

Evaluation of Wind Energy Potential of the State of Tamil Nadu, India Based on Trend Analysis

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An accurate estimate of wind resource assessment is essential for the identification of potential site for wind farm development. The hourly average wind speed measured at 50 m above ground level over a period of 39 years (1980- 2018) from 25 locations in Tamil Nadu, India have been used in this study. The annual and seasonal wind speed trends are analyzed using linear and Mann-Kendall statistical methods. The annual energy yield, and net capacity factor are obtained for the chosen wind turbine with 2 Mega Watt rated power. As per the linear trend analysis, Chennai and Kanchipuram possess a significantly decreasing trend, while Nagercoil, Thoothukudi, and Tirunelveli show an increasing trend. Mann-Kendall trend analysis shows that cities located in the southern peninsula and in the vicinity of the coastal regions have significant potential for wind energy development. Moreover, a majority of the cities show an increasing trend in the autumn season due to the influence of the retreating monsoons which is accompanied with heavy winds. The mean wind follows an oscillating pattern throughout the year at all the locations. Based on the net annual energy output, Nagercoil, Thoothukudi and Nagapattinam are found to be the most suitable locations for wind power deployment in Tamil Nadu, followed by Cuddalore, Kumbakonam, Thanjavur and Tirunelveli.

Keywords: Wind energy; Tamil Nadu; Trend analysis; Mann-Kendall test

1. INTRODUCTION

The global scientific community is concerned about the increasing concentration of greenhouse gases in the atmosphere. It is commonly accepted that burning of the fossil fuels and deforestation are the main causes both in local and international perspectives. Such activities have increased the global mean temperature, resulting in global warming and adverse climate changes. On a lesser scale, the magnitude and rate of atmospheric warming and its consequences may vary from region to region around the globe. Nonetheless, the prime reason for the unprecedented trend in variation of environmental and climatic features is attributed to the continuing over-dependency on fossil fuels for energy production [1]. This has eventually brought about a radical shift in global scientific perspectives with an increasing awareness for inter-disciplinary collaborations to seek alternative clean energy resources to combat the adverse climatic changes. The scope of green, clean, and self renewablesources of energy such as wind, solar photovoltaic, solar thermal, wave, hydropower, biogas, tidal, etc. are being currently explored for power generation. Of these green sources, wind energy has become both technologically and commercially acceptable and is being widely implemented in more than 80 countries.

Wind energy is attractive due to the rapid pace of technical advancement, availability of turbines of all sizes from few kilowatts to multi-megawatts, ease of installation, economical operation and maintenance, affordability, inexhaustibility, environmental friendliness, elegance, distributive nature, and being irrational for any political or physical boundaries [2]. Hence it is essential to devise proper tools and techniques to assess the wind energy potential in a given location for implementing effective strategy for power production.

Numerous studies have been reported on the assessment of wind energy potential in different countries across the world [3]. The potential for power production is generally denoted by power density, expressed as a ratio of average annual available power and the swept area of the turbine. Kainkwa [4] examined the pattern of wind speed and wind power available at Basotu, Tanzania and concluded that the average of wind power density per month from June to November as 114 W/m^2 . Ramachandra and Shruti [5] analysed the potential of wind energy at 18 locations in Karnataka using the wind speed data. Jaramillo and Borja [6] analyzed the statistical characteristics of speed of wind in La Ventosa, Oaxaca, Mexico. They used a bimodal Weibull function and Weibull probability distribution function to analyse the wind frequency distribution. Using Weibull distribution, Ngala et al. [7] performed a statistical analysis of wind energy potential in Maiduguri based on 10 years of wind speed data. In Turkey, Ucar and Balo [8] analysed the characteristics of wind speed at six locations using the wind speed data from 2000 to 2006. Tehran, the capital of Iran is found to be not suitable for

Received: August 2020, Accepted: November 2020

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doi: 10.5937/fme2101244N

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FME Transactions (2021) 49, 244-251 **244**

harnessing wind energy on a large scale. It is based upon the study of Keyhani et al [9] with wind speed data obtained over a period of eleven years. Rasuo and Bengin [10] presented a method for determination of optimum positions of single wind turbines within the wind farms installed on arbitrarily configured terrains to achieve maximum wind power production. A similar study was carried out by Rasuo et al. [11]. Rasuo et al. [12] conducted a review on the harmonization of new wind turbine rotor blades development.

