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A statistical analysis of Wind energy potential of Agartala (Tripura, India) based on different models- a case study

A.R.Sengupta
Ph.D. scholar/Department of ME
NIT Silchar, Assam,India

Dr.A.Biswas
Assistant Professor/Department of ME
NIT Silchar, Assam, India

Prof.(Dr).R.Gupta
Director/Department of ME
NIT Srinagar, NIT Silchar(on lien)
Jammu and Kashmir, India

Abstract—**To develop wind power system and estimate wind energy potential for a particular site, modeling and forecasting of wind characteristics are important requirements through proper analysis of wind data resource. The main objective of this study is to determine wind energy potential of Agartala (Tripura, India) by using different models over a period of five years from 2009-2013 which has not been done previously. For this analysis, daily 24 hours averaged wind speed data for those five years at 4.4 m height from mean sea level has been obtained and at 25 m height this data has been calculated. The peak average wind speed is found to be 1.51 m/s and 2.54 m/s at 4.4 m and 25 m heights respectively during the month of June which is significantly low. Furthermore, various wind speed probabilities are analyzed using Weibull and Rayleigh's distribution functions. After that autoregressive integrated moving average (ARIMA) model has been fitted to the time series data for validation and prediction purpose. Based on the present study it can be said that Agartala city has minimum suitability for conventional wind energy generators but some specially designed vertical axis turbines have been mentioned here which could be operational in such low wind speed terrain.**

Index terms -Wind velocity data, Power density, Weibull model, Rayleigh model, Wind rose, ARIMA model.

Nomenclature –

$F(v)$	*cumulative distribution function*
P/A	*average available wind power per unit area*
c	*Weibull scale parameter*
$f(v)$	*average probability of observing a wind velocity*
k	*Weibull shape parameter*
n	*total period of wind data collection over a month*
Γ	*gamma function*
ρ	*air density*
$\sum$	*summation operator*
σ^2	*variance*
v_i	*record of diurnal wind velocity in a day*
$\bar{v}$	*monthly mean of wind velocities*
v_1, v_2	*mean wind velocities at heights h_1 and h_2*

I. INTRODUCTION

To meet the energy demand of the people all over the world, wind energy has become very popular nowadays as it is a clean, inexpensive and inexhaustible source of renewable energy. It has been noticed that effective utilization of wind energy can make large wind turbines to deliver electricity to the grid at a cheap rate from conventional electricity sources. Globally wind turbine plants installation has been increasing rapidly every year. According to Global Wind Energy Council [1], global wind power capacity up to 2013 is 318,105 MW and expected wind energy generation will be 600 GW by 2018. To evaluate wind power characteristics of a particular location, analysis of wind resource data should be done and various wind characteristics like average wind speed and power density, several probability density functions, forecasting of wind speed data etc. should be investigated thoroughly. Several researchers have investigated wind energy potential for different locations based on Weibull and Rayleigh distributions (a special case of Weibull distribution) and most of them found that Weibull model showed a better fit curve for the actual data series than Rayleigh model [2-8]. Liu et al. [9] studied the performance comparison between ARIMA-ANN and ARIMA-Kalman models which were used to forecast the hourly wind speed data. They noticed that both models had well accepted accuracy range for wind speed and wind power prediction. Cadenas and Rivera [10] compared between ARIMA and ANN methods to predict wind speed data in the South coast of the state of Oaxaca, Mexico. Their analysis was based on seven years wind speed data which revealed that ARIMA model predicted wind speed more accurately that ANN model. Cadenas and Rivera [11] again compared the wind speed forecasting results in three different regions of Mexico using ARIMA model, ANN model and hybrid ARIMA-ANN model on the basis of hourly averaged wind speed data. They obtained that the hybrid model resulted in higher accuracy than the other two models for the three selected locations.

This study aims to determine wind energy potential of Agartala (Tripura, India) by using different models over five years period from 2009-2013. To achieve this, wind speed data at 4.4 m height has been obtained and at 25 m height this data has been calculated. Further, the wind rose model of this place is also studied and wind speed probability distributions are modeled by using Weibull and Rayleigh's distribution functions. Moreover autoregressive integrated moving average

(ARIMA) model has been used for predicting the wind speed of Agartala.

