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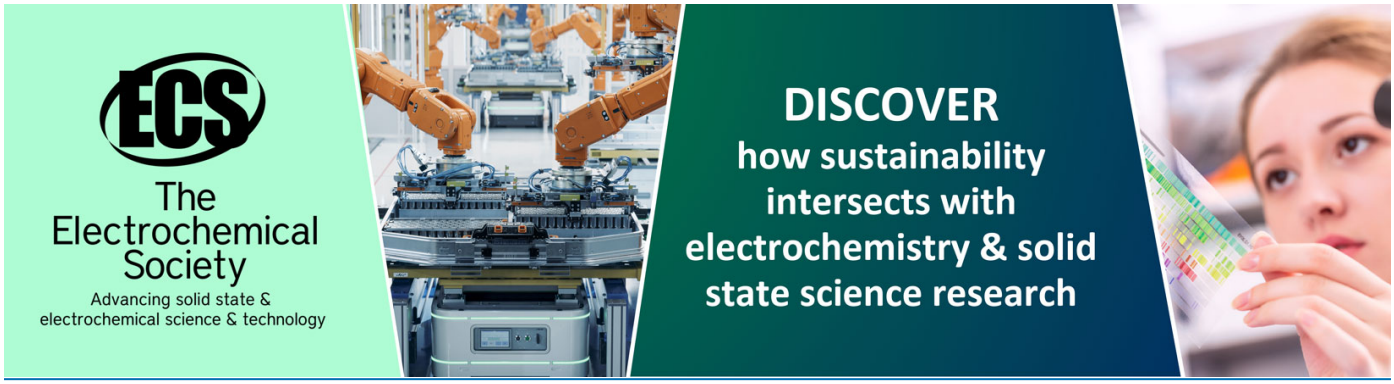

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Analysis of Wind Energy Possibilities of Different Sites in India.

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Abstract. Wind energy is one of the most cost effective renewable energy resources. The purpose of this study is to investigate wind energy potential at different sites in India from year 2008-2017 for six month basis (March to August). The average wind speed data for different sites indicates that the average wind speed for site Tiruchirappalli is highest. The normal probability plot shows that wind speed data are normally distributed except for the site Kolkata. Weibull cumulative probability plot shows that the higher probability of occurrence of wind energy was at higher average wind speed for each site. Weibull probability density function shows that the probability density function is minimum at higher average wind speed. It is also found that the scale parameter is an important parameter compare to shape parameter that affect wind speed. The analysis of power density shows that the average power density for site Tiruchirappalli is highest and lowest for site Agartala. The analysis also shows that higher wind energy possibility is in Tiruchirappalli followed by Coimbatore.

1. Introduction

Energy is very essential input for the growth of human development as it is directly correlated to the consumption of energy. The need of renewable energy to satisfy human needs and economic development of a country is increasing rapidly day by day [1]. Due to industrialization, development of technology and increasing population of a country, fossil fuel reserves got depleted and increase environmental pollution. The cost of fossil fuels is also increasing trends in recent years [2]. Therefore, all country needs to search for other sources of energy to overcome the shortage of conventional energy. Renewable energy can serve human need of energy. Renewable energy is energy which is collected from resources like bio-mass, sunlight, wind, tides, and geothermal heat. Accordingly, REN21's 2017 report, renewable energy resources contribute 19.3% to global energy consumption and 2.2% energy is collected from resources: wind, solar, geothermal, and biomass [3]. In India, the demand for energy has increased for satisfying people needs and India has ranked third for the consumption of energy after China and United States, and also second rank for coal consumption after China [4]. Wind energy is one of the most cost effective non-conventional energy sources which are non-polluting, cost effective, clean, and never-ending resource compared to conventional energy resources which can satisfy energy demand. Therefore the transformation of wind power to electrical energy has been developing very rapidly [5]. Wind energy met ~4% of global

