.98	1
Mar	0.19	0.57	0.80	0.97	0.97	0.99	1
Apr	0.17	0.52	0.78	0.95	0.95	0.97	1
May	0.09	0.26	0.66	0.90	0.90	0.95	1
June	0.09	0.24	0.60	0.87	0.87	0.95	1
July	0.03	0.11	0.51	0.81	0.81	0.92	1
Aug	0.07	0.17	0.56	0.82	0.82	0.92	1
Sept	0.17	0.50	0.76	0.94	0.94	0.97	1
Oct	0.17	0.51	0.78	0.95	0.95	0.98	1
Nov	0.17	0.49	0.75	0.91	0.91	0.97	1
Dec	0.15	0.45	0.74	0.90	0.90	0.94	1

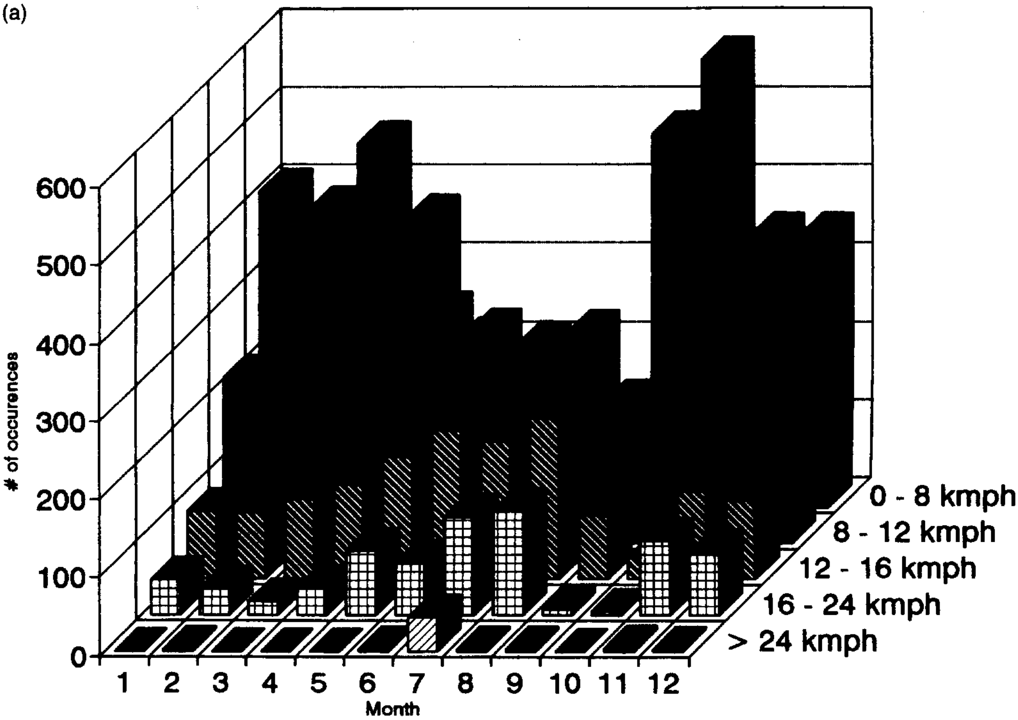
could be made available for harnessing wind energy. With this assumption we have computed the monthwise wind potential at Karwar, Kumta, Honnavar and Bhatkal taluks. Zones D and E refer to 5% and 10% of the total waste land available in 10 km width along the coastal tract. The last two columns in Table 10a and Table 10b indicate wind potential if land space available is about 5% and 10% of total waste land in these zones. We conclude that about 0.75 to 2 MW could be generated in Karwar and Kumta taluks during seasons in this tract.

5. WINDFARM AND TURBINE SIZE

Because windfarms consist of modular units of single design, it is thought that wind power technology offers significant economies of scale. This is very much true for turbine manufacturing and not for turbine deployment. The analysis is carried out with data and information provided by Tamilnadu Energy Developmental Agency (TEDA, India). This suggests that large windfarms are no more attractive compared to the small ones. Although construction and mobilisation costs may fall per unit for a larger windfarm, (i) total costs for turbines and civil works remain proportional to windfarm size; (ii) larger windfarm requires proportionally higher electric interconnection costs because of the need for more costly high voltage step-up facilities; and (iii) array efficiency decreases with wind farm size. It is found that, at present, the wind turbines of 225 kW each are economically attractive. If 10% of wasteland (in the region of 10 km width along the coastal tract), is made available for power generation, our calculation shows that along the coastal tract of Karwar and Kumta we can have wind farms of rated capacity 1.35 Megawatts (6 units of 225 kW each).