II. DESCRIPTION OF SITE

This paper analyzes the wind energy potential of Agartala which is located in the south-west corner of the north-eastern region of India. Coordinates of Agartala are 23.83° N, 91.27° E and this city is 12.8 meters above the mean sea level [12]. Fig. 1 shows the location of this city in India. In Agartala dry weather is experienced from October to March which is known as dry season. Rain starts here from early April and stays till September which is called rainy season. In this rainy season this city senses hot and wet summer. Winter is normally experienced at the end of November which remains up to February. Sometimes this city is found flooded during rainy season. In summer season average maximum temperature is 34^0C and average minimum temperature in winter is 15^0C. Annual humidity generally remains high here [12].

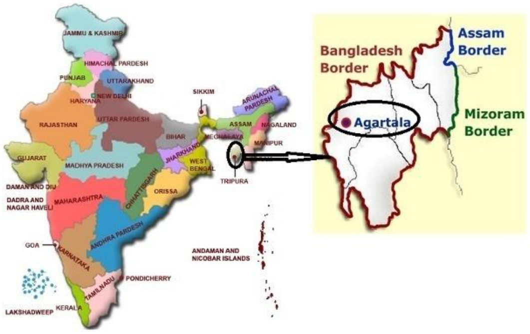


Figure 1. Location of Agartala city in India

III. WIND DATA ANALYSIS AND MEASUREMENT

For this analysis purpose wind data on daily 24 hours averaged basis per month for the time period 2009-2013 have been collected from Regional Meteorological Centre, Guwahati, Assam. A three-cup anemometer is used there to record wind speed at a height of 4.4 m. The wind velocity was recorded diurnally, which was averaged over 24 h daily. The sampling frequency of this wind data was 3 hrs. It is observed that with changed values of altitude, wind speed also changes and the relation between wind speed and altitude is called Hellmann exponential law which can calculate wind speed at a required altitude in terms of measured wind speed at any other altitude.

The equation of Hellmann exponential law [5, 13] used to estimate the wind speed data at 25 m height is:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^m \quad (1)$$

where v_2 and v_1 are mean wind velocities at heights h_2 and h_1 respectively. In this equation, the value of Hellmann exponent is dependent mainly on shape of the terrain and air stability. As Agartala can be considered as a small town, therefore this coefficient is taken as 0.3 in this analysis for calculating wind velocity at a height of 25 m [14].

Tables 1 and 2 are showing the monthly averaged values of wind speed for the time period 2009-2013 at 4.4 m and 25 m heights respectively. Taking the average values of the monthly mean wind speeds from the tables, Fig. 2 has been drawn which shows the diagram of the average of all the monthly mean wind speeds for the five years 2009-2013 at 4.4 m and 25 m heights respectively. It has been observed that March to September months are having higher wind velocities than the other five months and highest average wind velocity is found in June which is 1.51 m/s and 2.54 m/s for 4.4 m and 25 m heights respectively. Monthly variation of power density has been calculated and depicted in Figs. 3 and 4 for the time period 2009-2013 at 4.4 m and 25 m heights respectively. These diagrams reveal that the highest average power density is around 4.06 W/m^2 and 19.28 W/m^2 during the month of June for two different heights respectively. It can be noticed from the figures that as the height increases, wind power density also increases and at 25 m height some considerable power density is observed from April to July months.

The average wind power density, P/A is the average available wind power per unit area which is expressed as:

$$\frac{p}{A} = \frac{1}{2}\rho\frac{1}{n}\sum_{i=1}^{n} v_i^3 \qquad (2)$$

where n is the total period of wind data collection over a month, ρ is the air density (1.225 kg/m^3) and v_i is the record of diurnal wind velocity in a day [8].

Table 1. Monthly averaged values of wind speed (m/s) for the time period 2009-2013 at 4.4 m

Month	2009	2010	2011	2012	2013	Average
Jan	0.46	0.45	0.49	0.77	0.28	0.49
Feb	0.84	0.57	0.81	0.57	0.62	0.68
Mar	0.76	1.63	1.46	1.16	0.88	1.18
Apr	1.75	2.22	1.07	0.76	1.16	1.39
May	1.65	1.71	0.98	0.61	1.38	1.27
Jun	1.75	1.81	1.84	1.29	0.82	1.51
Jul	2.07	1.85	1.51	0.92	1.07	1.48
Aug	1.53	1.19	1.00	0.74	0.84	1.06
Sep	1.25	1.16	1.69	0.71	0.69	1.10

