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Optimal Siting Considerations for Proposed and Extant Wind Farms in India

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Abstract

Wind energy in India with a 49,368 MW estimated production potential has been gaining popularity- clean energy is produced with little recurring cost. The paper first deals with the possibility of wind-mediated power supply for Chennai city. Wind Rose distributions along with associated Weibull calculations show that Chennai with an average ambient wind speed of 2.3 ms^{-1} is unlikely to make any headway in wind power generation: in contrast, a similar wind farm sited in the district of Kanyakumari within the same state of Tamil Nadu would reap rich dividends. The paper further analyses the feasibility of installing wind farms in India appropriately without them marring the aesthetic appeal of the UNESCO World Cultural Heritage sites. First calculations are shown to analyze the downwind impact of a wind farm in Jaisalmer, Rajasthan. Land surface temperatures (LST) retrieved through satellite imagery during the South-West monsoon season show a 3.26°C reduction in temperature over a downwind distance of 21.77 km.

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Keywords: environmental impact assessment; heritage sites; land surface temperature; siting considerations; wind resource assessment

1. Introduction

The estimated potential of renewable energy in India as of 31st March 2011 was 89,760 MW of which 55% is the contribution from wind power [1] amounting to 49,368 MW of power. As the price of tapping

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wind energy becomes more competitive vis-à-vis conventional sources [2], India is working towards an installed capacity of almost 18 GW [3].

2. Analysis of potential wind power generation in Chennai

Wind potential data collected from CWET [4] and cyclone frequency data from NCRMP [5] was analysed and tabulated (Table 1). It revealed that Tamil Nadu has one of the highest estimated wind power potential of 14,152 MW and the least occurrences of cyclones relative to its neighbouring states on the East coast. This analysis establishes Tamil Nadu as the preferred region of interest.

Table 1. Cyclone and wind potential data for Eastern coastal Indian states

East Coast States	Number of Cyclones (1891 – 2000)	Estimated Wind Potential (MW)
West Bengal	69	22
Orissa	98	1384
Andhra Pradesh	79	14497
Tamil Nadu	62	14152

Chennai, the capital of Tamil Nadu, is a city on the Eastern coast of India. It is one of the major urban centres in India. However, it is prone to acute power shortage resulting in a hindrance to industrial, economic and social growth and development for its 4.6 million residents [6]. Thus, the viability of augmenting the power supply using wind energy in the city of Chennai was looked into. Table 2 briefly outlines the salient features considered in proposing Chennai as a wind farm site.

Table 2. Fact file: Chennai city

Chennai Data	Notes
Wind Resource Assessment	SW winds from April to October NE winds rest of the year Wind power density: 150 W/m^2
Ease of Grid Connection	Fairly simple connection to Southern grid through Chennai district substations
Social, Cultural and Economic Scene	Major educational hub, economic center and industrial center in India
Power Shortage Characteristics	Regular power cuts of 1-2 hours in certain localities in central Chennai and unscheduled power cuts in the outskirts of the city.

Wind data was obtained [7] from September 2011 to August 2012 for Meenambakkam, Chennai and was assumed to be similar for a few kilometres around Chennai. The data was analysed by making wind roses and Weibull distributions for each month. A Weibull distribution gives the best possible fit for the wind data [2]. The relevant formulae are as follows:

$$P(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (1)$$

Where, *P(v)* is the probability of the measured wind speed, *v*; *k* is the Weibull shape parameter (dimensionless); and *c* is the Weibull scale parameter (ms^{-1});

The cumulative frequency distribution *C(v)* is the integral of the Weibull probability density function and is given by

$$C(\mathrm{v}) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (2)$$

The average wind speed at Chennai was found to be 2.3 ms^{-1} for one year of data. The Vestas V80 2.0 MW GridStreamer^{TM} turbine model was used for wind power estimation in Chennai. The turbine has a rotor diameter of 80 m and cut in and cut out speeds of 3.5 ms^{-1} and 25 ms^{-1} respectively [8].

