WEPA: Wind energy potential assessment -spatial decision support system

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Abstract

Spatial Decision Support System (SDSS) assist in strategic decision-making activities considering spatial and temporal variables, which helps in regional planning. WEPA is a SDSS designed for assessment of wind potential spatially. A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. Wind energy can diversify the economies of rural communities, adding to the tax base and providing new types of income. Wind turbines can add a new source of property value in rural areas that have a hard time attracting new industry. Wind speed is an extremely important parameter for assessing the amount of energy a wind turbine can convert to electricity: the energy content of the wind varies with the cube (the third power) of the average wind speed. Estimation of the wind power potential for a site is the most important requirement for selecting a site for the installation of a wind electric generator and evaluating projects in economic terms. It is based on data of the wind frequency distribution at the site, which are collected from a meteorological mast consisting of wind anemometer and a wind vane and spatial parameters (like area available for setting up wind farm, landscape, etc.). The wind resource is governed by the climatology of the region concerned and has large variability with reference to space (spatial expanse) and time (season) at any fixed location. Hence the need to conduct wind resource survey and spatial analysis constitute vital components in programs for exploiting wind energy. SDSS for assessing wind potential of a region / location is designed with user friendly GUI's (Graphic User Interface) using visual basic as front end with microsoft Access database (backend). Validation and pilot testing of WEPA SDSS has been done with the data collected for 45 locations in Karnataka based on primary data at selected locations and data collected from the meteorological observatories of the India Meteorological Department (IMD). Wind energy and its characteristics have been analyzed for these locations to generate user-friendly reports and spatial maps. Energy Pattern Factor (EPF) and Power Densities are computed for sites with hourly wind data. With the knowledge of EPF and mean wind speed, mean power density is computed for the locations with only monthly data. Wind energy conversion systems would be most effective in these locations during May to August. The analyses show that coastal and dry arid zones in Karnataka have good wind potential, which if exploited would help local industries, coconut and areca plantations, and agriculture. Premonsoon availability of wind energy would help in irrigating these orchards, making wind energy a desirable alternative.

Keywords: Wind energy; Regional planning; SDSS; GIS; EPF; Renewable energy; Environment.

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1. Introduction

A decision support system (DSS) is an interactive system that is able to produce data and information and in some cases, even promote understanding related to a given application domain in order to give useful assistance in resolving complex and ill-defined problems [1]. It is a spatially based computer application or data that assists a researcher or planner in making decisions. It couples the intellectual resources of individuals with the capabilities of the computer to improve the quality decisions. Decision-making processes are analyzed from different viewpoints and the implementation of analytical methods and models and support tools must take into consideration not only the organizational structure in question, but also the procedures, processes and the dynamics of the decision makers involved. DSS includes the analysis of integrated, subject oriented, spatial and temporal data, and assist in decision making by:

1. Extending the decision maker's ability to tackle large-scale, time-consuming, complex problems;
2. Shortening the time associated with making a decision;
3. Improving the reliability of a decision process or outcome;
4. Encourage exploration and discovery of the decision maker;
5. Generating new evidence in support of a decision or confirmation of existing assumptions;
6. Improving the decision maker's ability to process information and knowledge;
7. Analyzing spatially the variability associated with the resources.

SDSS for assessing the wind potential is designed to assist the decision makers in regional planning in making appropriate decisions and also visualization of decisions.

1. 1. Wind energy

Solar energy falling on the earth produces large-scale motion of the atmosphere, on which is super-imposed, local variations caused by several factors. Winds are caused by rotation of the earth and heating of the atmosphere by the sun. Due to the heating of the air at the equatorial regions, the air becomes lighter and starts to rise, and at the poles the cold air starts sinking. The rising air at the equator moves northward and southward. Differential heating of sea causes more minor changes in the flow of air. The nature of the terrain, ranging from mountains and valleys to more local obstacles such as buildings and trees, also has an important effect on the wind [2].

The power in the wind is proportional to the cube of the wind speed or velocity. It is therefore essential to have detailed knowledge of the wind and its characteristics, if the performance of wind turbines is to be estimated accurately. Various parameters need to be known of the wind energy are mean wind speed, directional data and velocity variations periodically daily/yearly/monthly and height of the anemometer. These parameters are used to assess the performance and economics of the wind plant.

Harnessing of wind energy could play a significant role in the energy mix of a region. Windmills have been used for centuries to grind grain and pump water in rural areas. Wind energy is renewable and environmentally benign. It has the advantage of being harnessed locally for applications in rural and remote areas. Wind driven electric generators could be

utilized as an independent power source, and for purposes of augmenting the electricity supply from grids. In densely populated taluks, decentralized production of electricity would help local industries, especially seasonal agro-processing industries, etc.

The extent to which wind can be exploited as a source of energy depends on the probability density of occurrence different speeds. To optimize the design of a wind energy device, data on speed range over which the device must operate to maximize energy extractions are required, which requires the knowledge of frequency distribution of the wind speed. Data on mean monthly and annual wind speeds for a long time (30 - 50 years) are available at meteorological observatories and the data on frequency distribution is available from various locations. Various parameters need to be known of the wind energy are mean wind speed, directional data and velocity variations periodically – daily / yearly / monthly and height of the anemometer. These parameters are used to assess the performance and economics of the wind plant.

1. 2. Environmental issues

A comprehensive environmental assessment considering the following is required before the project implementation.
- Land use analysis: helps in assessing the changes in land use pattern for setting up wind energy stations.
- Ecological and Environmental Assessment: Impact on Flora and Fauna
- Visual and landscape assessment: a map is prepared showing those areas from which the wind turbines may be seen; more sophisticated techniques of visual assessment may be appropriate for larger projects.
- Noise assessment: to ensure the wind farm will not create any nuisance at local dwellings.
- Hydrological assessment: the impact of the proposed project on watercourses.
- Economic effects on local economy: includes an estimate of the number of permanent and temporary jobs, which may be created.
- Mitigating measures: ways in which any adverse environmental impact may be minimized.