Oct	0.79	0.75	0.74	0.49	0.49	0.65
Nov	0.57	0.60	0.57	0.33	0.37	0.49
Dec	0.35	0.59	0.64	0.28	0.32	0.44

Table 2. Monthly averaged values of wind speed (m/s) for the time period 2009-2013 at 25 m

Month	2009	2010	2011	2012	2013	Average
Jan	0.77	0.75	0.83	1.29	0.47	0.82
Feb	1.42	0.95	1.37	0.97	1.03	1.15
Mar	1.28	2.74	2.45	1.94	1.48	1.98
Apr	2.94	3.73	1.80	1.28	1.94	2.34
May	2.77	2.88	1.64	1.02	2.32	2.13
Jun	2.99	3.05	3.14	2.16	1.38	2.54
Jul	3.48	3.10	2.53	1.55	1.79	2.49
Aug	2.57	2.00	1.69	1.25	1.42	1.79
Sep	2.10	1.94	2.83	1.20	1.15	1.85
Oct	1.33	1.26	1.25	0.83	0.83	1.10
Nov	0.96	1.01	0.96	0.56	0.62	0.82
Dec	0.59	0.99	1.07	0.47	0.54	0.73

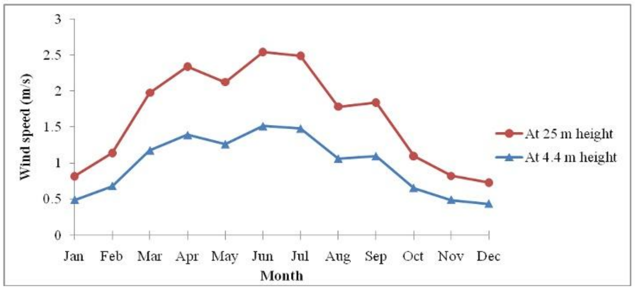


Figure 2. Average of all the monthly mean wind speeds for five years 2009-2013 at 4.4 m and 25m

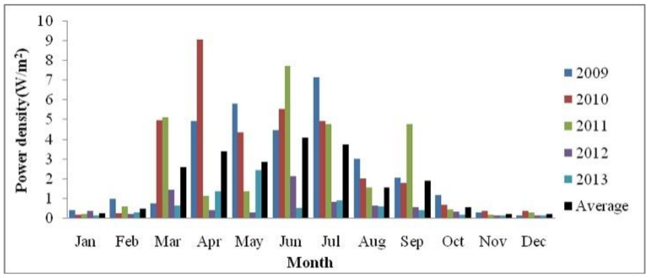


Figure 3. Monthly variation of power density for the time period 2009-2013 at 4.4 m

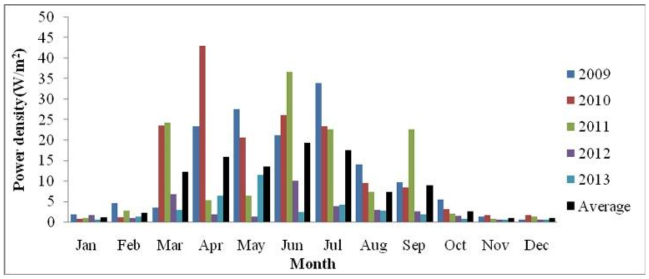


Figure 4. Monthly variation of power density for the time period 2009-2013 at 25 m

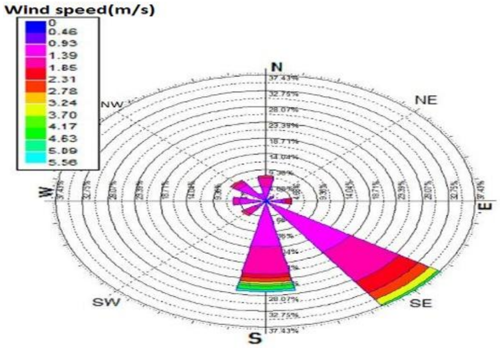


Figure 5. Annual wind rose based on the time period 2011-2013 at 4.4 m

The annual wind rose for the time period 2011-2013 has been shown in Fig. 5 which shows that wind speed ranging from 1-2 m/s occurred most frequently in Agartala city for the time period 2011-2013 and the prevalent wind blows from South and South-East direction.