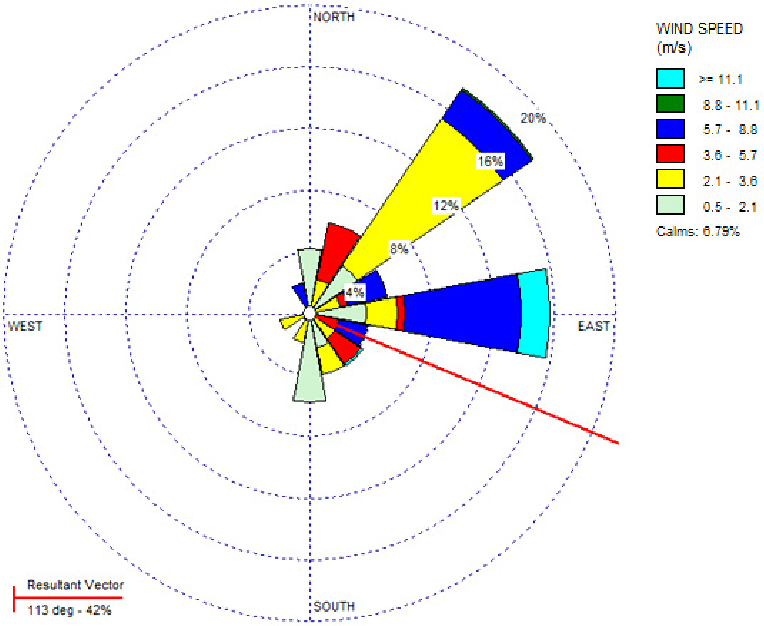

Fig. 1. Wind Rose Diagram for Chennai

It is evident from Fig. 1 that the average wind speed at Chennai is below the cut in speed of the wind turbine. The Weibull distribution of the wind speeds shown in Fig. 2 shows the probability of the wind speed at Chennai to lie between the cut-in and cut-out speeds to be 33.78 %. Thus, if a wind farm were to be set up in and around Chennai, it would be non-operational 66.22% of the time. Hence, Chennai was found to be an unsuitable location for a wind farm. The possibility of augmenting the power supply of Chennai using wind energy is concluded to be minimal.

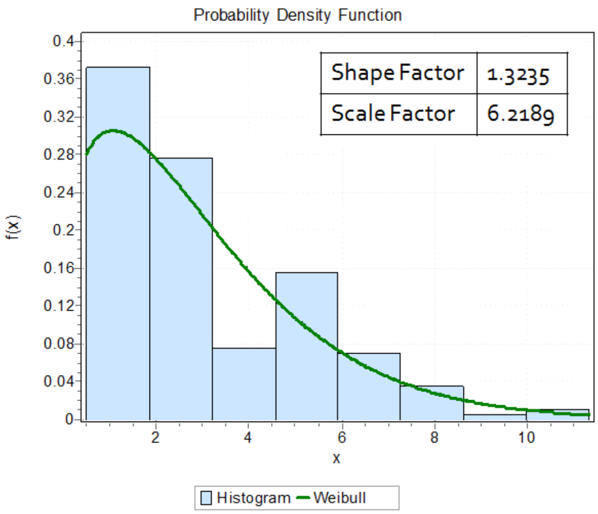

Fig. 2. Weibull Curve as a function of wind speed probability on the x-axis and wind speed on the y-axis.

A similar study was done for Kanyakumari, Tamil Nadu. Blessed with an enormous wind power potential owing to the strong, unhindered SW and NE monsoon winds, it is already host to one of the largest wind farms contributing to the Southern Grid. The results obtained were compared with those obtained for Chennai. The peaks of the Weibull curves indicate the most probable wind speeds which are about 1 ms^{-1} for Chennai and 8 ms^{-1} for Kanyakumari. It also shows that the average wind speed at Kanyakumari is significantly higher than that in Chennai as shown in Fig. 3. and Fig. 4. This comparison further verifies that it is not viable to augment the power supply in Chennai using a similar wind farm as that in Kanyakumari.