The land requirements for wind units were calculated, assuming that turbines were to be erected in rows with a between-row distance of 7 times rotor diameter and between turbine distance of 5 times rotor diameter. The rows are normally aligned perpendicular to the prevailing wind direction. For a turbine of about 200 kW, the rotor diameter would be

(a)



(b)

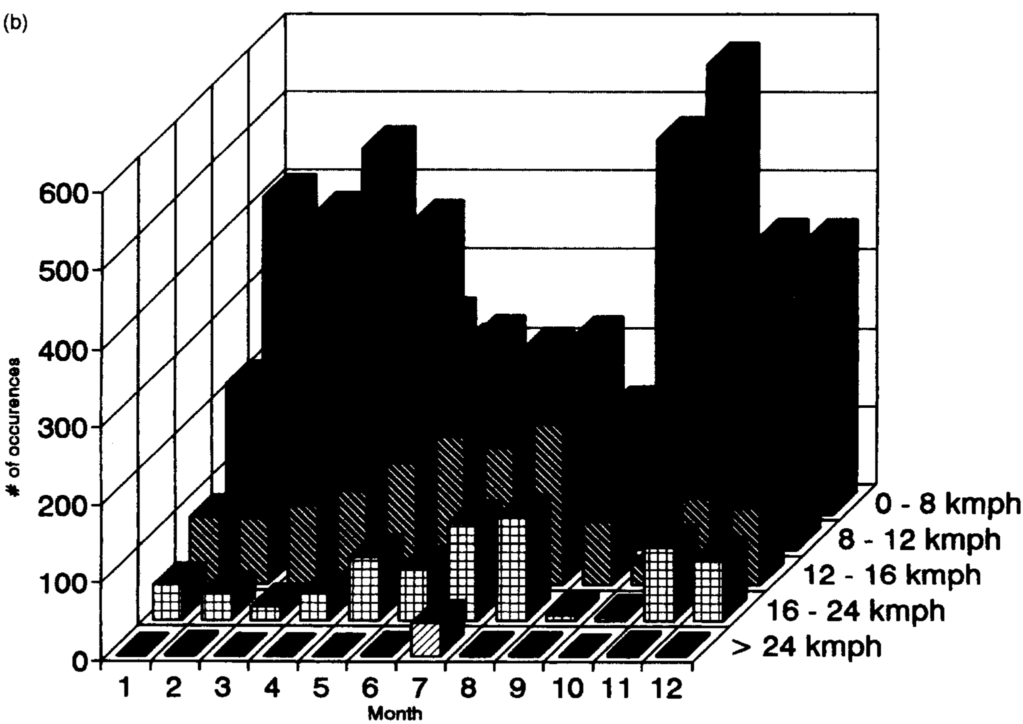
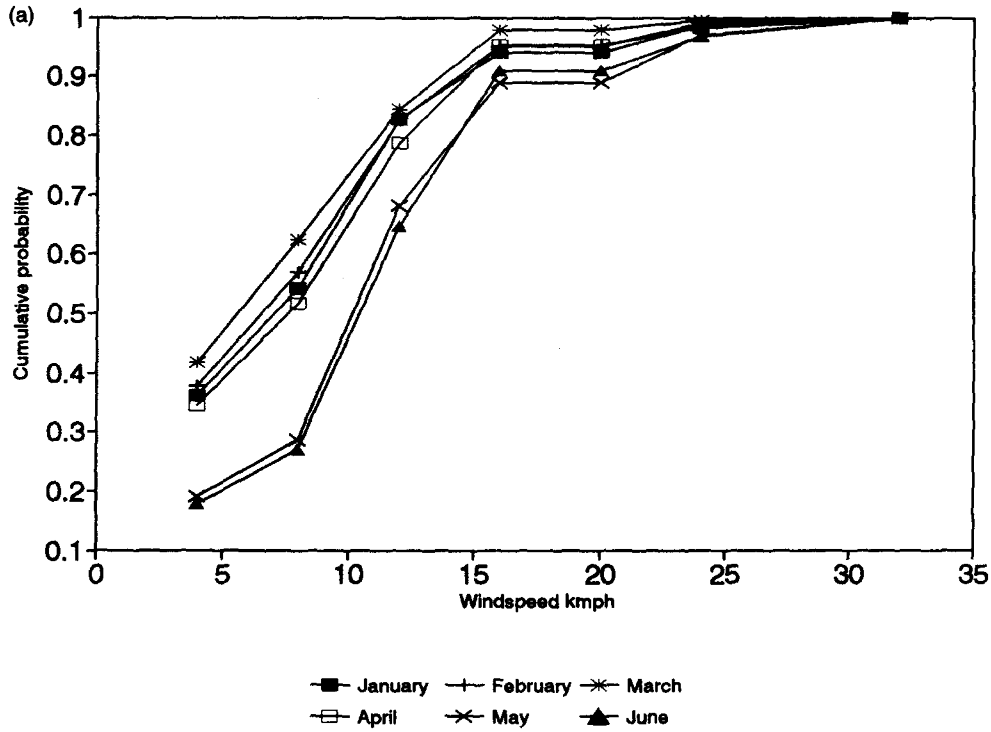