Chandel et al. [13] assessed the wind resource potential of the western Himalayan region in the Indian state of Himachal Pradesh using Weibull distribution. In that region, the peak value of daily mean wind speed was observed in the summer and the lowest in winters. Ko et al. [14] made a wind power resource assessment by installing a meteorological mast in Weno Island, Chuuk state. The expected annual energy production from a wind turbine of 20 kW rated power was reported to be 36,841.73 kWh. Baseer et al. [15] reported the wind power characteristics of seven sites in Jubail, Saudi Arabia using Weibull parameters. Goh et al. [16] assessed wind energy based on wind speed prediction using Mycielski algorithm and K-means clustering at Kudat, Malaysia. Allouhi et al. [17] evaluated the potential of wind energy along the coastal line at six locations (Al Hoceima, Tetouane, Assila, Essouira, Laayoune and Dakhla) in the Kingdom of Morocco. Salam et al. [18] analysed the wind speed characteristics at two different locations of Brunei Darussalam using Weibull distribution. It was reported that the annual energy production was found to be in the range of 1000 and 1500 kWh at 5 m/s wind speed for both the locations.

Rehman [3] has analyzed the wind energy potential in Saudi Arabia at 28 locations based on wind speed data collected over a long period of 37 years. The availability of wind speed for electricity production at Ranchi, Jamshedpur, Devghar, Lohardaga, and Chaibasa, in Jharkhand, India was evaluated by Singh and Prakash [19]. They concluded that the investigated locations were unsuitable for large scale electricity generation but can be used for small applications or loads. Samal and Tripathy [20] estimated the probability distribution for wind at Burla, Odisha along the eastern coast of India. They used Weibull, Gamma, Lognormal, Inverse Gaussian, mixture distributions for the estimation process. Rehman et al. [21] performed the latitudinal wind power resource assessment for selected sites in Tamil Nadu, India. Rehman et al. [22] also analysed the wind power potential across varying topographical features of Tamil Nadu, India. It is clearly evident from records that several studies have been conducted on the determination of wind energy potential around the globe at different places, but the assessment of potential of wind energy based on the trend analysis of wind speed are very less in the literature.

In this study, 25 cities from Tamil Nadu in India are chosen for the trend analysis. The annual and seasonal trends of wind speed are analyzed based on Mann-Kendall and linear statistical methods. Long term mean of annual and monthly wind speed are also calculated. The annual energy yield, net capacity factor, and percentage of duration of rated and zero output are also

calculated for using 2 MW rated power turbine to identify the most suitable locations for the generation of wind power in Tamil Nadu.

2. STUDY AREA AND METHODOLOGY

Chennai is the capital of the state of Tamil Nadu (TN) and is located in the southernmost region of the Indian peninsula. The state is bordered by the Eastern Ghats in the north (the Nilgiri Mountains), Anaimalai hills and Kerala in the west, Bay of Bengal in the east, Gulf of Mannar and Palk Strait in the southeast, and the Indian ocean in the south. The climate of Tamil Nadu ranges from sub-humid to semi-arid. The water needs of the state are highly dependent on the monsoon rainfall, more preferably from the north-east monsoon originating from the Bay of Bengal.

Table 1. Geographical details of the 25 cities located in the state of Tamil Nadu, India

S.No	Location	LAT (°N)	LON (°E)	ALT (m)
1	Ambur	12.79	78.71	323
2	Chennai	13.08	80.27	13
3	Coimbatore	11.01	76.95	420
4	Cuddalore	11.74	79.77	8
5	Dindugul	10.36	77.98	281
6	Erode	11.34	77.71	169
7	Hosur	12.74	77.82	872
8	Kanchipuram	12.83	79.70	89
9	Karaikudi	10.07	78.78	103
10	Karur	10.96	78.07	127
11	Kumbakonam	10.96	79.38	32
12	Madurai	9.92	78.11	137
13	Nagapattinam	10.76	79.84	9
14	Nagercoil	8.18	77.41	37
15	Neyveli	11.54	79.47	87
16	Pudukottai	10.37	78.82	101
17	Rajapalayam	9.46	77.52	172
18	Salem	11.66	78.14	286
19	Thanjavur	10.78	79.13	58
20	Thoothukudi	8.76	78.13	104
21	Tiruppur	11.10	77.34	300
22	Tirunelveli	8.71	77.75	41
23	Thiruvannamalai	12.22	79.07	186
24	Tiruchirappalli	10.79	78.70	93
25	Vellore	12.91	79.13	206

As mentioned earlier, the purpose of this particular study is to identify the suitable locations for electricity generation from wind resources of the state and to analyse the wind speed trends. Subsequently, 25 cities situated at distinct geographical locations in the state of Tamil Nadu are chosen, as shown in Figure 1. The geographical details such as latitude (LAT), longitude (LON) and altitude (ALT) of the chosen sites are provided in Table 1. Hourly mean wind speed data recorded at a height of 50m above ground level was obtained from MERRA -2 reanalysis database (NASA) for the period of Jan 1980 to May 2018 (more than 39 years).