IV. ESTIMATION OF WIND SPEED PROBABILITY DISTRIBUTION FUNCTION

For evaluating wind speed characteristics two probability distribution functions (Weibull and Rayleigh distribution) have been modeled here by applying proper equations found from the literature reviews.

Weibull function is a widely applicable probability density function which is characterized by a non-dimensional shape (k) parameter and scale (c) parameter (in unit of speed). Higher c values represent higher wind speed and the value of k is an indication of how much stable the wind speed is.

The Weibull density function is given by:

$$\mathrm{f}(\mathrm{v}) = \frac{k}{c}\left(\frac{v_i}{c}\right)^{k-1} \exp\left(-\left(\frac{\mathrm{v_i}}{\mathrm{c}}\right)^{k}\right) \quad (3)$$

wheref(v) is the probability of observing the particular wind speed v_i [2-6, 8, 13, 15].

The monthly mean ($\bar{v}$)of wind velocities and their variance (σ^2) can be calculated from available wind speed data using the following equations:

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \quad (4)$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(v_i - \bar{v}\right)^2 \quad (5)$$

where n is the number of hours in the considered period of time and v_i is the recorded wind velocities [2, 5, 8, 13].

Now, Weibull parameters k and c [5, 8, 13, 15] can be calculated by:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}, \quad (1 \le k \le 10) \qquad (6)$$

$$c = \frac{\bar{v}}{\Gamma.\left(1 + \frac{1}{k}\right)} \quad (7)$$

where Γ is the gamma function defined mathematically [5, 8, 15] in general x-variable as:

$$\Gamma(x) = \int_0^{\infty} \mathrm{e}^{-u} u^{x-1} du \quad (8)$$

The values of the Weibull parameters k and c on monthly basis have been found out by MATLAB 2013a software at two different heights (4.4 m and 25 m) which have been presented in Tables 3 and 4.

Table 3. Values of Weibull parameters k and c for the time period 2009-2013 at 4.4 m

Month	2009		2010		2011		2012		2013	
	k	c	k	c	k	c	k	c	k	c
Jan	1.55	0.65	2.26	0.64	2.14	0.71	3.05	1.10	3.15	0.39
Feb	1.75	1.11	2.02	0.73	2.37	1.06	3.16	0.77	2.59	0.79
Mar	1.64	1.09	1.93	2.36	1.61	2.09	2.40	1.68	2.47	1.27
Apr	2.50	2.45	2.78	3.11	2.64	1.50	2.89	1.06	2.63	1.62
May	1.94	2.40	2.53	2.49	1.86	1.41	2.37	0.88	2.43	2.00
Jun	3.03	2.48	2.46	2.54	2.05	2.31	2.30	1.80	2.80	1.15
Jul	2.78	2.99	2.88	2.66	1.88	2.18	2.29	1.34	3.18	1.53
Aug	2.68	2.21	2.09	1.72	1.84	1.98	1.98	1.08	2.38	1.21
Sept	2.32	1.76	2.17	1.62	2.34	2.36	2.07	1.00	2.20	0.95
Oct	1.55	1.12	1.90	1.09	2.29	1.08	1.69	0.70	2.53	0.70
Nov	2.34	0.80	2.05	0.84	3.21	0.79	2.85	0.46	2.73	0.51
Dec	2.05	0.50	2.02	0.84	2.46	0.92	2.59	0.39	2.47	0.46

Table 4. Values of Weibull parameters k and c for the time period 2009-2013 at 25 m

Month	2009		2010		2011		2012		2013	
	k	c	k	c	k	c	k	c	k	c
Jan	1.55	1.1	2.26	1.1	2.14	1.21	3.06	1.87	3.15	0.67
Feb	1.76	1.86	2.49	1.25	2.38	1.8	3.33	1.24	2.59	1.36
Mar	1.64	1.85	1.93	3.99	1.62	3.54	2.41	2.83	2.47	2.15
Apr	2.51	4.14	2.79	5.24	2.65	2.54	2.9	1.79	2.64	2.74
May	1.95	4.03	2.54	4.18	1.87	2.39	2.38	1.49	2.43	3.38
Jun	3.04	4.18	2.46	4.3	2.05	4.43	2.31	3.05	2.8	1.94
Jul	2.78	5.05	2.88	4.49	1.84	3.68	2.29	2.26	3.18	2.58
Aug	2.68	3.74	2.1	2.92	1.85	2.45	1.99	1.82	2.38	2.06
Sept	2.33	2.96	2.18	2.74	2.35	3.99	2.08	1.69	2.21	1.62
Oct	1.55	1.9	1.91	1.84	2.29	1.82	1.69	1.20	2.54	1.20
Nov	2.35	1.36	2.05	1.43	3.21	1.35	2.85	0.79	2.74	0.87
Dec	2.06	0.86	2.02	1.45	2.47	1.56	2.59	0.68	2.48	0.79