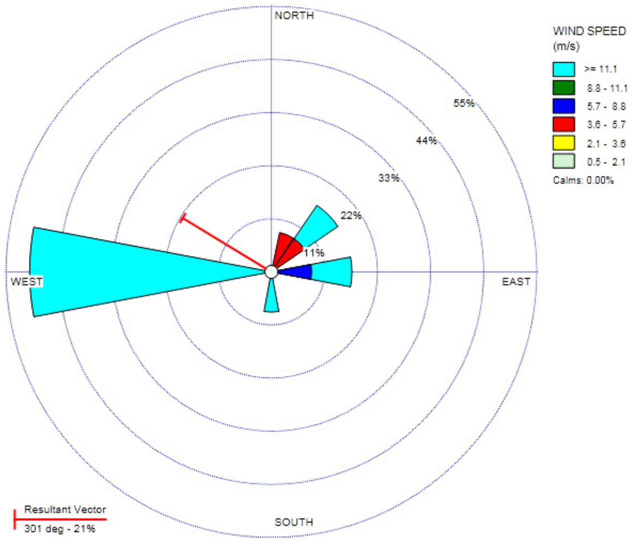

Fig. 3. Wind Rose Diagram for Kanyakumari

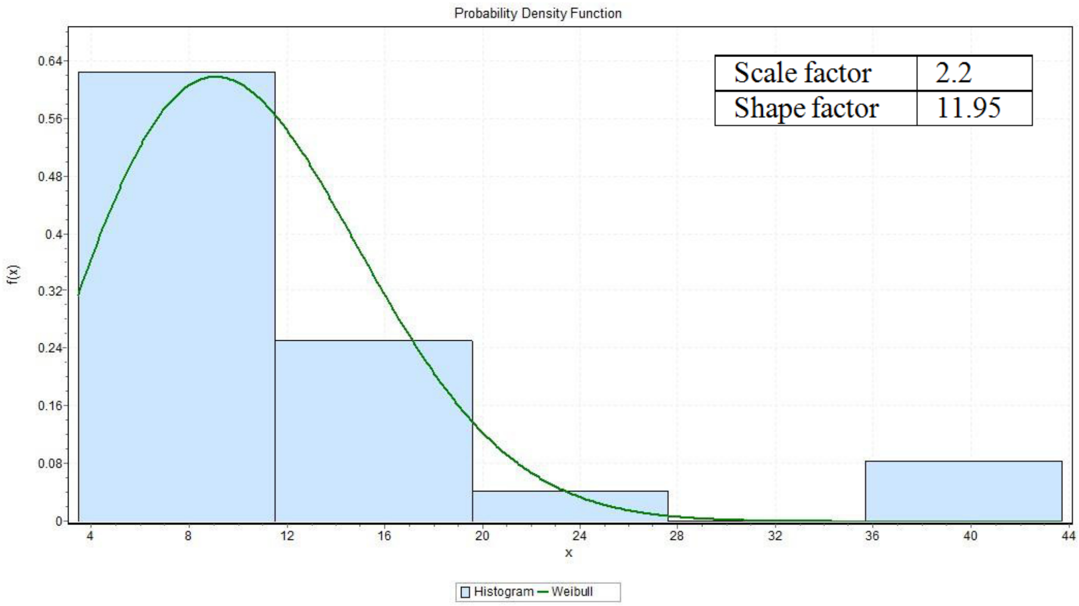

Fig. 4. Weibull Curve plot as a function of wind speed probability on x-axis and wind speed on y-axis

3. Determination of socio-economic impact of wind farms with special focus on the UNESCO world heritage sites in India

There have been claims that wind farms are unsightly and lower the aesthetic appeal of heritage sites. There have been various cases where a local tourism community has petitioned against the construction of a wind farm in their locality. Furthermore, property owners near proposed wind farms sites have showed concern that the real estate values drop on construction of wind farms close by. Finally, residents near wind farms have often complained about shadow flicker occurring due to rotating blades and noise pollution [9]. On the other hand, it has also been reported that some sections of the society find wind farms to be aesthetically pleasing and take initiatives to promote local wind farms under the "green technology" subtext. Due to such a wide range of opinions regarding the socio-economic impact of a wind farm, it is unreliable to depend wholly on public discussion forums and community polls. One of the most important socio-economic impacts of wind farms is the impact on aesthetic value of a region. In order to introduce an objective approach towards analysing the aesthetic value of a region the following ideology has been considered,

"When evaluating the visual impacts of wind-energy projects, the essential question is not whether people will find them beautiful or not, but instead to what degree they may affect the important visual resources in the surrounding area". [10]

The paper considers the proximity of some UNESCO World Heritage Sites (Cultural) in India [11] to the major wind farms [12] in the country. The greatest distance to which an observer can see a 143.8m object (height of the tallest windmill installed in India [3]) from a heritage site has been calculated and marked as a zone of visual influence around each heritage site.