Figure 1. Map of Tamil Nadu showing the chosen 25 cities (marked with square bullets)

2.1 Long-Term Wind Speed Trend analysis

Recognizing annual variation of the mean wind speed enables us to assess the availability of sufficient wind for power production from the wind turbines over the upcoming period. Moreover, the analysis would be helpful in planning and managing the energy output from the wind farms that may exist in the near future. The trends of the wind speed have been analyzed using two methods, namely linear regression and Mann-Kendall test.

2.2.1 Linear trend method

The mean of annual wind speeds for all the locations are plotted and the best regression line coefficients (A and B) and the corresponding coefficient of determination values (R^2) are determined. Based on the regression coefficient ' A ', the trend is categorized as increasing or decreasing or no trend.

2.2.2 Mann-Kendall test

Mann-Kendall test [23-25] is used to analyze the wind speed trend of 25 selected sites. It is a non-parametric test and it does not require the data to be normally distributed. This test possesses a low sensitivity to abrupt breaks due to inhomogeneous time series [26]. The null hypothesis H_0 states that the de-seasonalised data ($x_1, x_2, x_3, \dots, x_n$), a sample of n independent parameters are identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all $k, j \leq n$, with $k \neq j$. The test statistic S , which has a mean zero and a variance computed by Eqn. (3), is calculated using Eqns. (1) and (2), and is asymptotically normal:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_k - x_j) \quad (1)$$

$$\text{gn}(x_k - x_j) = \begin{cases} +1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases} \quad (2)$$

$$\text{var}(S) = \frac{[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)]}{18} \quad (3)$$

The notation t is the extent of any given tie, and \sum_t denotes the summation over all ties. In cases where the sample size $n > 10$, the standard normal variable Z is computed using Eqn. (4):

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

Positive values of Z indicate an increasing trend while negative values of Z show a decreasing trend. When testing either increasing or decreasing monotonic trends at the significance level, the null hypothesis was rejected for an absolute value of Z greater than $Z_{t-1/2}$, obtained from the standard normal cumulative distribution tables [27]. In this study, significance levels of $\alpha = 0.01, 0.05$ and 0.1 have been applied.

3. RESULTS AND DISCUSSION

The values of mean wind speed (MWS), median wind speed (MED), maximum wind speed (MXWS) and standard deviation (SD) are calculated yearly based on the wind speed data over the long term period and is provided in Table 2. For analysis purpose, the maximum value of annual wind speed is graphically represented in Figure 2. From Table 2, it is observed that Hosur has the maximum wind speed of 9.74 m/s and Madurai has the least with 7.24 m/s. There are four more sites that have been observed with the mean maximum wind speeds of more than 9 m/s (Ambur, Nagercoil, Thoothukudi, and Tiruppur). Figure 2 shows that all the 25 cities have a mean wind speed of more than 4 m/s. The estimated mean wind speed is in good agreement with the results provided in Rehman et al. [22] which is based on the Weibull parameters. However, there is a conceptual difference in defining the maximum wind speed for the selected locations as reported by Rehman [22] where the latter is based on the influence of scale and shape parameters and the nature of Weibull distributions. This corroborates with the observation of Phadke et al. [28] that Tamil Nadu is one of the states in India which has excellent potential for wind power deployment. Cuddalore, Nagapattinam, Nagercoil, and Thoothukudi locations have a long-term mean value of wind speed of more than 6 m/s which is an indicative of these sites being promising for wind energy generation.

The long-term annual mean wind speed values were analyzed to study the trends of wind speed over the last 38 years and linear equations are fitted to understand the

future of wind speed availability for wind power generation. Wind speed data of Hosur and Erode showed a minimum decreasing rate of less than 0.00007 per annum and hence can be regarded as having the same intensity of wind over entire data collection period.