energy demand in 2015. In recent years, wind power generation in India has significantly increasing. The wind generation capacity for state Tamil Nadu, India is ~29% of total capacity and a total installed wind capacity is 8,197 MW, followed by Gujarat [6].
Temitope R Ayodele et al. investigated wind power potential of Port Elizabeth using statistical Weibull parameters [7]. The results show that the average wind power density is maximum during spring season and lowest during autumn season. Hussain et al. studied the wind energy potential at different cities Assam, India and found that most suitable city for wind energy generation was Dibrugarh [8]. Kamran Abbas et al. developed best fitting distribution of wind speed in Islamabad on a daily basis from year 2001-2003 using different probability models: [9]. They found that Gamma, Lognormal and Burr distributions was more consistent compare to other models considered. Serap AKCAN compared time series methods for wind energy at nine stations in Turkey [10]. He found that the country Turkey was rich wind energy potential to compensate energy needs. Mahyoub H. Al Buhairi investigated possibility of renewable energy in country Yemen using statistical methods [11]. He found that the Weibull distribution showed better power density estimations compare to Rayleigh distribution. Djamal Hissein Didane et al. studied monthly and yearly wind speed data, and wind power density for different stations in Chad by using Weibull function [12]. The yearly averaged wind data revealed that the most suitable metrological station in Chad for generation of wind energy. Rajat Gupta and Agnimitra Biswas investigated the wind energy potential of district Silchar, Assam, India over a period of five years by using Weibull and Rayleigh's distribution functions [13]. The average wind velocity data showed that the region Silchar was considered as low wind power generation region. Sengupta et al. studied wind energy potential of Silchar (Assam, India) by using different models over a period of four years from 2008-2011 [14]. They found that the Weibull model best fitted compare to Rayleigh's model to measure the probability density distribution.
Therefore, the geographical position of wind speed and distribution of wind speed analysis by using the statistical model is essential for selection of a particular region for wind energy generation. So; in this article, an investigation has been made for possibility of wind energy potential for different region in India. The selected sites in this study were Dibrugarh Airport, Kolkata, Agartala, Tiruchirappalli, Coimbatore and Jai Prakash Narayan airport, Patna.

2. Location of Sites

The meteorological sites used in our study are Dibrugarh Airport (Dibrugarh Assam); Kolkata (West Bengal); Agartala (Tripura); Tiruchirappalli (Tamil Nadu); Coimbatore (Tamil Nadu); Jay Prakash Narayan Airport (Bihar). Dibrugarh Airport is located at a distance of ~15 km from Dibrugarh city, Assam, India. The airport is located at 110 m above sea level. The latitude and longitude of site Dibrugarh Airport is 27.4728° N and 94.9120° E respectively. The next site has been selected Kolkata which is known as capital of West Bengal, India. The latitude and longitude of site Kolkata are 22°33'45.47"N and 88°21'46.94"E respectively. Agartala, the capital of Tripura located at 23° 30' 0" N, 91° 30' 0" E. The geographic coordinates of Tiruchirappalli having latitude: 10°48′55″ N, longitude: 78°41′47″ E and 79 m elevation above sea level: 79 m. Coimbatore is a major site of Tamil Nadu, India. The latitude of Coimbatore is 11.0168° N, and the longitude is 76.9558° E. Coimbatore site elevation is 420 meters height above sea level. Jay Prakash Narayan Airport is located in Patna, the state capital of Bihar in India. The Latitude and longitude of Jai Prakash Narayan airport Patna is 25.5947° N and 85.0908° E respectively.

3. Data Collection

The necessary wind speed data for different sites for the month of March to August from year 2008-2017 have been collected from website www.weatheronline.in. The average wind speed data for six months for sites is shown in table 1.

