OPTIMAL PLANNING OF WIND FARMS USING WERA MODEL INTEGRATED WITH GIS

By

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DECLARATION

I hereby declare that this thesis entitled '**Optimal planning of wind farms using WERA model integrated with GIS '**is a bonafide record research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **'Optimal Planning of Wind Farms Using WERA model integrated with GIS'**is a record of research work done independently by Shri. Devanand U. Gorate under my guidance and supervision and that is not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Devanand U. Gorate

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SYMBOLS AND ABBREVIATIONS

A	-	Area, Square meter
AHP	-	Analytic Hierarchy project
ANN	-	Artificial Neural Network
BCR	-	Benefit cost ratio
DEM	-	Digital elevation model
dist.	-	District
DSS	-	Decision Supportive System
DTM	-	Digital terrain model
et al.	-	and other
EPF	-	Energy pattern factor
ESRI	-	Environmental System Research Institute
EWEA	-	European Wind Energy Association
Fig.	-	Figure
FLC	-	Fuzzy logic control
FPM&E	-	Farm Power Machinery & Energy
GIS	-	Geographical information system
GW	-	Giga Watt
HAWT	-	Horizontal Axis Wind Turbine
HIRLAM	-	High resolution limited area model
ILWIS	-	Integrated Land and Water Information System

J.	-	Journal
KCAET	-	Kelappaji College of Agricultural Engineering & Technology
LWRCE	-	Land and Water Resource & Conservation Engineering
MEP	-	Maximum entropy principle
MPH	-	Miles per hour
MSL	-	Mean sea level
OEE	-	Overall equipment efficiency
OREM	-	Optimal Renewable Energy Model
PBP	-	Pay back period
PDF	-	Probability density function
POT	-	Pearks-Over-Threshold
PVSV	-	Point cumulative semi variogram
SDSS	-	Spatial Decision support system
T	-	Time period
TIN	-	Triangulated Irregular Network
Trans	-	Transaction
WASP	-	Wind Atlas Application and Analysis Program
WE	-	Wind Economics
WEC	-	Wind energy converter
WECS	-	Wind energy conversion systems
WERA	-	Wind energy resource analysis
WinDS	-	Wind development system model

WPS	-	Wind power system
WPT	-	Wind power turbine
B_A	-	Benefit
C	-	Cost per kWh
C	-	Weibull scale factor
C_F	-	Capacity factor
C_I	-	Initial investment
dB	-	Decibel
E_D	-	Energy density
E_I	-	Energy intensity
E (i)	-	Estimated value
F (V)	-	Cumulative density function
f (V)	-	Probability density function
I	-	Discount rate
I_a	-	Index of agreement
k	-	Weibull shape factor
kJ	-	kilo Joule
kW	-	kilo Watt
kWh	-	kilo Watt hour
ln	-	Logarithm
L_P	-	Sound pressure level
L_W	-	Intensity of sound

m	-	Maintenance cost
m	-	meter
m/sec	-	meter per second
$\overline{M}$	-	Average of measured values
M (i)	-	Measured values
MW	-	Mega Watt
MWh	-	Mega Watt hour
n	-	Constant
n	-	Life
No.	-	Number
NPV	-	Net present value
P_N	-	Sound power
P_R	-	Rated power
P_V	-	Power at velocity
R	-	Distance from dwellings
Rs	-	Rupees
V	-	Actual velocity
V_{EMAX}	-	Velocity carrying maximum energy
V_{FMAX}	-	Most frequent wind velocity
V_m	-	Mean wind velocity
V_R	-	Rated wind velocity
V_I	-	Cut-in wind velocity

Viz	-	Namely
W	-	Watt
W/m	-	Watt per meter
X_i & X_r	-	Dimensionless velocities
%	-	One hundredth (Percentage)
/	-	Per
º	-	degree
ºE	-	degree East
ºN	-	degree North
ρ	-	Air density
σ	-	Standard deviation
∞	-	Infinity
Γ	-	Gamma function
Π	-	Pie $\left(\frac{22}{7}\right)$

INTRODUCTION

Exploitation of renewable sources of energy like wind is momentous as the fossil fuel resources recedes and global warming proceeds. Among the renewable energy sources, wind power has attracted great attention globally due to its techno-commercial viability and environment friendly nature. Therefore it is popularly known as ‘Green Power’. The special features of wind energy that makes it attractive are zero fuel cost, low gestation period, quicker benefits and usefulness for sustainable economic development.

Wind energy has been exploited to propel boats along the Nile River as early as 5000 BC. During the 19th century windmills were used to pump water for farms and later to generate electricity for homes and industry with the constraint of higher cost. During 1890, industrialization sparked the developments of large windmills called Wind Turbines that could extract kinetic energy in the wind to generate electrical or mechanical power economically (Ancona, 1989). But the popularity has always fluctuated with price of fissile fuels. With the advent of fossil fuel based generation technology, interest in wind energy declined in the later years. The oil crisis in 1980’s revoked human interest in wind energy. Today, the most attractive feature of wind energy is its environmentally friendly nature. With the current technology, cost of wind-generated electricity is very close to the power from conventional utility generation.

As a result wind energy has fastest growing energy source in the world today. It has been retaining this position consecutively for last six years. Average global growth rate of wind power is over 30 per cent. The total installed capacity has reached 59,300 MW by 2006. With the increasing thrust on renewables and reducing cost of wind generated electricity, the growth of wind energy will continue in the year to come. According to European Wind Energy Association (EWEA), wind, with its expected 230000 MW installation, can supply 12 percent of the global energy demand by 2010 (de Azua *et al*., 2003).

This indicates a market worth around 25 billion Euros. The installed capacity may reach a level of 1.2 million MW by 2020.

India ranks 6^{th} in the world in total energy consumption, whereas more than 70 percent of its primary energy needs are being met through imports, mainly in the form of crude oil and natural gas. The installed capacity of electric power in the country is 113000 MW consisting of 78400 MW thermal, 38000MW hydro, 2700 MW nuclear and 1900 MW wind energy (Kalam, A.P.J., 2004). Being a developing country, the energy technology base in India is relatively inefficient and has a slow turn over: Consequently the economy is highly energy intensive (Bhakthavatsalam, 2001).

The country also has evolved and implemented a purposeful strategy in harnessing non-conventional energy sources like wind through innovative portfolio of promotional measures. Globally, India is ranked 5^{th} in wind energy utilization. Over 200 sites have been identified as having adequate potential of grid quality wind power with a potential of more than 65000 MW, but the installed capacity is only 3000 MW. The leading states in the country with respect to installation of wind turbines and power generation are Tamil Nadu (933 MW), Maharashtra (399 MW), Gujarat (167 MW), Karnataka (121 MW), Andhra Pradesh (93 MW), Rajasthan (34 MW) and Kerala (2MW) (Pillai, 2003). With the view to harness this abundant and environment friendly source of energy, Government of India is formulating a number of ambitious projects. These progresses will be implemented and commissioned in the coming 5-10 years.

Energy scenario in Kerala is unique. Electric power demand in Kerala has increased from 7328 MU in 1990-91 to 26011 MU in 2003-2004, registering an increase of 255 per cent. However, the growth in the installed capacity during this period is only 197 per cent. As a result, when the state had surplus power of 528 MU in 1990-91, we are facing a shortage of 5817 MU of electricity in

2003-04. If the trend continues, the gap between the energy demand and availability would be widened further in the coming years.

This energy crisis, facing Kerala today, has resulted in frequent power cuts and load shedding, which in turn adversely affected the quality of life as well as the much-required industrial growth in the state. A drastic increase in the installed power capacity to cope up with the demand is not practical in the state due to technical, economical and environmental constraints. Presently, the state depends on Hydro and Thermal plants for its electric needs. Scope for large hydro-electric projects does not exist not only due to the lack of potential sites but also due to the stringent controls imposed on deforestation resulting from the growing environmental concern. Coalmines are in far away states and other fossil fuel based power generation has severe economic limitations. Similarly nuclear option is unwelcome in this thickly populated state due to obvious safety reasons. Hence one of the ways to overcome the energy crisis confronting the state today is to exploit the renewable energy resource available in the state.

Wind energy potential of Kerala state is estimated as 300 MW, out of which only 2MW capacity has been utilised till date. Identifying the importance of exploiting this abundant and environment friendly energy source, several initiatives are being taken by the Kerala Government for wind energy utilisation including the formulation of the wind energy policy. As a result, several ambitious wind projects are being realized in the state.

For the efficient and successful exploitation of this sustainable source of energy, a clear understanding on the nature and strength of wind spectra at prospective sites are essential. As wind is a stochastic phenomenon, statistical models are being extensively used to define the characteristics of wind in a given regime. Energy that can be generated by a wind turbine at a given site is a function of the nature of wind spectra, the characteristics of wind turbine and more importantly the effective interaction between the wind and the turbine.

Keeping all this in view, a model WERA (Wind Energy Resource Analysis) has been developed for defining the performance of wind turbine under fluctuating condition of wind regime. Software based on the model has been developed to stimulate the performance of wind turbines (Mathew, 2006).

Once the viability of the Wind Energy Conversion System (WECS) at a particular region is established, the next task is to select a suitable wind farm site from the available options and then specifically locate the turbine position at a selected site. For this several geographical parameters are to be considered including the topography of land and its accessibility to the grid and nearby roads. This will include the visibility of turbine from the identified key points and the sound propagation through ground having various geometry. Geographical Information system (GIS) is an effective tool for such an analysis. An effective tool for the optimal planning of wind farms-right from the wind regime analysis to micrositting of WECS is not available now. Such a tool can be developed by interlinking WERA with the GIS.

It is this context that the present investigation titled '**Optimal Planning of Wind Farms using the WERA model integrated with GIS**' has been undertaken with following objectives.

1. To validate the Wind Energy resource Analysis (WERA) model using long-term field performance data from an existing wind farm.
2. To develop an inter-link between WERA and Geographical Information System (GIS).
3. To apply the WERA-GIS integrated model for optimal planning of wind farms in some selected sites.

REVIEW OF LITERATURE

Research and developmental efforts pertaining to the current investigations, carried out at different parts of the world, have been critically reviewed for the current investigation and briefly presented here under the following heads:

2.1 Wind Energy Resource Analysis
2.2 Performance Evaluation of Wind Energy Conversion Systems
2.3 Economics of Wind Energy Conversion
2.4 Planning of Wind Farms
2.5 GIS for Wind Farm Planning

2.1 Wind Energy Resource Analysis

Owing present day’s energy crises, growing environmental concern and constantly escalating cost of fossil fuels, scientists, engineer's and policy makers, all over the world, are making every effort to supplement our energy base by renewable sources like wind. Identifying the potential of wind as an energy source at a given region is one of the important steps in such an initiative. Several attempts were made in this direction at different parts of the world even during the 60’s. For example, Exbote *et al*. (1962) analyzing the wind profile available at different parts of India, found that for the large part of the country, the optimum working speed of the wind turbine must be at 7 km/hr. However, under another investigation, French (1981) suggested that an annual average wind velocity of 10-12 miles per hour is required for an economical wind energy installation.

Muhammad (1988) conducted feasibility studies on wind turbines in Kerala. Based on the data collected, several potential sites were identified for the economical exploitation of wind energy in the state. In a similar effort, Kainkwa and Usio

(1989) conducted a preliminary survey on wind characteristics and available wind power in Tanzania. Monthly and annual mean wind speeds, coefficients of variation and estimates of available wind power were calculated using wind data availed from agro metrological stations. The analysis identified 10 stations with high wind power potential ranging between 83.9 and 172.5 W/m^2.

Ojosu *et al.* (1990) conducted a survey on wind energy potential in Nigeria. Wind speed, direction and frequency distribution data obtained from meteorological stations were used to analyze wind energy characteristics. It was observed that the WECS can be used to provide energy for the rural communities of Nigeria, which may in turn check rural to urban migration.

Eleven years of daily wind speed data from 21 locations in the State of Tamil Nadu, was analysed by Ranganathan *et al.* (1991). Weibull distribution was used as statistical tool for the analysis. It was observed that among 21 locations, six locations have maximum potential, which can be exploited for energy production. Similarly, Ramachandra *et al.* (1997) studied the availability of wind energy characteristics Kumta and Sirsi in Uttar Kannada district of Karnataka. Preliminary data were collected at selected sites for a period of 24 months. Monthly frequency distribution of wind speed had been analyzed using Weibull distribution. Energy Pattern Factor (EPF) and power curve also were deduced which reveled the suitability of wind energy generation at the study region.

Salmona and Walmsley (1999) proposed a two-site wind correlation model and tested it with long-term data from five pairs of Canadian weather stations. It was observed that the model results derived from 1 year of short-term simultaneous monitoring at the two stations and long-term data at the reference station outperform the estimates based solely on 2 year of monitoring at the target station.

Emeis (2001) measured 10 min average wind speed data with the help of mini-sodar for 13 months at different sites in Germany. The data presented were from a height of 25 to 140 m above the ground and the vertical resolution was 5 to 10 m. Monthly mean diurnal wind speed and directional shear had been computed. The typical features of the wind profile, characterizing level terrain and hill top sites, were analyzed.

A simulation model to describe the characteristics of a particular wind turbine at a given wind regime was developed by Lu. *et al.* (2002). In the study, wind speed and wind power density were obtained at different hub heights and the annual power generated by the wind turbine was computed. The simulation shows the potential for wind power generation on the islands surrounding Hong Kong.

Mathew *et al.* (2002) analyzed the characteristics of some selected wind regimes for energy estimation. A method for defining the nature of a wind regime was proposed. Rayleigh distribution, in terms of its probability density and cumulative distribution functions, was adopted for the analysis. The authors could identify the characteristics of wind machines suitable for these sites in terms of cut-in and cutout wind speeds.

Pandey (2002) reported that Pearks-Over-Threshold (POT) method is a useful alternative to the classical annual-maxima method for the estimation of wind potential. The study was conducted to model peak wind speeds exceeding a high threshold by the Pareto distribution. However, practical applications of POT method were found to be hindered by the threshold beyond which the Pareto model was not effective. This difficulty was further compounded by acute threshold sensitivity of wind speed estimates, which could be attributed to erratic variation of model and sampling error with selected threshold values. To improve the statistical accuracy and reduce the threshold sensitivity of POT estimates, the author presented an adaptive exponential model that relies on a quantitative notion of uncertainty used in information theory. In the proposed approach, an exponential prior was assigned to suitably preconditioned data, and was augmented with additional sample information in an optimal sense through the principle of Minimum Cross-Entropy. Novel features of this were systematic minimization of model error and sampling error by use of probability-weighted moments.

Weisser (2003) estimated the wind energy potential in Grenada adopting Weibull density function based on average daily/seasonal wind speeds. The analysis highlighted the importance of incorporating the variation in wind energy potential during diurnal cycles.

Aksoy *et al.* (2004) developed a synthetic data generation technique for long term wind speed data. In the study, a new wind speed data generation scheme based up on wavelet transformation was introduced and compared with the existing wind speed generation methods namely normal and Weibull distribution. It was proposed that the wavelet-based approach can be an alternative to the existing methods. Similarly, Jaramillo (2004) analyzed the statistical characteristics of wind speed in La Ventosa, Mexico. A mathematical formulation, using the Weibull based bio-model, had been developed to analyze wind energy potential in that area.

Another effort in this direction was by Akpinar and Akpinar (2005). Mean wind speed data were measured and hourly time series format were statistically analyzed for a period of six-years by the authors. The probability density distributions were derived from the time series data and their distributional parameters were identified. The wind energy characteristics of all the regions were studied based on the Weibull and Rayleigh distributions. Energy yield and capacity factors for the wind turbines were determined for wind machines of different sizes and observed that it varies between 300 and 2300 kW.

Li and Li. (2005) analyzed the wind characteristics at Waterloo region in Canada based on a data collected from 10 m above the ground level over a 5-year period. Characteristics such as annual, seasonal, monthly and diurnal wind speed variations and changes in wind direction were examined. A model derived from the maximum entropy principle (MEP) was applied to determine the diurnal; monthly, and seasonal and yearly wind speed frequency distributions. Corresponding Langrangian parameters were determined and based on this the yearly wind power density was found to be 105 W/m.

Sirdas (2005) analyzed the daily wind speed at Marmara region in Turkey using the harmonic analysis. The coefficients, amplitude, variance and phase angle, of each harmonic were calculated for the month of January, April, July and October. The total variance maps for spatial interpolations were developed.

2.2 Performance Evaluation of Wind Energy Conversation Systems

Several attempts were made for simulating the performance of wind turbines under fluctuating conditions of wind regimes. For example, Mengelkamp (1988) proposed a method for estimating the total energy output of wind turbine at a given site using Rayleigh and Weibull distributions. It was found that differences between the various distributions are mostly below 10 per cent. It was also shown that the use of the recommended 10 min average or any other average over-estimates the WECS efficiency up to 14 per cent depending on turbulence intensity. It was concluded that it is the wind power, not the wind speed, which is appropriate in power performance testing of wind turbines. Another attempt in this direction was by El-Mallah *et al.* (1989). They developed a nomogram for estimating the capacity factor of wind turbines using site and machine characteristics. It was suggested that the wind speed at the site have to be fitted to Weibull probability distribution function for the required period of the time. The wind turbine should be characterized by its cut-in, rated, cutout wind speeds.

Ahsan and Hoque (1994) developed a methodology for simulating wind farm performance. Capacity output of a WTG was derived using the probability density function (PDF) and the proposed model was applied to the generation expansion analysis of an isolated area.

Mathew and Pandey (2000) proposed a method for predicting the output of a simple multiblade windmill mechanically coupled to a reciprocating pump. The method adopted an integrated approach considering the interaction between the rotor, pump and the wind regime to model the system performance. The wind regime was characterized by the Raleigh distribution and the characteristics of the pump were also considered in the model. Wind data from few potential sites from the southern part of India were analyzed and the expected outputs at these sites were predicted using the proposed method. Jangamshetti and Rao (2001) also proposed a similar method to estimate the energy output of WECS at a given site. The influence of cut-in, cutout and rated velocities in the system performance was highlighted. Optimum sitting criteria for wind turbines at selected locations were also deduced under the investigation.

Balouktis *et al.* (2002) developed a nomogram for estimating the energy productivity of wind turbines. Based on the wind data and turbine characteristics, the performance of WECSs could be predicted from the nomogram. Chang *et al.* (2003) developed mathematical models to predict the performance of a WECS. The performance of wind machine was estimated on the basis of the cut-in, rated and cutout velocities of the turbine as well as the distribution of wind at the site. Capacity factor and availability factor were taken as the indices for system performance.

Performance of grid connected wind farms were analysed by Abderrazzaq (2004). The operational data of five wind turbines during six years of operation were analyzed under this study. A significant attempt in this area was by Pallabazar (2004). He conducted studies on provisional estimation of the energy output of wind generators based on the matching model of the WECS with the Weibull model for the wind regime. The parameters used are Weibull shape parameter, mean wind speed, turbine diameter, hub height, cut-in and nominal wind speeds, and nominal power.

Litifu *et al.* (2005) presented three transient models for computing power from wind turbines. These models could be used to analyze steady state and transient operation process wind power systems (WPS). Equations of turning torque and wind speed were incorporated in to the models.

Ozerdem *et al.* (2005) estimated the wind energy potential at the campus area of Izmir Institute of Technology. The wind data were collected at 10 and 30 m heights for a period of 16 month. It was observed that the mean wind speeds were 17.03 and 8.14 m/s at 10 and 30 m height respectively. The 'WasP’ and 'WindPRO' software's were used for the investigations. Suitable sites were selected according to the created wind power and energy maps.

2.3 Economics of Wind Farms.

Economic appraisal of the project is an important step in wind farm planning. Ramsdell, *et al.* (1989) developed a time series model for simulating wind speeds for economic evaluation of wind energy conversation systems. The model incorporates seasonal variation of the mean speeds, standard deviation and correlation of wind at the site. To demonstrate the model capabilities, performance of a wind turbine at a number of sites were simulated. Both the simulated and the real data were compared and found to agree reasonably.

Rand (2001) investigated the economic viability of wind energy conversion at Mt Grey ridgeline, 15 km West of Amberley, in North Canterbury. Feasibility of wind generation at the site was studied in terms of electricity productivity, income, and economic cost of energy generation and environmental impact. It was observed that the annual energy production from the hypothetical 660 kW turbines was 2270 MWh. The average electricity price generation is 3.50 cents per kWh.

A procedure for evaluating the economic viability of wind energy converters (WEC) was proposed by Papadopoulos *et al.* (2002). This procedure was based on the assessment of wind energy potential of an area, the limitations involved in selecting specific locations/sites for system installation in the area, the technical specification of a candidate site and the assessment of economic viability. The proposed procedure was illustrated by applying it in the Thrace area of Greece where WECs of 150-500 kW capacity were suggested.

Krokoszinski *et al.* (2003) introduced the concept of overall Equipment Effectiveness (Total OEE) for auditing the performance of wind farms. The model consists of an installation, i.e. properly selected wind energy converters and their arrangement to form a wind farm along with the processes of operation and maintaince. Theoretical production time, available production time and valuable production time were redefined in unit full load hours. A calculation scheme was developed to quantify wind farm production losses in terms of planned and speed or unplanned downtimes and speed losses. This was further related to the associated reduction of revenue to the theoretical maximum of annual wind park revenue.

Marafia *et al.* (2003) assessed the economical feasibility of offshore and on-shore wind energy projects in Qatar. The analysis was presented for long term data with an annual wind speed of 5.1 and 6.0 m/s. An economical assessment was presented by considering interest recovery factor, lifetime of wind energy conversion systems and operation and maintaince costs. The results indicated that the cost of electricity generation from wind in Qatar compares favorably to that from fossil.

Feasibility of utilizing wind power in Antarctic Station was evaluated by Teez *et al.* (2003). The analysis was based on the technical and economic aspect of installing and operating a wind turbine at remote locations. It considered the special attention like site accessibility, low temperatures, icing and snow, long transportation distances and environmental issues. It was observed that the yearly energy output was 430 MWh with a capacity factor of 0.49; at a mean wind speed of 10.8 m/s. Wind energy is found to be an attractive solution to reduce fuel consumption in the region.

Rahman (2005) estimated the energy output of wind turbines using RETs screen model and actual frequency & wind power curve. The energy output analysis was done for three wind energy conversion systems of rated capacity 600, 1000, and 1500 kW. The RETs screen software was also used to analyze the economical feasibility of the wind farms.

2.4 Planning of Wind Farms.

Iniyan *et al.* (1998) developed a renewable energy model (OREM) to determine the optimum level of renewable energy sources utilization in India for the year 2020-2021. The model aimed at minimizing cost/efficiency ratio and determined the optimum allocation of different energy sources for various uses. This model was used to predict the performance and reliability of wind energy farms. A 4 MW wind farm situated in Muppandal had been selected for the study. The wind farm had 20 wind turbines of 200 kW capacities. The average technical availability, real availability, and capacity factor had been analyzed from 1991 to 1995 and were found to be 94.1%, 76.4%, and 22.5% respectively. The reliability factor of the wind energy system was found to vary from 0.5 to 10.00.

Landberg (1999) described a model for predicting the power produced by wind farms connected to the electrical grid. This method uses the data from the High-Resolution Limited Area Model (HIRLAM) of the Danish Meteorological Institute. These predictions were made specific for individual sites (wind farms) by applying a matrix generated by the sub models of WASP (Wind Atlas Application and Analysis Program).

Mohamed *et al.* (2001) designed an advanced maximum power-tracking controller of WECS by using fuzzy logic for controlling the firing angle of the inverter in wind farms. In the study two conditions were considered: (a) the step model wind velocity, and (b) the on-site data with several deviations between maximum and minimum recorded wind velocity. Simulation results for both cases proved the robustness, fast response, and exact maximum power tracking capabilities for the designed Fuzzy Logic Control (FLC).

Oen (2001) developed a Point Cumulative Semi-Variogram (PVSV) for predicting the wind speed and topographic height records at a set of irregularly scattered sites over Turkey. On the basis of the PCVS, nearby site features were classified into five distinctive categories for possible application in wind farm planning.

A time series model using one-step transition probability matrix of a Markov Chain was developed by Torse *et al.* (2001) for application in wind farm development. The model had been applied to three Mediterranean Sites in Corsica and it was used to generate three hourly synthetic time series. In the study, using the main statistical characteristics of the wind speed (mean, variance, probability distribution, and autocorrection function), data were simulated and compared with the experimental data in order to check whether the wind speed behavior was correctly reproduced over the studied periods.

Sorenson *et al.* (2002**)** developed a wind model for observing dynamic interaction between wind farms and power system to which they were connected. The wind model was based on a power spectral description of the turbulence, including the coherence between wind speeds at different wind turbines on wind farm, together with the effect of rotational sampling of the wind turbine blades in the rotor of the individual wind turbines. Both the spatial variations of the turbulence and the shadow behind the wind turbine towers were included in the model for rotational sampling. The model was verified using measured wind speeds and power fluctuations from turbines.

Feasibility of wind farms for electricity generation at three different regions in Syria was assessed by Al Mohammed *et al*. (2003). A computer model was developed which allowed the operator to have a wide range of options especially over the turbine types and their efficiencies. The program was divided into three main parts. The first part processed and calculated the main parameters such as wind speed, wind power, and power density directly from the available data, which were essential for the wind farm planning. The second part of the program calculated the electricity produced from a wind farm using defined wind turbines with known output power speed curve and the third part calculated the economical feasibility for a proposed wind farms.

Ledesma *et al.* (2003) proposed a model for wind farms with typical fixed speed turbines integrated with simple grids. The effects of several electric, mechanical and operational parameters on the wind farm faults clearing time was evaluated under this study. It was concluded that the parameters were helpful to design fixed speed wind farms attending to transient stability requirements.

Visibility analysis within a topological surface has been used to explore the usual acceptability of wind farms (Burrough and McDonnell, 1998). For determining the best viewpoint position, spatial search techniques were used (Kidner *et al*. 2000).

Various computational techniques and search algorithms that could produce a suitable visibility search performance such as line-of-sight (De Floriani *et al.*, 1994), local view shed search (Wang *et al.* 1996; Lee and Stucky, 1998), optimum path on grid surface (Stefanakis and Kavouras, 1995).

Cavallaro *et al.* (2003) applied multi criteria approach of Decision Supportive System (DSS) for making a preliminary assessment on the feasibility of installing wind farms in Salina Island (Italy). Use of decision-making tools under a multi criteria approach was intended to aid the decision maker in the creation of a set of relations between alternatives. The main step involved was to identify the nature of the decision, potential actions, criteria definition, build payoff and aggregation of preferences.

Artificial neural network (ANN) is being applied for wind power analysis and wind farm planning (Cam *et al.*, 2005). Fifty years of wind data from the reverent region were obtained from meteorological stations. Software was developed using Mat lab for the analysis, in which longitude, latitude, altitude and height were used as an input layer while wind speeds and related power values were considered as an output layer. The neural networks were also used for predicting wind potential at varying heights. It was concluded that the network had successfully predicted the required output values for the test data and the mean error levels differed between 3 per cent and 6 per cent only. In a similar attempt, Flores *et al.* (2005) developed an algorithm based on artificial neural network for wind farm planning. Two types of wind data were used to test the algorithm. The first data collected was from an area of moderate wind and the second data were from a real wind farm of very low to high wind speeds.