Table 2. Statistical analysis of long term wind speed data

S.No	Location	MWS (m/s)	MED (m/s)	MXWS (m/s)	SD (m/s)
1	Ambur	5.41	4.91	9.36	1.24
2	Chennai	5.41	5.41	7.43	0.81
3	Coimbatore	4.72	4.45	8.17	1.39
4	Cuddalore	6.02	5.99	8.49	1.02
5	Dindugul	4.99	4.61	8.98	1.26
6	Erode	4.34	3.89	7.49	1.18
7	Hosur	5.47	5.06	9.74	1.36
8	Kanchipuram	5.41	5.41	7.43	0.81
9	Karaikudi	5.28	5.21	7.36	0.84
10	Karur	5.24	4.83	8.98	1.37
11	Kumbakonam	5.75	5.65	8.72	1.08
12	Madurai	4.54	4.40	7.24	0.85
13	Nagapattinam	6.26	6.27	8.96	1.14
14	Nagercoil	6.50	6.84	9.51	1.52
15	Neyveli	5.50	5.39	8.02	0.95
16	Pudukottai	5.30	5.15	8.48	1.02
17	Rajapalayam	4.08	3.70	7.32	1.27
18	Salem	4.74	4.53	7.73	1.00
19	Thanjavur	5.75	5.65	8.73	1.08
20	Thoothukudi	6.29	6.34	9.62	1.46
21	Tiruppur	5.41	4.62	9.31	1.69
22	Tirunelveli	5.61	5.53	9.02	1.55
23	Thiruvannamalai	5.20	5.16	7.51	0.84
24	Tiruchirappalli	5.46	5.28	8.94	1.21
25	Vellore	5.05	4.83	7.73	0.85

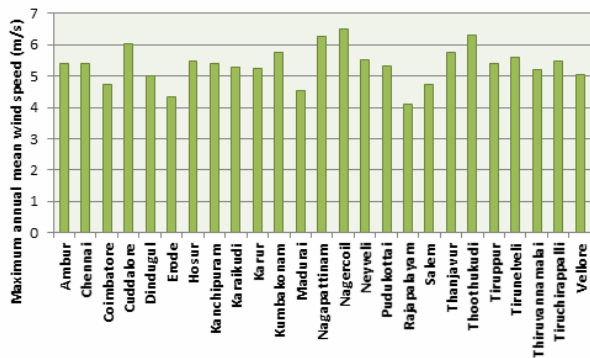


Figure 2. Maximum wind speed (averaged for the years) over Tamil Nadu

Karaikudi, Kumbakonam, Thanjavur, and Tiruppur have annual wind speed decreasing rates varying from 0.0003 to 0.0008 and can be regarded as sites having almost the same wind speed during the entire period of data reporting. Furthermore, the trend analysis showed that Ambur, Coimbatore, Cuddalore, Nagapattinam, Neyveli, Thiruvannamalai, and Vellore are having marginally decreasing trends of 0.0011 to 0.0032 m/s per year. Chennai and Kanchipuram are observed to have significantly decreasing trends of 0.0067 m/s per year. On the other hand, Nagercoil, Thoothukudi, and Tirunelveli showed a significantly increasing trend while Karur, Salem, Madurai, Tiruchirappalli, Rajapalayam, Dindugul and Pudukottai showed marginally increasing trends. A summary of the regression coef-

ficients and R^2 values obtained from the best fit regression lines for all the stations is provided in Table 3 and graphical representation of some representative wind speed trends are shown in Figure 3.

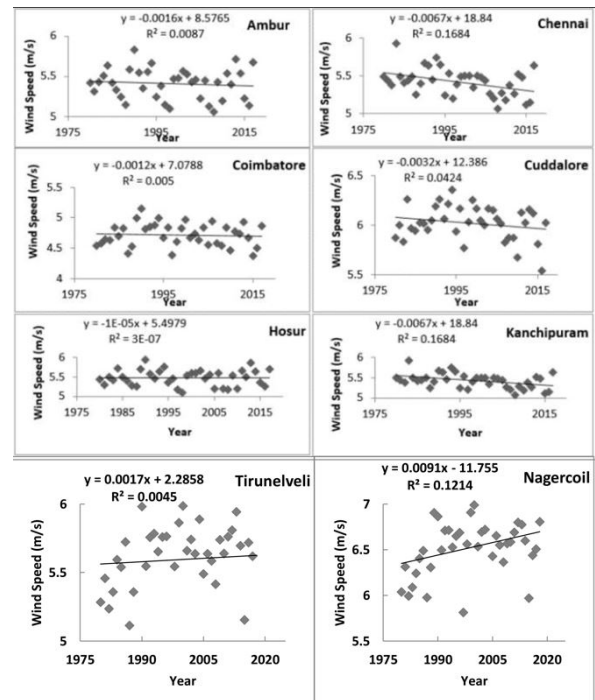


Figure 3. Variation of annual mean wind speed data along with best fit regression line