Radius of visual influence is calculated as follows:

$$R = 3.57(A^{0.5} + W^{0.5}) \tag{3}$$

Where *A* is the altitude of heritage site; *W* is the height of the tallest windmill installed

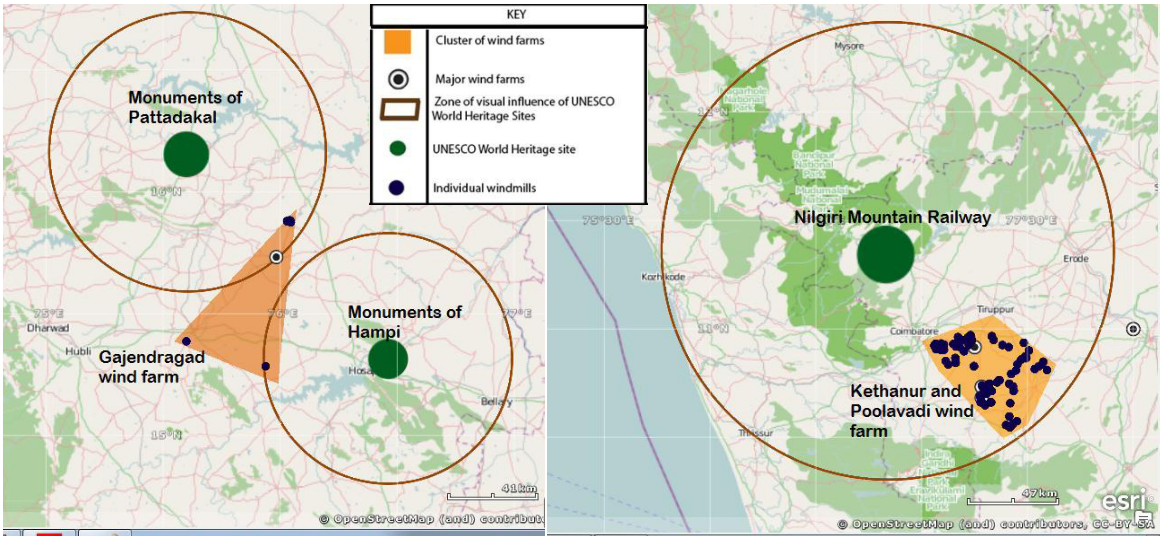

Fig. 5. On the left is the Gajendragad wind farm, which lies in the zone of visual of visual influence of two UNESCO World Heritage Sites. On the right are the Kethanur and Poolavadi wind farms which lie in the zone of visual influence of the Nilgiri Mountain Railway. In the centre is the key for the graphics.

Effects of mist and objects in the line of sight have not been considered in the analysis. The wind farms and the cultural UNESCO World Heritage sites are plotted on a map of India using ArcGIS Explorer. The zone of visual influence is marked around each site using *R* as the radius to provide a conservative estimate of the possibility of wind turbines being visible from UNESCO World Cultural Heritage Sites.

Fig. 5 demonstrates that three major wind farms in India lie in the zone of visual influence of UNESCO World Cultural Heritage Sites. The Gajendragad Wind Farm, Karnataka, India theoretically lies in zone of visual influence for the Monuments at Pattadakal and the Monuments at Hampi; both being UNESCO World Heritage Sites. It is also observed that the Kethanur Wind Farm, Tamil Nadu, India and Poolavadi Wind Farm ,Tamil Nadu, India theoretically lie in the zone of visual influence of Nilgiri Mountain Railways, a UNESCO World Heritage Site. Further analysis may be done to see whether these wind farms are visible from the heritage sites after factoring in objects in the line of sight. The analysis on siting of wind farms in India with respect to UNESCO World Heritage Sites also reveals Southern Tamil Nadu, Southern Karnataka and North Western Gujarat to be viable sites for wind power generation based on ample wind power density [2] and relatively large distances from UNESCO World Cultural Heritage Sites.

4. Impact of wind farms on Land Surface Temperatures

In this study, the region of interest is Jaisalmer Wind Park, Rajasthan, India and the surrounding areas. The centre of the wind park is located approximately at (26.965836, 70.91019). The region, being in the Thar Desert, is arid and dry. As of year 2012, the installed capacity of the wind park was 1064MW [13], making it one of the largest in India. Using Google maps the wind farm was located as in Fig. 6 and it roughly occupies an area of 9km x9km. In order to analyse the wake effect, the region of interest was extended 25km both Eastward and Westward.