Fig. 8. Frequency distribution (no. of occurrences) at (a) Sirsi; (b) Kumta.



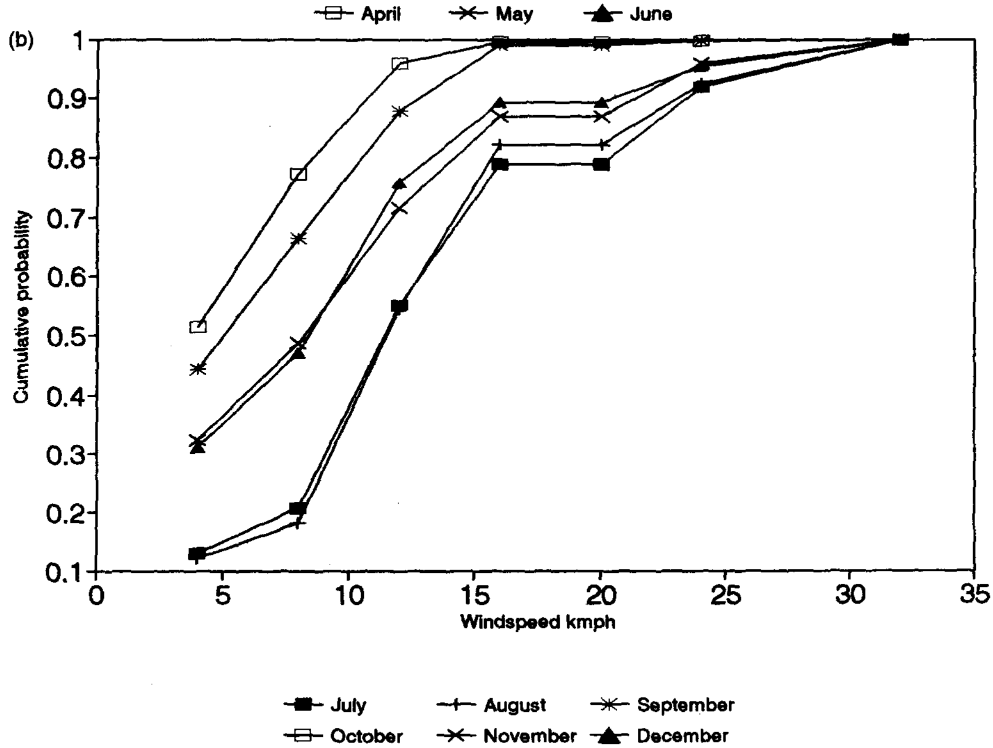


Fig. 9. CDF for (a) and (b), Sirsi; (c) and (d) Kumta.