2. Literature review

Fausto Cavallaro et al., have applied multi criteria approach of DSS to make a preliminary assessment regarding the feasibility of installing wind energy turbines in Salina island (Aeolian islands/Italy) [1]. The use of decision making tools under a multi criteria approach are intended to aid the decision maker in the creation of a set of relations between various alternatives. The main steps relating to the formulation of a multi criteria problem were applied to the study area and they were as follows: defining the nature of the decision, selecting potential actions, defining a set of criteria, build payoff matrix (quantitative and qualitative measures of the effect produced by that alternative with respect to that criterion), and aggregation of preferences and comparison of criteria. The final order of merit for all the alternatives (from the best to the worst) is obtained as a result of the procedure described above.

Al Mohamad et al., have evaluated total wind energy potential for 3 different regions in Syrian land using program written in C++ Language [3]. It was designed to allow 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 processes and calculates the main parameters such as wind speed, wind power, and power density directly from the available data, which are considered to be essential for the following evaluation of the wind energy potential and the produced electricity. The second part of the program calculates the electricity produced from a wind farm using defined wind turbines with known output power-speed curve and the third part calculates the economical feasibility for a proposed wind farm. The estimated amount of potential power, considering the ratio of the land available for use equals to 1, 2, 4 and 6% of the total windy lands with a wind speed of about 7 m/s and above, is found to be more than 20,000 MW in each of the mentioned three windy regions. It is found that in region 1 alone more than 20,000 MW of electricity can be generated if only 1% of the land was considered and in addition, it is found that region 2 and 3 have the potential of more than 10,000 MW each for the same ratio of lands.

A GIS based decision support system (DSS) is developed for evaluation of renewable energy sources (RES) potential and the financial analysis of renewable energy investments [4]. RES- DSS has been developed in MAPINFO Professional, a GIS environment under WINDOWS 95. A GIS database with data on wind, topography, urban area and special activities have been developed and used for the evaluation of theoretical potential through spatially continuous mapping of RE resources. The evaluation of wind potential is conducted in Crete Island by a sequence of steps, which represents sets of restrictions on the exploitation of the potential. In RES-DSS wind speed data is necessary for estimation of theoretical potential, which are modeled as region objects characterized by the attribute wind speed. Analysis presents high wind potential with wind velocity varying from 6 - 8 m/s.

3. Objective

The objective is to design a Decision Support System for assessing viability of harnessing wind energy considering the technical, economic and environmental parameters and site-specific data.

4. Methodology

The DSS for wind energy assessment is given in Fig 1, with user friendly Graphic User Interface (GUI) is developed using Microsoft Visual Basic 6.0 as frontend with MS Access database as backend. This GUI environment helps in entry, edit or update of database along with the options to compute the power and energy. Visualization of the data in the form of maps and graphs helps the decision maker in effective interpretation. Currently the database consists of the data for Karnataka state, India.

The Database consists of primary data (selected sites) and daily wind data for the period 1969-2000 from meteorological observatories of India Meteorological Department (IMD), Government of India (IMD, Pune and IMD, Bangalore). Cup counter anemometers with hemispherical cups measuring 7.62 cm in diameter were used in India Meteorological Department observatories until 1973. During 1973-1979, these anemometers were replaced

with 3-cup anemometers with 127 mm diameter conical cups, in conformity with international practice. The wind instruments are at 10 m above ground over open terrain in all these observatories.
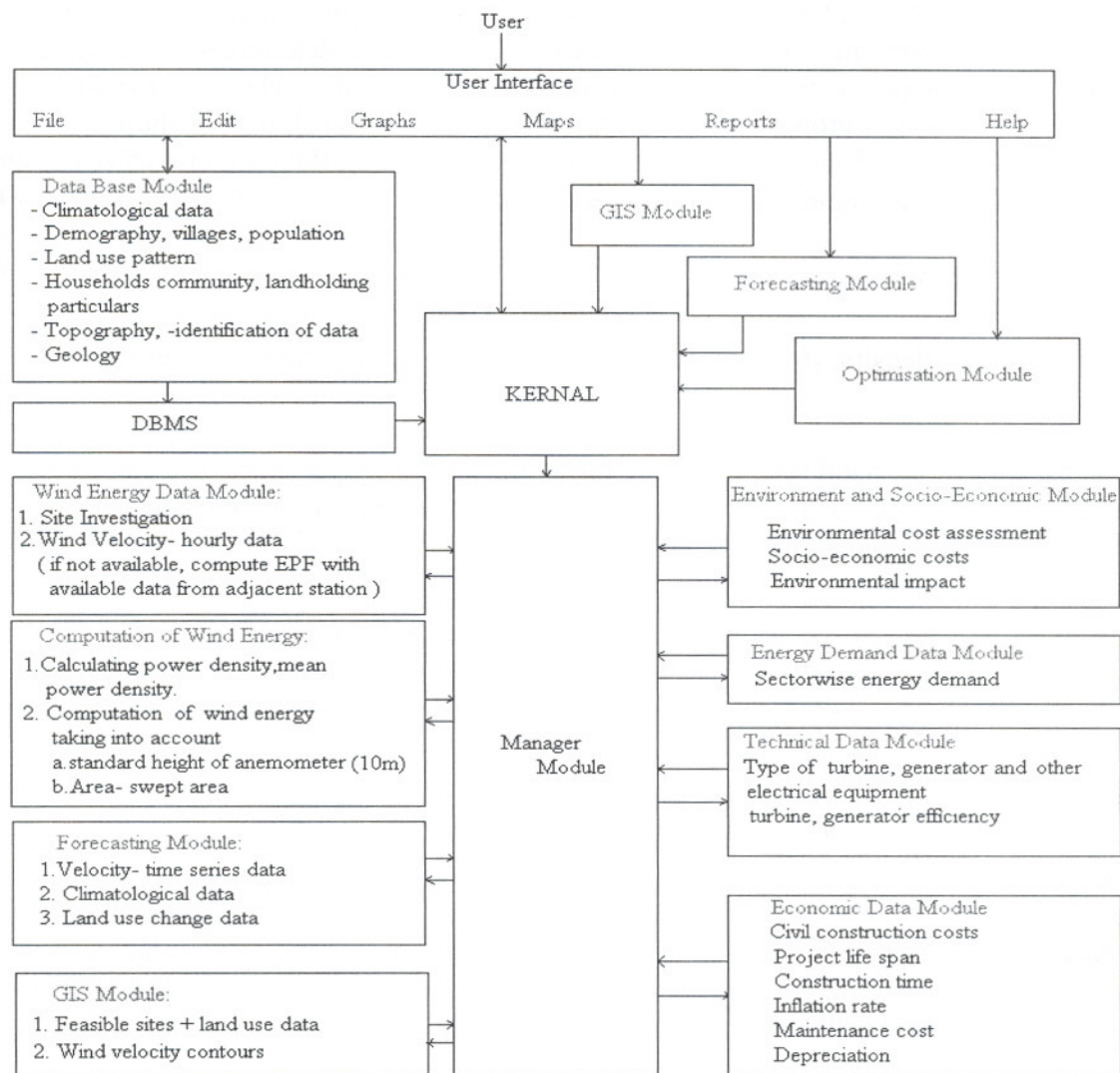