A special and simplified case appears when k is exactly 2 which is known as Rayleigh distribution. This function is written as:

$$\mathrm{f}(\mathrm{v}) = \frac{\pi v_i}{2\bar{v}^2} \exp\left(-\frac{\pi}{4}\left(\frac{v_i}{\bar{v}}\right)^2\right) \qquad (9)$$

where f(v) is the probability of observing the specific wind velocity v_i[5, 8, 13].

V. COMPARISON BETWEEN WEIBULL AND RAYLEIGH'S PROBABILITY DISTRIBUTION FUNCTIONS

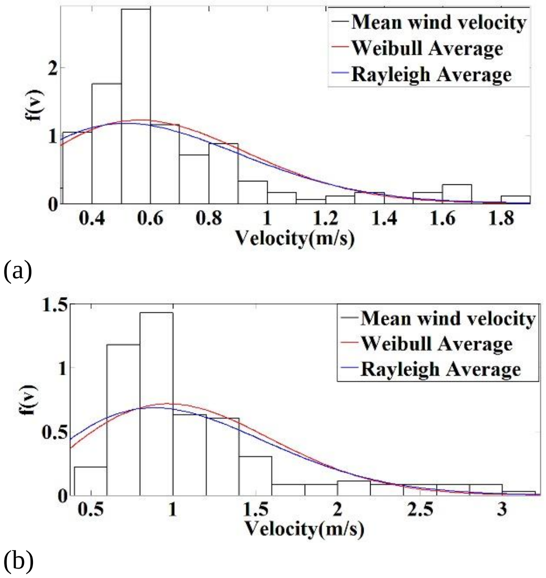
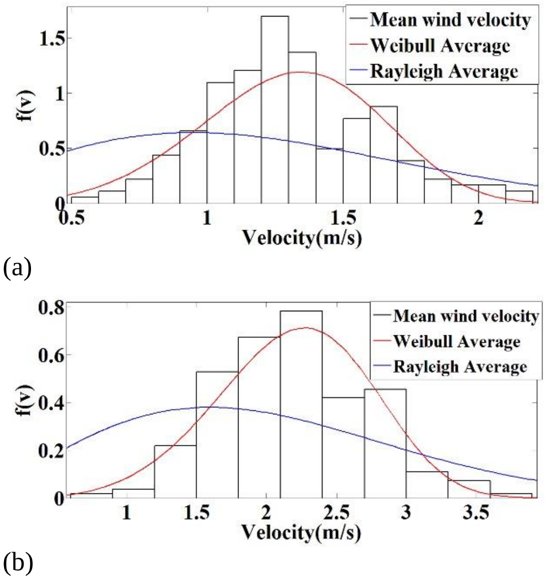


Figure 6. Comparison between average probability distributions of wind speed using Weibull and Rayleigh's method in dry season at (a) 4.4 m and (b) 25 m

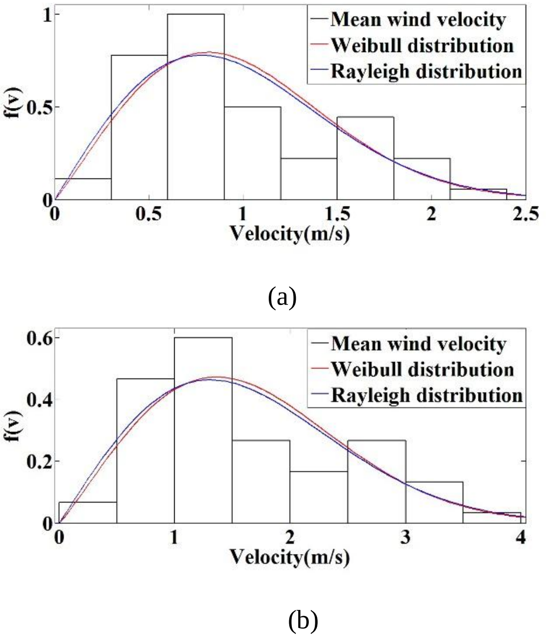


(a)