Fig. 6. Cluster of Wind Turbines at the Jaisalmer Wind Park as of December 2012

All data was obtained from USGS Global Visualization Viewer, specifically from 'LANDSAT 4-7 combined' .The data was obtained from landsat7, sensor 'ETM+' and the data is captured at 5:35 hrs GMT on 30th June, 2000 and 5:32hrs GMT on 20th April, 2003. For the purpose of analysis band 6 (band 61) was used. The resolution of the scene is 240m.The data used was readily available from GLOVIS [14] and similar data files for later years generated incomplete results. The wind park/Region of Interest (ROI) is located to the left bottom of the LANDSAT scene. The data downloaded from the USGS Global Visualisation Viewer was processed using ENVI 4.7. The data in the form of digital numbers was converted to at-sensor radiance and then to temperature. This yielded the result in Kelvin which was subsequently converted to Celsius. The following equations are used in LST calculations.

Digital number was converted to at-sensor radiance using the following equation:

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN} \right) \times \left(DN - QCALMIN \right) + LMIN_\lambda \qquad (4)$$

Where, *LMAX* (17.04 $Wsr^{-1}m^{-3}$) and *LMIN* (0.00 $Wsr^{-1}m^{-3}$) are spectral radiances for each band at digital numbers (*QCALMAX* and *QCALMIN*) of 1 and 255, *DN* is the pixel value and λ is the wavelength.
Sensor radiance was converted to temperature (in Kelvin) using the following equation:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (5)$$

Where, K_1 (666.09 W m^{-2} sr^{-1} μm^{-1}) and K_2 (1282.71K) are coefficients determined by effective wavelength of the satellite sensor. The final thermal image was obtained with LST in Celsius.
The wind direction was then compared to meteorological wind flow data to ascertain the downwind direction obtained from the analysis. Fig. 7 using data from the Indian Meteorological Department gives a 30 year average of the percentage of wind flowing from a particular direction at Jaisalmer.

The Jaisalmer Wind Park in Rajasthan was chosen for the downwind LST investigation using LANDSAT. The arrangement of all wind turbines in 2003 was not available; hence it is considered that the initial turbines in the park were installed in the lower left corner as in Fig. 6. This assumption is in accordance with the obtained results of a lowering of LST downwind from cluster of turbines [15][16][17] and is further validated by the close proximity to the sub-station.