Fig. 1. Decision support system for wind energy assessment

Wind speed is a continuously varying parameter, hence it is customary to average the wind speeds during each hour and use the hourly mean wind speed as the basic parameter in calculations of wind power.

4. 1. Mean wind speed and energy resource

The annual wind speed at a location is useful as an initial indicator of the value of the wind resource. The relationships between annual mean wind speed and potential value of the wind energy resource are listed in Table 1.

In locations where data are not available, a qualitative indication of a high annual mean wind speed can be inferred from geographical location, topographical features, wind-induced soil erosion, and deformation of vegetation. However, accurate determination of the mean annual wind speed requires anemometer data for at least 12 months. The power P due to the kinetic energy of wind is proportional to $(1/2)*[Mass \times (Velocity)^2]$, that is, the mass of air passing through an area A at velocity V. The mass of air passing through an area A per unit time is ρAV and the total power available from wind is,

$$P = [(1/2)^*(\rho AV)^* V^2] = [(1/2)^*(\rho AV^3)] \tag{1}$$

where ρ is the mass density, ρAV air mass flow rate, and V the air-stream velocity.

Table 1. Mean annual wind speed and the potential

Annual mean wind speed at 10 m Height	Indicated value of wind resource
< 4.5 m/s	Poor
4.5 – 5.4 m/s	Marginal
5.4 – 6.7 m/s	Good to Very Good
> 6.7 m/s	Exceptional

4. 2. Adjustment of heights of anemometer

Anemometers at different meteorological stations are set at different levels. The measurements and wind speed recorded at each station, prior to any analysis, had to be adjusted to the same height. A level of 10m is the standard for a typical meteorological station to measure the wind speed. If the data collected is at different height they are adjusted to 10 m by the India Meteorological Department according to Equation 2,

$$(V1/V2) = (H1/H2)^{\alpha} \tag{2}$$

where V1 is wind speed at height H1 of 10m above ground level, V2 wind speed at height H2 above ground level, and α the roughness factor (0.30).

4. 3. Wind speed frequency distribution

The wind speed frequency distribution at a given location is either tabulated from wind speed data measured as a function of time or approximated by a probability distribution function based on measured data or assumed wind resources characteristics. In recent years,

much effort has been made to construct an adequate statistical model for describing the wind frequency distribution. Earlier studies have shown that the Weibull distribution gives a good fit to the experimental wind speed data [5, 6]. The probability density function F (v) for wind data is given by,

$$F(v) = (k/c)*(V/c)^{k-1}*Exp[-(V/c)^k] \tag{3}$$

The cumulative distribution function (CDF) is

$$M(v) = 1 - Exp[-(V/c)^k] \tag{4}$$

where k is a dimensionless shape factor, c scale factor with units of speed, and F (v) the probability or percentage of occurrence per unit speed of the wind speed V.

4. 4. Energy pattern factor (EPF)

The power density per unit area is given by,

$$P = K_{Em}*[1/2(\rho*Vm^3)] \text{ for the month} \tag{5}$$

$$P = K_{Ea}*[1/2(\rho*Va^3)] \text{ for the year} \tag{6}$$

where, ρ is the density, and K_{Em} and K_{Ea} the energy pattern factor [EPF] for month and year respectively [7].

$$K_{Em} = \frac{\text{Total amount of power available in the wind}}{\text{Power calculated by cubing mean wind speed}}$$

$$= \frac{\text{Mean Power Density for the month}}{\text{Mean Power Density at monthly mean speed}}$$

$$= \frac{1/2*\rho\Sigma V_i^3/N_m}{1/2*\rho*V_m^3} = \frac{\Sigma V_i^3/N_m}{V_m^3} \tag{7}$$

where V_i is the hourly wind speed during the month, N_m the number of hourly wind speed values during the month and V_m the monthly mean wind speed $= \Sigma V_i/N_m$, while the annual energy pattern factor is,

$$K_{Ea} = \frac{\Sigma V_i^3/N_a}{V_a^3} \tag{8}$$

The mean power density for the month = $K_{Em} *1/2*\rho *V_m^3$, and for the year = $K_{Ea} *1/2*\rho *V_a^3$

4. 5. Wind farm and turbine size

It is found at present that the wind turbines of 225 kW each are economically attractive. If 10% of wasteland (in the region of 10 km width along the coastal tract) is made available for power generation, the calculations show that along the coastal tract of Karwar and Kumta, wind farm of rated capacity of 1.35 megawatt (6 units of 225kW each) can be established [8].

4. 6. Estimation of output

Turbine efficiency of 40% and electric generator efficiency of 85% are used in the calculation. With this, an overall efficiency of 35% in wind-electric generator units could be achieved. A load factor of 0.3 is assumed in the computation of energy output.

Apart from well-known day-night and seasonal variation of wind regime, it is to be noted that the wind is fairly reliable compared to Hydel resources (rainfall). The coefficient of variation (COV) of mean wind speed is about 5.85 per cent compared to a higher COV of rainfall (of about 28%).