Table 3. Regression coefficients and R2 obtained from the best fit regression line for annual mean wind speed trend analysis

S.No	Location	Regression coefficients		R^2
		A	B	
1	Ambur	-0.001	8.576	0.008
2	Chennai	-0.006	18.840	0.168
3	Coimbatore	-0.001	7.078	0.005
4	Cuddalore	-0.003	12.380	0.042
5	Dindugul	0.002	0.714	0.015
6	Erode	-7E-05	4.491	3E-05
7	Hosur	-1E-05	5.497	3E-07
8	Kanchipuram	-0.006	18.840	0.168
9	Karaikudi	-0.000	5.916	0.000
10	Karur	0.000	4.233	0.001
11	Kumbakonam	-0.000	7.185	0.002
12	Madurai	0.003	-2.844	0.065
13	Nagapattinam	-0.001	9.132	0.008
14	Nagercoil	0.008	-9.613	0.088
15	Neyveli	-0.001	7.641	0.006
16	Pudukottai	0.000	4.213	0.001
17	Rajapalayam	0.003	-1.899	0.046
18	Salem	8E-05	4.589	3E-05
19	Thanjavur	-0.000	7.185	0.002
20	Thoothukudi	0.007	-9.257	0.139
21	Tiruppur	-0.000	7.082	0.002
22	Tirunelveli	0.005	-5.651	0.065
23	Thiruvannamalai	-0.001	7.735	0.008
24	Tiruchirappalli	0.000	4.468	0.001
25	Vellore	-0.002	10.51	0.034

The highest rate of decrease of 0.0067 m/s in the annual mean value of wind speed is observed at Chennai

and Kanchipuram (Table 3). Similarly, a significant increase in the annual mean wind speed is observed at Nagercoil, Thoothukudi, and Tirunelveli with annual mean wind speed increasing at rates of 0.008 m/s, 0.0078 m/s, and 0.0056 m/s respectively. These three sites are located in the southern region of the state of Tamil Nadu (Figure1), indicating that the southern region has good chance to receive more high speed winds and a good potential for wind energy development. The sites with marginally increasing trends (Dindugul, Karur, Madurai, Salem, Tiruchirappalli, Pudukottai) are located in the central region of the state and such trends could be attributed to the sites being landlocked from all the sites. However, larger variations are observed in the annual mean values at Tiruchirappalli and Pudukottai relative to other landlocked sites which have relatively smaller annual changes.

3.1 Mann-Kendall test Results

This test provides an idea about the trend of long term annual and seasonal mean wind speeds (Table 4). Based on the Mann-Kendall test, Ambur and Thiruvannamalai cities showed neither an increasing nor a decreasing trend in any season. As far as the annual trend is concerned, Chennai and Kanchipuram showed a decreasing trend with a significance level of 0.05. On the other hand, Nagercoil and Thoothukudi showed an increasing trend of 0.1 at the same significance level. During summer, Chennai and Kanchipuram showed a decreasing trend at 0.01 significance level, and Cuddalore, and Vellore at significance levels 0.1 and 0.05 respectively. Nagercoil is the only site indicating a significantly increasing trend of 0.1 significance levels in summer.

During monsoon, a significantly decreasing trend was observed for Chennai, Coimbatore, Cuddalore, Erode, Kanchipuram, Karaikudi, Karur, Kumbakonam, Nagapattinam, Thanjavur, and Tiruppur. Neyveli is the only city which showed an increasing trend in the monsoon season at a significance level of 0.1. Except Neyveli, there were decreasing trends in wind speeds during monsoon at majority of the locations. A majority of the cities (Coimbatore, Dindugul, Erode, Hosur, Karaikudi, Karur, Kumbakonam, Madurai, Nagercoil, Pudukottai, Rajapalayam, Salem, Thanjavur, Thoothukudi, Tiruppur, and Tiruchirappalli) showed an increasing trend in the autumn (September-November) season. This may be due to the retreating north-east monsoon which is accompanied by monsoon winds from the western disturbances emerging over the Mediterranean Sea. During winter, Karaikudi, Madurai and Thoothukudi showed an increasing trend at a significance level of 0.1.