Table 1. Wind Speed Data (m/s), different sites of India

Site no.	Site	2008	2009	2010	2011	2012
1	Dibrugarh	1.59	1.36	2.06	1.50	1.74
2	Kolkata	0.54	0.85	0.93	0.84	0.82
3	Agartala	1.38	1.34	1.57	1.09	1.15
4	Tiruchirappalli	4.78	4.82	3.43	3.39	4.03
5	coimbatore	3.19	3.31	3.38	4.06	4.35
6	Patna	1.97	2.30	2.47	2.78	1.95
Site no.	Site	2013	2014	2015	2016	2017
1	Dibrugarh	1.82	1.78	1.53	2.18	2.41
2	kolkata	0.81	2.15	2.38	2.48	2.64
3	Agartala	1.17	1.17	1.01	1.03	0.98
4	Tiruchirappalli	4.37	4.07	3.43	3.61	3.28
5	coimbatore	4.14	4.05	3.36	3.22	3.85
6	Patna	2.93	2.48	2.35	2.99	2.24

4. Results and Discussion

4.1 Analysis of Average Wind Speed variation

The variation of average wind speed (six month basis) of different sites in India from year 2008 to 2017 is shown in figure 1. It has been observed from figure 1 that the average wind speed is maximum for the site Tiruchirappalli is highest in 2009, followed by site Coimbatore in 2012. The lowest wind speed has been observed in the site Kolkata in 2008 followed by site Agartala in the year 2017. The highest and lowest average wind speed for (six months average) for site Tiruchirappalli is 4.82 m/s in the year 2009 and 3.28 m/s in the year 2017 respectively. For site Coimbatore 4.35 m/s in 2012 and 3.19 m/s in 2008, for site Patna 2.99 m/s in 2016 and 1.95 m/s in the year 2012 respectively. The monthly average wind speed in all the years revealed that the wind speed is maximum for site Tiruchirappalli ~ 5.78 m/s in july and minimum for site Agartala in march ~ 0.9916 m/s. The average wind speed indicates that the site Tiruchirappalli is best suitable for wind power generation followed by site Coimbatore. The grand average wind speed in years considered shows that the grand average wind speed is highest 4.39 m/s for site Tiruchirappalli, followed by coimatore 4.12 m/s. The lowest grand average wind speed for the years considered is found in the city Agartala about 1.14 m/s. The analysis also revealed that the site Tiruchirappalli is best suitable for wind power generation followed by site Coimbatore.

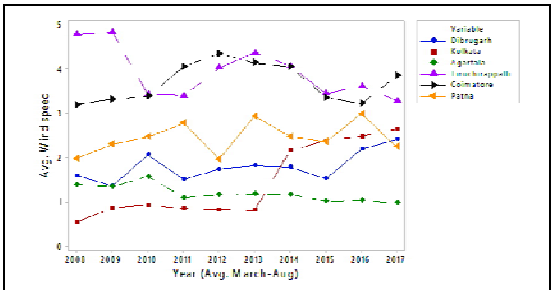


Figure 1. variation of average wind speed with different sites from year 2008-2017.

4.2 Frequency distribution against Average. Wind Speed

The frequency distribution of averages wind speed from the year 2008-2017 (for six months/year) as shown in figure 2. The figure revealed that the frequency of average wind speed for city Dibrugarh lies in between 1.3 m/s to 2.5 m/s and maximum frequency lies in between 1.5 m/s-1.9 m/s. For site Tiruchirappalli, the frequency distribution lies in between average wind speed 3.1 m/s- 4.9 m/s and maximum frequency of three for average wind speed lies 3.3 m/s-3.5m/s. The mean and standard deviation of wind speed for 10 years (March-August) for site Tiruchirappalli are 3.926m/s and 0.5825 respectively, which are maximum values compare to other sites considered. The mean wind speed and standard deviation for site Agartala are minimum compare to other sites. The frequency of average wind speed for each year six month basis is minimum at higher wind speed for all sites from year 2008-2017.