2.4 GIS for Wind Energy Planning.

The Geographical Information System (GIS) is an effective tool for the micro siting of wind farms. Hillring and Krieg (1998) presented a planning model for Swedish wind farms using GIS. The information on the candidate site were combined and analyzed in the geographical information systems (GIS) under Arc View. The result from the study indicated a great wind potential, which could be exploited for electricity generation.

Osman *et al*. (1998) evaluated the profitability of wind farms at 36 promising sites in California using geographical information systems (GIS). The Elfin electricity production cost model was used to estimate the value of the time-varying electricity output in the California electricity market over the life of the project. Digital elevation model (DEM) data for the areas around the sites was processed using the ARC/ INFO GIS software to supply 3D contour line projections on which wind turbine sites were manually placed. Estimated distance from roads and transmission lines were used for site development cost estimation. Results suggested that the profitability of wind farm increases over time.

Sorenson *et al.* (1999) developed GIS tool for renewable energy modeling. It was particularly suited for dealing with dispersed energy resources such as wind by matching the demand with supply. It was suggested that the model is useful to identify any mismatch entailing needs for energy trade and establishment of energy exchange facilities (power grid, distribution lines etc).

A technique to carry out visibility analysis of topological surfaces using GIS was suggested by Hoon and Clark (1999). Four algorithms were used viz. extensive iterative search technique; tornqvist based search algorithms, genetic algorithms, and simulated annealing technique. Performances of the four solution techniques were compared using a visibility site selection problem.

Baban and Parry (2001) developed a simple GIS assisted Wind farm location criterion for the United Kingdom. The information on candidate sites were combined and stored in different layers. Based on the perceived importance, information were graded and used in the decision making process. Similarly, Bishop (2001) developed a GIS based model to determine the relative perceived size of turbines. Image analysis was done to determine its typical contrast level and the effect of atmospheric scattering on the contrast. The estimations were made for the probability of turbine detection, recognition and visual impact at a distance up to 30 km.

Sorenson (2001) developed a computer-aided tool for wind farm planning and environmental impact analysis (WindPRO/ Wind PLAN). The module included three interrelated spatial planning models viz, a weighted visibility calculation model, a conflict check calculation and a wind resource weighted planning module. It was suggested that different analysis were heavily dependent on detailed GIS data showing object such as local housing, leisure areas, preservation areas etc.

Walter *et al.* (2003) presented a model called Wind Development Systems Model (WinDS) which is basically a multiregional, multi-time period, Geographic Information System (GIS) integrated with linear programming model. It was designed to address the principal market issues related to the penetration of the wind energy technologies into the electric sector through highly decentralized regional structure.

In Denmark more than 40% of the electricity consumption was covered by geographically scattered electricity source like wind power and local CHP plants (Ostergaard, 2005). This caused problem in load balancing and resulted in possible grid overloads. The possibilities of grid problems and methods for solving them were analyzed with the help of GIS. It was concluded that by introducing scattered load balancing using local CHP plants actively and using interruptible load such as heat pumps, requirement of grid were lowered by reducing or eliminating needs of grid reinforcement.

Geographical Information System is also employed in mapping the wind energy resource potential (Ramachandra, 2005). The wind energy potential in Karnataka, India was assessed and mapped for identifying locations suitable for tapping wind energy. A spatial database with data of wind velocities had been developed and used for evaluation of the theoretical potential through continuous monitoring and mapping of the wind resources. The study showed that the average wind velocity in Karnataka varies from 0.85 m/s in Bagalkot to 8.28 m/s in Chikkodi during the monsoon season. Chikkodi, in Belgaum district, has high wind velocity during May to September with a peak value of 9.18 m/s in July. Agro climatic zone wise analysis showed that the northern dry zone and central dry zone were identically suited for harvesting wind energy for regional economic development.

From the above review, it was evident that the Weibull and Rayleigh distributions are widely used for wind energy analysis. Mathematical formulations of various kinds, based on these distributions, are being used for wind resource analysis and simulating wind turbine performance. Wind energy density at the site and capacity factors are the indices in defining the wind energy potential of a given site. Yardsticks for evaluating the economic merits of wind energy projects and possibilities of using Geographical Information System (GIS) in wind farm planning also could be established under the review. On the basis of these previous investigations, the methodology to be adopted for the current investigation has been formulated, which is discussed in the next chapter.

MATERIALS AND METHODS

The materials used and the methodology adopted for the study are discussed in this chapter under the following heads:

3.1 Wind Resource Analysis
3.2 Performance Simulation of Wind Turbines
3.3 Validation of WERA Model
3.4 Linking WERA with GIS
3.5 Wind Farm Planning and Micro-siting

3.1 Wind Resource Analysis

Ten sites were initially considered for wind farm planning under the study. Details of these sites are given in Table3.1. Accurate assessment of the energy resource available at sites is the first step in planning process. For this, distribution of wind resource available at the region had to be characterised by suitable probability functions. Rayleigh and Weibull distributions, which are commonly used for wind energy analysis, were used for defining the prevailing wind regime. The probability density function *f (V)* and cumulative distribution function *F (V)* of Rayleigh distribution were computed by

$$F(V) = 1 - e^{-\frac{\pi}{4}(V/V_m)^2} \qquad (3.1)$$

and

$$f(V) = \frac{\pi}{2} \cdot \frac{V}{V_m{}^2} e^{-\frac{\pi}{4}(V/V_m)^2} \qquad (3.2)$$

Table 3.1. Details of the sites preliminarily selected for wind farm installation

No.	Location of the site	Latitude (^{o}N)	Longitude (^{o}E)	Elevation from MSL (m)	Sensor height (m)
1	Tolanur	10.42	76.30	100	20
2	Rameshwarm	9.17	79.20	4	20
3	Deogad	16.28	73.30	36	20
4	Meenakshipuram	9.52	77.18	290	20
5	Kanjikode	10.47	76.49	130	20
6	Sultanpet	10.52	77.11	398	20
7	Tuticorin	8.50	78.08	3	20
8	Kayattar	8.58	77.44	105	20
9	Andipatti	10.00	77.33	296	20
10	Okha	22.27	69.08	3	20

Where,

V is the velocity of interest.

Similarly, for Weibull distribution,

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(V/c\right)^{k}} \tag{3.3}$$

and

$$F(V) = \int_{0}^{\infty} f(V)dV = 1 - e^{-(V/c)^{k}} \tag{3.4}$$

where:

k - Weibull shape factor

c - Weibull scale factor

The Weibull factors k and C were determined by the expressions

$$k = \left(\frac{\sigma_V}{V_m}\right)^{-1.090} \tag{3.5}$$

and

$$c = \frac{2V_m}{\sqrt{\Pi}} \tag{3.6}$$

Where

$$Vm = \left(\frac{\sum_{i=1}^{N} f_i V_i^{\ 3}}{\sum_{i=1}^{N} f_i} \right)^{1/3} \tag{3.7}$$

and

$$\sigma_V = \sqrt{\frac{\sum_{i=1}^{N} f_i (V_i - V_m)^2}{\sum_{i=1}^{N} f_i}} \tag{3.8}$$

Wind energy potential of the sites were assessed in terms of the Wind energy density, wind energy intensity, velocity carrying maximum energy and the most frequent wind velocity.

Wind energy density is the power available in the regime per unit area of the rotor. Wind energy density, under Rayleigh based analysis, was calculated by using the equation (Mathew *et al.* 2002),

$$E_D = \int_0^\infty Pv.Fv.dv \tag{3.9}$$

where,

E_D = Energy Density, W/m2

P_v = Power at velocity, V

F_v = Probability density function

The above expression can further be simplified as

$$E_D = \frac{3}{\pi} \rho A V_m^3 \tag{3.10}$$

where,

ρ = Air density, Kg/m^2

A = Area, m^2

V_m = Mean velocity, m/s

Wind energy intensity is the total energy in the wind spectra, during a particular period of time. Wind energy intensity was calculated using the equation (Mathew *et al.* 2002),

$$E_I = TE_D = T\frac{3}{\pi}\rho A V_m{}^3 \tag{3.11}$$

where

E_I = Energy intensity, KWh

T = Time period, h

Similarly, the velocity carrying maximum energy V_{EMAX} and the most frequent wind velocity V_{FMAX} were computed using the expressions,

$$V_{EMAX} = 2\sqrt{\tfrac{2}{\pi}V_m} \tag{3.12}$$

$$V_{FMAX} = \sqrt{\tfrac{2}{\pi}V_m} \tag{3.13}$$

Under the Weibull based approach, wind energy density, wind energy intensity, velocity carrying maximum energy and the most frequent wind velocity were calculated using the expressions

$$E_D = \frac{\rho_a\ c^3}{2}\ \frac{3}{k}\ \Gamma\left(\frac{3}{k}\right) \tag{3.14}$$

$$E_I = E_D\, T = \frac{\rho_a\ c^3 T}{2}\ \left(\frac{3}{k}\right)\Gamma\left(\frac{3}{k}\right) \tag{3.15}$$

$$V_{E\,Max} = \frac{c\ \left(k+2\right)^{1/k}}{k^{1/k}} \tag{3.16}$$

and

$$V_{F\,Max} = c\left(\frac{k-1}{k}\right)^{1/k} \tag{3.17}$$

respectively.

Out of the 10 sites preliminarily selected for possible wind farm installation, five sites would be short listed on the basis of their wind resource potential for further analysis

3.2. Performance Simulation of Wind Turbines

In order to estimate the performance of wind turbine at fluctuating conditions of wind regime, wind regime characteristics of different sites were integrated with the wind turbine performance. Under the Rayleigh based approach, performance of turbines were predicted using the expression (Mathew *et al.* 2002),

$$E_{IR} = \frac{P_r 2^n V_m^{(n+1)} T}{\left(V_r^n - V_i^n\right)\pi^{n/2}} \int_{X_i}^{X_r} X^{n/2} e^{-X}\, dx + \frac{P_r T V_i^n}{\left(V_r^n - V_i^n\right)}\left[e^{-Xr} - e^{-Xi}\right] \tag{3.18}$$

where,

P_r is the rated power, W

V_r is the rated velocity, m/s

V_i is the cut in velocity, m/s

X_i and X_r are dimensionless velocities

n is the velocity-power proportionality

Under the Weibull based analysis, the performance was computed using the expression

$$E_T = E_{IR} + E_{RO} \tag{3.19}$$

where

$$E_{IR} = \frac{P_R T_c^{\ n}}{\left(V_R^{\ n} - V_I^{\ n}\right)} \int_{X_I}^{X_R} X^{\ n^{n/k}} e^{-x} dx - \frac{P_R T V_I^{\ n}}{\left(V_R^{\ n} - V_I^{\ n}\right)} \left[e^{-XI} - e^{-XR} \right]$$

(3.20)

and

$$E_{RO} = P_R T \int_{V_R}^{V_O} \frac{k}{c} \left(\frac{V}{c}\right)^{k-1} e^{-\left(V/c\right)^k} dV \tag{3.21}$$

Where V_o is the cutout velocity. As the above expressions cannot be analytically solved, numerical methods are to be adopted for further analysis. The WERA software, which is based on the models described above, was used under the study for wind resource analysis and wind turbine performance simulation. (Mathew 2006).

The Wind Energy Resource Analysis (WERA) software uses the above expressions for wind regime analysis. WERA can be used for analyzing the wind energy potential at a given site as well as estimating the performance of a Wind Energy Conversion System (WECS) at the site. It has three modules, Viz. site, wind turbine and wind pump. The site and wind turbine modules, which were used for this investigation, have provision to perform the analysis on the basis of either Weibull or Rayleigh distribution. Screenshot of the software is shown in Fig.3.1

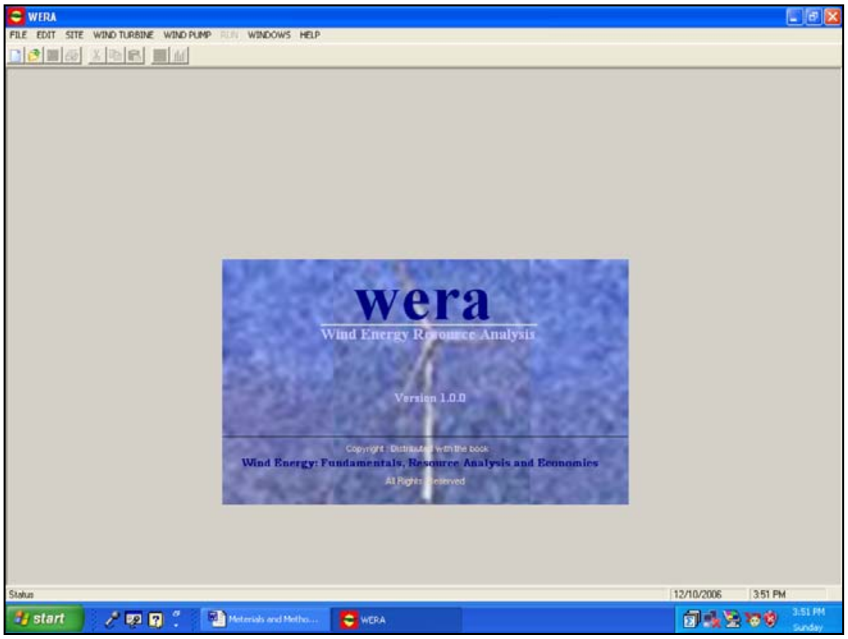

Fig. 3.1. Screen shot shows Window of WERA model.

3.3 Validation of the WERA Model

WERA model used for the analysis was validated using long-term wind data from the Kanjikode wind farm (10.47º N and 76.49º E) Palakkad dist, Kerala. Short-term (10 min) and long-term (30 min) data were collected for this purpose. Variations in the observed power and the power calculated using the WERA model were brought out under the validation process. Technical specifications of the wind turbines installed at Kanjikode wind farm are shown in Table. 3.2.

The velocity power proportionality has a profound effect on the power generated by the wind turbine. Ideally, variations in power with the velocity should be cubic in nature. However in practice, this can take any form such as linear, quadratic, cubic or even higher powers and combinations. Hence the first step in the validation process was to identify velocity power proportionality at a given wind farm site and turbine.

Table 3.2. Technical specifications of the wind turbines

Company	VESTAS
Type/variant	V27
Rated power	225 kW
Type of generator	Induction
Rated voltage	400V
Small generator	50 kW
Variable speed	Two-generator
Power control	Pitch
Blade type	VESTAS 13
Rotor diameter	27 meter
Swept area	573 m^2
Power per sq. meter	0.393 kW/m^2
Cut in wind speed	3.5 m/s
Cut out wind speed	25 m/s
Standard hub height	32 meter
Tower	Lattice type

The power response of the turbines at various wind velocities were recorded for this purpose and compared with the theoretical power estimated using the equation

$$P_V = P_R\left(\frac{V^n - V_I^{\,n}}{V_R^{\,n} - V_I^{\,n}}\right) \qquad (3.22)$$

For quantifying the differences in measured and estimated power values for different n, the index of agreement between the observed and predicted values are computed by

$$Ia = 1.0 - \frac{\sum_{i=1}^{N} (M(i) - E(i))^2}{\sum_{i=1}^{N} \left(\left| E(i) - \overline{M} \right| + \left| M(i) - \overline{M} \right| \right)^2} \tag{3.23}$$

Where,

M (i) - Measured values

E (i) – Estimated values

$\overline{M}$ - Average of measured values

After identifying the velocity-power proportionality, wind turbine performance module of the WERA programme was validated using the data collected from the Kanjikode wind farm. Both the Weibull and Rayleigh modules were validated with the field data.

3.4. Linking WERA with GIS

Among the five short listed sites, the site yielding the lowest generation cost should be selected for wind farm installations. Hence the economics of converting wind to electric power at short-listed sites had been analysed. The wind turbine performance simulation done using WERA formed the basis of this analysis.

Possibilitities of sound pollution due to proposed wind farm at the nearby dwelling areas were computed. Spherical sound propagation path was assumed and the distance between the turbine and the nearest household was considered. Sound pressure level from each turbine at these points was computed as

$$Lp = L_W - 10\log_{10}\left(2\prod R^2\right) - \alpha R \tag{3.24}$$

and sound power level of 10 turbines

$$P_N = 10^{\left(\frac{L_p - 90}{10}\right)} \tag{3.25}$$

Corresponding total sound pressure level of the turbine

$$L_P = 10\log_{10}\left(P_N\right) + 90 \tag{3.26}$$

For selecting a suitable site from the shortlist and further sitting turbines at this location with the help of GIS tools, an intermediate programme was required. Thus a programme named WE, linking the result of WERA with GIS, was developed in MS Excel. The input parameters for the programme are shown in Table 3.3. The economic merits of the site were judged in terms of cost/kWh of electricity generated, Net Present Value of the project, Benefit Cost Ratio and Payback Period, which were computed by the following expressions in the programme.

Table 3.3. Input parameter for WE programme

S.No.	Input parameter
1	Cost of turbine with tower, control & electrical fittings
2	Cost of transformer including tax & transportation
3	Land required per acre
4	Cost of land per acre
5	Total cost of land
6	Distance from grid, meter
7	Cost for grid integration per meter
8	Distance from road to farm, meter
9	Total cost for construction of road to farm
10	Installation charges including foundation per turbine
11	Rated power
12	Capacity factor
13	Useful life, years
14	Maintenance charges
15	Discount rate

Cost per kWh wind-generated electricity was calculated by

$$c = \frac{NPV\,(C_A)}{E_I} = \frac{C_I}{8760\;n}\left(\frac{1}{P_R\;C_F}\right)\left\{1 + m\left[\frac{(1+I)^n - 1}{I\;(1+I)^n}\right]\right\} \qquad (3.27)$$

Where,

C_I is the initial investment cost, Rs

N is the life of turbine, Years

P_R is the rated power, kW

C_F is the capacity factor

M is the maintenance cost and

I is the discounting rate

Net present value was computed as

$$NPV = B_A\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right] - \left\{C_I\left[1 + m\left(\frac{(1+i)^n - 1}{I(1+I)^n}\right)\right]\right\} \tag{3.28}$$

and benefit cost ratio (BCR) was estimated by

$$BCR = \frac{B_A\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right]}{C_I\left[1 + m\left(\frac{(1+I)^n - 1}{I(1+I)^n}\right)\right]} \tag{3.29}$$

A project is acceptable if BCR is greater than 1. The pay back period of the project, which indicates the minimum period which the investment for the project is recovered, was calculated using the expression,

$$n = \frac{\ln\left[1 - \left(\frac{IC_I}{B_A - mC_I}\right)\right]}{\ln(1+I)} \tag{3.30}$$

Best on the result of WERA and WE, a site were finally selected for wind farm installation.

3.5 Wind Farm Planning and Micro-siting

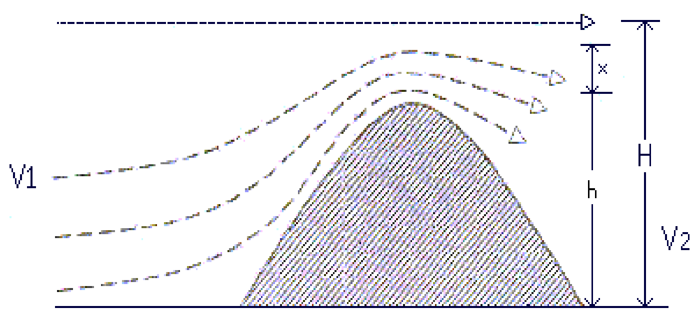

Fig. 3.2. Acceleration effect over a ridge.

Micrositing involves laying out turbine and its accessories at optimum locations at the selected site. The Micrositing was done using Geographical Information System (GIS). ILWIS 3.3 software was used for this purpose.

Digital elevation map of the selected location was developed from the contour map of the site, indicating the elevations of various points from mean sea level. This difference in height at various points at the site leads to variations in wind speed driving the turbines, and consequently in to differences in energy yield.

3.5.1. Digitizing contour lines

- From the File menu of the Main Window, select Map Reference. The Map Reference dialog box is opened.
- Expand the create item in the operation-tree and double-click New segment Map. The Create Segment Map dialog box is opened.
- Type ‘Isolines’ for the name of map.
- Select landuse from the list box Coordinate System” Unknown”.
- Click the Create Domain button. The Create Domain dialog box appears.
- Type ‘Isolines’ for the Domain Name and select domain Type Value.
- Type 6 to 38 in the Min, Max text boxes, and type 0.5 in the text box Precision.
- Close the Create Domain dialog box by clicking OK. You are now back in the Create Segment map dialog box. Click OK.
- From the Edit menu of the segment editor, select Insert Code the Edit dialog box is opened.
- Type the value: 6. This will be the default value for all segments that will digitize from now on. Click OK
- Digitize the contour lines with the altitude 6. After you finished digitizing each line, click OK in the Edit dialog box.

- Subsequently digitize a contour line of altitude 14.0. In the Edit dialog box, which appears after you finished digitizing the line, change the value into 14.0 and click OK. Continue to digitize the rest of the contour lines. Make sure to snap different parts of the same contour lines.
- From the File Menu of the segment editor, select Check Segments, Code Consistency.
- Accept the defaults in the Check Segments dialog box and click OK. If the programme finds an error, it will indicate the place of the error with a red box and a dialog box appears stating the nature of the error: Different codes ‘value’ and ‘value’ at node. Zoom in on error?
- Click Yes to zoom in and correct the errors by recording the wrong segments.
- Press the Exit Editor button when the digitizing is finished. When the segment editor is closed, the segments are displayed in a map window; segments are displayed with system representation Pseudo.
- Close the map window when you have seen the result.

3.5.2. Digital Elevation Model: Contour Interpolation

- Click with right mouse button on segment map contour Interpolation from the context-sensitive menu. The Interpolate contour map dialog box is opened.
- Type ‘DEM’ as Output Raster Map.
- Select Georeference as SCAN.
- Type the command on command line:

Dembound=iff (isundef (Boundary),?, Isoline)

- Accept all other defaults and click show.

For calculating the maximum velocity potential according to the topography of the land acceleration effect on elevated spots was taken in to consideration. The acceleration is caused by squeezing of the wind layers over the mount as shown in Fig. 3.2. Applying the continuity equation, changes in wind velocity due to elevation differences was deduced to be

$$V_2 = \frac{H}{(H - h)} \times V_1 \tag{3.31}$$

Where

V_1 is the free stream velocity

V_2 is the velocity at the elevated spot

From the digital elevation map velocity contour map was deduced using the above expression. An area corresponding to 1.5 times to the rotor diameter had to be left free from wind farm activities. As the diameter of the turbine is 80 m, a distance of 120 m had to cut for this purpose. The boundary map and reverse boundary map were prepared accordingly. The next step was to locate the distance of each point at the boundary of the unusable area from a referral point. The distance boundary map was drawn for this purpose. Suitability of various points in the selected area from the wind farm installation was determined by normalizing the region, based on velocity differences. Suitability of various was weighted in scale ranging from 0-1 where 0 represents the region of lowest velocity and 1 represents the region of highest velocity (which obviously most suited spot for wind farm erection). Thus, finally 10 spots having highest velocity were spotted from the selected region for turbine installation.

RESULTS AND DISCUSSION

The results obtained from various investigations conducted under the study are presented and discussed under the following heads.

4.1 Verification of the WERA Model

4.2 Wind Energy Resource Analysis at the Selected Sites Using WERA

4.3 WERA-GIS Interlinking Programme for the Final Site Selection.

4.4 Micro-siting

4.1. Validation of WERA Model.

The WERA model used for the present investigation has been validated using field data from the Kanjikode wind farm (10.47º N and 76.49º E), Palakkad, Kerala. For this the velocity-power proportionality (n) had to be identified for the turbines installed at the site. Instantaneous values of velocity and power recorded using the automated data acquisition system was used for this purpose. Results are shown in Figs.4.1 through 4.5 in which the observed and predicted values of instantaneous powers for n ranging form 1 to 3.5 are shown. The scattered points indicate the measured values whereas the straight line represents the estimated power. It can be observed that better agreements in predicted and measured values are observed while the value of n is between 1 and 2.

For precise identification of optimum value of n, index of agreement between the observed and predicted values were computed. Index of Agreement for n ranging from 1 to 3.5 is displayed in Fig.4.6. As in the previous figures, better agreement between observed and predicated power is archived for n between 1 and 2. Third degree polynomial curve was fitted on the Index of Agreement at different n as shown in the figure. The equation defining this curve is

$$y = 0.0155x^3 - 0.1508x^2 + 0.3822x + 0.6233 \tag{4.1}$$

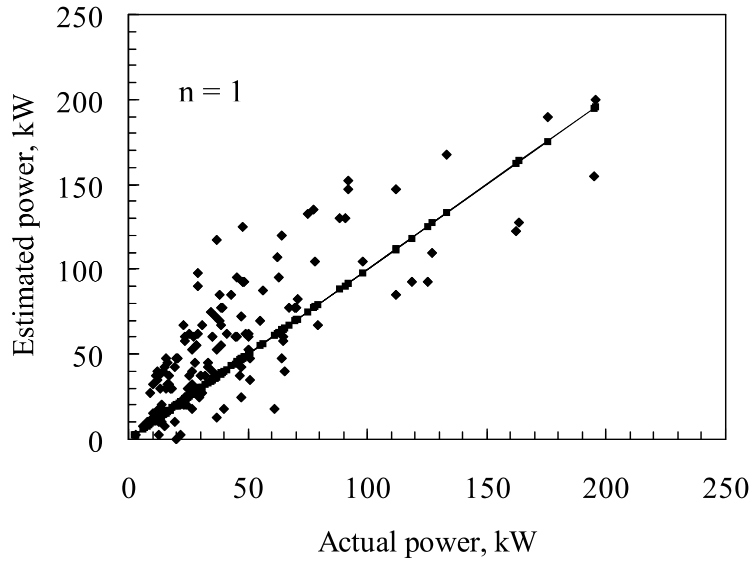

Fig.4.1. Actual and estimated power for n=1.

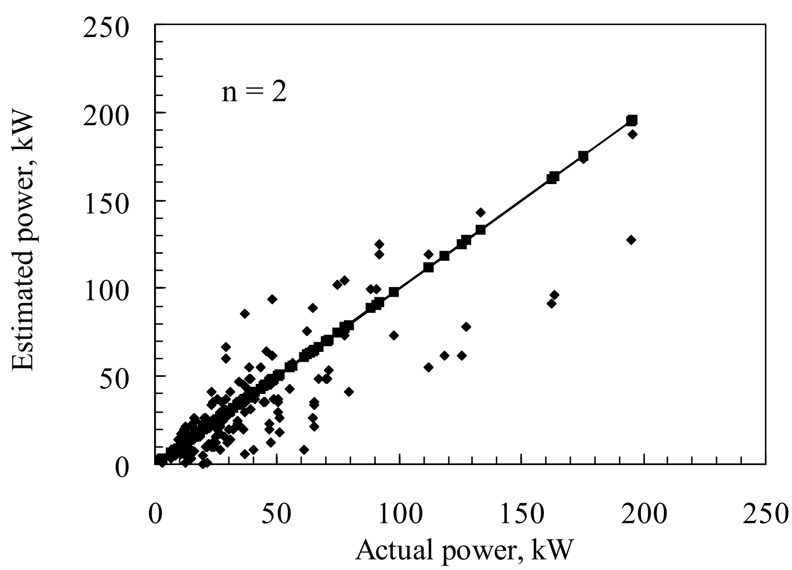

Fig.4.2. Actual and estimated power for n=2.