It is imperative to analyse the results from the two methods of trend analysis. It is observed from Tables 3 and 4 that the cities showing significant trend (either positive or negative) are quite same for both the tests. For example, Chennai and Kanchipuram showed significantly decreasing trends while Nagercoil, Thoothukudi and Tirunelveli increasing trends. Furthermore, there are locations where the abrupt changes in the annual average values may not be possible to derive meaningful conclusions based on linear trend test only. However, Mann-Kendall test provided further details on the trend in various seasons, thus enabling sound reasoning to consider the possibilities of seasonal variations in wind speed in response to the climatic conditions.

Table 4. Results of the statistical tests for the seasonal and annual wind speed for the period 1980-2018.

S.No	Cites	Annual	Seasons			
			Summer	Monsoon	Autumn	Winter
1	Ambur	-0.45	-0.91	-0.98	0.93	-1.06
2	Chennai	-2.21**	-3.29***	-1.99**	-1.26	0.45
3	Coimbatore	-0.28	0.10	-2.72***	2.56**	-0.43
4	Cuddalore	-0.83	-1.79*	-3.09***	1.08	1.00
5	Dindugul	0.65	0.45	-1.48	3.07***	0.23
6	Erode	0.20	-0.05	-1.73*	2.99***	-0.48
7	Hosur	0.28	0.28	-1.23	2.09**	-1.06
8	Kanchipuram	-2.21**	-3.29***	-1.99**	-1.26	0.45
9	Karaikudi	0.18	0.23	-2.79***	2.06**	1.68*
10	Karur	0.40	0.33	-1.71*	2.64***	-0.25
11	Kumbakonam	0.10	-0.45	-2.01**	1.86*	1.58
12	Madurai	1.28	1.51	-1.26	2.49**	1.73*
13	Nagapattinam	0.00	-0.78	-2.87***	1.53	1.58
14	Nagercoil	1.73*	1.73*	0.18	2.09**	1.31
15	Neyveli	0.18	-0.70	1.89*	1.16	0.96
16	Pudukottai	0.25	0.18	-1.51	2.19**	1.43
17	Rajapalayam	1.26	1.11	-0.78	3.37***	0.03
18	Salem	0.35	0.58	-1.26	2.41**	-0.33
19	Thanjavur	0.10	-0.45	-2.01**	1.86*	1.58
20	Thoothukudi	2.19**	1.41	0.43	2.97***	1.79*
21	Tiruppur	-0.38	-0.50	-2.24**	2.26**	-0.38
22	Tirunelveli	1.53	1.18	-0.33	2.19**	1.01
23	Thiruvannamalai	-0.35	-1.53	-0.78	0.70	0.35
24	Tiruchirappalli	0.45	0.45	-1.58	2.29**	0.63
25	Vellore	-0.91	-2.19**	-0.85	-0.48	0.18

(* Significant at 10% significance level; ** Significant at 5% significance level, *** Significant at 1% significance level)

3.2 Annual energy yield estimation

To obtain annual wind energy yield at all the locations considered in the study, an efficient turbine VT 110 of 2 MW rated power from Vestas with 110m rotor diameter, and 80 m hub height is chosen. The cut-in-speed and the rated speed of the turbine are 3 m/s and 10.5 m/s respectively. The wind power curve of the chosen turbine is shown in Figure 4. The wind speed at hub height is obtained using the 1/7th power law and the resulting values of the wind speed at hub height are depicted in Figure 5. The hub height wind speed varies from 4.4 m/s to 6.9 m/s (Figure 5).

The net annual energy was more than 6000 MWh at Nagercoil, Thoothukudi, and Nagapattinam (Figure 6). These cities are located in the southern and eastern region are situated in the vicinity of the coast. The energy output for Cuddalore, Kumbakonam, Thanjavur and Tirunelveli is observed between 5000 and 6000 MWh /yr. The energy output for Ambur, Chennai, Hosur, Kanchipuram, Karaikudi, Karur, Neyveli, Pudukottai, Tiruppur, Tiruchirapalli, and Thiruvannamalai is seen between 4000 and 5000 MWh/yr. At Coimbatore, Dindugul, Salem and Vellore, the net energy output is between 3000 and 4000 MWh/yr. The energy output at Erode, Rajapalayam, and Madurai is below 3000MWh/yr. These cities are located inland and are landlocked. It is evident from the above discussion that the cities located near the coast possess a high wind power potential compared to inland sites.