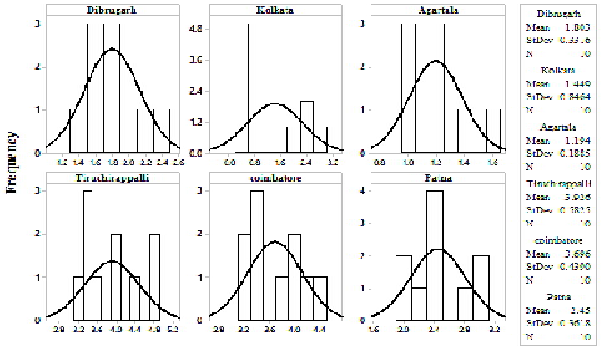


Figure 2. Frequency Disribution of Avgerage Wind Speed for sites, 2008-2017(March-August)

4.3 Normal probability plot

Figure 3 shows probability plot of average wind speed for considered sites from 2008-2017. It is observed from the figure that the data are normally distributed for all sites except the site Kolkata at 95% confidence interval since p-value >.05. The figure shows that the speed variation is minimum for site Agartala as standard deviation is minimm followed by site Dibrugarh. The figure also revealed that the variation of wind speed is maximum for site Kolkata followed by site Tiruchirappalli and Coimbatore.

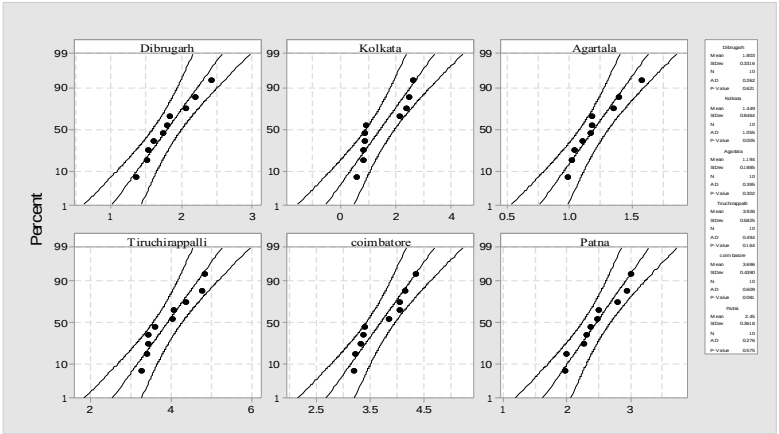


Figure 3. Normal probability plot of Average Wind Speed for sites, 2008-2017(March-August)

4.4 Weibull cumulative probability plot

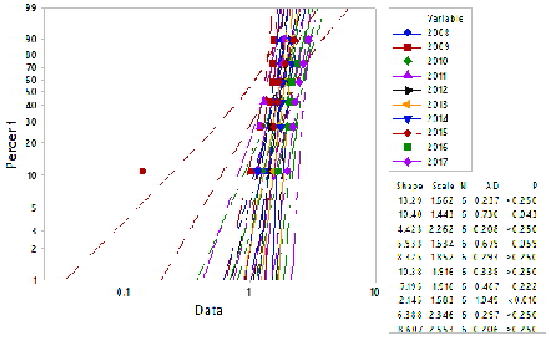
Probability distributions and functions are used to analyze wind speed data. In the articles, Weibull plot is widely used for this purpose [15-16]. Table 2 shows that the cumulative probability of average wind speeds from year 2008-2017. The table 2 revealed that the higher probability of occurrence of wind power at higher average wind speed for site Dibrgarh. The occurrence of maximum average wind speed (2.41667 m/s) for site Dibrugarh is 97.6071% in 2017. Similarly, the occurrence of maximum average wind speed for site 95.0277% in the year 2009.

Table 2. Weibull cumulative probability of different sites in India.