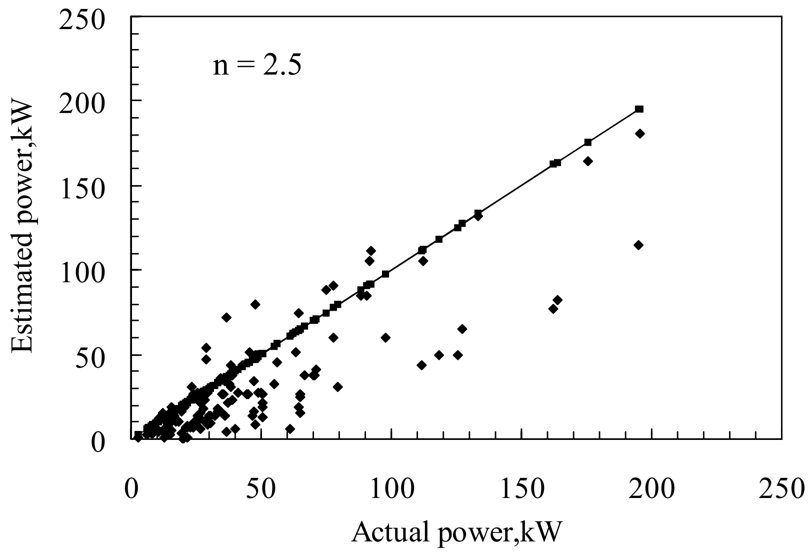

Fig.4.3. Actual and estimated power for n=2.5.

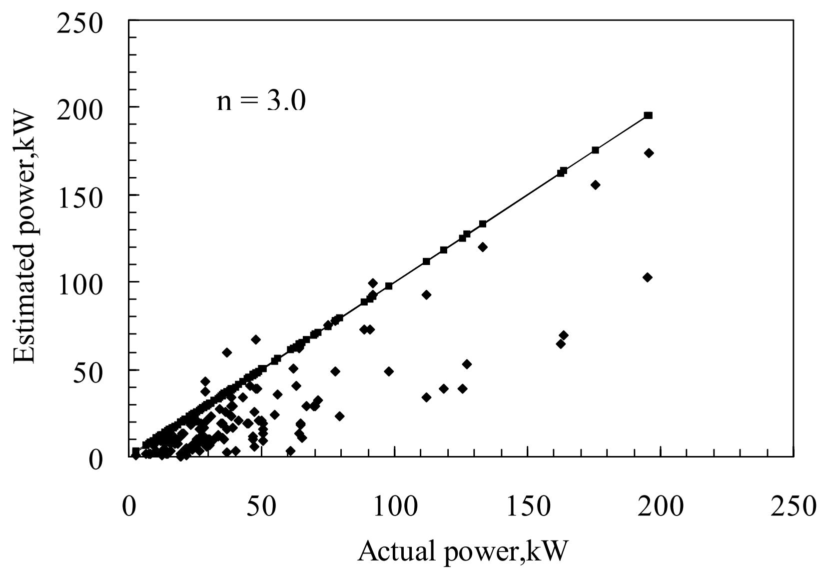

Fig. 4.4. Actual and estimated power for n=3.0.

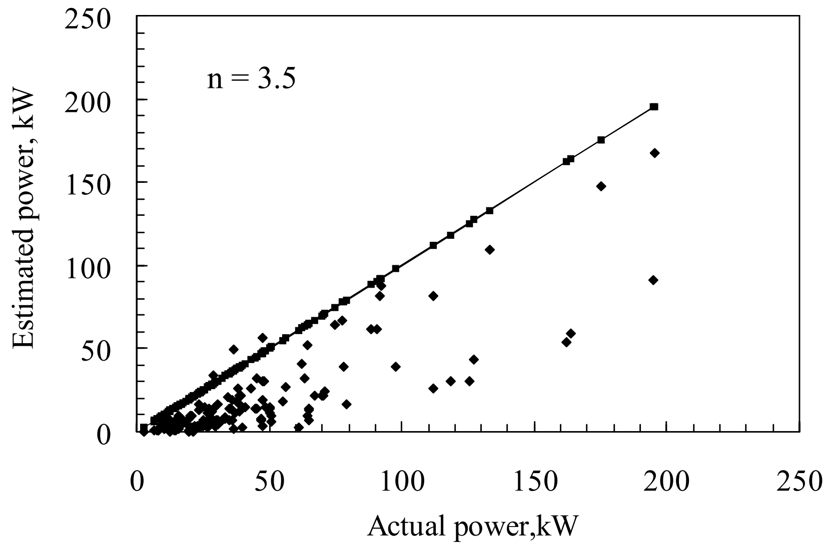

Fig.4.5. Actual and estimated power for n=3.5.

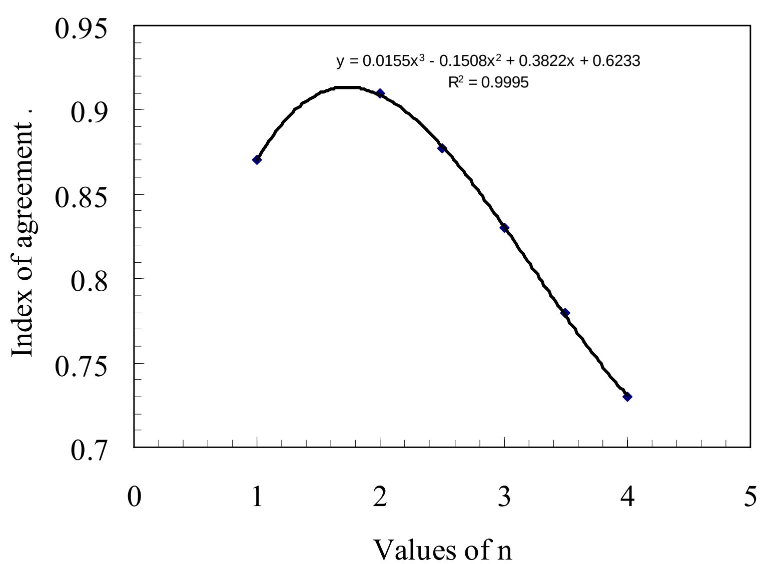

Fig.4.6. Variation in index of agreement with n.

where x and y represent the values of n and index of agreement respectively. R^2 for the above equation is 0.99. In order to locate the maximum value of n, the condition of maxima was applied to the deduced equation. Thus,

$$\frac{dy}{dx} = (3\times 0.0155)x^2 - (2\times 0.1508)x + 0.3822 = 0 \qquad (4.2)$$

and

$$\frac{d^2y}{dx^2} = (2\times 0.0465)x - 0.3016 \qquad (4.3)$$

Solving equation (4.2) and selecting the root satisfying the maxima condition in equation (4.3) we get x=1.75. Thus, n is taken as 1.75 in the preceding computations.

After identifying the value of n for the wind turbine, the Raleigh based module for wind turbine performance of the WERA model was validated. 30-minute interval data from different turbines were collected and averaged over daily basis for this purpose. Variations in measured and estimated energy with the mean wind velocity are shown in Fig. 4.7. The straight line represents the energy estimated using WERA-Raleigh model where as the scattered points line indicates the actual measurements. A reasonable agreement is observed between the estimated and measured values of energy. For further validation of WERA-Raleigh model estimated and measured performances of the system were compared as shown in Fig.4.8. The scattered points and the straight line indicate the measured and estimated energy respectively. Index of agreement for the observed and simulated performance of a turbine, in this case, is found to be 0.864. For establishing the model validity further F-Test was performed on measured and simulated data, which yielded an F value of 1.025 at 5 per cent level. The result of F-test is given in Table 4.1. As the computed F-value is well within the critical value, it can be concluded that the Raleigh module of the WERA model could simulate the turbine performance successfully.

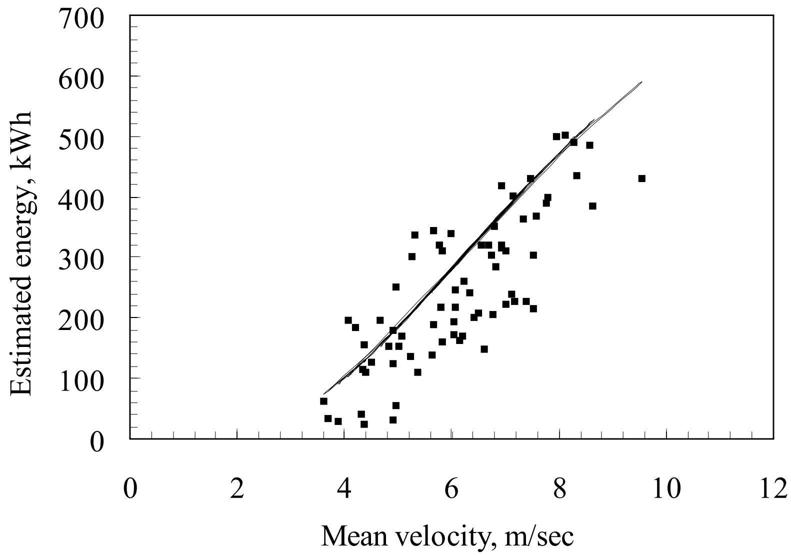

Fig.4.7. Mean velocity and estimated energy for data at 30-minute interval.

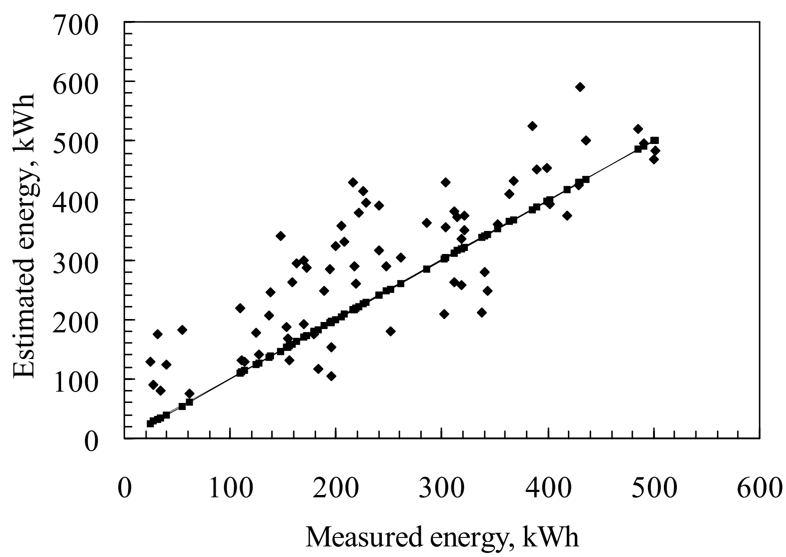

Fig.4.8. Measured energy and estimated energy for data at 30-minute interval.

Table 4.1 Results of F-test conducted on measured and simulated performances of the turbine using WERA-Rayleigh model

Mean (Simulated performance)	296.17 kWh
Mean (Measured performance)	245.47
Variance (Simulated performance)	15652.3
Variance (Measured performance)	15264.08
Computed F-value	1.025
Critical F-value at 5 per cent level	1.481

The Weibull module of WERA model was also validated using field observations. 10-minute interval data on velocity and energy were used for this purpose. The results are shown in Fig.4.9 where the measured and estimated energy productions have been compared. The straight line indicates the estimated energy whereas the scattered points represent the corresponding measured values. Index of agreement between the measured and estimated energy was 0.898. Results of t-test, performed to establish the model validity is shown in Table 4.2.

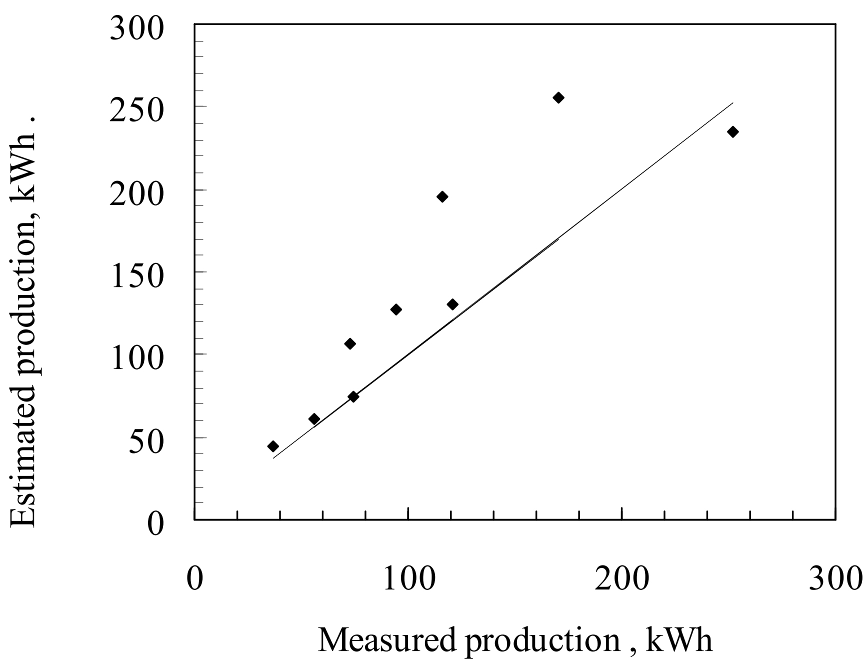

Fig.4.9. Measured and estimated energy production for data at 10-minute interval.

Table 4.2. Results of t-test.

Mean (Simulated performance)	110.33 kWh
Mean (Measured performance)	136.49 kWh
Variance (Simulated performance)	4387.75
Variance (Measured performance)	5768.50
Computed t-value	0.4471
Critical t-value at 5 per cent level	2.119

The index of agreement and results of t test established the capability of WERA-Weibull module in predicting the field performance of the turbine. Thus, it can be concluded that both the Raleigh and Weibull modules of the WERA model can be used with confidence in estimating the energy yield from wind turbines installed at a specific site. When adequate wind data collected over shorter interval are available, the Weibull model may be used for performance simulation whereas if the data available is in the form of velocity averaged over a period, the Raleigh model would be more appropriate.

4.2. Wind Energy Resource Analysis at the Selected Sites Using WERA.

The energy potential of wind spectra available at 10 prospective sites were analyzed using the WERA model. Details of ten sites, preliminary selected for the analysis are shown in Table 4.3, indicating the mean wind velocity and standard deviation on a yearly basis. The Weibull parameters k and c, computed using the standard deviation method is also displaying in the table. From theses 10 sites the sites having annual mean wind velocity 7 m/sec and above were short listed for further analysis. The short listed sites are Rameshwarm, Kanjikode, Andipatti, Kayattar and Sultanpet. The wind characteristic of these sites described by probability density and cumulative distribution function of the prevailing wind spectra are shown in Fig. 4.10 through 4.19.

Table 4.3. Mean velocity, Standard deviation, Weibull k & C factors of the selected sites for wind farm installation.

S.No.	Location	Mean Velocity, Vm	Standard deviation, σ_v	Weibull shape factor, k	Weibull scale factor, C
1	Tolanur	5.60	2.88	2.06	6.32
2	Meenakshipuram	6.79	4.41	1.60	7.66
3	Okha	6.20	2.53	2.66	7.00
4	Deogad	5.74	2.78	2.21	6.87
5	Tuticorin	6.09	2.89	2.25	6.48
6	Rameshwaram	7.75	3.11	2.70	8.74
7	Andipatti	7.46	4.56	1.71	8.42
8	Kanjikode	6.99	2.50	3.06	7.89
9	Sultanpet	7.00	3.78	1.96	7.90
10	Kayattar	7.63	4.29	1.87	8.61

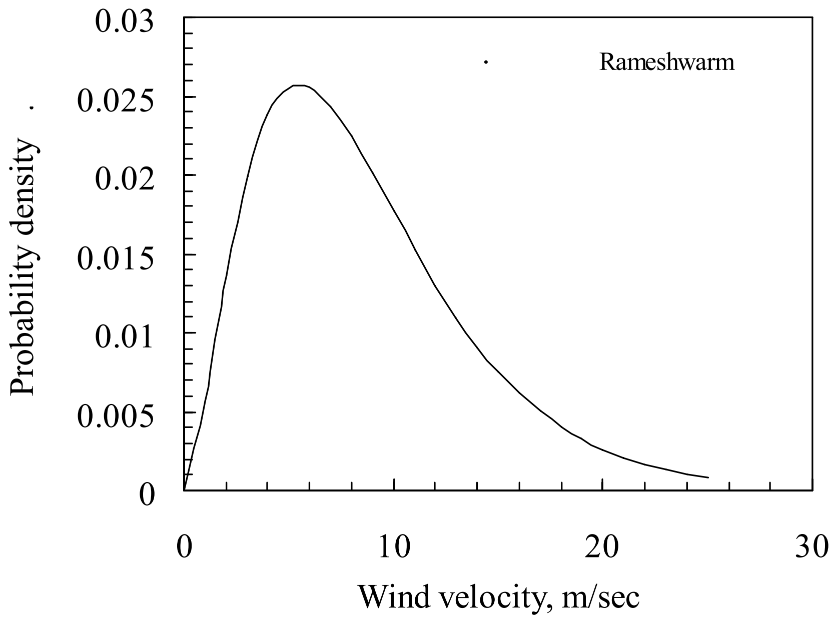

Fig.4.10. Weibull probability density of wind velocity at Rameshwaram.

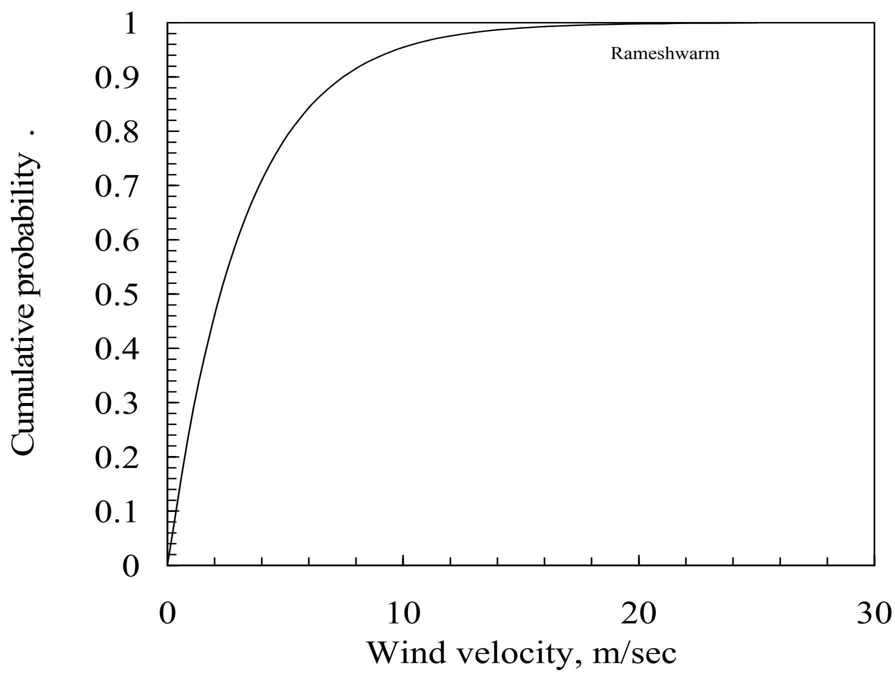

Fig.4.11. Weibull cumulative probability of wind velocity at Rameshwaram

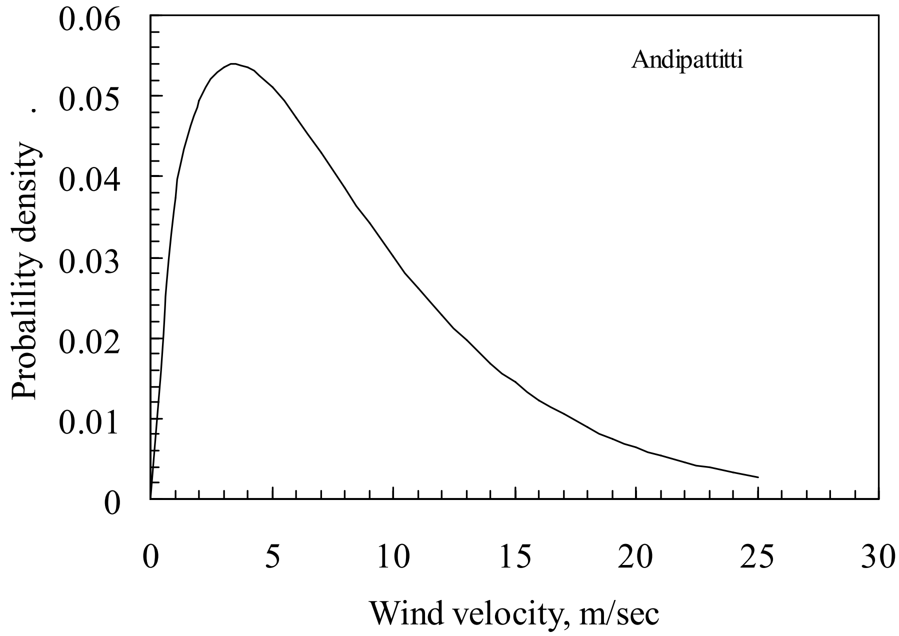

Fig.4.12. Weibull probability density of wind velocity at Andipatti.

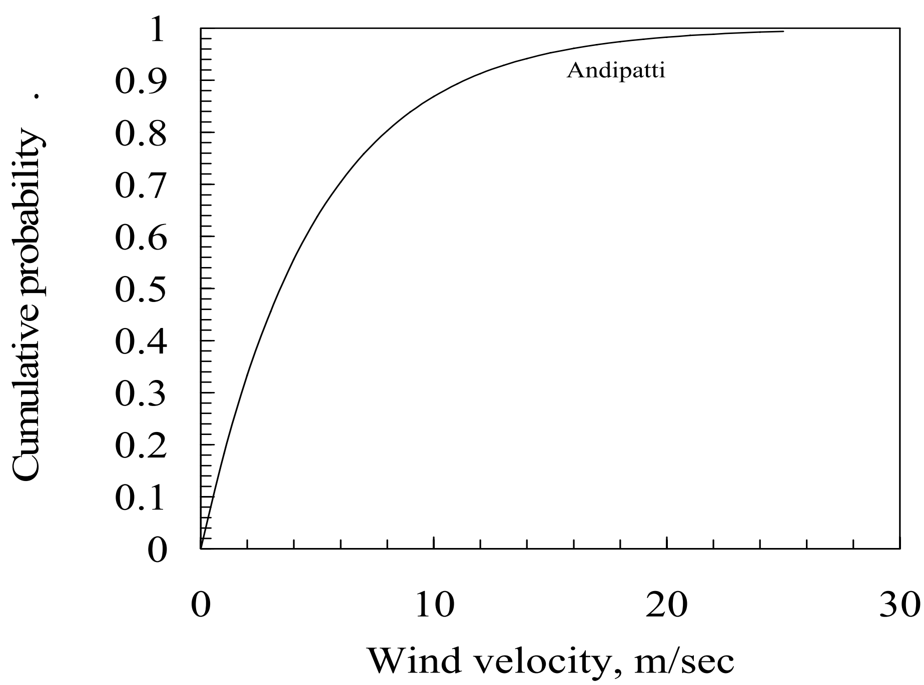

Fig.4.13. Weibull cumulative probability of wind velocity at Andipatti.

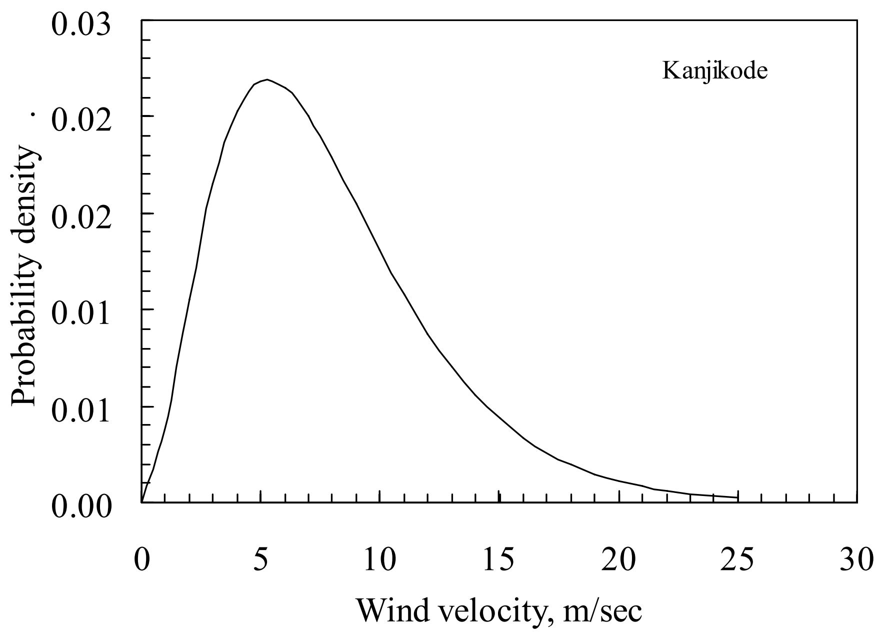

Fig.4.14. Weibull probability density of wind velocity at Kanjikode

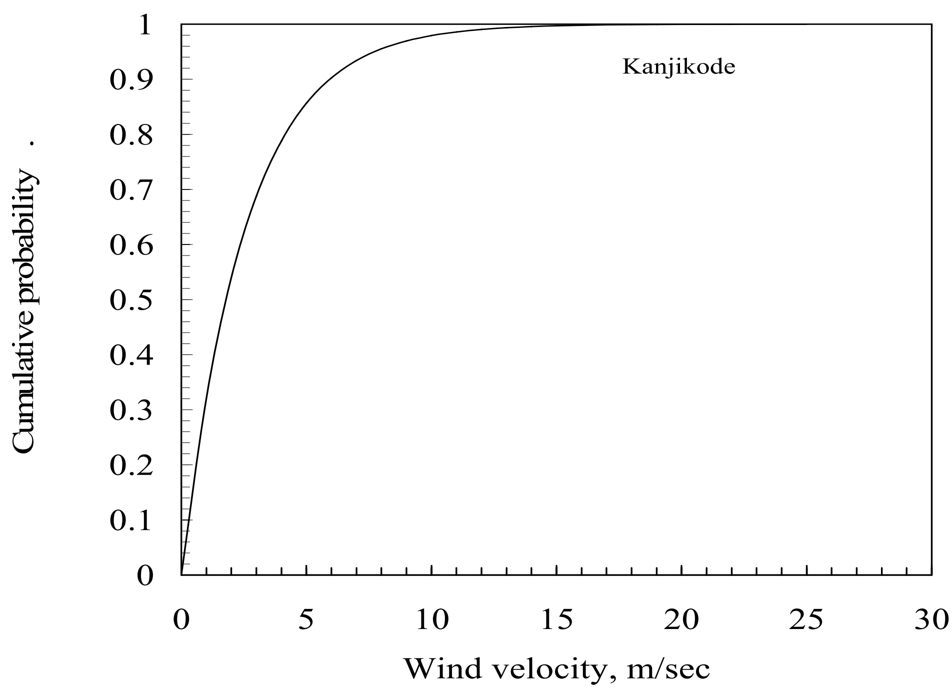

Fig.4.15. Weibull cumulative probability of wind velocity at Kanjikode.