(b)

Figure 7. Comparison between average probability distributions of wind speed using Weibull and Rayleigh's method in rainy season at (a) 4.4 m and (b) 25m

Figs. 6 and 7 show the comparison between Weibull and Rayleigh's distribution functions for wind velocities in the dry season and in the rainy season at 4.4 m and 25 m heights respectively. For these seasonal probability distributions, it has been seen that in case of dry season there is not much variation between Weibull and Rayleigh distributions, but in case of rainy season Weibull model fits the wind data better. In rainy season wind speed fluctuates in a great extent in this Agartala region and so the k and c parameters. Therefore the Weibull model, which can cover a large range of k ($1 \leq k \leq 10$), fitted the wind data better compared to Rayleigh model which is applicable for only $k = 2$. In this dry season the average probability of observing wind velocity 0.6 m/s and 1 m/s is the highest in the five years period. But in case of rainy season, at 4.4 m height Weibull model gives higher probabilities for wind speeds ranging from 1-1.8 m/s and at 25 m height also Weibull model does the same for wind speeds ranging from 2-3 m/s. At 4.4 m height, for very low wind speeds (less than 1 m/s) and very high wind speeds (greater than 2 m/s), Rayleigh distribution shows higher probabilities compared to Weibull distribution. At 25 m height also Rayleigh model shows higher probabilities for less than 1.5 m/s and greater than 3.5 m/s wind speeds comparatively. It has been observed that in this rainy season 1.4 m/s and 2.3 m/s wind speeds are having highest average probabilities at 4.4 m and 25 m height respectively in the five years time period.

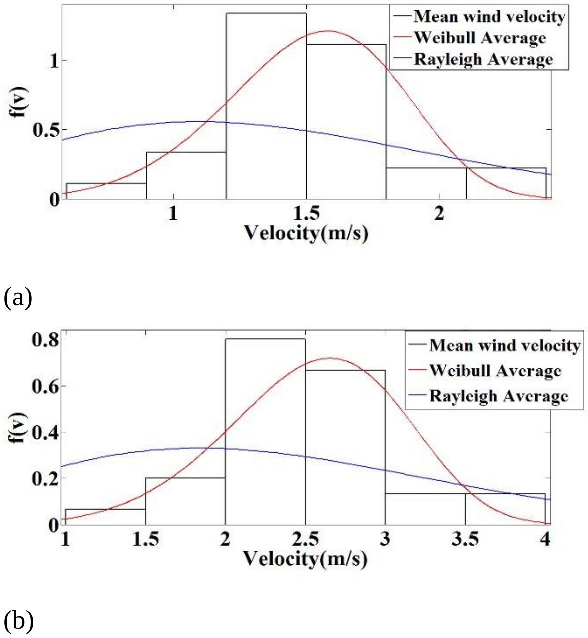


(a)

(b)

Figure 8. Weibull and Rayleigh's comparison for the average wind speed of all months for 5 years (2009-2013) at (a) 4.4 m and (b) 25 m

In Fig. 8 Weibull and Rayleigh model has been plotted considering all monthly mean wind speeds of five years period. From these figures, it is observed that there is very little difference between the two models to fit the wind speed data. However to check the wind probability on monthly basis, probability distribution graphs have been plotted for June and July months (as these two months have the highest average wind speed for the considered time period 2009-2013 for both heights).