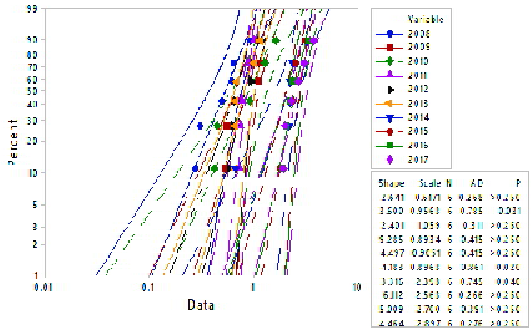
Dibrugarh		kolkata	
Weibull with shape = 5.981 and scale = 1.939		Weibull with shape = 1.947 and scale = 1.646	
x	P(X ≤ x)	x	P(X ≤ x)
1.59722	0.269162	0.5463	0.110223
1.36574	0.115669	0.85648	0.244438
2.06019	0.762371	0.93519	0.282958
1.50926	0.200246	0.84722	0.23999
1.74537	0.413158	0.82407	0.22896
1.82407	0.500372	0.81481	0.224585
1.78704	0.458695	2.15278	0.814815
1.53241	0.217099	2.38426	0.872214
2.18981	0.873816	2.48148	0.891813
2.41667	0.976071	2.64352	0.919166
Tiruchirappalli		coimbatore	
Weibull with shape = 7.543 and scale = 4.174		Weibull with shape = 9.942 and scale = 3.885	
x	P(X ≤ x)	x	P(X ≤ x)
4.78241	0.938635	3.19907	0.134937
4.8287	0.950277	3.31944	0.188824
3.43056	0.203664	3.38889	0.22671
3.39815	0.191034	4.06019	0.787832
4.03241	0.53736	4.35648	0.955972
4.375	0.759693	4.14352	0.850043
4.07407	0.565237	4.05093	0.78032
3.43981	0.20738	3.36111	0.210931
3.61574	0.287215	3.22685	0.146119
3.28241	0.150608	3.85185	0.600817
Patna		Agartala	
Weibull with shape = 7.856 and scale = 2.602		Weibull with shape = 6.653 and scale = 1.274	
x	P(X ≤ x)	x	P(X ≤ x)
1.97685	0.109064	1.38889	0.830708
2.30093	0.316539	1.34259	0.757679

2.47222	0.487791	1.57407	0.983165
2.78241	0.816075	1.09722	0.309375
1.95833	0.101701	1.15741	0.410251
2.93519	0.923988	1.17593	0.443938
2.48148	0.497903	1.1713	0.43542
2.35648	0.368111	1.01389	0.196564
2.99074	0.949502	1.03241	0.218754
2.24537	0.269552	0.98148	0.16165

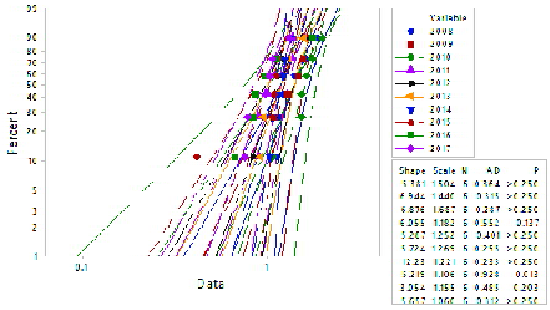
The cumulative probability plot for different sites from year 2008-2017 is shown in figure 4(a)-(f). The Weibull shape parameter (k) and scale parameter (c) for different sites were evaluated by using MINITAB version 18 as shown in figure 3. It is observed from figures that the two parameters are high at higher average wind speed. The scale parameter for site Tiruchirappalli is maximum about 4.174 m/s, followed by site Coimbatore. The minimum value of scale parameter for site Agartala is 1.646 m/s. From the analysis it is observed that the scale parameter is an important parameter compare to shape parameter that affect wind speed.



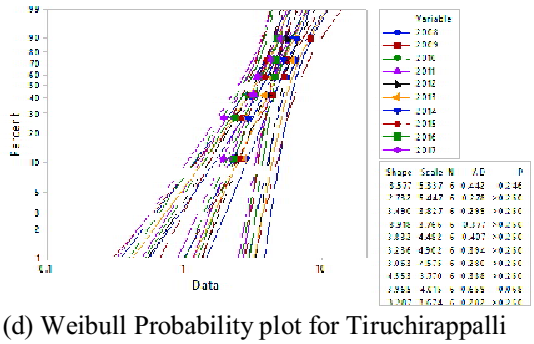
(a) Weibull Probability plot for Dibrugarh from year 2008-2017