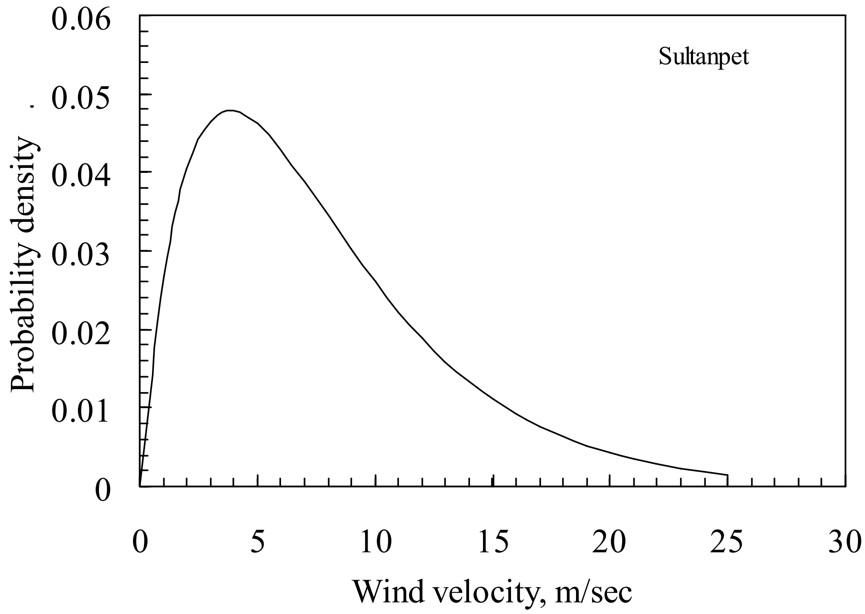

Fig. 4.16. Weibull probability density of wind velocity at Sultanpet.

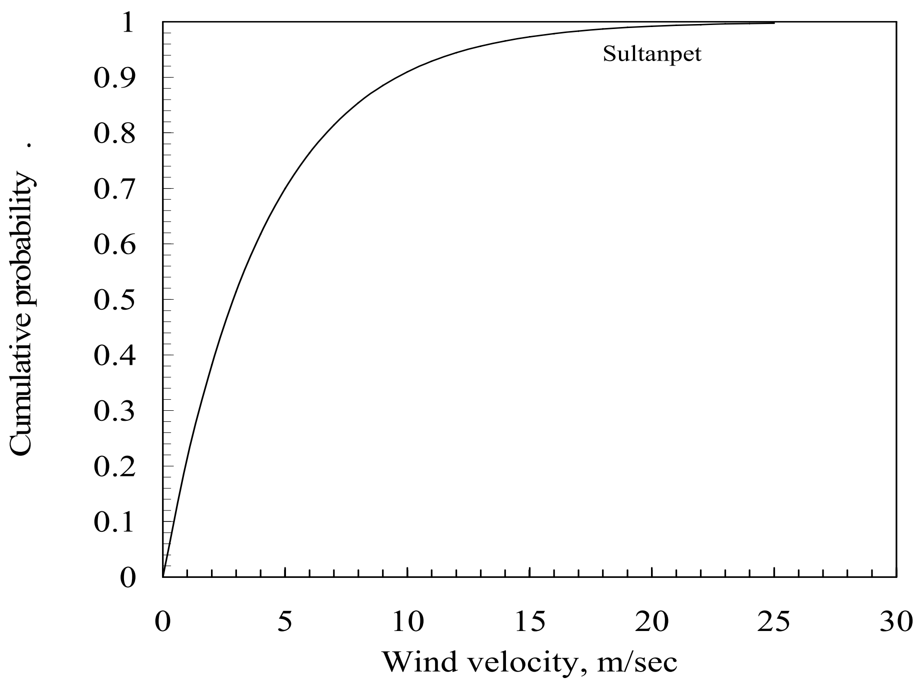

Fig.4.17. Weibull cumulative probability of wind velocity at Sultanpet.

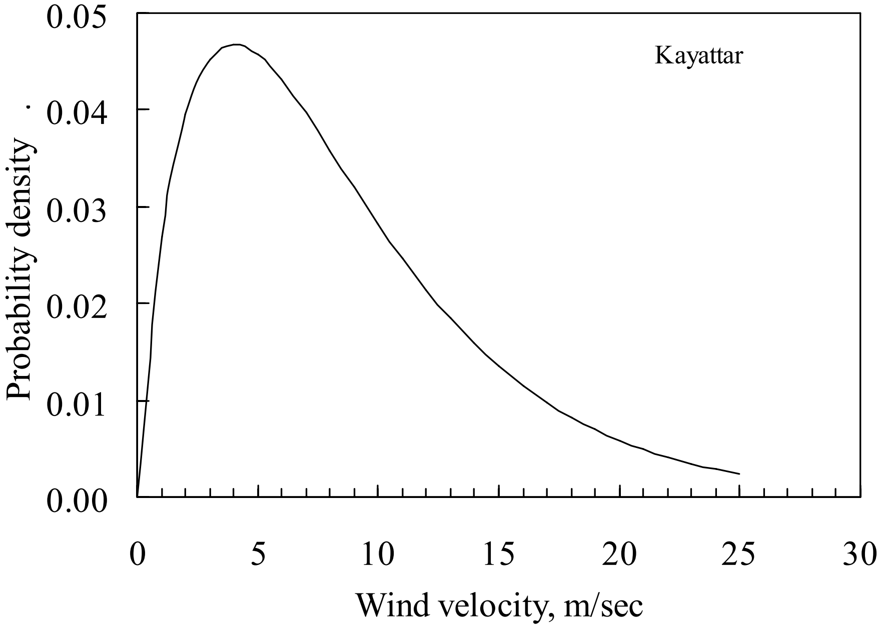

Fig.4.18. Weibull probability density of wind velocity at Kayattar.

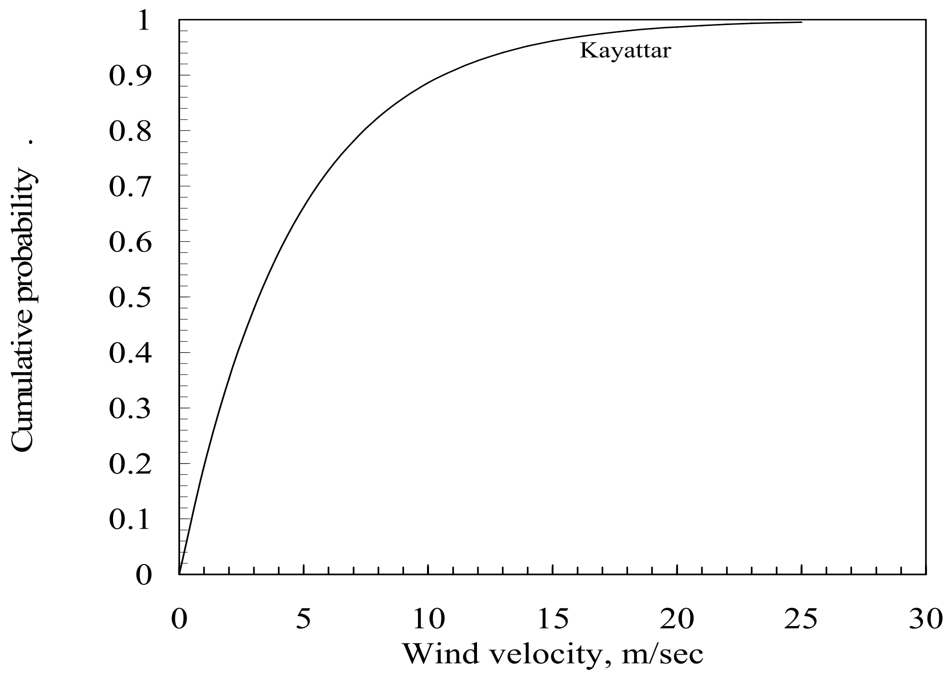

Fig.4.19. Weibull cumulative probability of wind velocity at Kayattar.

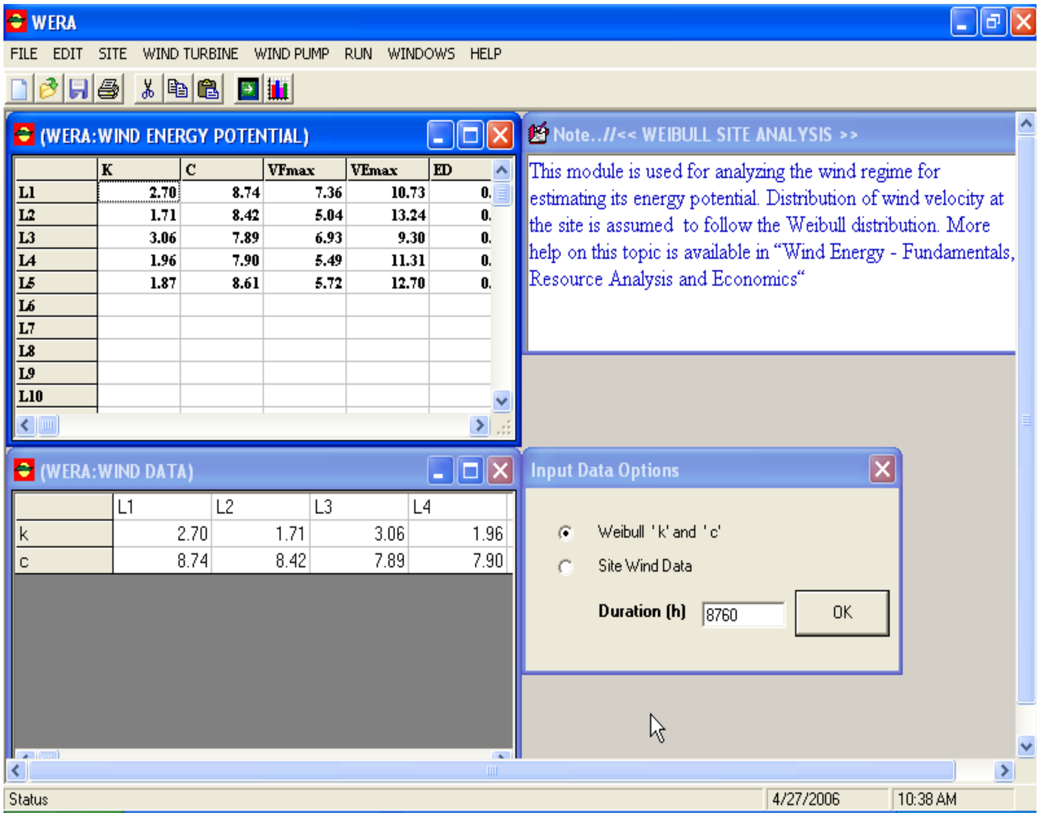

Fig.4.20. Screen shot showing the wind resource analysis using WERA

Peak of the probability density curve indicated the most frequent wind velocity at the regime. Similarly, the cumulative distribution functions tell us the fraction of time for which the velocity is above a given value in the regime. Indication on the time for which a given turbine is functional at a sit could be deduced from the cumulative distribution function.

Wind resource potential of the 5 short listed was deduced by the WERA software. Screenshot of the programme under this analysis is shown in Fig. 4.20. Results of the analysis are shown in Table 4.4. The energy density is found to be maximum (0.59 kW/m^2) at Andipatti and minimum at Kanjikode (0.30 kW/m^2). Energy available with wind spectra also follows same trend.

Table 4.4. V_{FMax}, $V_E$max , E_D and E_I at selected location.

S.No.	Locations	V_{FMax}	V_{EMax}	E_D	E_I
1	Rameshwarm	7.36	10.73	0.43	3784.57
2	Kayattar	5.72	12.70	0.56	4932.69
3	Andipatti	5.04	13.24	0.59	5192.07
4	Kanjikode	6.93	9.30	0.30	2624.30
5	Sultanpet	5.49	11.31	0.41	3609.25

As the proposed wind farm is of capacity 20 MW. 10 turbines of 2 MW capacities are considered in this analysis. In order to simulate the performance of these turbines of the five short-listed sites the WERA wind turbine module was used. Technical specifications of the turbines in terms of cut-in, cut-off and rated velocity along with rated capacity were punched in to turbine specification forms of the programme. Results of this analysis are shown in table 4.5. Screen shot of these analyses is shown in Fig. 4.15.

Table 4.5. Results of wind turbine performance analysis using WERA

S.No.	Locations	K	C	E_T	C_F
1	Kayattar	1.87	8.61	5620987.76	0.32
2	Rameshwarm	3.20	8.74	5586592.29	0.32
3	Andipatti	1.71	8.42	5452535.29	0.31
4	Kanjikode	3.06	7.89	4327879.30	0.25
5	Sultanpet	1.96	7.90	4739942.88	0.27

It can be seen that the highest energy yield (E_T) could be observed at Kayattar (5620987.76) followed by Rameshwarm (5586592.29) corresponding values are Andipatti, Kanjikode and Sultanpet were 5452535.29, 4327879.30, 4739942.88

respectively. The capacity factor of the systems at these sites also followed the same trend.

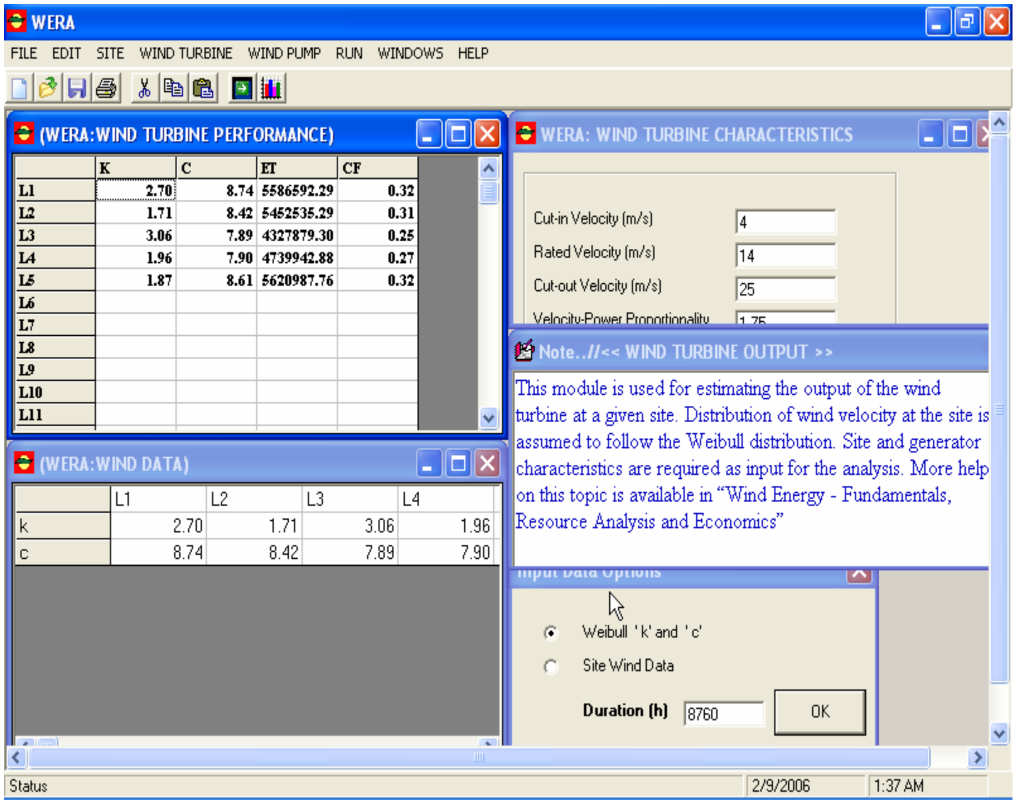

Fig.4.21. Screen shot showing wind turbine performance analysis using WERA.

Possibilitities of sound pollution due to proposed wind farm at the nearby dwelling areas were computed. Spherical sound propagation path was assumed and the distance between the turbine and the nearest household was considered. Sound pressure level from each turbine at these points were calculated which was then converted into the sound power level of 10 turbine clubbed together. From this combined sound power level, the total noise emitted by the turbine and felt in the dwellings spot were calculated as displayed in table 4.6. From the table it is evident that the noise from the wind farms at points at human activity are not seviour as pressure level is within the acceptable limit 50 dBA. Hence all the five sites are environmentally acceptable for wind farm installation.

Table 4.6. Sound pressure level and its corresponding sound power level.

S.No.	Location	Distance, m	Sound pressure level, Lp dB(A)	Sound Power, P_N dB(A)	Total Lp dB(A)
1	Rameshwarm	550	38.46	7.01×10^{-6}	48.46.
2	Kanjikode	500	39.54	8.99×10^{-6}	49.54.
3	Andipatti	480	40.00	9.98×10^{-6}	50.00.
4	Kayattar	700	35.62	3.64×10^{-6}	45.62.
5	Sultanpet	600	37.46	5.56×10^{-6}	47.46.

4.3. WERA-GIS Interlinking Programme for the Final Site Selection

Among the five short listed sites, the site yielding the lowest generation cost should be selected for wind farm installations. Hence the economics of converting wind to electric power has to be analyzed for the short-listed sites. Results of the wind energy analysis done using WERA would be the basis of this analysis. Results of the economic appraisals would further be used for micrositting of the turbine with the help of GIS tools. Thus a programme named WE, linking the results of WERA with GIS, was developed. The basic economic models used in this investigation are described in section 3.4.The introductory window of the programme is shown in Fig. 4.22. Various input data required for the computation are as displayed in Figs. 4.23 through 4.25. With these input information, the programme judges the economic merits of the sites in terms of cost/kWh of electricity generated, Net Present Value of the project, Benefit Cost Ratio and Payback Period. These indices calculated for five short listed sites and shown in the table 4.7.

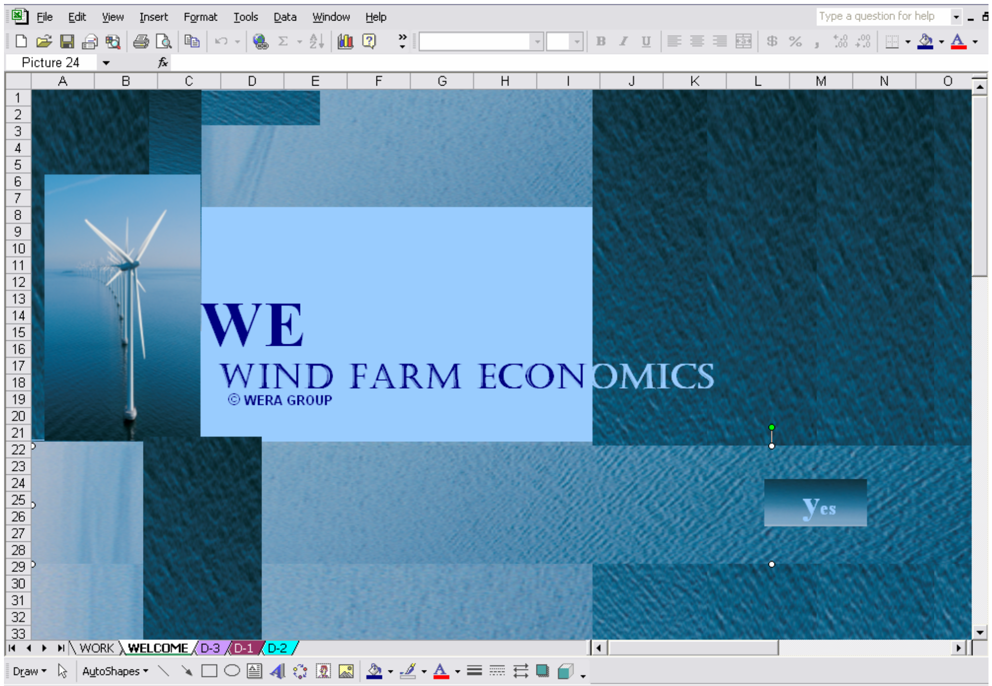

Fig. 4.22. Screen shot of introductory window of WE programme

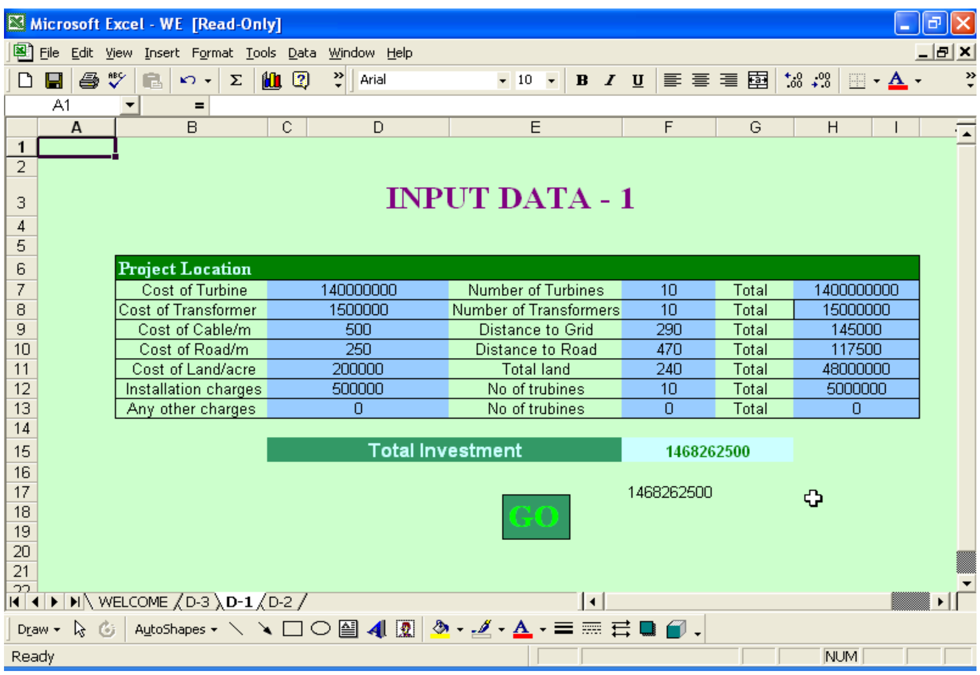

Fig. 4.23. Screen shot of input data-1 window of WE programme

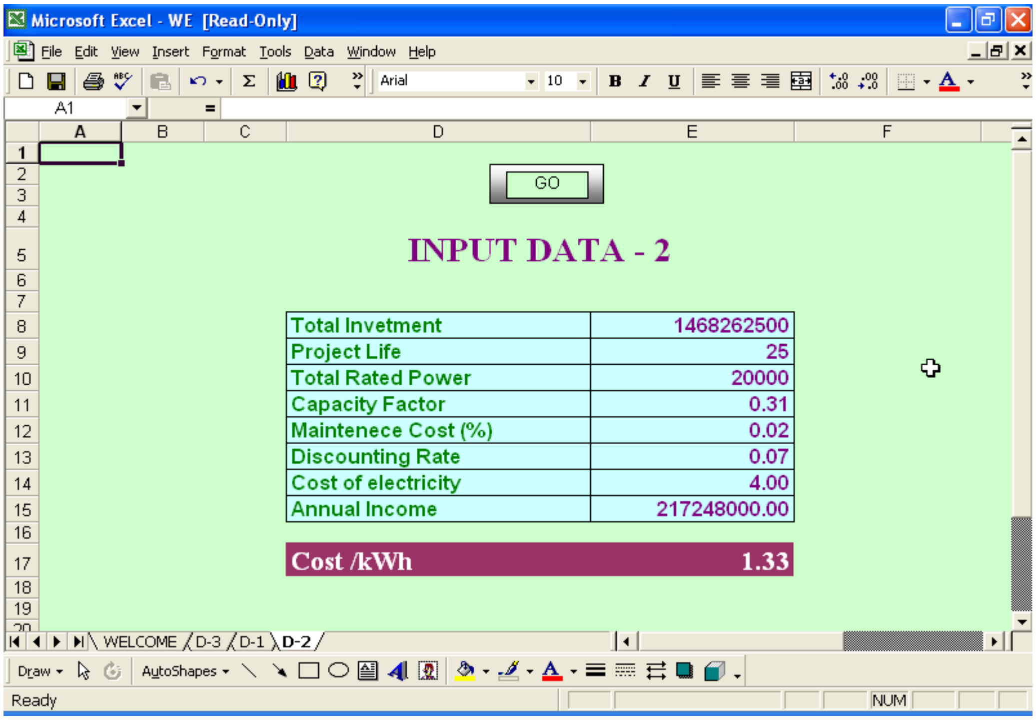

Fig. 4.24. Screen shot of input data-2 window of WE programme

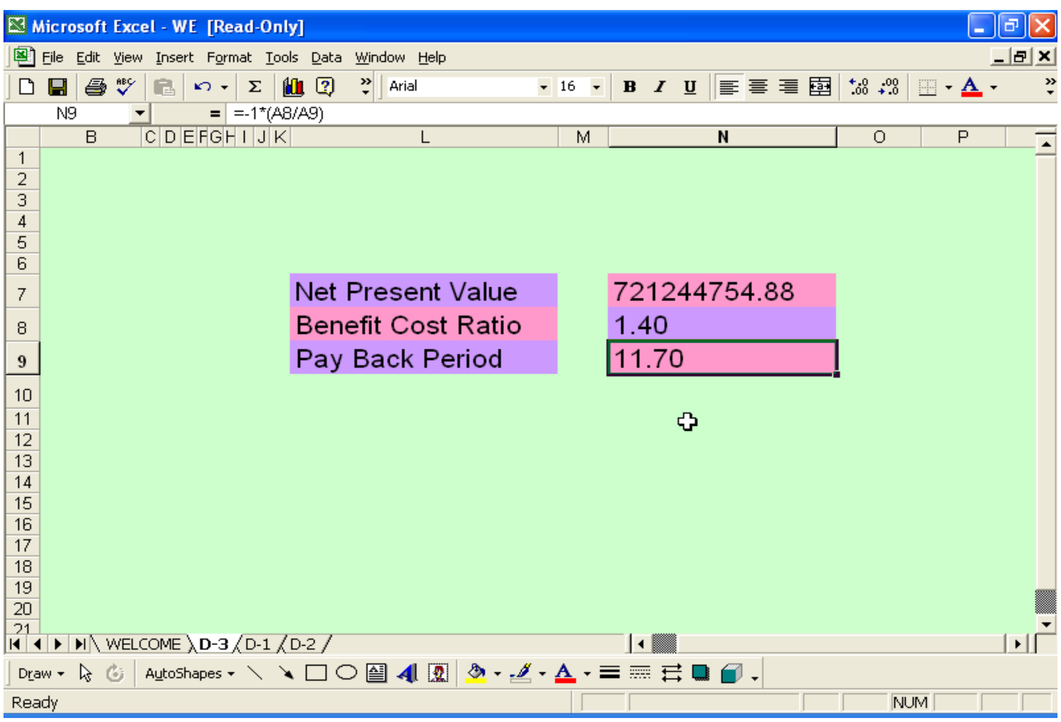

Fig. 4.25. Screen shot of output window of WE programme

Table 4.7. Economic indices of wind energy generation at the short listed sites.