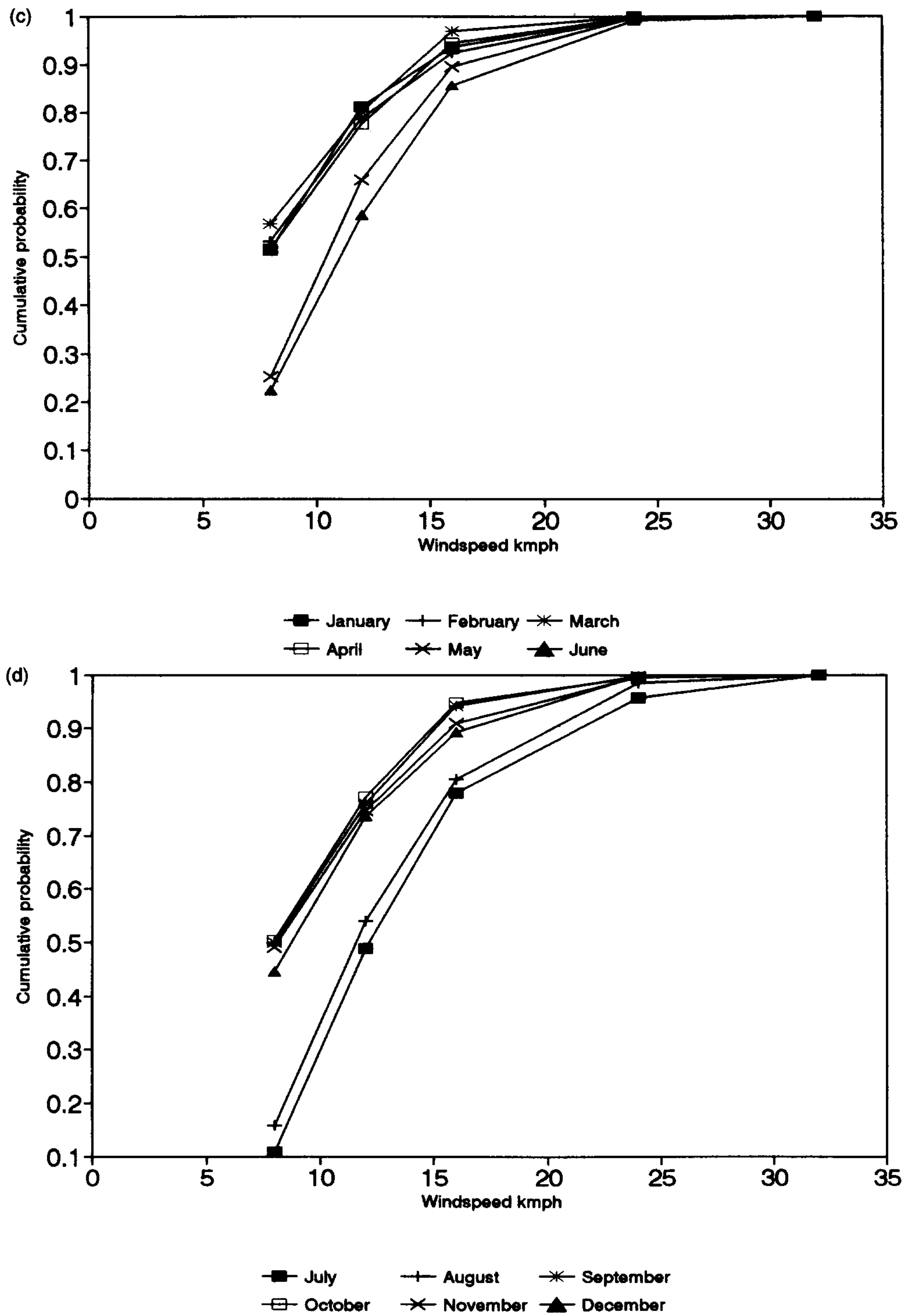


Fig. 9.—*Continued.*

Table 6. Weibull parameters (c and k) for Sirsi and Kumta

Month	Sirsi		Kumta	
	c	k	c	k
January	8.38	2.09	8.10	1.96
February	8.74	2.24	11.45	2.34
March	10.46	2.97	9.47	2.54
April	8.53	2.14	8.17	3.44
May	10.62	2.95	8.12	2.93
June	10.72	2.00	11.71	2.02
July	10.69	1.21	10.41	1.32
August	13.36	1.73	10.23	1.47
September	12.24	3.74	11.69	3.43
October	11.06	2.59	11.14	3.21
November	9.23	1.23	10.65	3.01
December	9.78	1.42	11.07	3.18

Table 7. Energy pattern factor (EPF) for Sirsi and Kumta

Month	EPF–Kumta	EPF–Sirsi
January	2.30	1.84
February	2.29	1.99
March	2.23	2.24
April	2.62	2.78
May	2.58	2.80
June	2.56	2.88
July	2.33	3.02
August	2.92	2.78
September	2.42	2.40
October	2.21	1.79
November	2.07	1.48
December	2.18	1.90

Table 8. Mean power density for Kumta and Sirsi

	Kumta		Sirsi	
	V(+km/h)	Pd (W/m^2)	V (−km/h)	Pd (W/m^2)
January	5.95	6.25	6.93	7.87
February	7.77	13.79	6.89	8.37
March	9.10	21.59	7.20	10.77
April	9.42	28.26	8.38	21.06
May	9.88	31.99	9.10	27.12
June	11.84	54.79	11.20	51.97
July	13.03	66.36	18.17	233.06
August	11.54	57.77	14.20	102.29
September	6.71	9.41	11.15	42.73
October	6.60	8.15	8.40	13.63
November	6.30	6.65	7.72	8.77
December	7.74	12.99	8.42	14.6
Annual Avg.	8.82	26.49	9.81	45.18
Annual Sd.	2.27	20.82	3.26	62.85
Maximum	13.03	66.36	18.17	233.06
Minimum	5.95	6.25	6.89	7.87