(a)

(b)

Figure 9. Comparison between probability distributions of wind speed using Weibull and Rayleigh method for June month at (a) 4.4 m and (b) 25 m

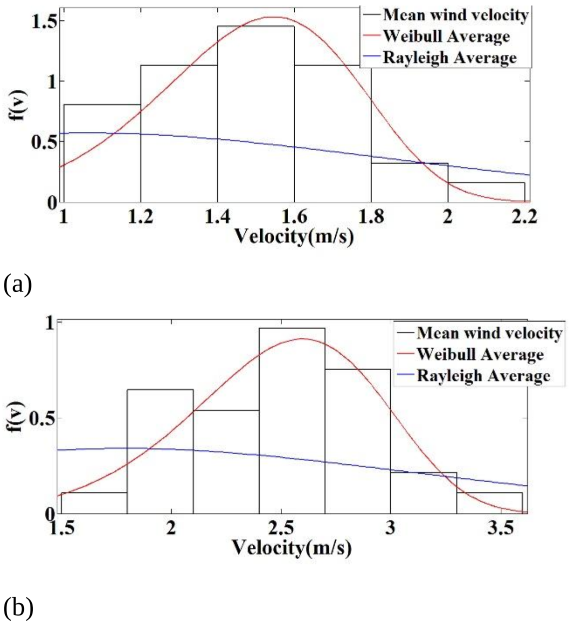


Figure 10. Comparison between probability distributions of wind speed using Weibull and Rayleigh method for July month at (a) 4.4 m and (b) 25 m

From the Figs. 9 and 10 it can be seen that in case of monthly probability distributions, Weibull curve fits better the actual wind speed data compared to Rayleigh distribution unlike Fig. 8. So it can be said that Weibull is a better fit model in case of monthly and rainy seasonal data for Agartala city which is dissimilar for dry seasonal and annual wind data.

If a wind turbine is installed in this particular site, then by this cumulative distribution the working time period of the turbine can be predicted which can help researchers to estimate annual wind energy generation from that turbine [6].

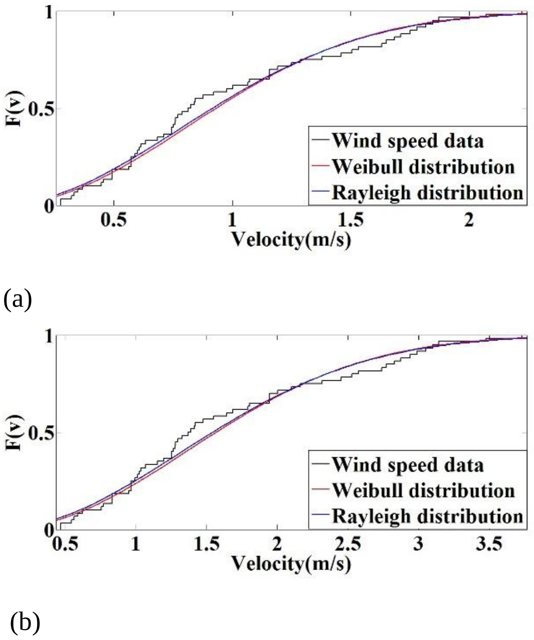


Figure 11. Cumulative distribution function of the annual mean wind velocity at (a) 4.4 m and (b) 25 m of five years

Cumulative distribution functions have been plotted in Fig. 11 at two different heights obtained from the mean wind speed data incorporating Weibull and Rayleigh models. From the diagram it is seen that both the models match the wind speed data almost equally.

VI. ARIMA PROCESS FOR PREDICTION AND VALIDATION OF WIND SPEED DATA

To predict future points in a time-series data by validating current data points in that series, autoregressive integrated moving average (ARIMA) models are used. To avoid complex computation for different hybrid models, single ARIMA model is used as it gives accepted level of accuracy [10]. It is normally known as an ARIMA (p,d,q) model and the parameters p, d and q are non-negative integers that indicate the order of the autoregressive, integrated, and moving average parts of the model respectively. This model has the capability to analysis both seasonal and non-seasonal data.