S. No	Particulars	Locations				
		Kayattar	Rameshwarm	Kanjikode	Sultanpet	Andipatti
1	Capacity Factor	0.32	0.32	0.25	0.27	0.31
2	Total initial investment	1454884000	1490817500	1526558500	1454843750	1454762500
3	Cost/kWh	1.28	1.31	1.72	1.52	1.32
4	Net present value	819409715.05	775101134.43	159351743.71	411117791.62	737891222.34
5	Benefit cost ratio	1.46	1.42	1.08	1.23	1.41
6	Pay back period	10.90	11.37	19.83	14.94	11.52

The lowest cost/kWh (Rs.1.28) was observed for Kayattar followed by Rameshwaram (Rs.1.31), Andipatti (Rs.1.32), Sultanpet (Rs.1.52) and Kanjikode (Rs.1.72). The major factor influenced in this variation in cost of generation is the site capacity factor as evidence from the table. However, it should be noted that though the site Kayattar and Rameshwaram have same capacity factor, cost of unit generation is lower for Kayattar due to the lower land cost prevailing in that area, which in turn reduced the initial investment required for the project. Net Present Value, Benefit Cost Ratio and Pay Back Period followed the same trend as in case of cost/kWh generation. The payback period of the project, which has a life span of 25 years, ranges from 10.9 to 19.83, depending on the energy potential at these sites. In view of the distinct economic merit, location Kayattar had been finally selected for wind farm installation.

4.5 Micro-siting

Specific spots, at which the 10 turbines are to be erected in the selected areas, have been identified through micro siting using Geographical Information System (GIS) techniques. Contour map of the selected area indicating the elevation difference is shown in Fig. 4.26. Elevation of various points from mean sea level varied from 6 m to 38 m.

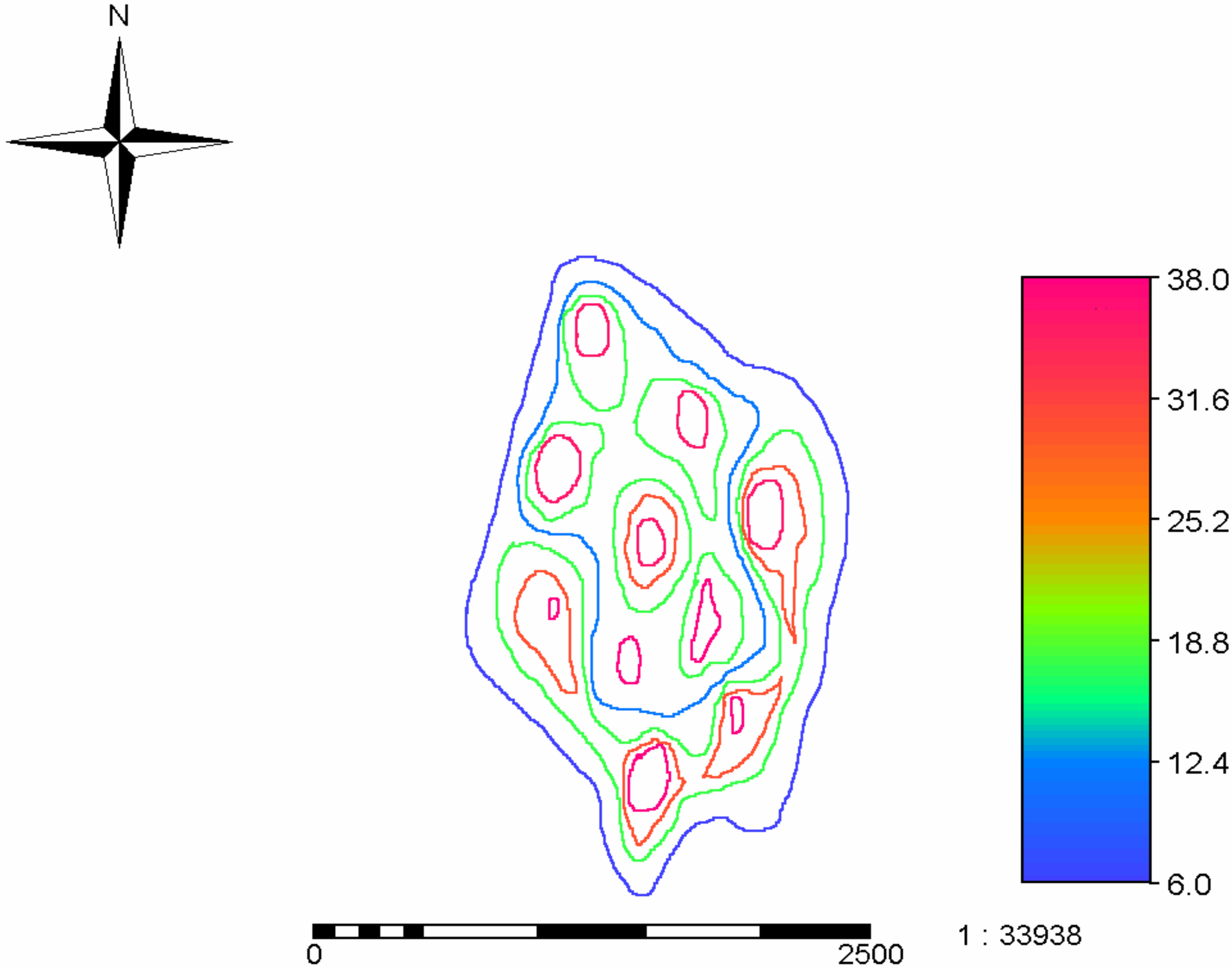

Fig. 4.26.Elevation contour map of the selected area.

Due to compression of flow lines as discussed in methodology section, velocity also varied at different points at the site. Obviously, it is advantageous to install the turbines at points of highest velocity. Digital elevation map of the area was developed from the contour map for the region, which is shown in Fig. 4.27.

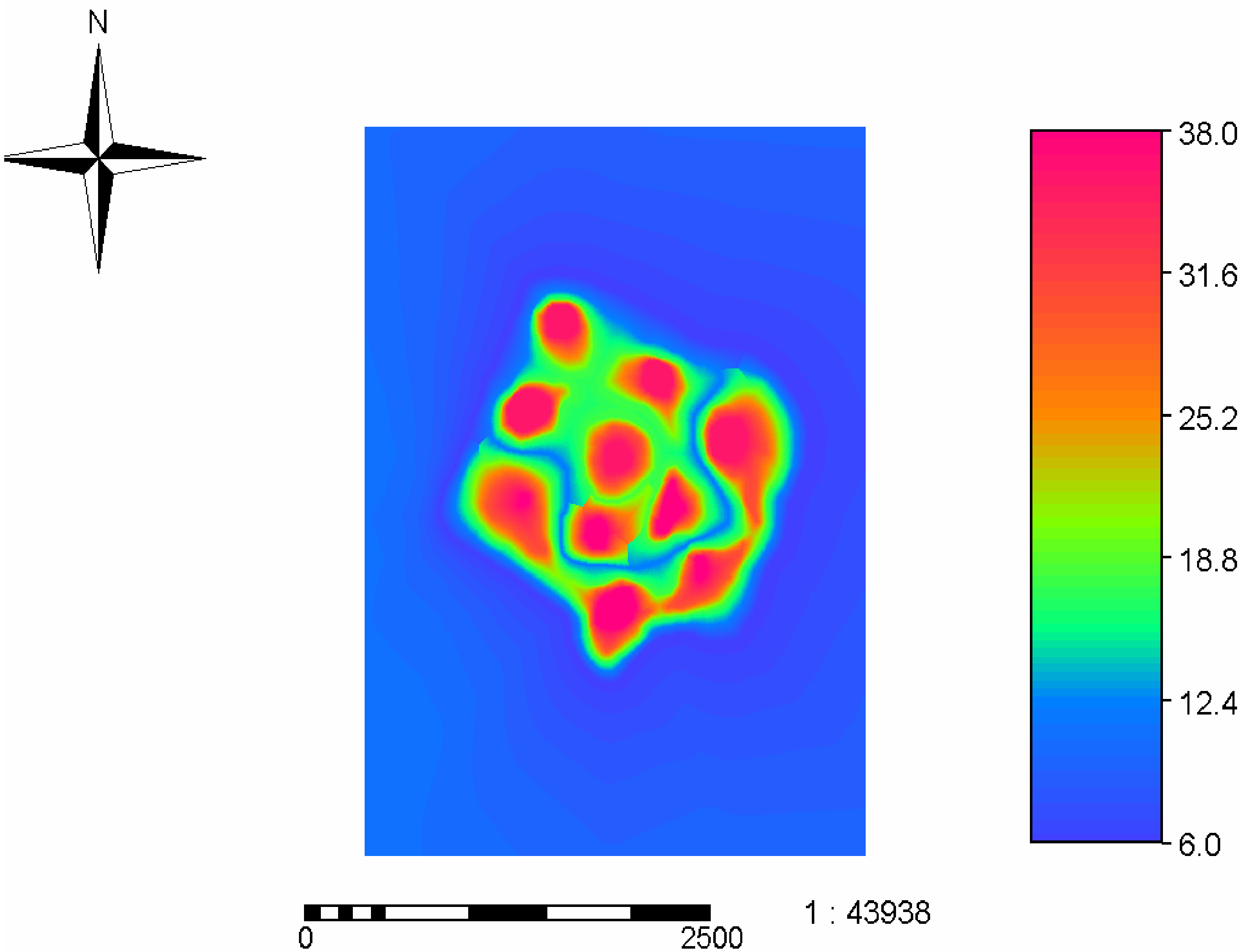

Fig. 4.27. Digital elevation model of the selected area.

From the digital elevation map velocity contour map was deduced as shown in Fig. 4.28. Variations in velocity with elevation was given by

$$V_2 = \frac{H}{(H - h)} \times V_1 \tag{4.4}$$

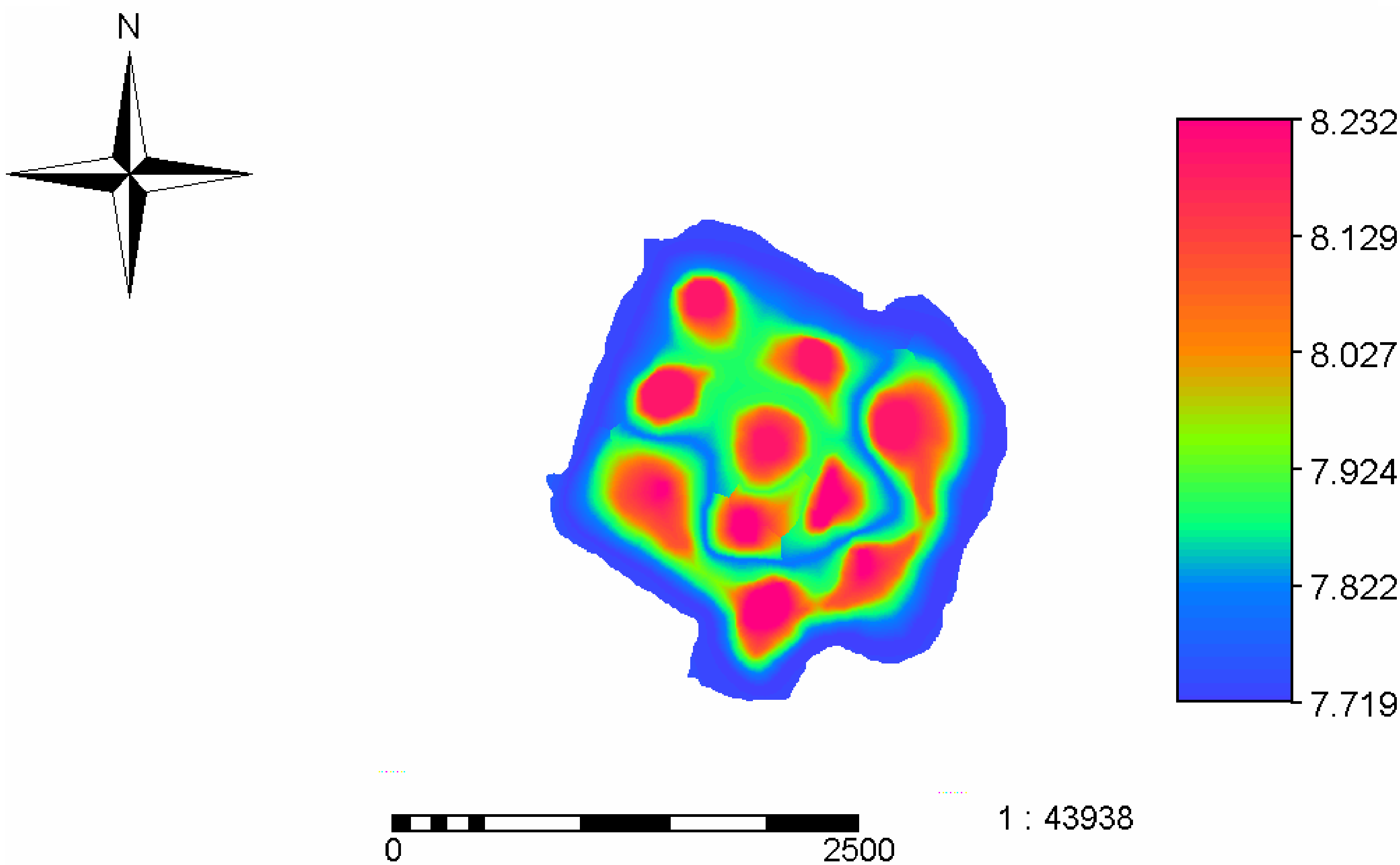

Fig. 4.28. Velocity contour map of the selected area.

As an area corresponding to 1.5 times to the rotor diameter had to be left free from wind farm activities. As the diameter of the turbine is 80 m, a distance of 120 m had to be cut for this purpose. The boundary map and reverse boundary map prepared accordingly are shown in Fig. 4.29 and 4.30. The next step was to locate the distance of each point at the boundary of the unusable area from a referral point. The distance boundary map drawn for this purpose is shown in Fig. 4.31. As evident from the figure the farthest point is 965.8 m away from the boundary.

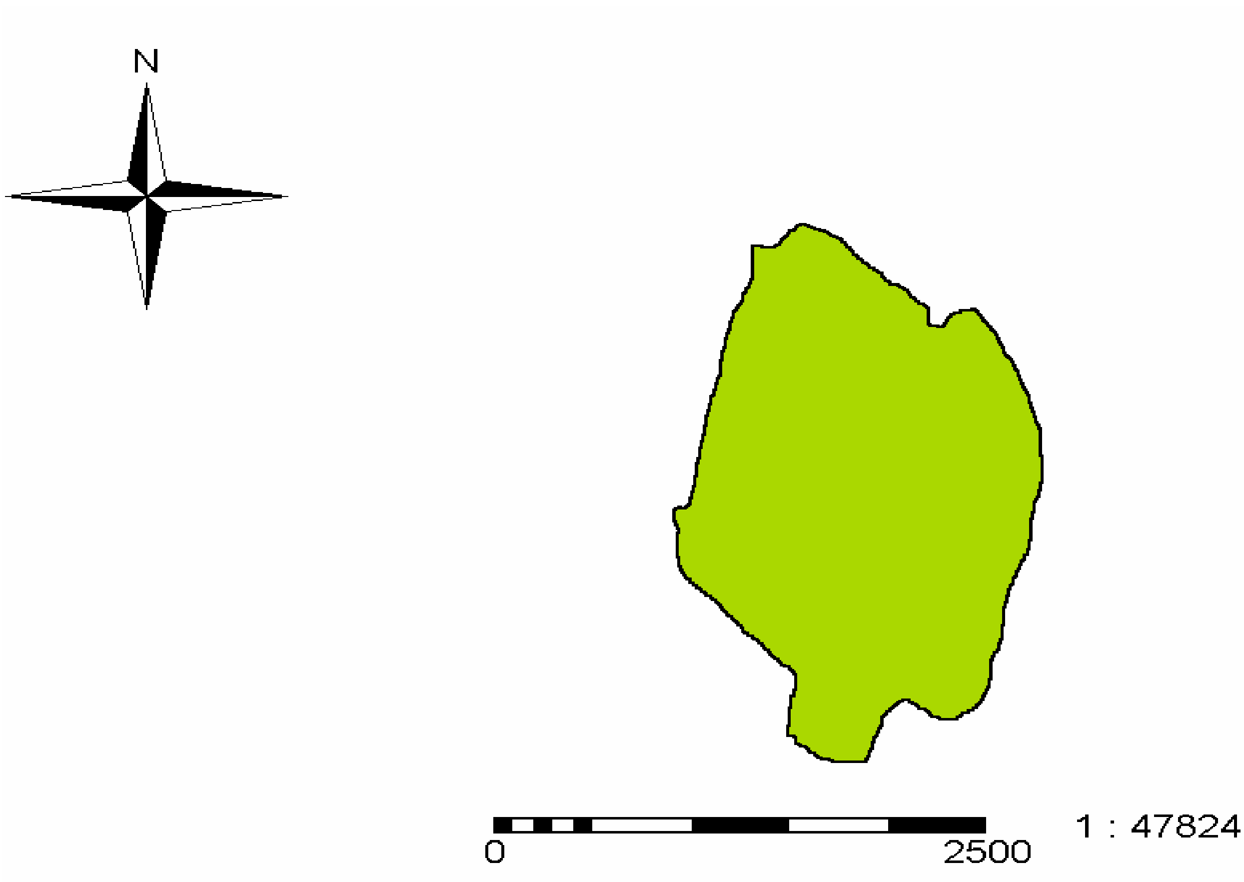

Fig.4.29. Boundary map of the selected area.

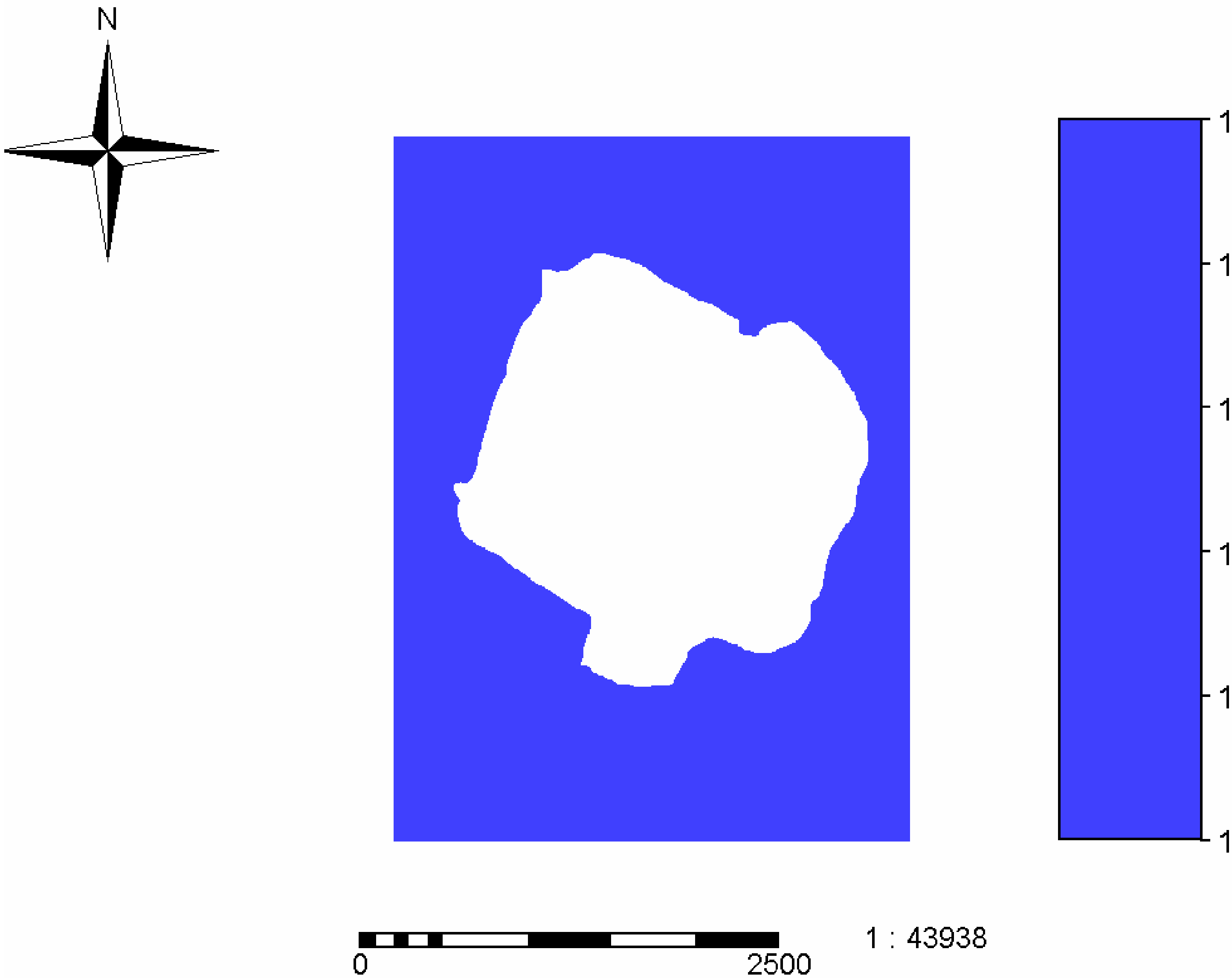

Fig.4.30. Reverse boundary map of the selected area.

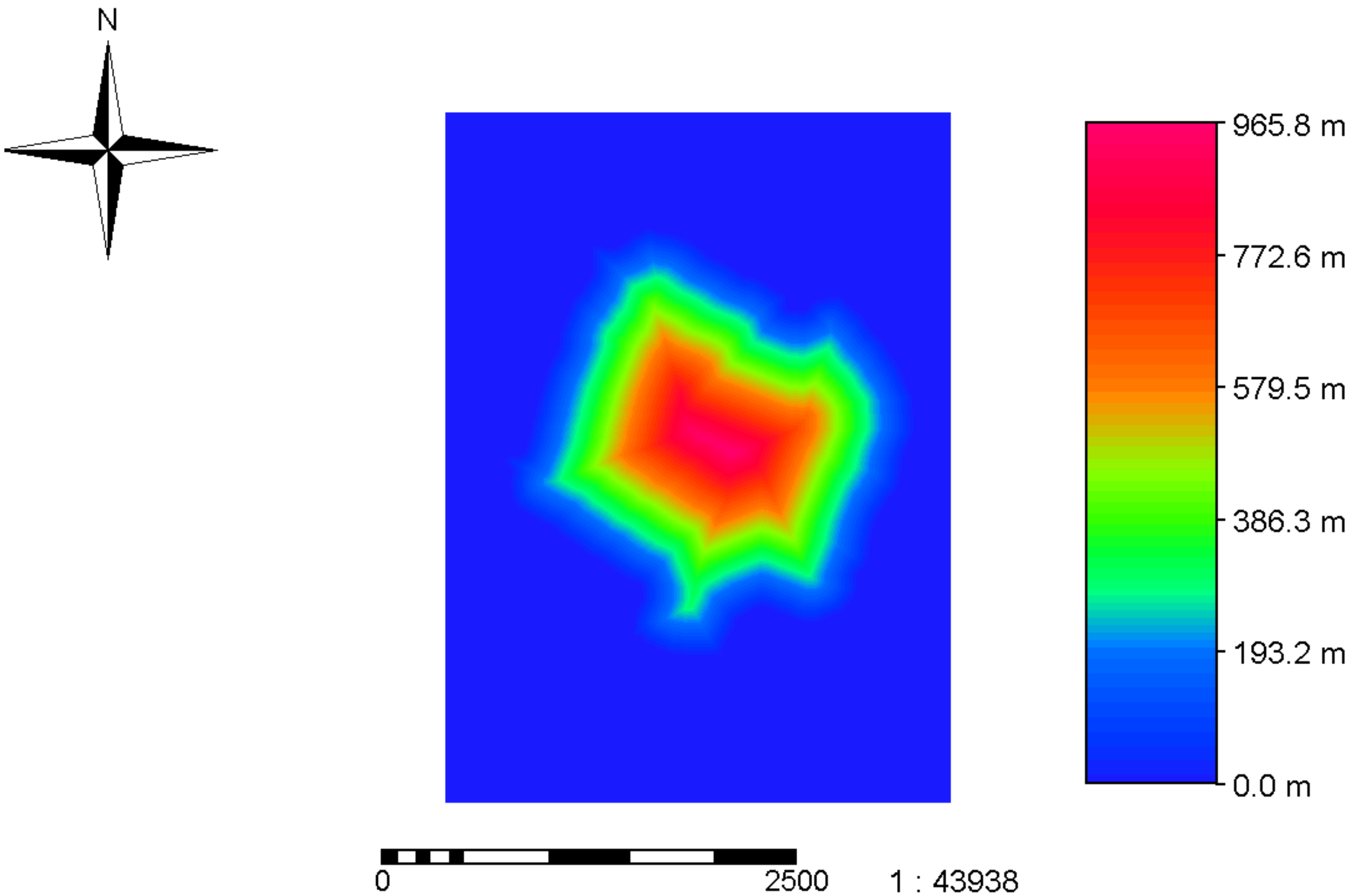

Fig.4.31. Distance boundary map of the selected area.

After discarding the unusable boundary area the velocity map is again reconstructed as shown in Fig. 4.32.