Table 9. Monthly mean power density at Karwar, Honnavar and Shirali

Month	Kumta EPF	Karwar V (km/h)	Karwar Pd (W/m^2)	Honnavar V (km/h)	Honnavar Pd (W/m^2)	Shirali V (km/h)	Shirali Pd(W/m^2)
January	1.84	5.96	6.26	5.95	6.23	6.78	9.23
February	1.99	6.55	8.27	6.00	6.37	6.87	9.53
March	2.24	8.15	15.55	6.10	6.52	7.03	9.95
April	2.78	9.65	30.38	6.20	8.06	7.25	12.90
May	2.8	11.82	54.84	7.21	12.45	7.84	16.03
June	2.88	12.01	57.18	7.50	13.93	8.30	18.88
July	3.02	15.27	106.80	7.72	13.78	8.50	18.41
August	2.78	11.98	64.63	6.66	11.09	7.64	16.78
September	2.4	7.44	12.83	4.87	3.58	5.56	5.35
October	1.79	5.41	4.51	4.55	2.68	5.42	4.53
November	1.48	4.75	2.85	5.04	3.41	6.76	8.22
December	1.9	5.04	3.59	6.00	6.06	9.51	24.11
Average	2.33	8.67	30.64	6.15	7.85	7.29	12.83

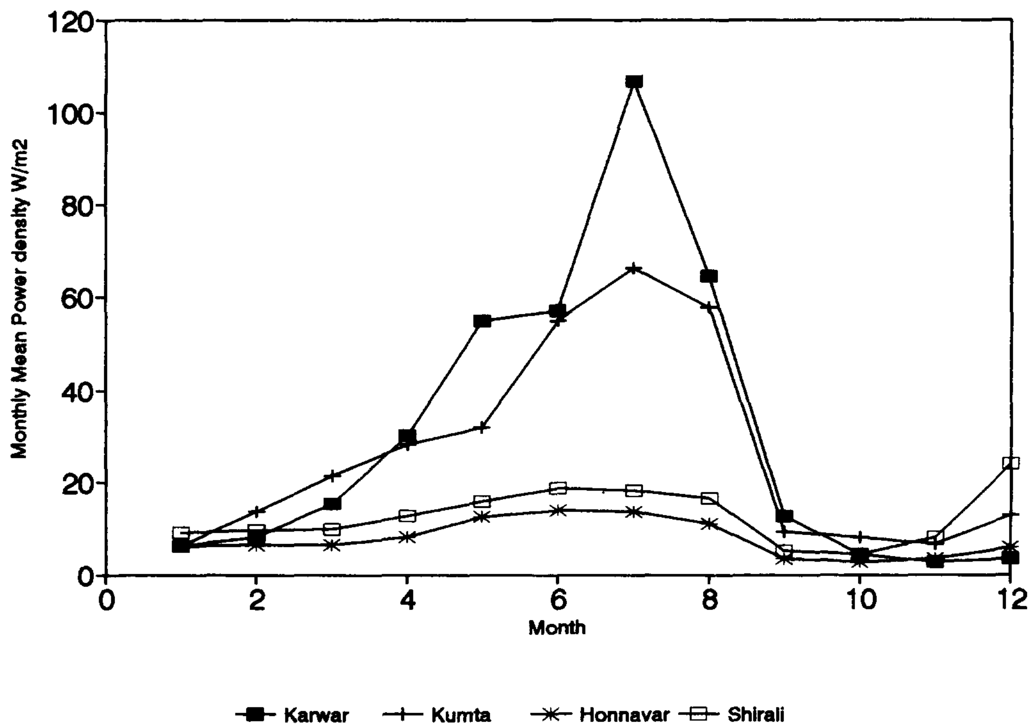


Fig. 10. Monthly average wind power density (Karwar, Kumta, Shirali and Honnavar).