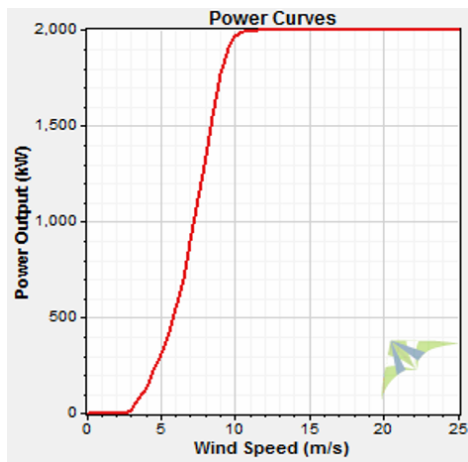


Figure 4. Wind power curve of Vestas VT110 2 MW wind turbine (obtained from Windographer software[29])

The capacity factor is determined by dividing the average power generated by the rated peak power. The net capacity factor (after deduction of the losses, i.e. availability loss = 3%, wake effect loss = 6%, turbine performance loss = 6%, electrical loss = 2%) for all the locations is shown in Figure 7. The net capacity factor is found to be above 40% at Nagercoil, between 35 % and 40% at Nagapattinam and Thoothukudi, between 30% and 35% at Cuddalore. For majority of the cities, namely, Ambur, Chennai, Hosur, Kumbakonam, Kanchipuram, Neyveli, Thanjavur, Tiruppur, Triunelveli, and Tiruchirapalli, the net capacity factor lies between 25% and 30%. At Dindugul, Karaikudi, Karur, Pudukottai, Thiruvannamalai and Vellore, the net

capacity factor lies between 20% and 25%. At Coimbatore, Madurai and Salem, the net capacity factor varies from 15% and 20%. At Erode and Rajapalayam, the net capacity factor lies below 15%.

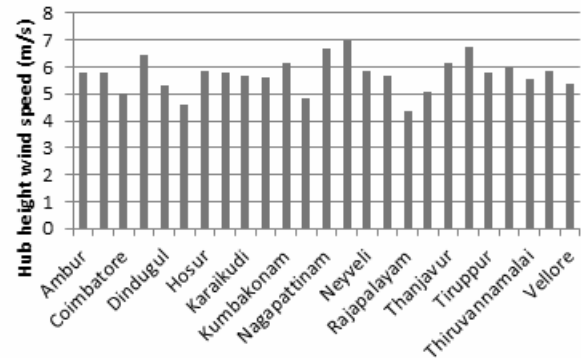


Figure 5. Wind speed at hub height of 80m at all locations

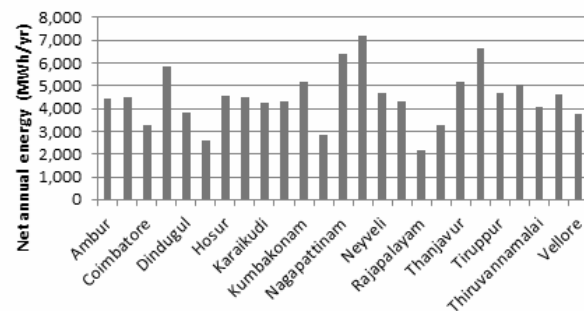


Figure 6. Net annual energy from Vestas VT110 2 MW wind turbine

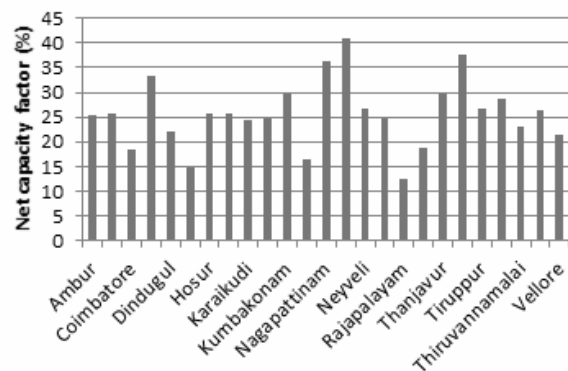


Figure 7. Annual mean plant capacity factor at all the locations

4. CONCLUSION

In this study, the wind speeds (50 m above ground level) from 25 stations collected over a period of 39 years were analyzed to study the long term wind speed trends and potentiality for wind power generation. The conclusions derived from this study are as follows:

1. Hosur has a maximum wind speed of 9.74 m/s and Madurai the least of 7.4 m/s.
2. Highly promising wind speed of more than 6 m/s are observed at Coimbatore, Nagapattinam, Nagercoil, and Thoothukudi.
3. As per the linear trend analysis, Chennai and Kanchipuram showed significantly decreasing trends of wind speed of 0.0067 m/s per year while

Nagercoil, Thoothukudi, and Tirunelveli increasing trends of 0.008, 0.0078, and 0.0056 m/s; respectively. Hence the later sites are more likely to be further explored for detailed techno-economic feasibility of erecting wind turbines at these sites.