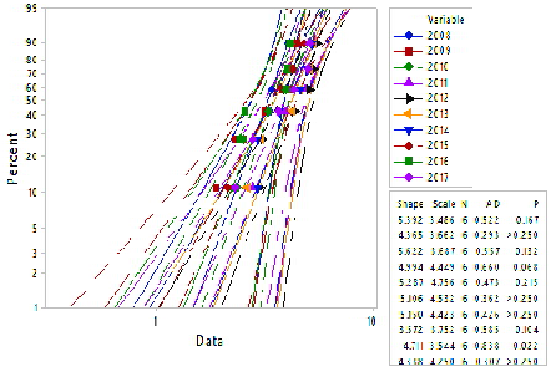
(b) Weibull Probability plot for Kolkata from year 2008-2017



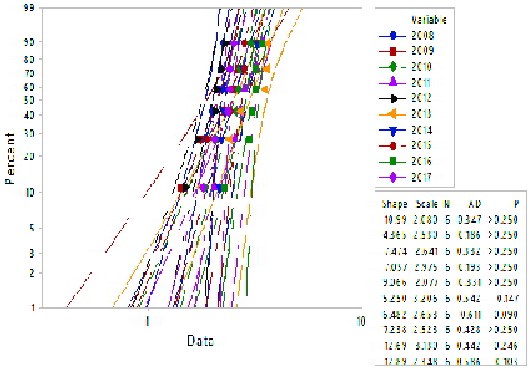
(c) Weibull Probability plot for Agartala from year 2008-2017



(d) Weibull Probability plot for Tiruchirappalli from year 2008-2017



(e) Weibull Probability plot for Coimbatore from year 2008-2017



(f) Weibull Probability plot for Patna from year 2008-2017

Figure. 4(a)-(f) Weibull Probability plot for different sites

4.5 Probability density function plot

The Weibull probability density function plot for different sites from year 208-2017 is shown in figure 5. From the figure 4, it is observed that the probability density function is minimum for site Tiruchirappalli at higher average wind speed and maximum for site Agartala at lower average wind speed. This indicates that at higher average wind speed, probability density function is minimum.

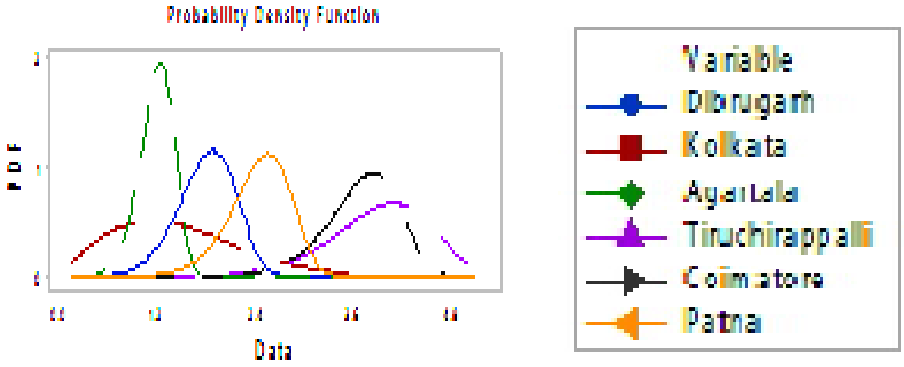


Figure. 5 Weibull Probability plot for different sites from year 2008-2017

4.6 Wind Power Density

The wind power density based on Weibull distribution function is calculated using the following equation [17]:

$$\frac{P}{A}=\frac{1}{2}\rho c^3\Gamma\left(\frac{k+3}{k}\right)$$

Where,

k is Weibull shape parameter

c is Weibull scale parameter

ρ is density of air =1.225 kg/m^3

Table 3 shows the average power density for different sites for six month basis. The average wind power density for site Dibrugarh is highest in the year 2017 and equal to 9.084104 W/m^2. The average wind power density for site Tiruchirappalli is 103.493 W/m^2 in the year 2009. The average wind