Table 10a. Monthly mean power at Karwar, Honnavar and Shirali

Karwar Month	Pd (W/m²)	Estimated power in kW Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% waste land)		1376.93	1786.93	2134.73	10673.65	21347.30
Jan	6.26	8.61	11.18	13.35	66.77	133.55
Feb	8.27	11.38	14.77	17.65	88.25	176.50
Mar	15.55	21.41	27.78	33.19	165.94	331.88
Apr	30.38	41.83	54.28	64.85	324.24	648.48
May	54.84	75.51	98.00	117.07	585.36	1170.72
June	57.18	78.73	102.18	122.07	610.33	1220.66
July	106.80	147.05	190.84	227.99	1139.93	2279.86
Aug	64.63	88.99	115.49	137.97	689.83	1379.67
Sept	12.83	17.66	22.92	27.39	136.93	273.86
Oct	4.51	6.20	8.05	9.62	48.09	96.17
Nov	2.85	3.92	5.09	6.08	30.41	60.83
Dec	3.59	4.94	6.41	7.66	38.31	76.62
Average	30.64	42.19	54.75	65.41	327.03	654.07

Kumta Month	Pd (W/m²)	Estimated power in kW Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% waste land)		1493.31	1956.36	2893.80	14469.00	28938.00
Jan	6.25	9.33	12.23	18.09	90.43	180.86
Feb	13.79	20.59	26.98	39.91	199.53	399.06
Mar	21.59	32.24	42.24	62.48	312.39	624.77
Apr	28.26	42.20	55.29	81.78	408.89	817.79
May	31.99	47.77	62.58	92.57	462.86	925.73
June	54.79	81.82	107.19	158.55	792.76	1585.51
July	66.36	99.10	129.82	192.03	960.16	1920.33
Aug	57.77	86.27	113.02	167.17	835.87	1671.75
Sept	9.41	14.05	18.41	27.23	136.15	272.31
Oct	8.15	12.17	15.94	23.58	117.92	235.84
Nov	6.65	9.93	13.01	19.24	96.22	192.44
Dec	12.99	19.40	25.41	37.59	187.95	375.90
Average	26.49	39.57	51.84	76.69	383.43	766.86

Honnavar Month	Pd (W/m²)	Estimated power in kW Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% of waste land)		1178.82	1426.82	2122.87	10614.35	21228.70
Jan	6.23	7.34	8.89	13.23	66.13	132.27
Feb	6.37	7.51	9.09	13.53	67.63	135.26
Mar	6.52	7.69	9.30	13.84	69.20	138.40
Apr	8.06	9.51	11.51	17.12	85.60	171.20
May	12.45	14.67	17.76	26.43	132.13	264.26
June	13.93	16.42	19.88	29.58	147.88	295.76
July	13.78	16.24	19.66	29.25	146.24	292.48
Aug	11.09	13.07	15.82	23.53	117.67	235.34
Sept	3.58	4.23	5.11	7.61	38.05	76.10
Oct	2.68	3.16	3.82	5.69	28.45	56.90
Nov	3.41	4.03	4.87	7.25	36.25	72.49
Dec	6.06	7.14	8.64	12.86	64.28	128.55
Average	7.85	9.25	11.20	16.66	83.29	166.59

Table 10a.—*Continued.*

Shirali Month	Pd (W/m^2)	Estimated power in kW Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% waste land)		1186.04	1588.28	1748.58	8742.90	17485.80
Jan	9.23	10.94	14.65	16.13	80.66	161.32
Feb	9.53	11.31	15.14	16.67	83.36	166.73
Mar	9.95	11.80	15.81	17.40	87.01	174.02
Apr	12.90	15.30	20.49	22.55	112.77	225.54
May	16.03	19.02	25.47	28.04	140.19	280.38
June	18.88	22.40	29.99	33.02	165.09	330.19
July	18.41	21.83	29.24	32.19	160.95	321.91
Aug	16.78	19.90	26.64	29.33	146.66	293.33
Sept	5.35	6.34	8.50	9.35	46.77	93.53
Oct	4.53	5.37	7.19	7.91	39.56	79.13
Nov	8.22	9.75	13.06	14.38	71.90	143.79
Dec	24.11	28.60	38.30	42.16	210.81	421.63
Average	12.83	15.21	20.37	22.43	112.14	224.29