4. According to Mann-Kendall test, decreasing trends are found at Chennai and Kachipuram while at Nagercoil and Thoothukudi showed increasing trend. During summer, Chennai, Cuddalore, Kanchipuram, and Vellore observed decreasing trends but Nagercoil observed an increasing trend. Majority of the cities showed significantly decreasing trends during the monsoon season except Neyveli. On the other hand, a reverse phenomenon is observed in the autumn, with majority of the cities showing increasing trends. During winter, Karaikudi, Madurai and Thoothukudi show a significantly increasing trend.
5. Based on the comparison between the two methods of trend analysis, Mann-Kendall method provided sufficient details to explain the variability in annual trends in consideration with the seasonal changes. However, there is close similarity in the results from both methods in identifying the locations with significant positive and negative trends.
6. Cities located in the southern region in the vicinity of the coastal line possess a significant potential for wind energy development. Majority of the cities showed an increasing trend in the autumn season due to the influence of the retreat of the monsoons which is accompanied with heavy winds.
7. The net annual energy output from the chosen turbine at a hub height of 80m is more than 6000 MWh at Nagercoil, Thoothukudi, and Nagapattinam; between 5000 and 6000 MWh at Cuddalore, Kumbakonam, Thanjavur and Tirunelveli; and between 4000 and 5000 MWh at Ambur, Chennai, Hosur, Kanchipuram, Karaikudi, Karur, Neyveli, Pudukottai, Tiruppur, Tiruchirappalli, and Thiruvannamalai.
8. The net capacity factor is above 40% at Nagercoil; between 35% and 40% at Nagapattinam and Thoothukudi; between 30% and 35% at Cuddalore; and between 25% and 30% at Ambur, Chennai, Hosur, Kumbakonam, Kanchipuram, Neyveli, Thanjavur, Tiruppur, Tirunelveli, and Tiruchirappalli.

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ACRONYMS

ALT	- Altitude
LAT	- Latitude
LON	- Longitude
MED	- Median
MWS	- Mean wind speed
MXWS	- Maximum wind speed
SD	- Standard deviation

NOMENCLATURE

x_i	- representative data (wind speed)
n	- no. of independent parameters
i, j, k	- dimensions of sample domain
S	- test statistic term
sgn	- sign function
var	- variance
t	- extent of tie
Z	- standard normal variable

ЕВАЛУАЦИЈА ПОТЕНЦИЈАЛА ЕНЕРГИЈЕ ВЕТРА У ИНДИЈСКОЈ ДРЖАВИ ТАМИЛ НАДУ КОРИШЋЕЊЕМ АНАЛИЗЕ КРЕТАЊА БРЗИНЕ ВЕТРА

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М. Васудеван**

Прецизна процена потенцијала енергије ветра је од значаја за одређивање локације за подизање ветропарка. У раду су коришћени подаци добијени у периоду од 39 година (1980-2018) за просечну брзину ветра/час измерену на висини од 50м изнад тла на 25 локација у држави Тамил Наду. Годишње и сезонско кретање ветра се анализира применом линеарне и Ман-Кендалове статистичке методе. Годишњи принос ветра и фактор нето капацитета израчунат је за ветротурбину 2MW. Анализа тренда линеарног кретања брзине ветра показује да Ченај и Канчипурам имају значајно опадајући тренд кретања док обрнути тренд имају Нагеркоил, Тутукуди и Тирунелвели. Примена Ман-Кендалове анализе потврдила је да градови на југу полуострва и у приобалном појасу имају значајан потенцијал за подизање ветропаркова. У већини градова брзина ветра се повећава у периоду јесени услед утицаја монсуна који слаби а што прате појачани ветрови. Просечна вредност кретања ветра осцилира током године на свим локацијама. Према годишњој нето излазној енергији ветра утврђено је да су најпогоднији за подизање ветропаркова Нагеркоил, Тутукуди и Нагапатинам а потом следе Кудалор, Кумбаконам, Танџавур и Тирунелвели.