5. Case study: Karnataka

The study area, Karnataka state, is situated between 11° 40' and 18° 27' north latitude and 74° 5' and 78° 33' east longitude in the center of western peninsular India, covering an area of 19.1 Mha and accounts for 5.8% of the country's total geographic area. It has a 350 km long coastline, which forms the western boundary. According to the 2001 provisional census the population of the state is 52.6 million (26.8 million males and 25.8 million females), with a rural population of 66.02% and an urban population of 33.98%. The quality and quantity of bio-resource in a region depends on various parameters such as physiography, climate, geology, soil, etc., which are discussed for Karnataka state next.

5. 1. Physiography

The state is divided into three major physiographic divisions—the Deccan plateau, hill ranges and the coastal plain. The plateau is divided into malnad and maidan. The Ghats with evergreen and semi-evergreen forests constitute the core of the malnad. Malnad is an undulating upland covering 6.2 Mha in the districts of Belgaum, Uttara Kannada, Dharwad, Chikmagalur, Kodagu and Hassan. The maidan lies east of the malnad and has a rolling surface with gentle slopes. It is further subdivided into the northern and the southern maidan. The landscape characteristics of the southern maidan are a series of rolling granite hills between Tumkur and Kolar districts. The northern maidan has a mountainous, treeless expansive plateau.

The Deccan plateau is a continuation of the Malwa plateau and extends southwards. It has a triangular slope and is flanked on both sides by the Western Ghats and the Eastern Ghats. The height of the Deccan plateau varies from 300 to 900 m. The Western Ghats runs parallel to the western coast of Karnataka covering an area of 2.4 Mha. The Eastern Ghats is formed by a group of low and discontinuous mountains on the eastern side of the Deccan plateau. They occur along the southeastern border of Karnataka, covering an area of about 0.38 ha. The Eastern and

the Western Ghats converge at the Nilgiri Hills. The plains cover an area of about 0.74 ha and lies between the Western Ghats and the Arabian Sea, from Karwar in the north to Mangalore in the south.

5. 2. Topography

Karnataka has representatives of all types of variations in topography—high mountains, plateaus, residual hills and coastal plains. Chains of mountains to its west, east and south enclose the state. It consists mainly of plateau, which has higher elevation of 600 to 900 m above mean sea level. The entire landscape is undulating, broken up by mountains and deep ravines. Plain land of elevation less than 300 m above mean sea level is to be found only in the narrow coastal belt, facing the Arabian Sea. There are quite a few high peaks both in the Western and Eastern Ghat systems with altitudes more than 1500 m. A series of cross-sections drawn from west to east across the Western Ghat generally exhibit a narrow coastal plain followed to the east by small and short plateaus at different altitudes, then suddenly rising up to great heights.

Then it follows the gentle east and east-north-west sloping plateau. Among the tallest peaks of Karnataka are the Mullayyana Giri (1925 m), Bababudangiri (Chandradrona Parvata 1894 m) and the Kudremukh (1895 m) all in Chikmagalur district and the Pushpagiri (1908 m) in Kodagu district. There are a dozen peaks, which rise above the height of 1500 m.

5. 3. Agro climatic zones

Karnataka is divided into 10 agro climatic zones taking into consideration the rainfall pattern-quantum and distribution, soil types, texture, depth and physico-chemical properties, elevation, topography, major crops and type of vegetation.

- Northern dry zone
- Northern transition zone
- Northeastern transition zone
- Northeastern dry zone
- Coastal zone
- Central dry zone
- Eastern dry zone
- Southern dry zone
- Southern transition zone
- Hilly zone

6. Results and discussion

The flowchart for navigating DSS is given in Fig 2. An Executable file is provided for this application and by executing, the login form is displayed as given in Fig 3. This allows user to enter login name and organization for existing users and new users are prompted to create a new login name and organization. With these information input, user is allowed to either append data to the database or browse the data, which is given in Fig 4.
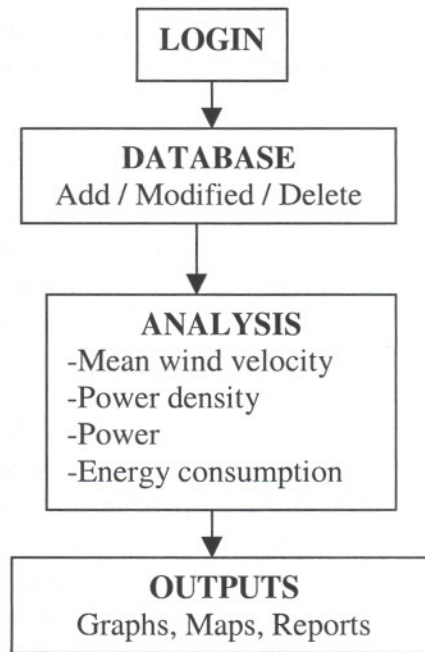
Fig 2. Flowchart for navigating DSS