Table 10b. Monthly mean energy at Karwar, Honnavar and Shirali

Karwar Month	Pd (W/m^2)	Estimated energy in kWh Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% waste land)		1376.93	1786.93	2134.73	10673.65	21347.30
Jan	6.26	2243.06	2910.96	3477.53	17387.66	34775.32
Feb	8.27	2677.65	3474.96	4151.31	20756.57	41513.13
Mar	15.55	5574.28	7234.10	8642.12	43210.58	86421.16
Apr	30.38	10540.67	13679.30	16341.78	81708.88	163417.76
May	54.84	19663.61	25518.72	30485.57	152427.84	304855.68
June	57.18	19840.98	25748.91	30760.56	153802.82	307605.64
July	106.80	38292.92	49695.17	59367.61	296838.05	593676.11
Aug	64.63	23173.14	30073.26	35926.58	179632.92	359265.85
Sept	12.83	4451.38	5776.84	6901.21	34506.07	69012.14
Oct	4.51	1615.33	2096.32	2504.34	12521.70	25043.40
Nov	2.85	988.69	1283.08	1532.81	7664.07	15328.15
Dec	3.59	1286.90	1670.09	1995.15	9975.76	19951.51
Sum in kilo units k kWh		130.35	169.16	202.09	1010.43	2020.87

Kumta Month	Pd (W/m^2)	Estimated energy in kWh Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% waste land)		1493.31	1956.36	2893.80	14469.00	28938.00
Jan	6.25	2430.36	3183.98	4709.66	23548.30	47096.60
Feb	13.79	4843.41	6345.27	9385.77	46928.87	93857.74
Mar	21.59	8395.44	10998.73	16269.05	81345.24	162690.48
Apr	28.26	10634.64	13932.26	20608.25	103041.27	206082.55
May	31.99	12439.56	16296.86	24105.92	120529.61	241059.21
June	54.79	20618.25	27011.62	39954.93	199774.64	399549.28
July	66.36	25804.61	33806.18	50005.28	250026.40	500052.81
Aug	57.77	22464.32	29430.13	43532.32	217661.62	435323.25
Sept	9.41	3541.12	4639.16	6862.13	34310.63	68621.26
Oct	8.15	3169.19	4151.90	6141.40	30706.98	681413.96
Nov	6.65	2502.49	3278.47	4849.43	24247.15	48494.30
Dec	12.99	5051.26	6617.58	9788.56	48942.78	97885.56
Sum in kilo units k kWh		121.89	159.69	236.21	1181.06	2362.13

Table 10b.—*Continued.*

Honnavar Month	Pd (W/m^2)	Estimated energy in kWh Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% waste land)		1178.82	1426.82	2122.87	10614.35	21228.70
Jan	6.23	1912.54	2314.90	3444.19	17220.94	34441.88
Feb	6.37	1766.61	2138.27	3181.39	15906.97	31813.93
Mar	6.52	2001.31	2422.35	3604.05	18020.27	36040.54
Apr	8.06	2395.67	2899.67	4314.23	21571.14	41342.28
May	12.45	3821.24	4625.15	6881.45	34407.26	68814.51
June	13.93	4138.76	5009.48	7453.26	37266.32	74532.64
July	13.78	4229.22	5118.97	7616.17	38080.85	76161.70
Aug	11.09	3403.05	4118.98	6128.35	30641.77	61283.53
Sept	3.58	1064.86	1288.89	1917.65	9588.27	19176.53
Oct	2.68	822.72	995.80	1481.59	7407.95	14815.91
Nov	3.41	1014.41	1227.83	1826.80	9134.00	18268.00
Dec	6.06	1858.84	2249.90	3347.48	16737.41	33474.83
Sum in kilo units k kWh		28.43	34.41	51.20	255.98	511.97

Shirali Month	Pd (W/m^2)	Estimated energy in kWh Zone-A	Zone-B	Zone-C	5% Zone-D	10% Zone-E
Land (1% waste land)		1186.04	1588.28	1748.58	8742.90	17485.80
Jan	9.23	2849.38	3815.73	4200.84	21004.22	42008.43
Feb	9.53	2659.83	3561.90	3921.39	19606.95	39213.89
Mar	9.95	3073.61	4116.02	4531.43	22657.16	45314.33
Apr	12.90	3855.09	5162.52	5683.56	28417.80	56835.60
May	16.03	4952.16	6631.67	7300.98	36504.90	73009.81
June	18.88	5643.82	7557.89	8320.69	41603.43	83206.85
July	18.41	5685.69	7613.96	8382.42	41912.09	83824.17
Aug	16.78	5180.89	6937.97	7638.20	38190.99	76381.97
Sept	5.35	1598.76	2140.97	2357.05	11785.27	23570.54
Oct	4.53	1397.57	1871.55	2060.44	10302.21	20604.42
Nov	8.22	2457.84	3291.41	3623.60	18118.00	36236.00
Dec	24.11	7447.01	9972.63	10979.14	54895.69	109791.39
Sum in kilo units k kWh		46.80	62.67	69.00	345.00	690.00

Table 10c. Rated power energy could be generated at Karwar, Kumta, Honnavar and Shirali