power density for site Coimbatore is 58.6611W/m^2 in the year 2012. The grand all-year average power density for site Tiruchirappalli is highest (52.66388 W/m^2), followed by Coimbatore (38.00481 W/m^2), Patna (10.428 W/m^2), Kolkata (4.413379 W/m^2), Dibrugarh (4.38688 W/m^2) and Agartala (1.24900 W/m^2). The variation of Average Wind Power Density with respect to years, 2008-2017 as shown in figure 6 and the figure revealed that the most suitable site for wind power generation is site Tiruchirappalli, followed by Coimbatore, Jai Prakash Narayan airport Patna, Kolkata, Dibrugarh, Agartala.

Table 3. Average Wind Power Density for different sites of India

Year	Dibrugarh	Kolkata	Agartala	Tiruchirappalli	Coimbatore	Patna
2008	2.563727	0.153338	1.85338	87.73091	23.07605	4.97145
2009	1.655031	0.503871	1.62038	103.493	27.26018	8.98949
2010	6.41341	0.82394	2.60511	32.56471	27.09907	10.0098
2011	2.368662	0.390568	0.89626	30.09393	48.19865	14.2918
2012	3.463323	0.410012	1.07013	51.11856	58.6611	4.90227
2013	3.873912	0.402221	1.11054	70.07961	50.86569	17.9757
2014	3.819065	8.086015	1.01168	58.15169	47.25627	10.1287
2015	3.623622	9.136266	0.73826	29.58649	30.49365	8.72109
2016	7.003945	10.77062	0.9368	36.49443	24.48805	17.0785
2017	9.084104	13.45694	0.64749	27.32547	42.64933	7.21613
Average	4.38688	4.413379	1.249	52.66388	38.00481	10.428

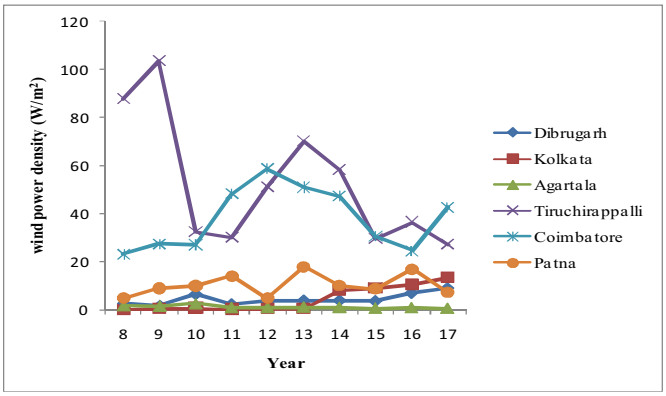


Figure 6. Variation of Average Wind Power Density vs. years 2008-2017.

5. Conclusion

In this article an investigation has been made to evaluate the possibility of wind energy potential at different sites in India by using statistical tools. The variation of average wind speed of different sites in India revelled that the average wind speed for the site Tiruchirappalli is the highest compare to other sites considered and lowest average wind speed is for site Agartala. The frequency of average wind speed for each year is minimum at higher wind speed for all sites. The normal probability plot shows that the wind data are normally distributed except for site Kolkata and the variation of average wind speed is maximum for site Kolkata. Weibull cumulative probability plot revealed that the higher probability of occurrence of wind power at higher average wind speed. The Weibull probability density function shows that at higher average wind speed, probability density function is minimum. It is also found that the scale parameter is an important parameter compare to shape parameter that affect

wind speed. The most important factor of the wind energy is the wind speed. The six-month average power density from year 2008-2017 for site Tiruchirappalli is highest (52.66388 W/m^2), followed by Coimbatore (38.00481 W/m^2) and minimum for site Agartala (1.24900 W/m^2). Therefore, high wind power generation possibility is in the region Tiruchirappalli followed by Coimbatore. So, an accurate evaluation of probability distribution of wind speed data is necessary to find wind energy possibility at different sites.

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