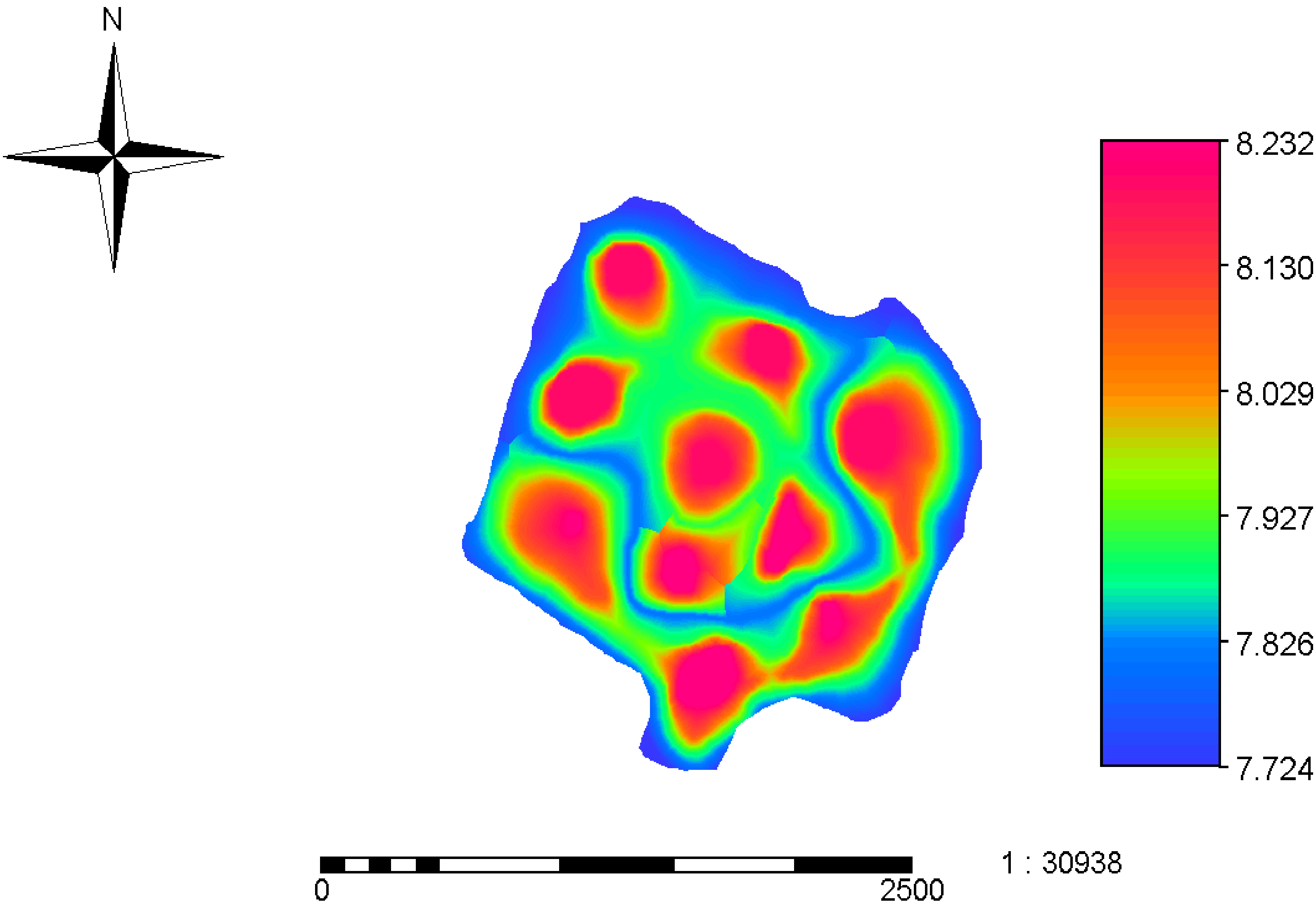

Fig. 4.32. Cut velocity map of the selected area.

Variations in velocity at different points were in the tune of 7.72 to 8.23 m/sec. Suitability of various points in the selected area from the wind farm installation was determined by normalizing the region, based on velocity differences. Suitability of various points was weighted in scale ranging from 0-1 where 0 represents the region of lowest velocity and 1 represents the region of highest velocity (which obviously most suited spot for wind farm erection) Fig. 4.33 shows the suitability map.

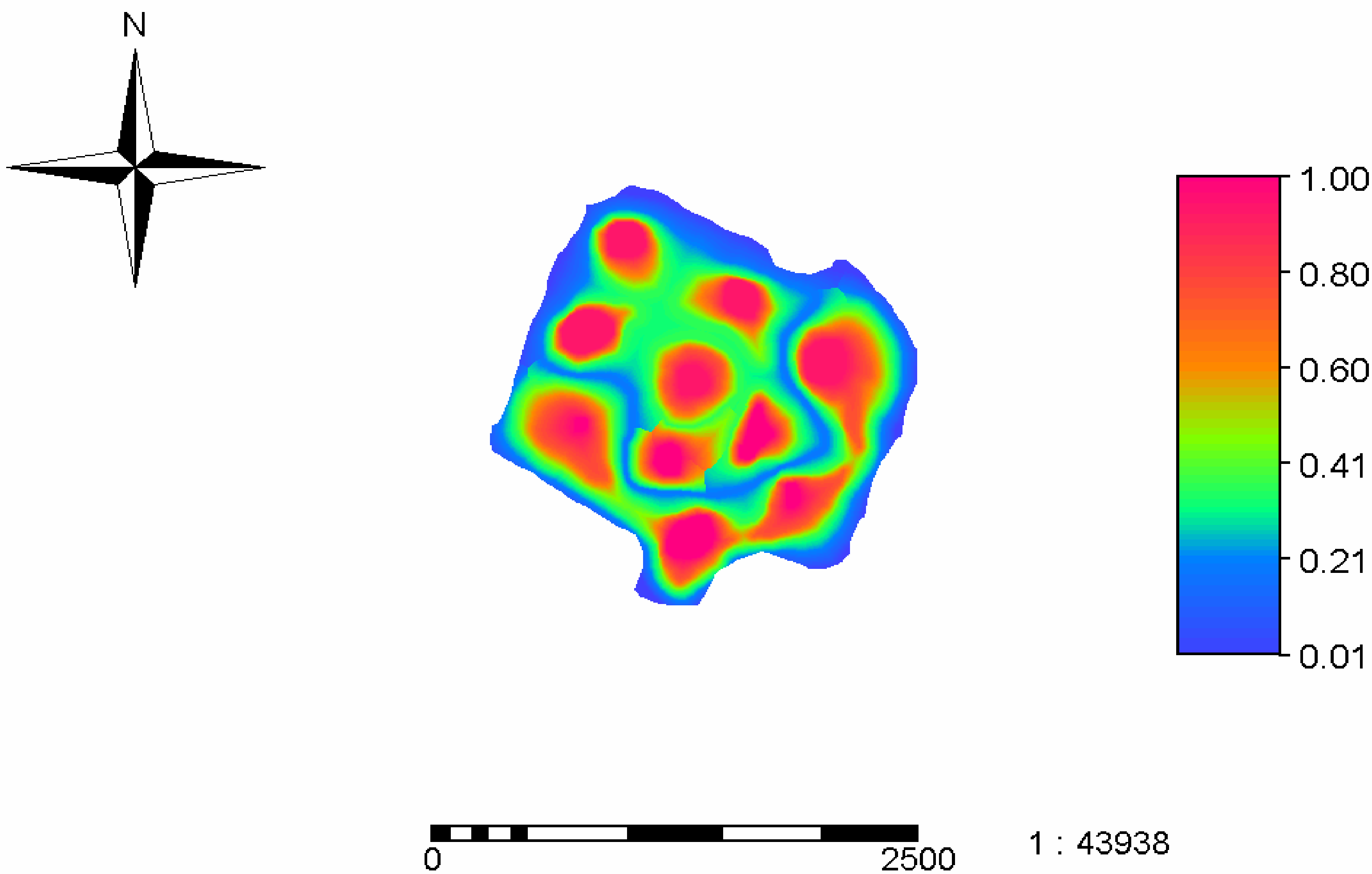

Fig.4.33. Suitability map of the selected area.

Now the task reduces to identifying 10 spots having highest velocity rating from the available options in the region. The locations of such selected spots are shown in Fig. 4.34. The intensity of velocity, which is basically weight on the 0-1 scales, is also indicated at the spot. Hence, points, which are most suited for turbine installation, could be identified as indicated in Table 4.8.

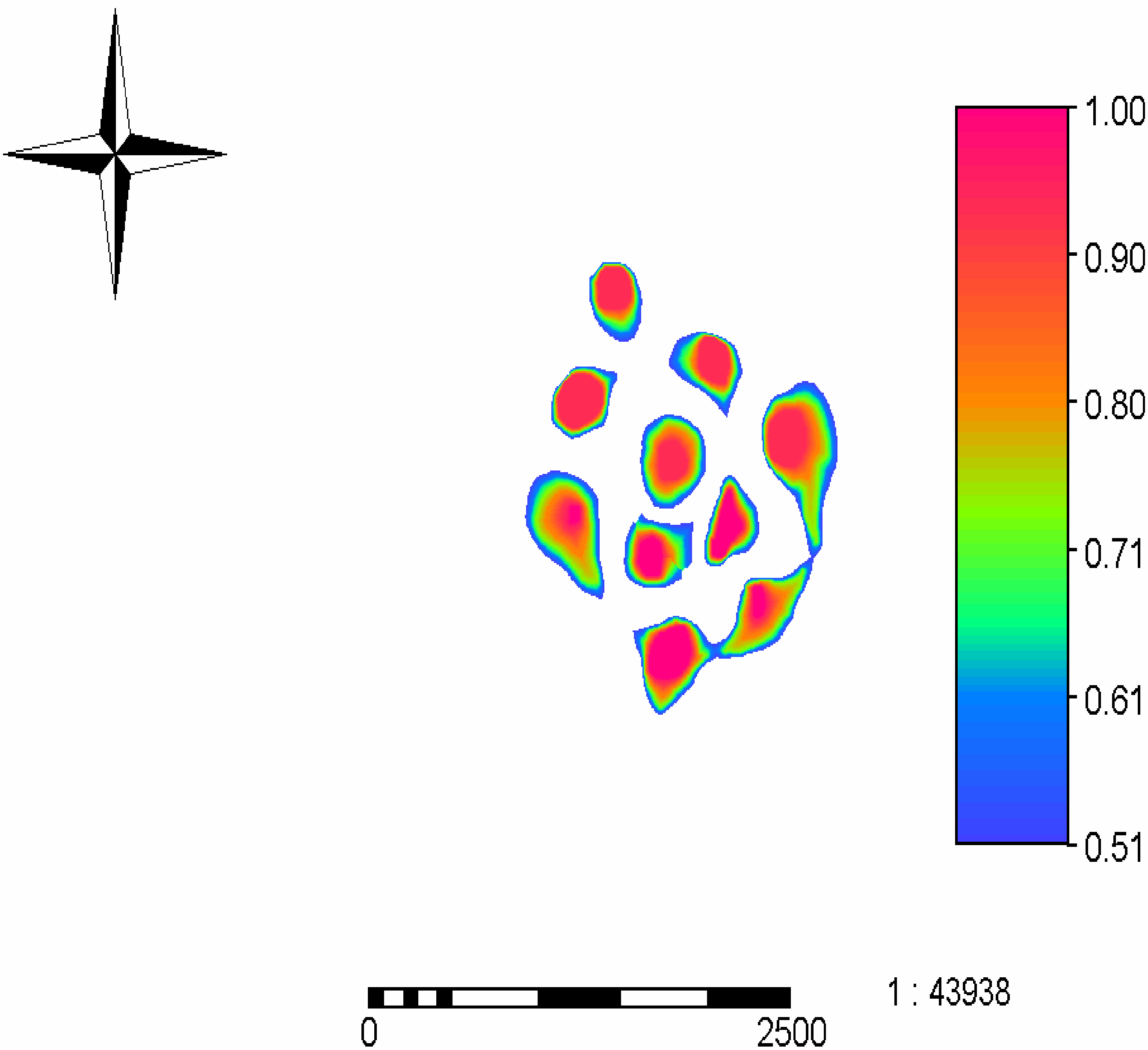

Fig.4.34. Location map of the selected area.

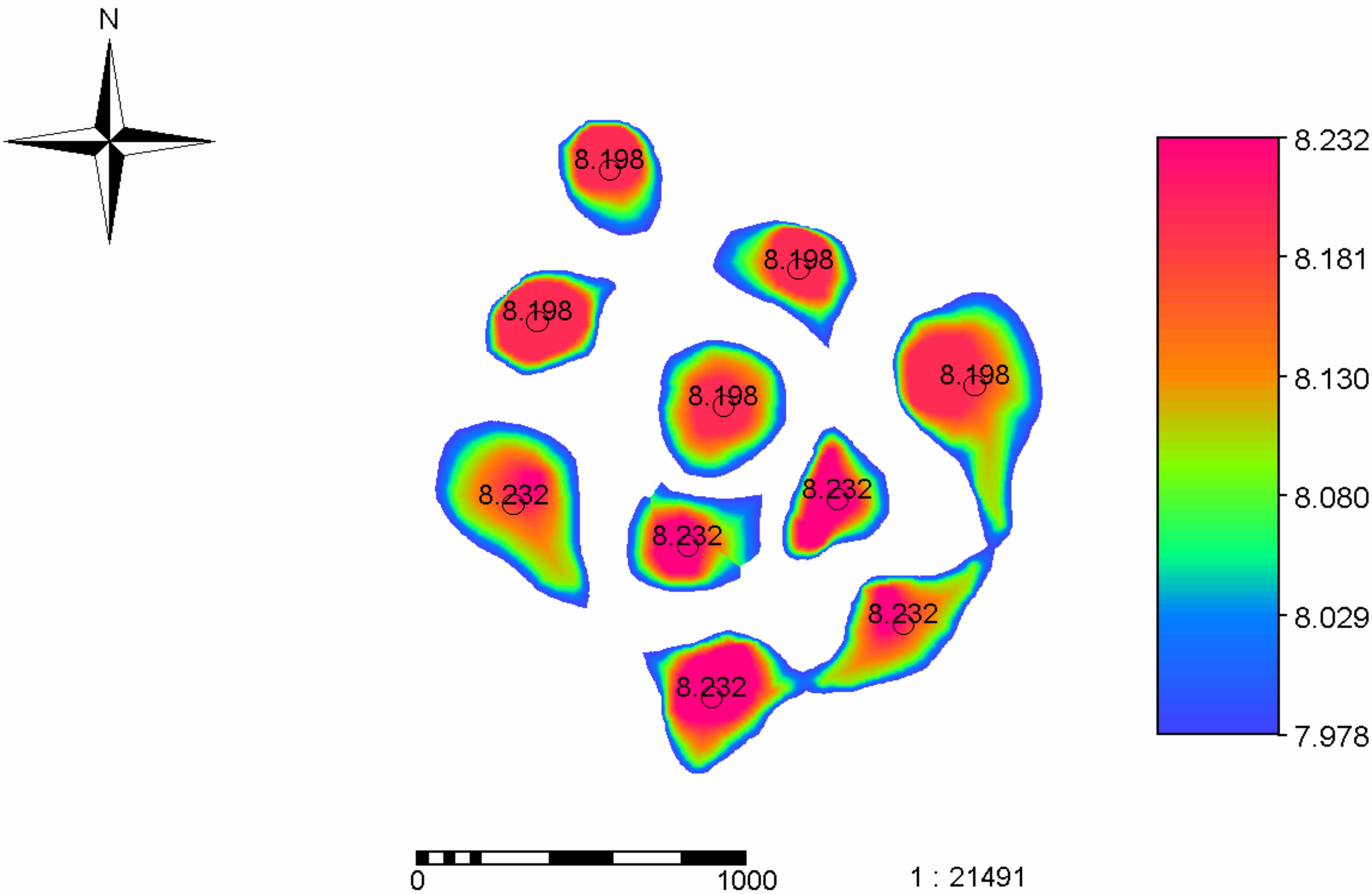

Fig.4.35. Location of maximum velocity area map of the selected area.

Table 4.8. Locations of the turbines of the selected area.

S.No.	Turbine No.	X Coordinate	Y Coordinate	Velocity, m/sec
1	1	919.38	3988.52	8.198
2	2	753.45	3365.94	8.198
3	3	698.14	2611.67	8.232
4	4	1182.10	3018.74	8.198
5	5	1354.94	3581.45	8.198
6	6	1762.85	3102.55	8.198
7	7	1099.13	2444.06	8.232
8	8	1444.82	2635.62	8.232
9	9	1596.92	2120.80	8.232
10	10	1154.44	1821.49	8.232

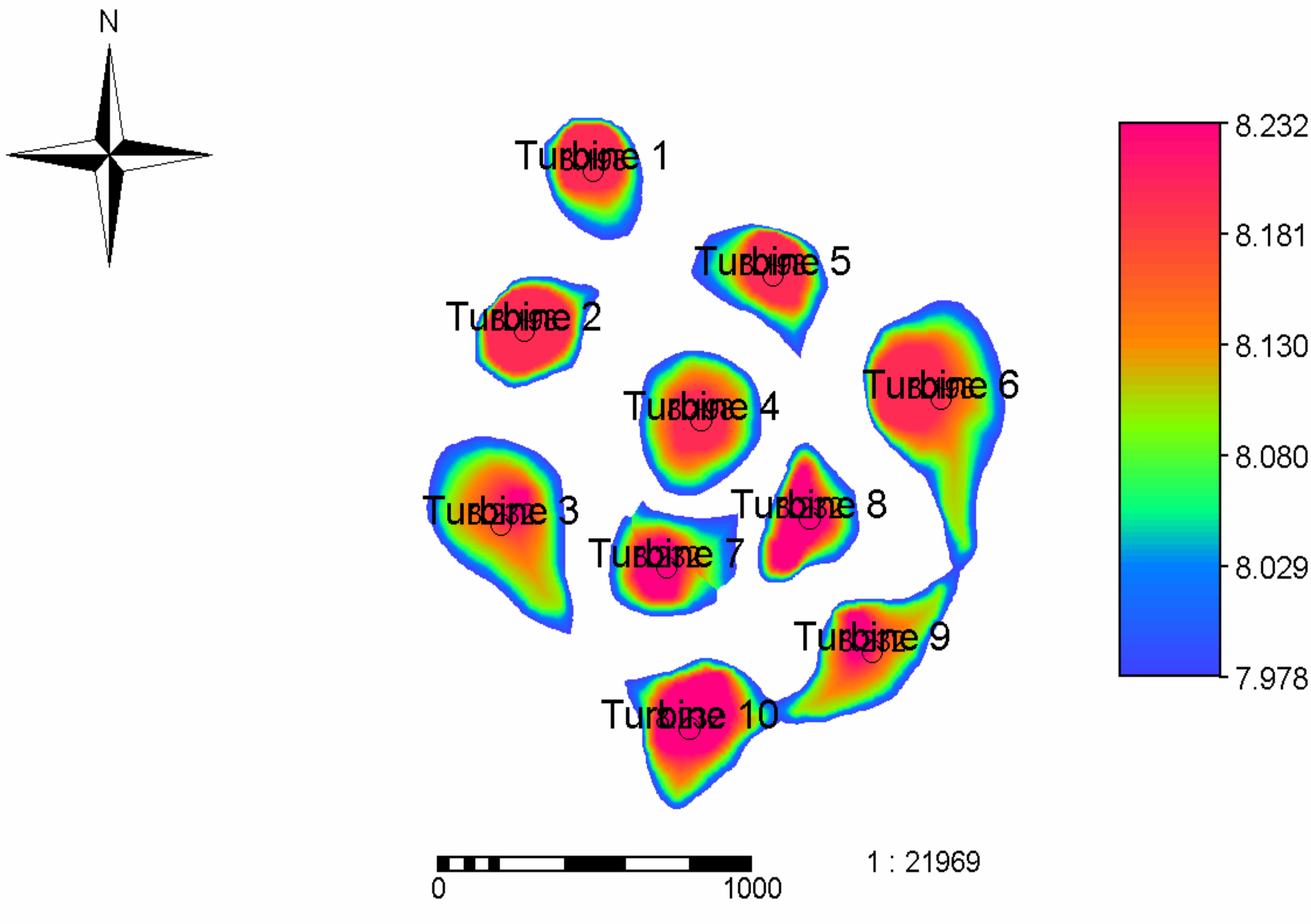

Fig.4.36. Position of the turbine map of the selected area.

Table 4.9. Annual energy yield from individual turbines of the wind farm

S.No.	Turbine No.	Velocity, m/sec	Annual energy, E_T (MWh)
1	1	8.198	4587300.35
2	2	8.198	4587300.35
3	3	8.232	4598220.83
4	4	8.198	4587300.35
5	5	8.198	4587300.35
6	6	8.198	4587300.35
7	7	8.232	4598220.83
8	8	8.232	4598220.83
9	9	8.232	4598220.83
10	10	8.232	4598220.83
Total annual energy, (E_T) MWh			45927605.9

Performance of individual turbine at the farm, in terms of annual energy production, is shown in Table 4.8. It can be seen that the proposed wind farm can yield 45927605.9 MWh annually, and thus can contribute significantly to the energy needs of the nearby community.

SUMMARY AND CONCLUSION

1) The WERA model has been validated using long term as well as short term data from Kanjikode wind farm, Palakkad, Kerala.

2) Velocity-power proportionality of three bladed horizontal axis wind turbine at the wind farm was computed as 1.75.

3) Index of agreement of WERA Raleigh model and WERA Weibull model were computed as 0.864 and 0.898 respectively.

4) Wind energy resource analysis of 10 sites were analyzed using WERA model and 5 sites were short listed for possible wind farm activities. The sites are Kayattar, Rameshwarm, Kanjikode, Sultanpet and Andipatti were short listed.

5) From the performance of commercial 2 MW turbine was simulated using WERA software.

6) An interlinking programme correlating the result of above analysis and GIS was developed.

7) Economics of wind energy conversion systems at these sites was estimated using above programme.

8) It was found that the cost of wind in a kWh basis ranges from Rs.1.28 toRs.1.72.

9) Based on economic viability, the site Kayattar was finally selected for the wind farm activity.

10) A method based on wind potential and site constrain was developed for Micrositing of the turbine using GIS. Elevation contour map, digital elevation

model, velocity map, distance from boundary map. Cut velocity map, suitability map, location map were developed.

11) Energy yield of turbine installed at the site were computed using WERA software the total energy of the wind farm is estimated as 45927605.9 MWh.

12) A systematic procedure for Optimal planning and laying out wind turbine at prospective site could be developed under this investigation.

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APPENDIX I

Performance data of wind generators at 30 minute interval

Date 18-6-05									
	Rotor No.1			Rotor No.2			Rotor No.3		
S. No	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	1.2	0.2	2736368	3.5	4.5	3061423	3.3	1.8	3645503
2	3.2	5	2736374	4.3	14.5	3061450	4.1	6.1	3645516
3	3.7	6.4	2736387	5.9	29	3061463	5	24.9	3645523
4	3.2	10.7	2736393	7.6	38.8	3061487	4.5	16	3645543
5	3.9	12.2	2736408	5.6	18.5	3061504	4.2	16.5	3645557
6	3.2	3.3	2736413	3.4	3.1	3061513	3.9	9.2	3645581
7	6.3	30.1	2736459	3.9	17.6	3061548	6.2	26.8	3645592
8	7.9	51.8	2736487	8.6	120.1	3061563	8.1	48.5	3645605
9	7.1	23.5	2736504	7.4	60.4	3061587	5.2	13.7	3645613
10	4.3	4.9	2736517	5.8	46.1	3061607	5.8	28.3	3645627
11	4.2	18.9	2736524	6.3	23.7	3061612	3.9	12.7	3645636

	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
S. No	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	3.7	8.1	2447303	2.6	4.2	1754656	2.5	4.2	2511008
2	3.2	11.8	2447308	4.3	10.4	1754662	2.4	1.4	2511104
3	3.6	7.7	2447312	2	4.3	1754681	2.7	6.8	2511108
4	2.4	2.3	2447318	3.6	12.1	1754698	3.1	4.7	2511119
5	4.1	17	2447329	3.2	11.1	1754704	3.5	2.3	2511127
6	3.2	8.2	2447331	3.5	16.6	1754719	4	27.1	2511138
7	3.6	8.4	2447338	5.9	29.7	1754736	8.2	56.8	2511152
8	6.3	33.3	2447342	8.2	66.3	1754742	7.5	47.8	2511176
9	3.7	11.1	2447347	7.3	45.9	1754758	3.3	6.3	2511186
10	3.5	11.2	2447356	5.2	16.8	1754761	4.9	11.4	2511197
11	2.6	0.1	2447364	2.5	0.2	1754765	2.6	2.4	2511203

Date: 19-6-05									
	Rotor No.1			Rotor No.2			Rotor No.3		
S. No	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	6.6	25.6	2736739	3.6	10.5	3061736	6.5	29.4	3645648
2	5.9	31.8	2736748	6.4	23.3	3061752	4.9	20.1	3645651
3	8.3	71.5	2736765	6.2	41.2	3061772	7.3	30.9	3645672
4	8.5	114.9	2736793	10.1	136.1	3061811	7.2	35.8	3645712
5	6.5	57.3	2736812	8.1	85.5	3061832	8.3	139.1	3645738
6	6.9	76.1	2736838	10.9	114.4	3061870	8	79.8	3645780
7	8.1	122.7	2736875	7.9	64.8	3061910	6.4	58.2	3645819
8	8.3	96.9	2736916	5.6	39.1	3061953	9.9	148.5	3645867
9	9.7	117.5	2737007	10.7	122.7	3062063	8.1	62.4	3645985
10	5.1	20.2	2737032	9.3	75	3062093	6.3	49.8	3646008
11	5.7	20.5	2737041	6.2	44.1	3062108	7.7	64.3	3646024
12	3.5	12.5	2737054	8.3	46.3	3062126	5.1	33	3646050

	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
S. No	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	8.8	51.3	2447608	4.4	11.4	1755025	5	23.5	2511542
2	5.6	24.6	2447618	2.9	8.4	1755035	7.7	83	2511552
3	10.4	124.3	2447635	4.4	24.1	1755051	6.7	55	2511579
4	3.3	12.1	2447649	3.2	16	1755070	4.2	18.7	2511605
5	4.5	21	2447661	8.5	87.9	1755087	4.6	21.2	2511627
6	4.8	28.1	2447667	4.6	12.8	1755114	8.8	122.9	2511658
7	4.6	26	2447699	6.3	50.7	1755142	5.6	46	2511693
8	7.1	55.4	2447723	7.2	38.8	1755175	7.2	84.4	2511730
9	6.2	39.5	2447782	4.5	26.1	1755243	5.4	17.1	2511814
10	7.1	50.5	2447798	2.7	3.9	1755256	4.4	21.9	2511827
11	6.5	32.8	2447810	5.7	26.7	1755266	5.9	22.3	2511841
12	4	24.6	2447825	5.1	18.5	1755276	4.4	9.3	2511853

Date: 20-6-05									
	Rotor No. 1			Rotor No. 2			Rotor No. 3		
S. No.	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	5.2	11	2737524	4.8	22.5	3062848	4	21.3	3646831
2	7.7	56.3	2737536	6.4	38.5	3062863	3.3	12	3646849
3	6.3	28.1	2737546	6.5	30.6	3062882	4.8	51.5	3646861
4	5.4	28.5	2737564	6.6	25.9	3062902	6.1	41.3	3646883
5	5.4	18.7	2737587	5.6	18.4	3062917	4.3	23.1	3646892
6	6	17.2	2737596	4.2	19.8	3062923	3.2	12.1	3646908
7	5.1	17.9	2737598	3.6	22	3062944	3.8	14	3646924
8	6.3	39.4	2737609	6.7	47.6	3062962	5.7	44.3	3646945
9	5.1	24.4	2737620	5.8	38.2	3062983	7.1	48.4	3646961
10	15.8	234.9	2737646	11.2	215.3	3063011	6.8	112.3	3647010