If LF = 0.45		Energy in kilo units '000 kWh				
		Zone-A	Zone-B	Zone-C	Zone-D	Zone-E
Karwar	63	119.68	155.32	185.55	927.77	1855.53
Kumta	48	98.55	129.11	190.98	954.90	1909.81
Honnavar	12	19.29	23.35	34.74	173.71	347.42
Shirali	20	27.16	36.38	40.05	200.24	400.48

Table 10c. —*Continued.*

If LF = 0.3

	Avg power in kW	Zone-A	1% Zone-B	5% Zone-C	10% Zone-D	Zone-E
Karwar	63	86.43	112.16	133.99	669.94	1339.88
Kumta	48	71.43	93.58	138.42	692.11	1384.22
Honnavar	12	13.98	16.92	25.18	125.91	251.81
Shirali	16.60	19.69	26.37	29.03	145.13	290.27
		Energy in kilo units '000 kWh Zone-A	Zone-B	Zone-C	Zone-D	Zone-E
Karwar	63	79.49	103.16	123.24	616.21	1232.42
Kumta	48	65.70	86.08	127.32	636.60	1273.21
Honnavar	12	12.86	15.57	23.16	115.81	231.62
Shirali	17	18.11	24.25	26.70	133.49	266.99

Table 10d. Cost per kWh, production cost per MW

Turbines million Rs	15
Electrical works	1.31
Civil works	1.75
Land acquisition	0.75
Total	18.81
Levelised capital (20 years life time, discount rate 10%)	2.21
Annual maintenance (2% capital costs)	0.33
Annual wages	0.07
Total per year	2.61
Total per MW (million Rs)	2.61
Total energy, mWh	2014.00
Cost/unit	1.30

about 30 m. With these assumptions, we notice that for one Megawatt installed capacity, land required is about 20 hectares. Of this area, 10% is directly used for foundations, roads and other facilities.

6. ESTIMATION OF OUTPUT

The monthly energy output at respective sites based on wind data is listed in Table 10b. It is seen that approximately two million units could be generated at Karwar and Kumta by using 10% of the wasteland along the 10 km wide coastal tract.

Turbine efficiency of 40% and electric generator efficiency of 85% are used in our calculation. With this we get an overall efficiency of 35% in wind electric generator units. A load factor of 0.3 is assumed in the computation of energy output.

Apart from well known day–night and seasonal variations of wind regime, it is to be noted that the wind is fairly reliable compared to hydro resources (rainfall). The coefficient of variation of mean wind speed is about 5.85% compared to a higher COV of rainfall (of about 28%).

Table 10c lists rated capacity in each region and energy that could be generated using wind energy conversion system. When wind speeds are low, the wind machine will remain idle. As wind speeds rise to cut-in wind speed, the generating unit will start functioning. The rated output is computed by taking the average of the windy months in a year. It is the power output that the machine produces when it is operating at rated wind speed. Wind speeds above the rated output would not produce greater power output levels.

7. COST ESTIMATES

The cost estimates include (a) wind turbines including control systems, panels, environmental protection, capacitor banks, assembly and erection; (b) electrical works including transmission and distribution; and (c) civil works, fencing and land acquisition. The amortised total annual cost (ATAC) for the wind generation system is given by,

$$\mathrm{ATAC} = \frac{C^{*}r^{*}(1+r)^{*}t}{(1+r)^{t}-1} + \mathrm{O\&M}, \tag{9}$$

where C = total capital cost, t = expected life (assumed as 20 years), r = discount rate (10% is assumed) and O&M = annual operation and maintenance charge.

Dividing this (ATAC) by annual generated energy, we get cost per unit. Cost computed based on the data of Kayathar windfarm [7] in Tamilnadu works out to be Rs.1.30/unit (kWh). The details of electrical, civil and the annual maintenance costs are listed in Table 10d.

8. CONCLUSIONS

Human pressure on forests to meet the daily energy requirement in the form of fuel wood and fodder for domestic purposes and rural industry needs is quite evident from the barren hill tops in the coastal belt of Uttara Kannada District. Therefore, harnessing renewable sources like solar, wind, etc. at feasible sites would help in the eco-development of a region. Analyses of wind data clearly indicate that the coastal areas, especially Karwar and Kumta taluks, have good wind potential. The availability of wind resources is quantified and characterised in this paper. Local need for energy in a decentralised way for industrial needs, and for irrigation purposes (in the pre-monsoon period for agriculture and plantations like areca, coconut) make the exploitation of wind energy feasible and desirable.

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