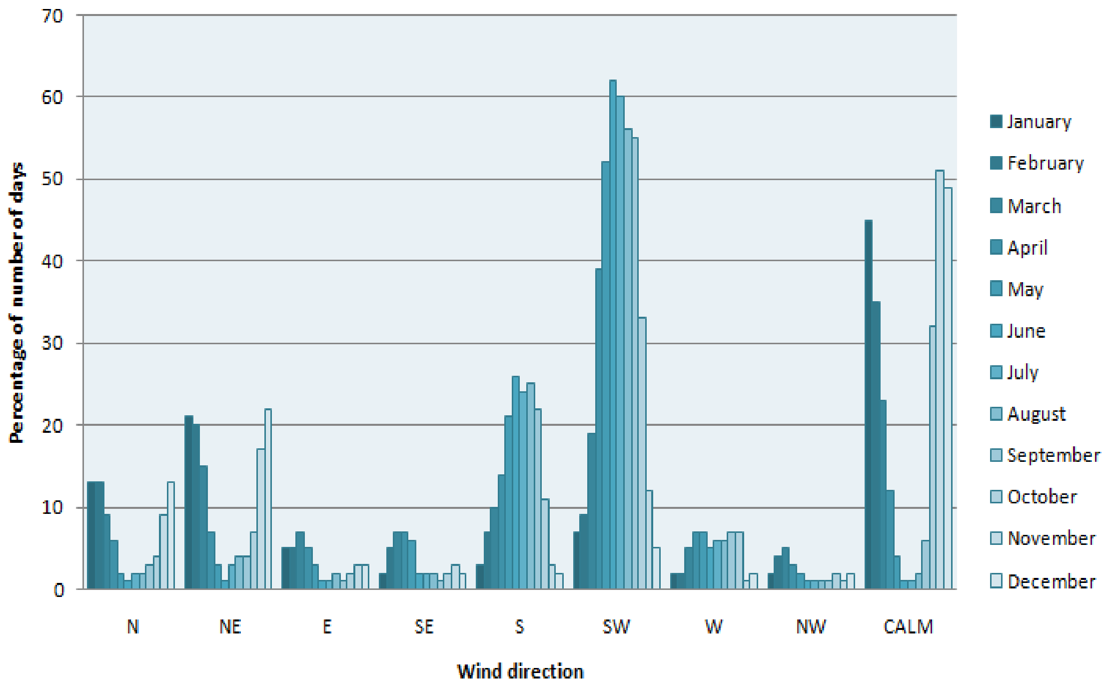

Fig. 7. Graphical representation of wind direction in Jaisalmer for all months of the year

Results of the LST study are provided in Fig. 8 and Fig. 9. The results have also been summarised in Table 3. On analysis through ENVI 4.7, the land surface temperatures in the downwind direction of the wind farm were found to be 3.26° C lower than that of the surrounding area. This effect was observed extending 21.77 km North-East from the wind farm. In order to ascertain the downwind direction for the day the result of the analysis was compared to the meteorological wind flow data and was found to be concordant. This result provides further evidence of the cooling effect of wind farms in the downwind direction during the day.

Table 3. Key results from LST study over Jaisalmer Wind Park

Date	30th June, 2000	20th April, 2003
Range of Effect on Hydrometeorology	0 km	21.77 km
Average LST of ROI	33.33°C	38.02°C
Average LST of Surrounding Area	34.58°C	41.28°C
Reduction in LST	1.25°C	3.26°C

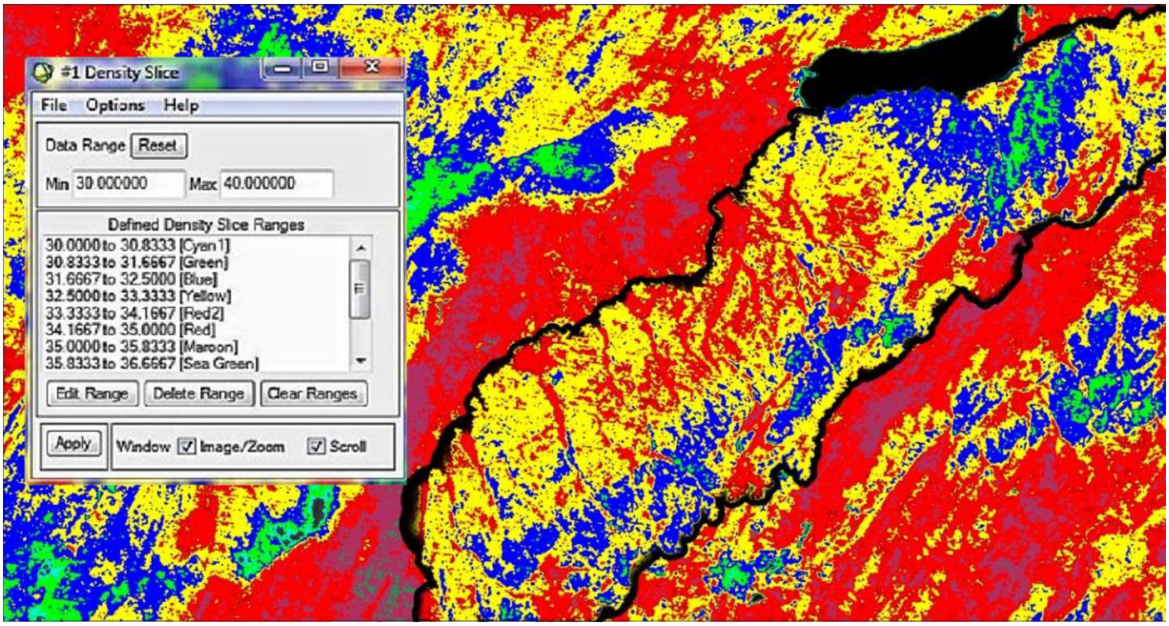

Fig. 8. Variation of LST in the ROI (area with a black boundary) at 5:35 hrs GMT on June 30, 2000. The figure shows the baseline temperature variation pattern in the ROI before construction of the wind farm.