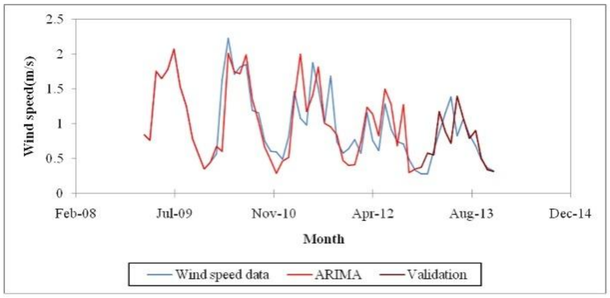


Figure 12. ARIMA model for validating wind speed data at 4.4 m height

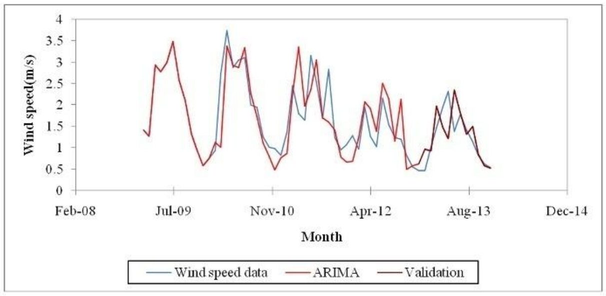


Figure 13. ARIMA model for validating wind speed data at 25 m height

ARIMA (1 0 0) is a well applicable and accepted form of this model which has been applied here for calculation purpose in statistical software [16]. For modeling the process, five years (2009-2013) wind speed data series have been averaged on monthly basis. Figs. 12 and 13 show the ARIMA model at two different heights that has been presented for all the 5 years and the data of 2013 has been chosen for validation purpose. The overall residual for ARIMA model was within ±1 m/s. It can be observed from the figures that the actual wind speed data and the data generated by ARIMA model have very less divergence and close to each other for both 4.4 m and 25 m heights.

However, on the basis of attained results of wind speed and power for the considered time period of Agartala, it can be said that this city is a low wind speed region and conventional wind energy generators have minimum scope for power generation in this place. But, presently some vertical axis wind turbines came into picture which are having low cut-in wind speed and could be installed for power production in low wind speed terrain like the current place considered. Several researchers have manufactured such type of wind turbines [17, 18] which have start-up wind speed in the range of 1-2 m/s and cut-in wind speed in the range of 2-3 m/s but thorough research is needed on these turbines as detailed analytical data is not yet available for these vertical axis wind turbines.

VII. CONCLUSION

The main objective of this study is to determine wind energy potential of Agartala (Tripura, India) by using various models over a period of five years from 2009-2013. The following conclusions can be drawn based on the present study:

- In Agartala, significantly low wind speed is observed, the highest being 1.51 m/s at 4.4 m height and 2.54 m/s at 25 m height in the month of June. At 25 m height better average wind velocity is observed in the period from March to June when the wind velocity always remains greater than or equal to 2 m/s.
- During the month of June, the average power density is found highest which are about 4.06 W/m^2 and 19.28 W/m^2 at 4.4 m and 25 m respectively. So, it can be concluded that Agartala city falls in a low wind power potential region.
- Wind rose diagram reveals that most frequent wind velocity ranging from 1-2 m/s in Agartala city blows from South and South-East direction.
- Compared to Rayleigh model, Weibull model fits the recorded wind speed data better in case of monthly and rainy seasonal data plot to measure the probability density distribution for the time period 2009-2013.
- ARIMA model gives good wind speed prediction which is closer to the actual wind speed data. Therefore, single ARIMA model itself can be useful for prediction of wind speed data of Agartala city. By using this model, future wind speed data for every year on monthly basis can also be predicted.
- Agartala city can be considered as a low wind speed region which is less suitable for wind energy development but some specially designed vertical axis wind turbines have the capability to successfully operate in such low wind stream region.

ACKNOWLEDGEMENT

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Authors Profile

A.R.Senguptareceived his**B.E**degree in Mechanical engineering from National Institute of Technology, Agartala, India in 2010. In 2012 he received his **M.Tech** degree in Thermal engineering from National Institute of Technology, Silchar, India. Currently he is a**Ph.D.**studentin Mechanical engineering in NIT, Silchar, India. His research interest is in the field of wind energy, fluid dynamics analysis.

Dr. A.Biswasreceived his **M.Tech** degree in Thermal Engineering fromNational Institute of Technology, Silchar, India.He has done **Ph.D** from NIT Silchar in the year 2010.Currently he working as an Assistant Professor in the Mechanical Engineering dept. of NIT Silchar. He has published about 30 papers in different International/National Journal/Conferences. His research interest is in the field of renewable energy, thermal engineering.

Prof.(Dr.)R.Guptahas done **Ph.D** from Indian Institute of Technology, Delhi, India in the year 1995. Currently he is the Director of NIT Srinagar. He has published more than 120 papers in different International/National Journal/Conferences. His research interest is in the field of thermal engineering, fluid dynamics and its applications, wind energy etc.