11	4.4	18.8	2737671						

S. No	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	6.9	45.8	2448241	3.9	10.9	1755658	5.3	23.1	2512364
2	4.8	14	2448255	4.2	13.7	1755672	5.2	20.5	2512370
3	6.8	52.2	2448271	3.2	19.5	1755680	3.6	26.9	2512393
4	4.9	22.5	2448281	4.3	24.3	1755688	7.2	50.7	2512402
5	4.6	18.6	2448289	3.8	18.4	1755690	6.4	14.2	2512418
6	4.2	12.1	2448296	4.2	17.3	1755696	4.8	20.8	2512426
7	4.8	10.8	2448307	6.5	40.4	1755714	5.4	37.9	2512445
8	4.7	15.7	2448316	5.6	27.3	1755725	3.9	19.4	2512453
9	3.6	19.8	2448323	4.6	26.7	1755737	4.6	35.4	2512465
10	8.3	86.6	2448350	3.2	17.7	1755772	6	35.2	2512501

S. No	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
	Wind velocity, m/sec	**Power, kW**	**Production, kWH**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWH**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWH**
1	3.4	26.8	2448863	5.8	31.2	1756199	7.7	76.5	2513146
2	7.2	68	2448886	3.5	4.2	1756219	4.8	35.7	2513167
3	6.9	64	2448909	5.6	40.5	1756237	6	48.8	2513188
4	7.6	85.5	2448925	7.1	104.3	1756256	6.5	46.2	2513210
5	12	177	2448965	6	58.6	1756290	8.8	106.7	2513240
6	9.1	123	2449010	5.5	52.2	1756326	6.5	50.3	2513277
7	6.5	97.1	2449050	5	20.5	1756359	8.7	120.1	2513315
8	7.2	85	2449074	5.2	18.3	1756372	7.6	62.3	2513331
9	4.2	39.5	2449140	7.2	54.8	1756443	8.3	123.5	2513404
10	7.1	97.6	2449175	3.3	12.7	1756467	8.6	92.3	2513439
11	6.3	18.7	2449192	9	79	1756489	7.9	106.1	2513471
12	4.2	60	2449215	6.1	70.9	1756518	6.6	48.8	2513510

Date: 23-6-05									
S. No	**Rotor No. 1**			**Rotor No. 2**			**Rotor No. 3**		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	4.8	16.1	2739723	7.3	84.4	3065876	5.6	34.9	3650176
2	5.7	29.2	2739738	7	67	3065896	5	42	3650202
3	4.7	15.8	2739756	6.3	72	3065927	8	69.9	3650237
4	7.4	62.3	2739773	9.2	89	3065955	8.1	60.09	3650267
5	8.6	70.6	2739797	9	78.8	3065989	7.6	75.6	3650300
6	5.1	33	2739809	7.1	24.6	3065993	6.1	70.9	3650319
7	7.7	64.3	2739817	6.2	32.8	3066001	9	79	3650332
8	6.3	49.8	2739829	4.6	50.5	3066013	3.6	12.5	3650367
9	9.9	62.4	2739967	4.8	39.5	3066138	5.2	18.3	3650383

10	6.4	148.5	2739982	10.4	55.4	3066152	5	20.5	3650397
11	8	58.2	2739993	6.5	26	3066163	5.5	52.2	3650408
12	7.3	30.9	2739008	5.8	28.1	3066187	6	58.6	3650437

S. No	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	4.5	15.7	2450067	5	-0.2	1757375	6.6	47.3	2514616
2	8.5	89	2450086	5.5	49.2	1757387	9	93.1	2514644
3	6.6	62.1	2450105	6.2	52.6	1757402	6.2	53	2514668
4	11	122.8	2450120	5.7	50.2	1757417	6.4	46.4	2514691
5	7	10.3	2450142	7.7	80.1	1757441	3.8	40.9	2514725
6	7.7	40.8	2450169	8.6	60.4	1757463	4.4	9.3	2514753
7	6.6	106.1	2450193	7.7	46.1	1757478	5.9	22.3	2514767
8	6	92.3	2450208	6.3	23.7	1757489	4.4	21.9	2514779
9	7.6	62.2	2450239	10.7	46.3	1757563	5.4	17.1	2514801
10	8.6	76.5	2450246	6.4	39.1	1757578	7.2	84.4	2514817
11	8.3	37.7	2450257	7.9	122.7	1757592	5.6	46	2514823
12	7.9	50.3	2450283	8.3	46.3	1757603	4.6	21.2	2514834

Date 24-6-05									
S. No	**Rotor No. 1**			**Rotor No. 2**			**Rotor No. 3**		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	12.6	183.1	2740771	11.4	207.4	3067276	7.4	113.5	3651745
2	10.7	115.9	2740826	8.8	144.5	3067346	11.7	185.7	3651817
3	8.4	72.5	2740872	10.9	137.7	3067402	9.8	152.1	3651870
4	8.4	114.3	2740912	7.4	82.4	3067453	7.9	122.7	3651922
5	10.1	115.2	2740963	8.1	93.8	3067472	8.2	76.3	3651949
6	10.4	128.1	2740989	8.3	87.3	3067507	9.6	125.3	3651966
7	9.3	89.1	2741064	7.5	66.5	3067620	8.2	93.7	3652081
8	6.2	37.6	2741078	6.1	44.9	3067639	9.5	90	3652099
9	7.7	45.5	2741107	9.9	119.9	3067667	14.2	211.5	3652135
10	6.7	37.7	2741128	9.4	92.9	3067683	13.9	224.5	3652142
11	7.4	63.2	2741142	9.2	89	3067697	8	69.9	3652163
12	5.7	29.2	2741156	9	78.8	3067712	6.1	70.9	3652176

S. No.	**Rotor No.4 (5)**			**Rotor No.5 (7)**			**Rotor No.6 (9)**		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	13.6	202.4	2450894	6.6	63.9	1758252	8.7	115.3	2515710
2	10	99.9	2450941	9.8	124.1	1758296	10.2	121.7	2515758
3	10.1	143	2450972	10.4	150.3	1758328	10.4	154	2515794
4	4.8	12	2451009	5	23.3	1758362	6.2	83.1	2515837
5	4.8	15.6	2451023	6.3	85.9	1758381	8.4	79.8	2515853
6	4.4	20.3	2451035	4.5	23	1758396	6.2	61	2515884
7	4.5	9.1	2451099	4.9	22.2	1758465	9.3	105.1	2515982

8	4.6	10.1	2451123	6.8	81.9	1758479	8.9	101.1	2516007
9	7	51.2	2451145	8.9	112.9	1758510	6.9	79.3	2516042
10	10.7	145.7	2451152	5.4	64.9	1758538	5.5	68	2516078
11	8.3	122.8	2451173	5.7	122.8	1758552	6.6	47.3	2516097
12	7.6	62.1	2451198	6.2	46.1	1758573	6.4	46.4	2516109

Date: 25-6-05

S. No	Rotor No. 1			Rotor No. 2			Rotor No. 3		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	6.1	27.6	2742020	9.3	78.5	3068567	7.1	36.8	3653443
2	6.2	55.4	2742037	6.6	66.4	3068582	7.6	44.6	3653457
3	6.6	42.3	2742042	8.8	122.6	3068594	13.6	204	3653475
4	10.9	108.9	2742081	3.8	12.7	3068643	6.2	62.3	3653523
5	7.8	57.8	2742111	8.4	130.3	3068679	8.9	90.9	3653564
6	8.1	81.5	2742141	9.6	88.6	3068715	7.7	51.3	3653601
7	8.1	112.6	2742183	10.1	120.1	3068769	10.7	133.8	3653647
8	8.7	71.7	2742203	8.8	96.2	3068782	6	35.8	3653679
9	7.6	59.8	2742356	8.4	82.2	3068973	11.4	173.1	3653844
10	5.9	24.9	2742381	9.3	105.3	3069009	6.9	33.6	3653881
11	5.7	38.4	2742403	7.4	610	3069042	6.5	60.4	3653915
12	7.8	61.2	2742449	7.1	53.9	3069068	6.8	73.6	3653933

S. No	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	4.5	40.2	2451791	2.9	9.4	1759227	4.1	9.8	2516911
2	4.9	50.8	2451809	5.1	18.7	1759239	4.8	19	2516928
3	4.5	39.3	2451827	6	53.8	1759257	9	94.1	2516945
4	4.8	20.3	2451840	6.3	59.4	1759277	7.8	72.7	2516971
5	5.4	46	2451871	6.1	78.9	1759302	8.4	78.4	2517003
6	8.1	125.8	2451894	4.7	39.4	1759326	7.5	58.9	2517041
7	6.2	37.8	2451946	7.3	77.7	1759353	5.7	44.3	2517082
8	5.7	20.2	2451971	6.8	86.3	1759371	6.1	31.9	2517097
9	9.2	158.7	2452050	5.3	83.5	1759479	6.9	39.1	2517246
10	5.2	62	2452078	6	70.2	1759499	7.2	81.1	2517271
11	6.2	46	2452100	3.5	4	1759517	8.5	82.8	2517303
12	7.2	42.1	2452131	6.3	37.2	1759529	7.1	63.8	2517329

Date 26-6-05

S. No	Rotor No. 1			Rotor No. 2			Rotor No. 3		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	4.8	31.7	2743092	7.9	52.1	3069906	7.1	46.5	3654933
2	4.9	11.6	2743118	5	35.1	3069927	5.7	37.6	3654941
3	5.2	24.4	2743120	7.5	52.6	3069940	4.6	40.8	3654968
4	4.8	32.4	2743138	7.4	52.3	3069962	5.1	32.8	3654994

5	8.6	71.1	2743167	7.7	60.7	3069997	6.9	44.5	3655038
6	8.5	145.3	2743198	10.7	160.9	3070044	8.5	66.9	3655092
7	5	39.6	2743224	5.6	60.5	3070076	4.7	49.5	3655127
8	6.6	61	2743258	7.6	66.1	3070089	7.1	102.6	3655145
9	8.2	55	2743295	6.1	38.8	3070177	4.7	15.3	3655224
10	8.3	48.5	2743300	7.7	60	3070225	6.9	49.3	3655276

S.No.	**Rotor No.4 (5)**			**Rotor No.5 (7)**			**Rotor No.6 (9)**		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	5.6	38.9	2452579	4.8	26.5	1760065	6.9	38.5	2517617
2	3.9	10.5	2452584	5.3	23.4	1760071	8.7	42.6	2517632
3	5.7	40.2	2452595	5.1	22.7	1760078	5.4	32	2517689
4	4.8	15.1	2452609	6.8	54.8	1760099	5.4	34.6	2517698
5	5.2	21.9	2452624	6.3	32.5	1760118	9	97.9	2517713
6	3.2	13.3	2452657	5.9	14.5	1760145	5.1	37.2	2517739
7	2.9	9.3	2452677	3.3	14.9	1760158	5.7	19.5	2517747
8	5.5	16.3	2452692	3	9.7	1760163	5.3	23.4	2517753
9	6.5	39.3	2452737	3.7	24.1	1760200	3.5	8.2	2517609
10	3.3	33.2	2452775	6.6	39	1760235	11	113.3	2517619

Date: 27-6-05									
S. No	**Rotor No. 1**			**Rotor No. 2**			**Rotor No. 3**		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	6	32.1	2743667	3.9	18.8	3070751	4.3	13.9	3655858
2	4.4	10.6	2743674	2.5	13.3	3070766	3.2	8.4	3655873
3	4.8	18.3	2743682	5.1	35.3	3070772	5.8	80.5	3655880
4	5.7	36.5	2743702	5.1	19.4	3070805	2.1	5.3	3655917
5	4.6	16.3	2743710	4.3	12.2	3070816	5.7	20.4	3655931
6	4.9	10	2743733	9.2	95.2	3070853	5.1	23.3	3655972
7	6.5	29.7	2743746	8.7	60	3070873	4.1	19.7	3655998
8	6.7	36.2	2743758	6.3	51.9	3050895	6.8	38.2	3656022
9	6.3	29	2743810	112	163.2	3050985	7.2	95.7	3656123
10	10.4	112.2	2743861	11.1	151.1	3071054	8.7	101.6	3653196

S. No	**Rotor No.4 (5)**			**Rotor No.5 (7)**			**Rotor No.6 (9)**		
	Wind velocity, m/sec	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**	**Wind velocity, m/sec**	**Power, kW**	**Production, kWh**
1	6.6	31.8	2453085	6.3	29.6	1760518	4.2	23.3	2518569
2	4.3	14.2	2453091	3.7	5.7	1760527	4.3	20.1	2518578
3	7.9	70.7	2453100	6.9	52.8	1760538	5.4	13.4	2518593
4	3.9	22.2	2453114	5.1	40.1	1760534	4.1	9.2	2518601
5	8.6	50.7	2453122	7.4	14.2	1760545	6.9	51.4	2518626
6	7.1	53.8	2453149	5.7	51.3	1760551	5.8	33.6	2518641
7	5.1	38.3	2453163	4.2	14.3	1760565	7.1	34.2	2518654
8	5.1	61.6	2453180	4.2	27.2	1760575	7.7	50.3	2518669

9	13.9	206.9	2453257	6.7	66	1760671	6.9	98.1	2518762
10	11.3	128.5	2453311	10.3	131.3	1760690	11.7	163.3	2518796

Date: 28-6-05

S. No	Rotor No. 1			Rotor No. 2			Rotor No. 3		
	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	4.8	23.1	2744721	6.9	67.7	3072309	3.9	28.2	3657535
2	8.1	49.3	2744743	5	35.8	3072328	4.1	18.6	3657552
3	7.2	84.5	2744760	5.1	44.6	3072349	9.2	76.6	3657573
4	4.8	31.2	2744768	6.2	57	3072375	6	36.7	3657601
5	2.9	4.7	2744783	6.2	37.8	3072397	7.5	67.1	3657626
6	7.1	71.6	2744798	6.1	53.2	3072424	6.6	90.2	3657653
7	5.2	26.6	2744815	6	34.1	3072460	6.3	90.4	3657689
8	4.5	20.9	2744836	7.9	50.6	3072481	7.9	114	3657701
9	5.2	37.7	2744864	6.3	71.5	3072524	8.6	97	3657754
10	12.1	173.1	2744890	7.7	93.1	3072550	11.2	164	3657775

S. No	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	4.7	48.6	2454139	6.5	47.5	1761431	4.9	27.9	2519734
2	3.2	9.8	2454143	5.7	33.3	1761436	5.3	35.1	2519745
3	5.2	11.7	2454158	7.7	45.8	1761442	6.5	66.8	2519759
4	3.9	21.3	2454184	3.8	14.6	1761450	4.2	20.1	2519765
5	4.8	22.3	2454198	5.6	30.1	1761461	4.3	25.2	2519776
6	6.3	34.7	2454217	5.6	23.9	1761475	3	7.8	2519789
7	9.3	82	2454249	5.4	39.2	1761487	10.4	121.5	2519814
8	4.8	47.4	2454261	5.2	34.6	1761517	11.3	152	2519845
9	8.7	71.6	2454287	5.7	49.7	1761548	10.9	166.5	2519911
10	7.3	51	2454298	5.1	36.8	1761569	6.8	67.9	2519939

Date: 29-6-05

S. No	Rotor No. 1			Rotor No. 2			Rotor No. 3		
	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	3.9	5.1	2745730	4.9	23.1	3073637	5.7	62	3658962
2	4.3	17.9	2745745	7	34.8	3073661	7.7	78.1	3658988
3	6.2	35.2	2745759	6.5	32.3	3073679	4.6	13.6	3659007
4	4.2	16.6	2745768	6	30.1	3073685	4	10.6	3659022
5	6.1	39.1	2745776	6.2	33.3	3073699	6.9	52.2	3659036
6	6.2	27.7	2745815	5.7	31	3073763	4.3	28.4	3659096
7	6.2	30.8	2745825	7.6	42.2	3073774	7.2	33.5	3659114
8	6	29.4	2745841	9.3	108.6	3073799	7.8	99.9	3659145
9	4.2	29.9	2745860	7.3	60.6	3073822	7.2	73.8	3659168
10	7.2	56.7	2745884	9.5	90.1	3073858	5.4	50.7	3659209

S. No	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	4	26.1	2454954	3.8	19.5	1762258	7.2	48.2	2520730
2	3.8	13.6	2454969	4.1	16.7	1762268	3	14	2520740
3	3.9	7.6	2545980	3.3	5.6	1762277	4.9	16.9	2520756
4	3.5	8.7	2454985	3.2	10.8	1762389	3.9	18.8	2520767
5	4.1	9	2454996	3.6	14.9	1762310	6.2	23.3	2520801
6	4.8	19.6	2455032	5	26.4	1762321	5.6	37	2520813
7	6.3	68.1	2455042	2.7	16.1	1762330	4.3	23.8	2520830
8	5	23.4	2455058	4.8	51.9	1762346	7	66	2520862
9	7.7	97.1	2455082	9.8	97.2	1762367	12.3	183	2520887
10	7.1	73	2455107	4.7	19.1	1762385	6.7	82.7	2520973

Date: 30-6-05									
S.No.	Rotor No. 1			Rotor No. 2			Rotor No. 3		
	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	3	6.2	2746531	3	5.1	3074858	3.5	6.2	3660243
2	3.2	7.8	2746532	3.3	5.3	3074859	3.9	6.3	3660256
3	4.4	15.5	2746537	4.4	26.2	3074867	5.4	30.2	3660267
4	3.2	6.3	2746545	4.6	14.5	3074878	6	56.8	3660278
5	4.8	14.7	2746552	5	12.4	3074891	5.6	19.9	3660290
6	4.6	12.8	2746559	5.6	14.6	3074898	5.4	18.6	3660297

S. No	Rotor No.4 (5)			Rotor No.5 (7)			Rotor No.6 (9)		
	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh	Wind velocity, m/sec	Power, kW	Production, kWh
1	3.1	5.2	2455726	3.5	7.8	1762914	3.2	4	2521604
2	3.2	5.7	2455729	3.9	8.1	1762915	3.7	4.5	2521608
3	7.9	47.3	2455736	3.3	5.5	1762921	3.2	4.6	2521615
4	6.2	45.6	2455744	6.1	29.8	1762930	4	9.4	2521624
5	2.3	4.5	2455750	3.2	6	1762934	3.9	19.1	2521632
6	6.8	40.3	2455758	6.2	26.6	1762939	4.2	20.2	2521638

APPENDIX II

Performance data of wind generators at 10 minute interval

S.No.	Rotor No. 1 Date: 20-6-05 Wind velocity, m/sec	Power, kW	Production, kWH	Rotor No.2 Date: 21-6-05 Wind velocity, m/sec	Power, kW	Production, kWH
1	5	11.6	2737468	7.3	63.1	3063680
2	4.4	21.9	2737470	7.2	47.7	3063683
3	5	16.8	2737472	9.4	91.9	3063692
4	5.7	28.2	2737475	6.9	38.4	3063701
5	5.2	19.5	2737477	5	32.1	3063712
6	5.4	0.2	2737480	8.7	88.5	3063722
7	4.9	12.2	2737483	5.9	27.4	3063732
8	4.2	12.6	2737486	11.1	175.3	3063741
9	5.4	20.5	2737490	8.8	74.8	3063748
10	5	12.7	2737495	8.7	90.5	3063761
11	4.3	21	2737498	9.6	92	3063771
12	6.5	34.3	2737503	6.3	54.9	3063781
13	4.6	9.3	2737505	7.7	77.9	3063792
14	3.9	7.8	2737507	5.4	15.7	3063805
15	4.3	13.7	2737509	6.4	47.3	3063814
16	5	30	2737511	5.9	35.4	3063823
17	3.9	12.7	2737515	6.6	66.9	3063832
18	5.9	35	2737519	7.7	97.8	3063839

S.No.	Rotor No.3 Date: 23-6-05 Wind velocity, m/sec	Power, kW	Production, kWH	Rotor No. 4 Date: 24-6-05 Wind velocity, m/sec	Power, kW	Production, kWH
1	2	-0.2	3650130	6	41.1	2617985
2	2.3	-0.3	3650130	10.2	133.2	2617998
3	2.3	-0.2	3650130	6.2	79.2	2618012
4	1.4	-0.2	3650130	6.2	30.8	2618024
5	2.8	-0.8	3650130	5.1	65.1	2618036
6	2.9	0.3	3650131	8.3	64.4	2618047
7	2.7	-0.2	1350131	6.6	70.3	2618060
8	4	1.8	3650131	5.1	26.5	2618073
9	4.3	9.3	3650132	8.4	162.3	2618082
10	2.6	4.4	3650133	7.2	125.3	2618110
11	4.2	22.1	3650135	6.2	38.6	2618120
12	6.2	36.3	3650137	6.6	39.1	2618130
13	5.2	38.8	3650141	6.9	111.7	2618141
14	3.4	14.8	3650144	5.4	50.8	2618156
15	3.7	9.6	3650148	5.6	50.3	2618166
16	5.2	15.6	3650152	8.6	163.7	2618194
17	5.8	64.7	3650158	11.5	195.4	2618207
18	4.2	18.3	3650163	7.9	127.3	2618229

S.No.	Rotor No.5 Date: 25-6-05 Wind velocity, m/sec	Rotor No.5 Date: 25-6-05 Power, kW	Rotor No.5 Date: 25-6-05 Production, kWH	Rotor No. 6 Date: 26-6-05 Wind velocity, m/sec	Rotor No. 6 Date: 26-6-05 Power, kW	Rotor No. 6 Date: 26-6-05 Production, kWH
1	5.2	33.5	2451761	3.3	2.8	1950176
2	5	30.3	2451771	3.9	19.5	1950179
3	5.1	14.8	2451775	5.2	15.4	1950182
4	5.9	50.4	2451778	4.5	23.8	1950185
5	8.9	77.7	2451785	4.3	21.6	1950191
6	3.9	14.1	2451788	4.5	23.5	1950193
7	4.7	17.3	2451797	7.1	28.9	1950198
8	4.9	50.8	2451807	5.6	26.6	1950203
9	4.7	18.4	2451809	7.3	45.5	1950208
10	3.6	12.6	2451811	5.3	16.3	1950210
11	3.8	14.9	2451819	4.5	29.4	1950215
12	4.2	61.1	2451824	7.2	118.4	1950223
13	5.8	64.9	2451830	5.7	28.4	1950226
14	4.7	24.6	2451840	3.1	6.5	1950229
15	4.3	21.2	2451848	7	56.1	1950237
16	7.8	62.2	2451859	4.8	16.8	1950244
17	4.5	47.5	2451864	5.9	23.8	1950253
18	5.2	47	2451871	6	50.1	1950265

S.No.	Rotor No.7 Date: 27-6-05 Wind velocity, m/sec	Rotor No.7 Date: 27-6-05 Power, kW	Rotor No.7 Date: 27-6-05 Production, kWH	Rotor No. 8 Date: 28-6-05 Wind velocity, m/sec	Rotor No. 8 Date: 28-6-05 Power, kW	Rotor No. 8 Date: 28-6-05 Production, kWH
1	5	25.3	1760518	4.3	24	2047559
2	4.5	25	1760522	4.8	26.7	2047561
3	3.9	8.2	1760524	6.6	38.8	2047565
4	3.8	6.3	1760528	2.9	12	2047568
5	4	10.5	1760531	6.4	36.2	2047571
6	4.2	40.1	1760534	2.5	6.7	2047574
7	8.2	36.8	1760537	3.3	25.2	2047577
8	4.8	10.4	1760539	4.3	22.9	2047581
9	3.2	6.4	1760540	3.1	12.3	2047584
10	4.7	13.6	1760544	4.4	22.9	2047586
11	4.2	14.2	1760545	4.7	28.5	2047593
12	3.9	8.2	1760548	5.3	27.9	2047597
13	4.1	10.4	1760551	2.3	2.6	2047600
14	6.6	69.8	1760565	5.9	45.2	2047603
15	5.9	44.5	1760568	4.2	26.8	2047609
16	6.3	37.9	1760574	3.1	8.6	2047611
17	6	29.3	1760578	5.9	64.9	2047620
18	5.3	33.5	1760586	3.6	2.9	2047626

ROTOR NO.9			
DATE 29-6-05			
S.No.	**Wind velocity, m/sec**	**Power, kW**	**Production, kWH**
1	7.2	48.2	2520730
2	5	36.1	2520734
3	6.9	43	2520740
4	4.7	15.6	2520746
5	6.8	71	2520750
6	4.8	16.6	2520756
7	3.6	21.5	2520761
8	3.5	19.8	2520763
9	5.8	23.4	2520768
10	5.6	37	2520772
11	6.2	23.3	2520776
12	5.1	35.1	2520779
13	4.6	30.7	2520792
14	4.1	15.8	2520819
15	5.1	12.3	2520823
16	7.4	28.8	2520830
17	4.3	23.7	2520834
18	5.7	39	2520848

APPENDIX III

Velocity-Power proportionality

Wind velocity, m/sec	Power, kW	1	2	2.5	3	3.5
5.00	11.60	37.5	19.92	14.02	9.67	6.57
4.40	21.90	22.5	11.11	7.52	4.98	3.25
5.00	16.80	37.5	19.92	14.02	9.67	6.57
5.70	28.20	55	31.63	23.22	16.76	11.93
5.20	19.50	42.5	23.11	16.46	11.51	7.93
5.40	20.20	47.5	26.42	19.06	13.50	9.42
4.90	12.20	35	18.38	12.85	8.81	5.94
4.20	12.60	17.5	8.42	5.62	3.68	2.36
5.40	20.50	47.5	26.42	19.06	13.50	9.42
5.00	12.70	37.5	19.92	14.02	9.67	6.57
4.30	21.00	20	9.75	6.55	4.31	2.79
6.50	34.30	75	46.88	36.03	27.30	20.44
4.60	9.30	27.5	13.92	9.55	6.41	4.24
3.90	7.80	10	4.63	3.03	1.94	1.22
4.30	13.70	20	9.75	6.55	4.31	2.79
5.00	30.00	37.5	19.92	14.02	9.67	6.57
3.90	12.70	10	4.63	3.03	1.94	1.22
5.90	35.00	60	35.25	26.19	19.14	13.80
8.50	47.70	125	93.75	79.77	67.29	56.38
7.30	63.10	95	64.13	51.44	40.77	32.01
7.20	47.70	92.5	61.86	49.37	38.91	30.37
9.40	91.90	147.5	118.92	105.38	92.78	81.31
6.90	38.40	85	55.25	43.40	33.64	25.80
5.00	32.10	37.5	19.92	14.02	9.67	6.57
8.70	88.50	130	99.13	85.13	72.51	61.39
5.90	27.40	60	35.25	26.19	19.14	13.80
11.10	175.30	190	173.38	164.69	156.04	147.57
8.80	74.80	132.5	101.86	87.88	75.22	64.00
8.70	90.50	130	99.13	85.13	72.51	61.39
9.60	92.00	152.5	124.86	111.60	99.16	87.73
6.30	54.90	70	42.88	32.59	24.40	18.05
7.70	77.90	105	73.50	60.17	48.72	39.12
5.40	15.70	47.5	26.42	19.06	13.50	9.42
6.40	47.30	72.5	44.86	34.29	25.83	19.22
5.90	35.40	60	35.25	26.19	19.14	13.80
6.60	66.90	77.5	48.92	37.81	28.81	21.70
7.70	97.80	105	73.50	60.17	48.72	39.12
9.40	112.10	147.5	118.92	105.38	92.78	81.31
6.00	41.10	62.5	37.11	27.73	20.39	14.80
10.20	133.20	167.5	143.42	131.45	119.94	109.09