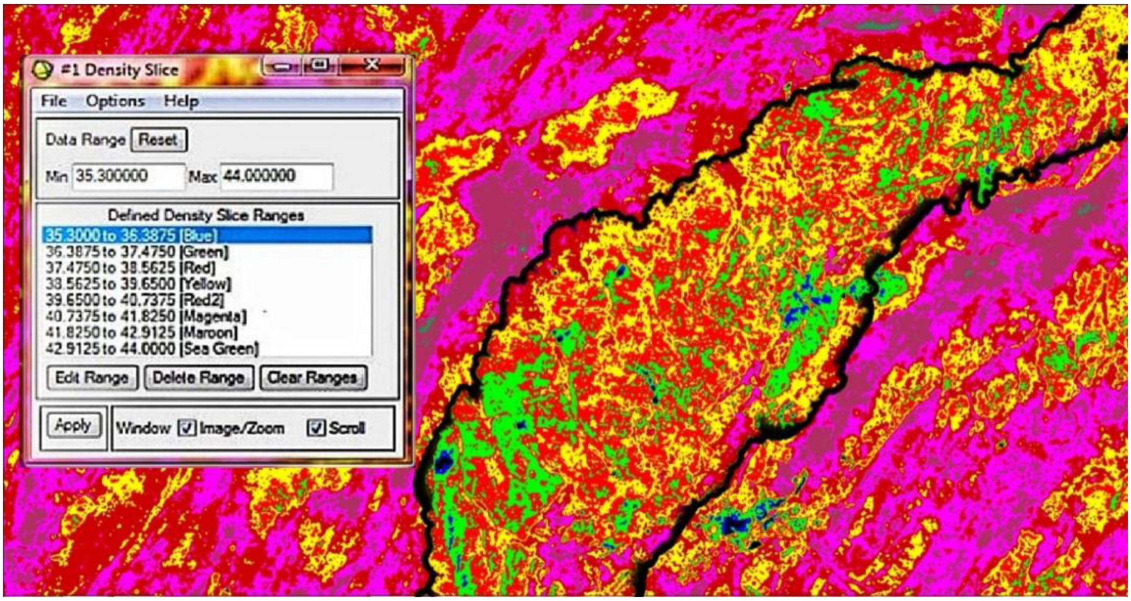

Fig. 9. Variation of LST in the ROI (area with a black boundary) at 5:32 hrs GMT on April 20, 2003, two years after commencement of wind farm construction

5. Conclusions

Wind rose mapping and Weibull distributions of the wind speed data obtained for Chennai gave an average wind speed of 2.3 ms^{-1}, well below the cut-in wind speed of 3.5 ms^{-1} of the selected Vestas V80 wind turbine. The wind speed at Chennai was found to be within the range of energy generation for the chosen turbine only 33.78% of the time throughout September 2011 to August 2012. Thus, it is concluded that is not viable to augment the power supply of Chennai through wind energy.

To assess the impact of existing wind farms on UNESCO World Heritage Sites, the location of all 29 UNESCO World Heritage Sites were compared with the major wind farms in India. Gajendragad Wind Farm (Karnataka), Poolavadi Wind Farm (Tamil Nadu) and Kethanur Wind Farm (Tamil Nadu) were found to be in the zone of visual influence of UNESCO World Cultural Heritage Sites. However, further verification studies factoring in line of sight objects are recommended. Furthermore, the study reveals North West Gujarat, Southern Tamil Nadu and Southern Karnataka to be viable regions for future wind power projects which would not impact the aesthetic appeal of UNESCO World Heritage Sites in India.

The Jaisalmer Wind Park in Rajasthan was chosen for the downwind LST investigation using LANDSAT. On analysis through ENVI 4.7 the land surface temperatures in the downwind direction of the wind farm were found to be between 3.26° C lower than the surrounding area at 5:32 hrs GMT for 20th April, 2003. This was observed 21.77 km downwind. The result provides further evidence of the cooling effect of wind farms in the downwind direction during the day. On comparison of the obtained results with those from the studies on the San Gorgonio wind farm [17], it is observed that Jaisalmer Wind Park produces a larger LST variation although there it has lower wind turbine density. This may be due to the larger turbines (350 kW- 2.25MW) installed in Jaisalmer Wind Park.

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