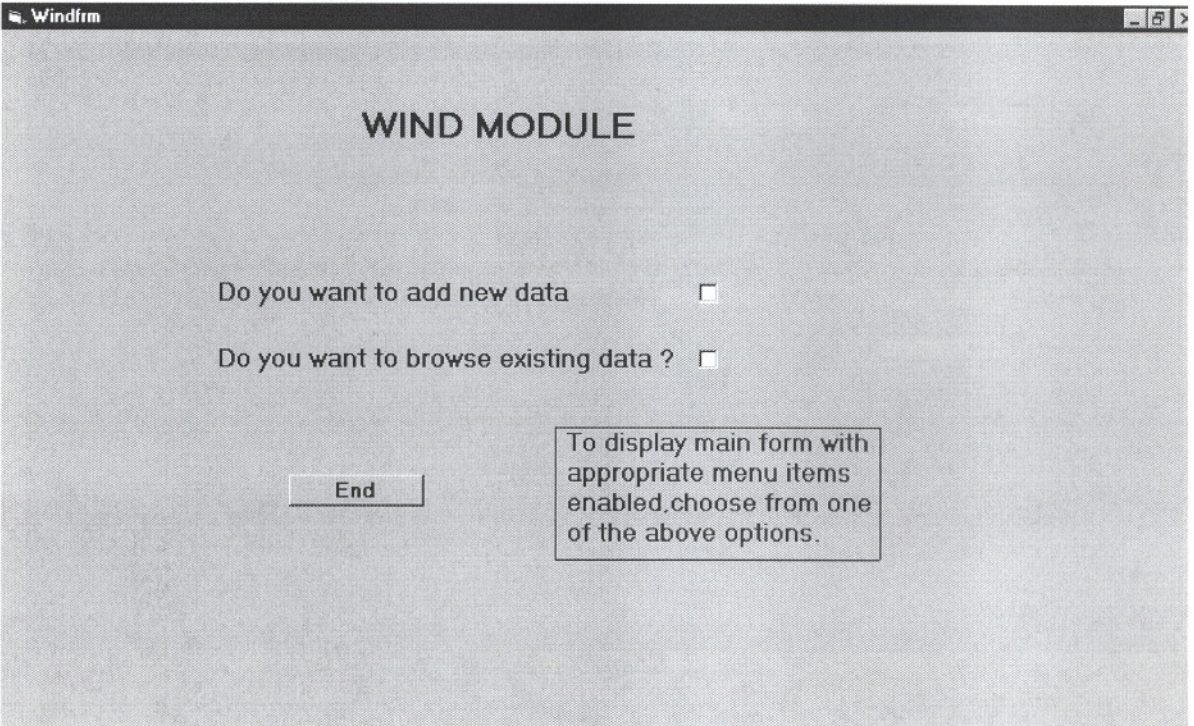
Fig. 3. Log in entry form

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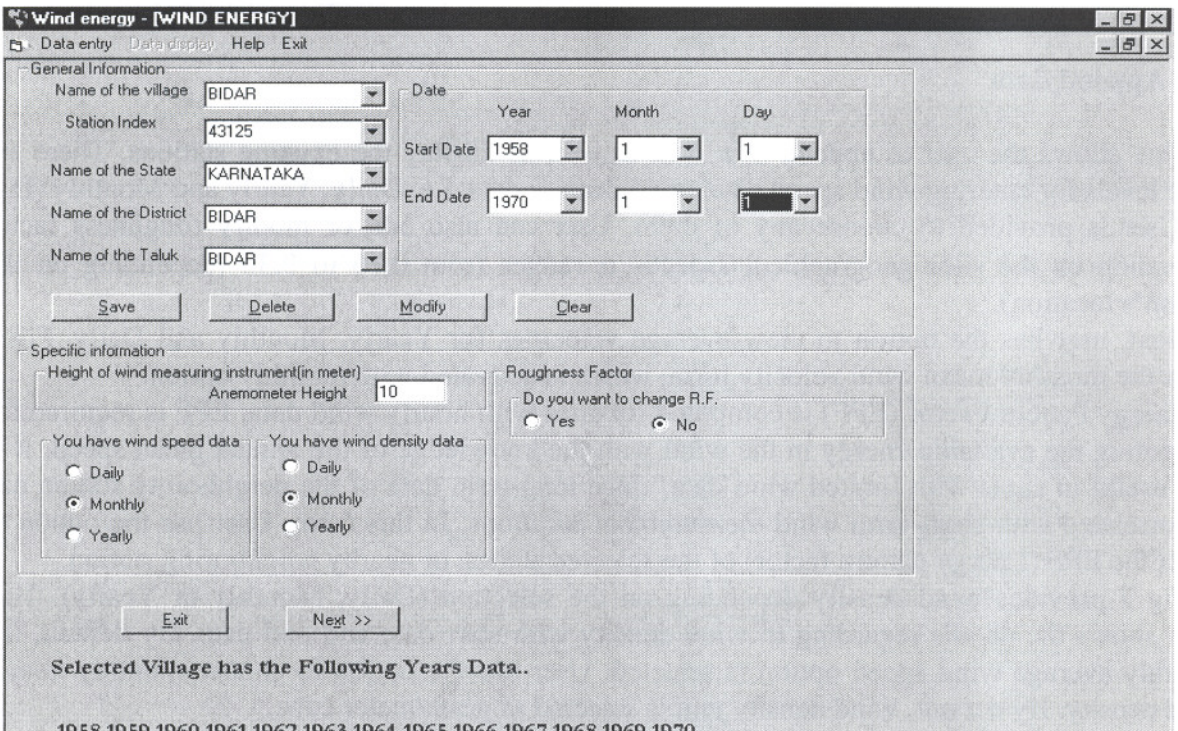Fig. 4. Information input, user database or browse data

Fig 6. Mean monthly wind velocity form

6. 1. Append data

This allows the user to append new data as well as display the existing stations. There are three levels for entering wind speed data, wind density data. i.e. Daily, Yearly and Monthly (Fig. 5). User is provided to choose any of them. User can also add or modify roughness factor depending on the sites geographical aspects. α ranges from 0.16 to 0.30 (depending on the station's location).

Next, user has the option to view average velocities for Yearly, Monthly and Daily. Fig 6 gives the monthly mean wind velocity form, which is activated with monthly option.

Energy Pattern Factor (EPF) is computed for sites with hourly wind data. EPF is required for computing the available energy in the wind with the knowledge of the annual mean speed. It is also useful in cases with limited wind data, since long-term data of the neighboring station can be correlated with short-term wind measurement locations. In this form, User has the option to select the EPF (Energy pattern factor) of the selected station or nearby neighboring station.

Fig 7 provides wind density depending on the selection (Daily, Monthly or Yearly). This form shows the details regarding to wind density with start date and end date. By default, the monthly average wind speed option is selected. User has the option to choose monthly hourly wind density. By default, wind density unit is selected as gram/meter cube.