6.20	79.20	67.5	40.92	30.93	23.02	16.92
6.20	30.80	67.5	40.92	30.93	23.02	16.92
5.10	65.10	40	21.50	15.22	10.57	7.23
8.30	64.40	120	88.50	74.60	62.30	51.66
6.60	70.30	77.5	48.92	37.81	28.81	21.70
5.10	26.50	40	21.50	15.22	10.57	7.23
8.40	162.30	122.5	91.11	77.16	64.76	53.99
7.20	125.30	92.5	61.86	49.37	38.91	30.37
6.20	38.60	67.5	40.92	30.93	23.02	16.92
6.60	39.10	77.5	48.92	37.81	28.81	21.70
6.90	111.70	85	55.25	43.40	33.64	25.80
5.40	50.80	47.5	26.42	19.06	13.50	9.42
5.60	50.30	52.5	29.86	21.80	15.63	11.06
8.60	163.70	127.5	96.42	82.42	69.87	58.85
11.50	195.40	200	187.50	180.83	174.09	167.38
7.90	127.30	110	78.38	64.80	53.02	43.04
9.70	195.00	155	127.88	114.78	102.45	91.06
5.20	33.50	42.5	23.11	16.46	11.51	7.93
5.00	30.30	37.5	19.92	14.02	9.67	6.57
5.10	14.80	40	21.50	15.22	10.57	7.23
5.90	50.40	60	35.25	26.19	19.14	13.80
8.90	77.70	135	104.63	90.67	77.99	66.69
3.90	14.10	10	4.63	3.03	1.94	1.22
4.70	17.30	30	15.38	10.61	7.18	4.78
4.90	50.80	35	18.38	12.85	8.81	5.94
4.70	18.40	30	15.38	10.61	7.18	4.78
3.60	12.60	2.5	1.11	0.71	0.45	0.27
3.80	14.90	7.5	3.42	2.22	1.41	0.88
4.20	61.10	17.5	8.42	5.62	3.68	2.36
5.80	64.90	57.5	33.42	24.69	17.93	12.85
4.70	24.60	30	15.38	10.61	7.18	4.78
4.30	21.20	20	9.75	6.55	4.31	2.79
7.80	62.20	107.5	75.92	62.46	50.85	41.05
4.50	47.50	25	12.50	8.52	5.68	3.73
5.20	47.00	42.5	23.11	16.46	11.51	7.93
6.00	48.80	62.5	37.11	27.73	20.39	14.80
3.30	2.80	-5	-2.13	-1.33	-0.82	-0.49
3.90	19.50	10	4.63	3.03	1.94	1.22
5.20	15.40	42.5	23.11	16.46	11.51	7.93
4.50	23.80	25	12.50	8.52	5.68	3.73
4.30	21.60	20	9.75	6.55	4.31	2.79
4.50	23.50	25	12.50	8.52	5.68	3.73
7.10	28.90	90	59.63	47.34	37.11	28.80
5.60	26.60	52.5	29.86	21.80	15.63	11.06
7.30	45.50	95	64.13	51.44	40.77	32.01
5.30	16.30	45	24.75	17.74	12.49	8.65
4.50	29.40	25	12.50	8.52	5.68	3.73
7.20	118.40	92.5	61.86	49.37	38.91	30.37

5.70	28.40	55	31.63	23.22	16.76	11.93
3.10	6.50	-10	-4.13	-2.55	-1.54	-0.92
7.00	56.10	87.5	57.42	45.35	35.35	27.27
4.80	16.80	32.5	16.86	11.71	7.98	5.34
5.90	23.80	60	35.25	26.19	19.14	13.80
6.00	50.10	62.5	37.11	27.73	20.39	14.80
6.00	25.40	62.5	37.11	27.73	20.39	14.80
5.00	25.30	37.5	19.92	14.02	9.67	6.57
4.50	25.00	25	12.50	8.52	5.68	3.73
3.90	8.20	10	4.63	3.03	1.94	1.22
3.80	6.30	7.5	3.42	2.22	1.41	0.88
4.00	10.50	12.5	5.86	3.86	2.49	1.58
4.20	40.10	17.5	8.42	5.62	3.68	2.36
8.20	36.80	117.5	85.92	72.08	59.89	49.41
4.80	10.40	32.5	16.86	11.71	7.98	5.34
3.20	6.40	-7.5	-3.14	-1.95	-1.19	-0.71
4.70	13.60	30	15.38	10.61	7.18	4.78
4.20	14.20	17.5	8.42	5.62	3.68	2.36
3.90	8.20	10	4.63	3.03	1.94	1.22
4.10	10.40	15	7.13	4.73	3.07	1.96
6.60	69.80	77.5	48.92	37.81	28.81	21.70
5.90	44.50	60	35.25	26.19	19.14	13.80
6.30	37.90	70	42.88	32.59	24.40	18.05
6.00	29.30	62.5	37.11	27.73	20.39	14.80
5.30	33.50	45	24.75	17.74	12.49	8.65
4.00	36.70	12.5	5.86	3.86	2.49	1.58
4.30	24.00	20	9.75	6.55	4.31	2.79
4.80	26.70	32.5	16.86	11.71	7.98	5.34
6.60	38.80	77.5	48.92	37.81	28.81	21.70
2.90	12.00	-15	-6.00	-3.65	-2.18	-1.28
6.40	36.20	72.5	44.86	34.29	25.83	19.22
2.50	6.70	-25	-9.38	-5.54	-3.21	-1.83
3.30	25.20	-5	-2.13	-1.33	-0.82	-0.49
4.30	22.90	20	9.75	6.55	4.31	2.79
3.10	12.30	-10	-4.13	-2.55	-1.54	-0.92
4.40	22.90	22.5	11.11	7.52	4.98	3.25
4.70	28.50	30	15.38	10.61	7.18	4.78
5.30	27.90	45	24.75	17.74	12.49	8.65
2.30	2.60	-30	-10.88	-6.33	-3.62	-2.04
5.90	45.20	60	35.25	26.19	19.14	13.80
4.20	26.80	17.5	8.42	5.62	3.68	2.36
3.10	8.60	-10	-4.13	-2.55	-1.54	-0.92
5.90	64.90	60	35.25	26.19	19.14	13.80
3.60	2.90	2.5	1.11	0.71	0.45	0.27
5.00	46.70	37.5	19.92	14.02	9.67	6.57
7.20	48.20	92.5	61.86	49.37	38.91	30.37
5.00	36.10	37.5	19.92	14.02	9.67	6.57
6.90	43.00	85	55.25	43.40	33.64	25.80

4.70	15.60	30	15.38	10.61	7.18	4.78
6.80	71.00	82.5	53.11	41.50	31.99	24.39
4.80	16.60	32.5	16.86	11.71	7.98	5.34
3.60	21.50	2.5	1.11	0.71	0.45	0.27
3.50	19.80	0	0.00	0.00	0.00	0.00
5.80	23.40	57.5	33.42	24.69	17.93	12.85
5.60	37.00	52.5	29.86	21.80	15.63	11.06
6.20	23.30	67.5	40.92	30.93	23.02	16.92
5.10	35.10	40	21.50	15.22	10.57	7.23
4.60	30.70	27.5	13.92	9.55	6.41	4.24
4.10	15.80	15	7.13	4.73	3.07	1.96
5.10	12.30	40	21.50	15.22	10.57	7.23
7.40	28.80	97.5	66.42	53.56	42.68	33.70
4.30	23.70	20	9.75	6.55	4.31	2.79
5.70	39.00	55	31.63	23.22	16.76	11.93
5.40	64.40	47.5	26.42	19.06	13.50	9.42

APPENDIX IV

Index of Agreement

S.No.	Values of n	Index of Agreement
1	1	0.87
2	2	0.90
3	2.5	0.87
4	3.0	0.83
5	3.5	0.78
6	4.0	0.73

APPENDIX V

WERA validated data of 30-minute interval by Raleigh's distribution

S.No.	Mean velocity, Vm, (m/sec)	Estimated production, kWh	Measured production, kWh
1	4.38	130.07	156
2	5.66	247.57	189
3	4.92	177.01	124
4	3.62	74.33	61
5	4.39	130.89	111
6	4.06	104.92	195
7	6.92	372.23	315
8	7.77	451.96	390
9	7.14	393.44	402
10	6.07	288.2	217
11	4.95	179.75	251
12	5.82	263.36	311
13	6.6	340.87	147
14	6.14	295.18	163
15	4.91	176.1	179
16	5.36	218.35	109
17	4.35	127.62	114
18	5.24	206.86	137
19	7.57	433.79	368
20	8.57	520.04	485
21	7.95	467.95	500
22	6.8	360.53	352
23	5.77	258.41	319
24	7.33	411.47	364
25	6.82	362.49	285
26	7.01	380.95	311
27	6.22	303.15	261
28	7.52	429.18	216
29	7.16	395.35	228
30	5.79	260.39	218
31	8.63	524.82	385
32	8.33	500.45	436
33	9.54	590.94	431

34	7.53	430.1	304
35	6.7	350.73	321
36	7.8	454.65	399
37	7.47	424.55	429
38	8.13	483.56	501
39	8.28	496.28	490
40	5.99	280.24	340
41	5.25	207.82	302
42	6.93	373.2	418
43	6.49	329.99	208
44	6.55	335.93	319
45	5.67	248.55	343
46	4.66	153.79	196
47	5.08	191.78	170
48	6.93	373.2	321
49	6.03	284.22	194
50	6.74	354.66	303
51	5.3	212.59	338
52	7.38	416.16	226
53	6.05	286.21	172
54	6.41	322.05	200
55	6.19	300.16	169
56	6.34	315.09	241
57	7.13	392.49	240
58	5.82	263.36	159
59	5.63	244.62	138
60	6.76	356.62	205
61	4.83	168.85	154
62	7	379.98	221
63	6.08	289.2	247
64	5.02	186.2	153
65	4.51	140.9	127
66	4.21	116.43	183
67	3.87	91.1	28
68	4.31	124.38	40
69	4.97	181.59	54
70	4.91	176.1	32
71	4.37	129.25	25
72	3.7	79.52	34

APPENDIX VI

WERA validated data of 10minute interval by Weibull distribution.

Turbine No.	Measured production, kWh	Estimated production, kWh
1	56	61.3
2	170	255.18
3	37	44.7
4	252	234.42
5	116	195.3
6	94	126.93
7	73	106.34
8	74	74.1
9	121	130.17

APPENDIX VII

Wind Potential data for 10 selected sites.

S.No.	Station: Tolanur			Station: Rameshwarm		
	Velocity Interval	Velocity, Km/hr	Velocity, m/sec	Velocity Interval	Velocity, Km/hr	Velocity, m/sec
1	00	1.3	4.68	00	0.8	2.88
2	1-2	3.3	11.88	1-2	0.8	2.88
3	3-4	4.7	16.92	3-4	1.1	3.96
4	5-6	7.0	25.2	5-6	1.6	5.76
5	7-8	9.6	34.56	7-8	2.6	9.36
6	9-10	10.3	37.08	9-10	3.8	13.68
7	11-12	9.4	33.84	11-12	4.8	17.28
8	13-14	7.9	28.44	13-14	4.8	17.28
9	15-16	6.4	23.04	15-16	5.6	20.16
10	17-18	4.5	16.02	17-18	4.9	17.64
11	19-20	5.6	20.16	19-20	6.8	24.48
12	21-22	5.5	19.8	21-22	7.0	25.2
13	23-24	5.3	19.08	23-24	7.4	26.64
14	25-26	4.7	16.92	25-26	7.3	26.68
15	27-28	4.2	15.12	27-28	6.9	24.84
16	29-30	3.2	11.52	29-30	6.4	23.04
17	31-32	2.1	7.56	31-32	5.6	20.16
18	33-34	1.6	5.76	33-34	5.3	19.08
19	35-36	1.3	4.68	35-36	4.1	14.76
20	37-38	0.8	2.88	37-38	3.4	12.24
21	39-40	0.6	2.16	39-40	2.7	9.72
22	41-42	0.3	1.08	41-42	2.0	7.2
23	43-44	0.2	0.72	43-44	1.6	5.76
24	45-46	0.1	0.36	45-46	1.1	3.96
25	47-48	0	0	47-48	0.7	2.52
26				49-50	0.4	1.44
27				51-50	0.2	0.72
28				53-54	0.1	0.36
29				55-56	0	0
30				57-58	0	0
31				59-60	0	0

S.No.	Station: Deogad			Station: Meenakshipuram		
	Velocity Interval	Velocity, Km/hr	Velocity, m/sec	Velocity Interval	Velocity, Km/hr	Velocity, m/sec
1	00	1.5	5.4	00	8.7	31.32
2	1-2	2.5	9.0	1-2	10.5	37.8
3	3-4	3.3	11.88	3-4	7.8	28.08
4	5-6	4.5	16.2	5-6	6.6	23.76
5	7-8	7.1	25.56	7-8	5.5	19.8
6	9-10	9.1	32.76	9-10	4.4	15.84
7	11-12	10.4	37.44	11-12	4.0	14.4
8	13-14	10.0	36.00	13-14	4.0	14.4
9	15-16	8.6	30.96	15-16	3.9	14.04
10	17-18	6.2	22.32	17-18	3.1	11.16
11	19-20	6.8	24.48	19-20	4.2	15.12
12	21-22	5.8	20.88	21-22	4.5	16.20
13	23-24	5.0	18.00	23-24	4.5	16.20
14	25-26	4.2	15.12	25-26	4.3	15.48
15	27-28	3.7	13.32	27-28	4.1	14.76
16	29-30	3.1	11.16	29-30	3.6	12.96
17	31-32	2.3	8.58	31-32	3.1	11.16
18	33-34	1.9	6.84	33-34	2.5	9.0
19	35-36	1.4	5.04	35-36	2.0	7.2
20	37-38	1.1	3.96	37-38	1.6	5.76
21	39-40	0.6	2.16	39-40	1.4	5.04
22	41-42	0.4	1.44	41-42	1.3	4.68
23	43-44	0.2	0.72	43-44	1.0	3.60
24	45-46	0.1	0.36	47-48	0.6	2.16
25	47-48	0.1	0.36	49-50	0.5	1.8
26	49-50	00	00	51-50	0.4	1.44
27	51-50	00	00	53-54	0.2	0.72
28	53-54	00	00	55-56	0.2	0.72
29	55-56	00	00	57-58	0.2	0.72
30	57-58	00	00	59-60	0.1	0.36
31	59-60	00	00	61-62	0.1	0.36
32	61-62	00	00	63-64	0.1	0.36
33	63-64	00	00	65-66	0.1	0.36
34	65-66	00	00			
35	67-68	00	00			

S.No.	Station: Kanjikode			Station: Sultanpet		
	Velocity Interval	Velocity, Km/hr	Velocity, m/sec	Velocity Interval	Velocity, Km/hr	Velocity, m/sec
1	00	0.3	1.08	00	0.6	2.16
2	1-2	1.1	3.96	1-2	5.3	19.08
3	3-4	1.5	5.40	3-4	4.5	16.20
4	5-6	1.9	6.84	5-6	5.5	19.80
5	7-8	2.3	8.28	7-8	7.1	25.56
6	9-10	2.8	10.08	9-10	7.5	27.00
7	11-12	3.4	12.24	11-12	7.6	27.36
8	13-14	4.6	16.56	13-14	7.1	25.56
9	15-16	6.1	21.96	15-16	5.6	20.16
10	17-18	6.1	21.96	17-18	3.7	13.32
11	19-20	8.8	31.68	19-20	4.1	14.76
12	21-22	9.5	34.20	21-22	3.7	13.32
13	23-24	9.4	33.84	23-24	3.7	13.32
14	25-26	9.0	32.40	25-26	3.9	14.04
15	27-28	8.2	29.52	27-28	4.1	14.76
16	29-30	7.4	26.64	29-30	4.4	15.84
17	31-32	6.3	22.68	31-32	4.1	14.76
18	33-34	4.3	15.48	33-34	4.2	15.12
19	35-36	3.0	10.80	35-36	3.8	13.68
20	37-38	1.8	6.48	37-38	2.8	10.08
21	39-40	1.1	3.96	39-40	2.2	7.92
22	41-42	0.5	1.80	41-42	1.8	6.48
23	43-44	0.3	1.08	43-44	1.3	4.68
24	45-46	0.1	0.36	45-46	0.7	2.52
25	47-48	00	00	47-48	0.5	1.80
26	49-50	00	00	49-50	0.2	0.72
27	51-50	00	00	51-50	0.1	0.36
28	53-54	00	00	53-54	0.1	0.36
29	55-56	00	00			

S.No.	Station: Tuticorin			Station: Kayattar		
	Velocity Interval	Velocity, Km/hr	Velocity, m/sec	Velocity Interval	Velocity, Km/hr	Velocity, m/sec
1	00	1.1	3.96	00	0	0
2	1-2	2.4	8.64	1-2	2.8	10.08
3	3-4	3.4	12.24	3-4	4.4	15.84
4	5-6	4.5	16.2	5-6	5.6	20.16
5	7-8	6.5	23.4	7-8	6.6	23.76
6	9-10	7.7	27.72	9-10	7.9	28.44
7	11-12	8.3	29.88	11-12	8	28.8
8	13-14	8.4	30.24	13-14	6.9	24.84
9	15-16	7.8	38.08	15-16	5.8	20.88
10	17-18	5.7	20.52	17-18	3.8	13.68
11	19-20	6.8	24.48	19-20	4.5	16.2
12	21-22	6.5	23.4	21-22	3.9	14.04
13	23-24	6.3	22.68	23-24	3.4	12.24
14	25-26	5.9	21.24	25-26	3.1	11.16

15	27-28	5.0	18.00	27-28	2.7	9.72
16	29-30	4.0	14.4	29-30	2.9	10.44
17	31-32	3.0	10.8	31-32	2.7	9.72
18	33-34	2.2	7.92	35-36	2.9	10.44
19	35-36	1.5	5.4	37-38	3	10.8
20	37-38	1.1	3.96	39-40	2.9	10.44
21	39-40	0.7	2.52	43-44	2.3	8.28
22	41-42	0.5	1.8	45-46	1.9	6.84
23	43-44	0.3	1.08	47-48	1.6	5.76
24	45-46	0.2	0.72	49-50	1.2	4.32
25	47-48	0.1	0.36	51-52	0.9	3.24
26	49-50	0.1	0.36	53-54	0.6	2.16
27				55-56	0.3	1.08
28				57-58	0.1	0.36
29				59-60	0.1	0.36

S.No.	**Station: Andipatti**			**Station: Okha**		
	Velocity Interval	**Velocity, Km/hr**	**Velocity, m/sec**	**Velocity Interval**	**Velocity, Km/hr**	**Velocity, m/sec**
1	00	4	14.4	00	3.1	11.16
2	1-2	6.5	23.4	1-2	0.6	2.16
3	3-4	6.8	24.48	3-4	0.8	2.88
4	5-6	7	25.2	5-6	1.6	5.76
5	7-8	7	25.2	7-8	3.2	11.52
6	9-10	6.7	24.12	9-10	5.2	18.72
7	11-12	6.1	21.96	11-12	7	25.2
8	13-14	5.5	19.8	13-14	8.3	29.88
9	15-16	4.9	17.64	15-16	9.7	34.92
10	17-18	3.2	11.52	17-18	7.9	28.44
11	19-20	3.7	13.32	19-20	10.2	36.72
12	21-22	3.1	11.16	21-22	9.2	33.12
13	23-24	2.8	10.08	23-24	8	28.8
14	25-26	2.5	9	25-26	6.7	24.12
15	27-28	2.6	9.36	27-28	5.3	19.08
16	29-30	2.5	9	29-30	4.1	14.76
17	31-32	2.7	9.72	31-32	3.0	10.8
18	33-34	3.1	11.16	33-34	2.1	7.56
19	35-36	3.2	11.52	35-36	1.4	5.04
20	37-38	2.9	10.44	37-38	0.9	3.24
21	39-40	3.3	11.88	39-40	0.7	2.52
22	41-42	2.6	9.36	41-42	0.4	1.44
23	43-44	2.3	8.28	43-44	0.3	1.08
24	45-46	1.9	6.84	45-46	0.1	0.36
25	47-48	1.3	4.68	47-48	0.1	0.36
26	49-50	0.8	2.88			
27	51-50	0.4	1.44			
28	53-54	0.3	1.08			
29	55-56	0.1	0.36			

APPENDIX VIII

Input data used for economic analysis

S.No	Particulars	For one turbine	For 10 turbine
	Name of the site	**Kayattar**	
	Rated power, MW	2000	
	Number of turbine	10	
	Total farm capacity, MW	20000	
1	Cost of turbine with tower, control & electrical fittings	140000000	
2	Total cost for turbine, Rs		1400000000
3	Cost of transformer including tax & transportation	150000	
4	Total cost for transformer		1500000
5	Land required, acres	24	240
6	Cost of land per acre	200000	
7	Total cost for land		48000000
8	Distance from grid, meter	540	
9	Cost for grid integration per meter	500	
10	Total Cost for grid integration, Rs		2700000
11	Distance of road to farm, meter	456	
12	Cost for construction of road per meter	250	
13	Total cost to construction of road to farm		228000
14	Installation charges including foundation per turbine	500000	5000000

S.No	Particulars	For one turbine	For 10 turbine
	Name of the site	**Rameshwarm**	
	Rated power, MW	2000	
	Number of turbine	10	
	Total farm capacity, MW	20000	
1	Cost of turbine with tower, control & electrical fittings	140000000	
2	Total cost for turbine, Rs		1400000000
3	Cost of transformer including tax & transportation	150000	
4	Total cost for transformer		1500000
5	Land required, acres	24	240
6	Cost of land per acre	350000	84000000
7	Total cost for land		48000000
8	Distance from grid, meter	420	
9	Cost for grid integration per meter	500	
10	Total Cost for grid integration, Rs		2700000
11	Distance of road to farm, meter	430	
12	Cost for construction of road per meter	250	
13	Total cost to construction of road to farm		228000
14	Installation charges including foundation per turbine	500000	5000000

S.No	Particulars	For one turbine	For 10 turbine
	Name of the site	**Kanjikode**	
	Rated power, MW	2000	
	Number of turbine	10	
	Total farm capacity, MW	20000	
1	Cost of turbine with tower, control & electrical fittings	140000000	
2	Total cost for turbine, Rs		1400000000
3	Cost of transformer including tax & transportation	150000	
4	Total cost for transformer		1500000
5	Land required, acres	24	240
6	Cost of land per acre	500000	
7	Total cost for land		48000000
8	Distance from grid, meter	110	
9	Cost for grid integration per meter	500	
10	Total Cost for grid integration, Rs		2700000
11	Distance of road to farm, meter	14	
12	Cost for construction of road per meter	250	
13	Total cost to construction of road to farm		228000
14	Installation charges including foundation per turbine	500000	5000000

S.No	Particulars	For one turbine	For 10 turbine
	Name of the site	**Sultanpet**	
	Rated power, MW	2000	
	Number of turbine	10	
	Total farm capacity, MW	20000	
1	Cost of turbine with tower, control & electrical fittings	140000000	
2	Total cost for turbine, Rs		1400000000
3	Cost of transformer including tax & transportation	150000	
4	Total cost for transformer		1500000
5	Land required, acres	24	
6	Cost of land per acre	200000	
7	Total cost for land		48000000
8	Distance from grid, meter	480	
9	Cost for grid integration per meter	500	
10	Total Cost for grid integration, Rs		2700000
11	Distance of road to farm, meter	415	
12	Cost for construction of road per meter	250	
13	Total cost to construction of road to farm		228000
14	Installation charges including foundation per turbine	500000	5000000

S.No	Particulars	For one turbine	For 10 turbine
	Name of the site	**Andipatti**	
	Rated power, MW	2000	
	Number of turbine	10	
	Total farm capacity, MW	20000	
1	Cost of turbine with tower, control & electrical fittings	140000000	
2	Total cost for turbine, Rs		1400000000
3	Cost of transformer including tax & transportation	150000	
4	Total cost for transformer		1500000
5	Land required, acres	24	240
6	Cost of land per acre	200000	
7	Total cost for land		48000000
8	Distance from grid, meter	290	
9	Cost for grid integration per meter	500	
10	Total Cost for grid integration, Rs		2700000
11	Distance of road to farm, meter	470	
12	Cost for construction of road per meter	250	
13	Total cost to construction of road to farm		228000
14	Installation charges including foundation per turbine	500000	5000000

OPTIMAL PLANNING OF WIND FARMS USING WERA MODEL INTEGRATED WITH GIS

By

DEVANAND U. GORATE

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

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ABSTRACT

The present study brings out a systematic procedure for Optimal planning and laying out wind turbine at prospective wind farm site. The Wind Energy Resource Analysis (WERA) model was used here for the wind energy analysis and turbine performance simulation. WERA model was validated using long term as well as short term field performance data from Kanjikode wind farm, Palakkad, Kerala. The velocity-power proportionality for the three bladed horizontal axis wind turbine at the wind farm was computed as 1.75. Wind energy potential of 10 prospective sites were analyzed using WERA among which 5 sites were short listed for possible wind farm activities. The short listed sites are Kayattar, Rameshwarm, Kanjikode, Sultanpet and Andipatti. Performance of a 2 MW commercial wind turbine at these sites was simulated using WERA software. An interlinking programme correlating the result of above analysis with GIS was developed. Economics of wind energy conversion systems at these sites was estimated using above programme. It was found that the cost of wind energy in a kWh basis ranges from Rs.1.28 toRs.1.72 at the short listed sites. Based on economic viability, the site Kayattar was finally selected for the wind farm activity. Considering the wind potential and site constraints, a method was developed for micro-siting of the turbine at this site using Geographical Information System. Accordingly, elevation contour map, digital elevation model, velocity map, distance from boundary map, cut velocity map, suitability map and location map were developed. Optimal locations of the turbines for a 20 MW wind farm at this site were identified. Energy yield of individual turbines installed at the site were computed using WERA software. The total energy output of the wind farm is found to be 45927605.9 MWh.