Fig 8 gives power density and status of wind power potential (depending on the velocity as given in table 1). By choosing the appropriate option from wind potential report (monthly / yearly), results are displayed in grid.
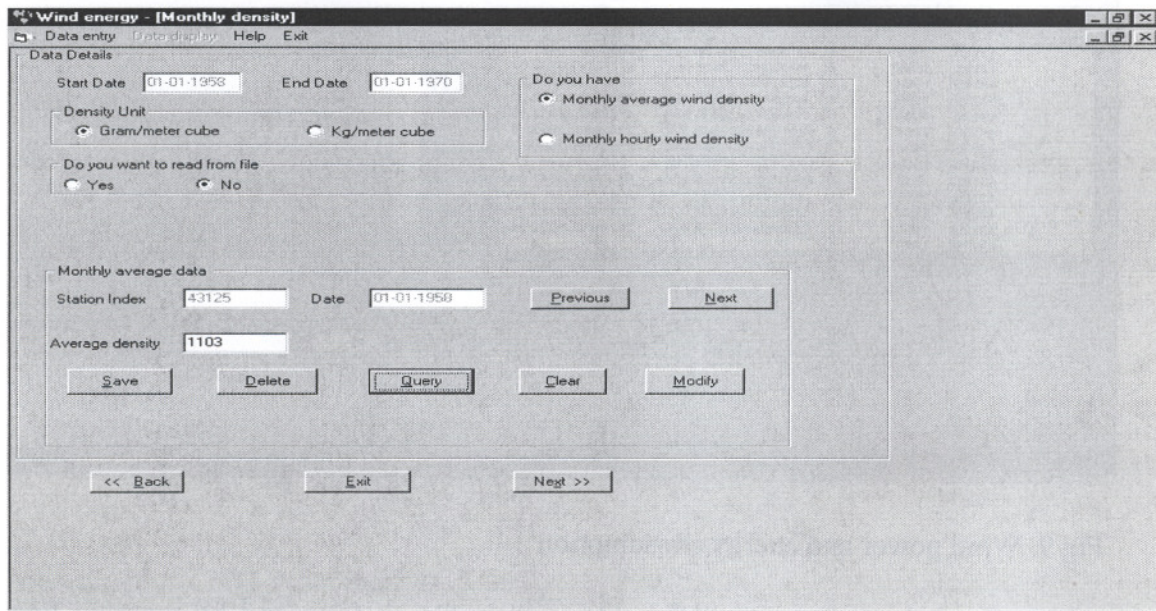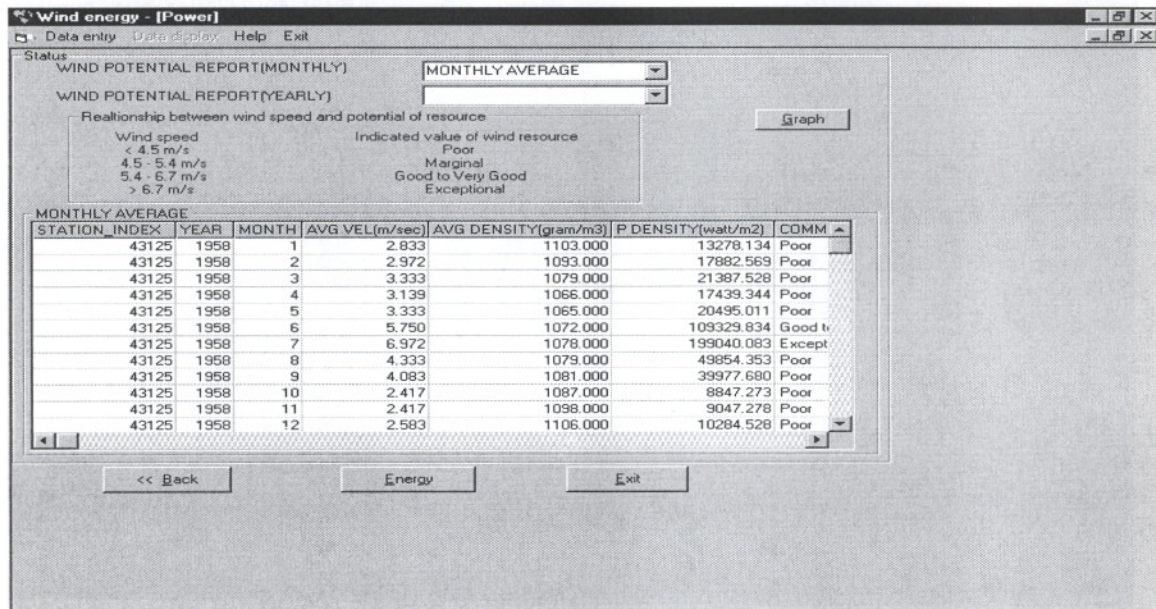

Fig 7. Monthly wind density form
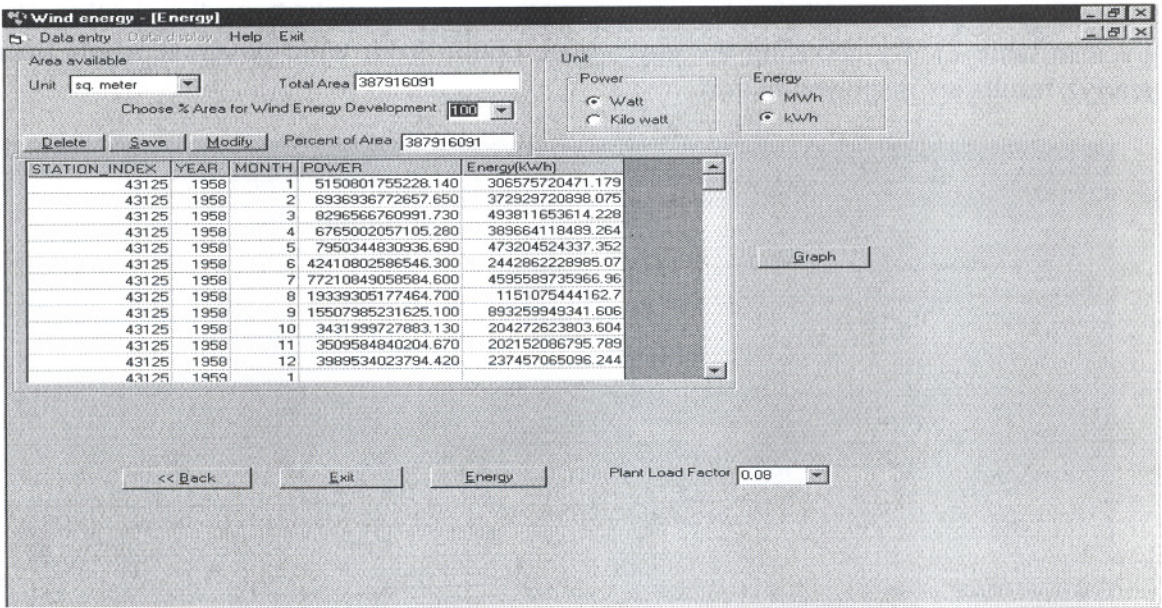

Fig 8. Wind power density calculation

Fig 9. Wind power and energy consumption

By pressing Graph button, user will be able to view Graph form and by pressing Energy button, Energy form of wind module is displayed. Fig 9 gives the energy computation for particular site. Here, to compute wind power potential and the corresponding energy, data such as the area availability for installing wind mill/ farm (wind swept area) is to be provided.

Fig 10. Bar chart of average monthly velocity of Bidar district
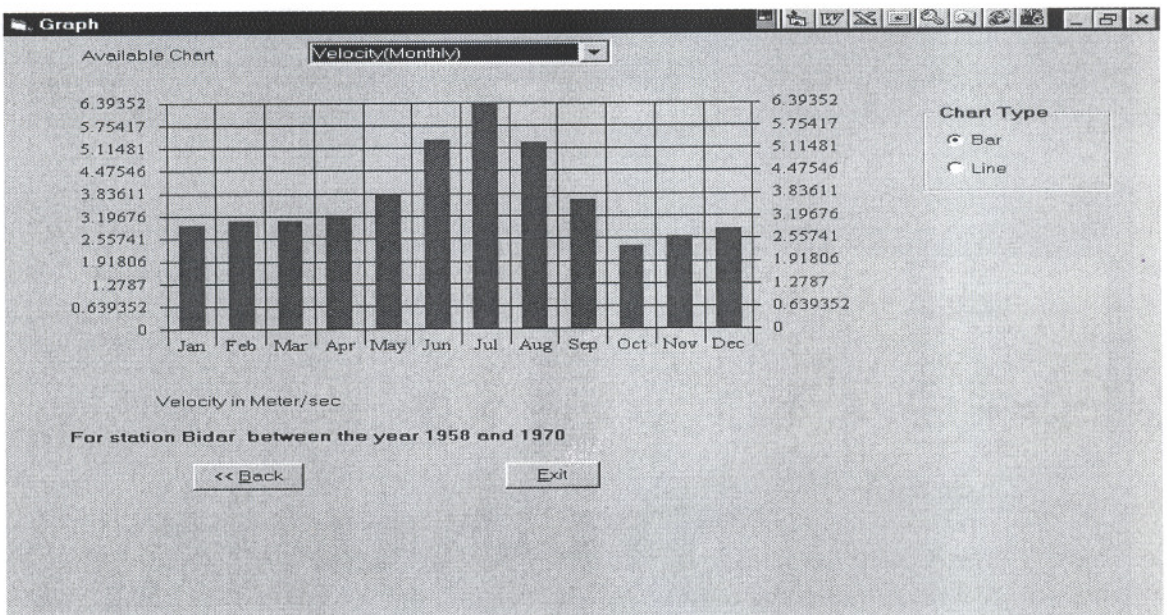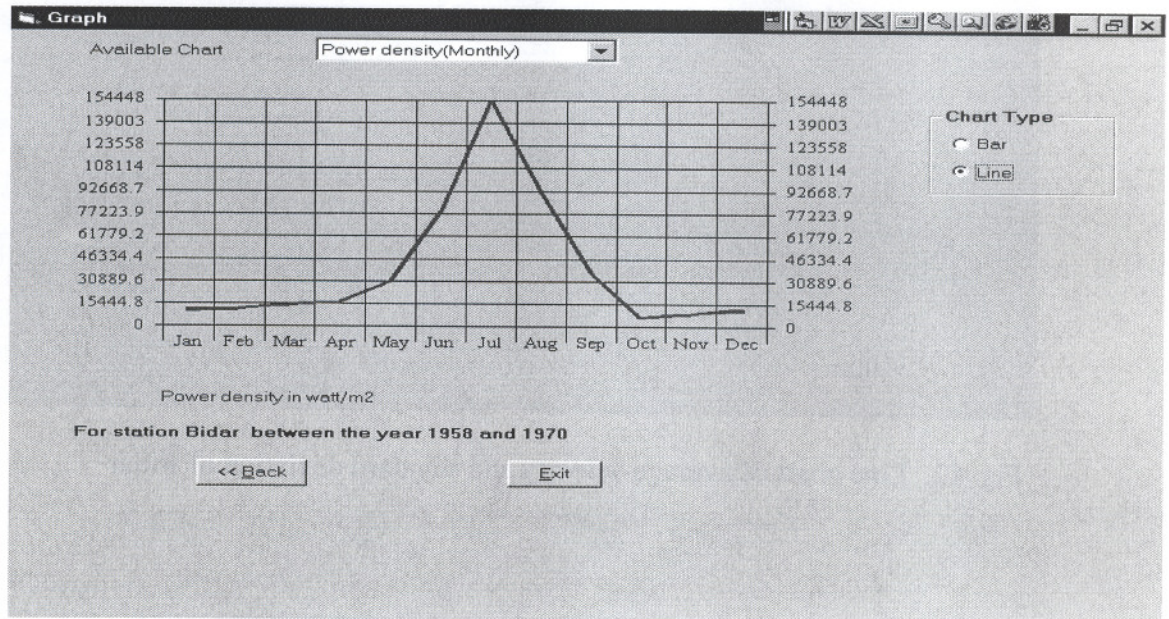
Fig 10. Bar chart of average monthly velocity of Bidar district

Fig. 11. Line chart of average power density of Bidar district

Wind power is computed as follows,

   Wind power = average (power density) * area   (9)

   Wind energy =[[wind power * (count of days * 24)]/1000] * plant load factor   (10)

Fig 10 and 11, shows bar and Line chart options for displaying mean velocity. Fig 12 depicts mean velocity along with standard deviation. Bar chart of monthly average energy generation of Bidar district is shown in Figs 13 and 14.

In order to provide the user spatial analyses capability, Geographic information systems (GIS) is embedded in the WEPA DSS. This helps to display the results and identify the needed modifications to the constraints so as to consider the spatial structure. It is used for identifying and quantifying the effect of local constraints on the wind energy potential. This helped in providing the flexibility to enrich the database, with spatial data on which decisions are based. Wind potential maps across various seasons were generated using GIS considering seasonal wind velocities at various locations. Wind velocities are presented as thematic layers, which helps to identify the sites with higher energy production. Fig 15 depicts the wind potential variability during monsoon across districts in Karnataka state, India. The wind potential is evaluated station wise and is represented by a polygon in the map.
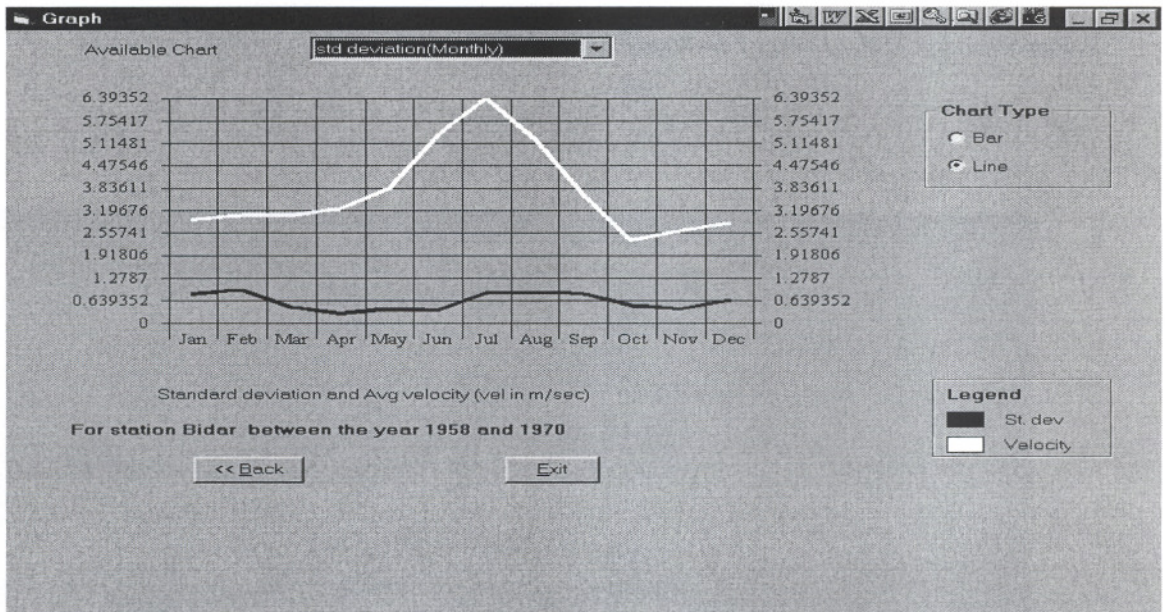
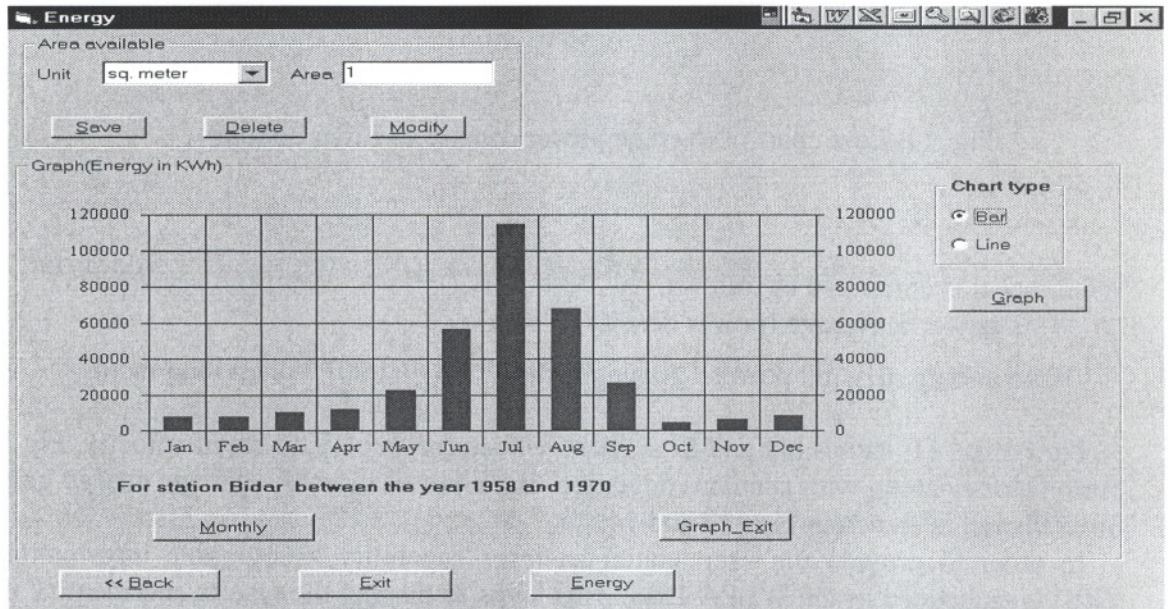Fig. 12. Line chart of average velocity and standard deviation of Bidar

Fig. 13. Bar chart of monthly average energy generation of Bidar district

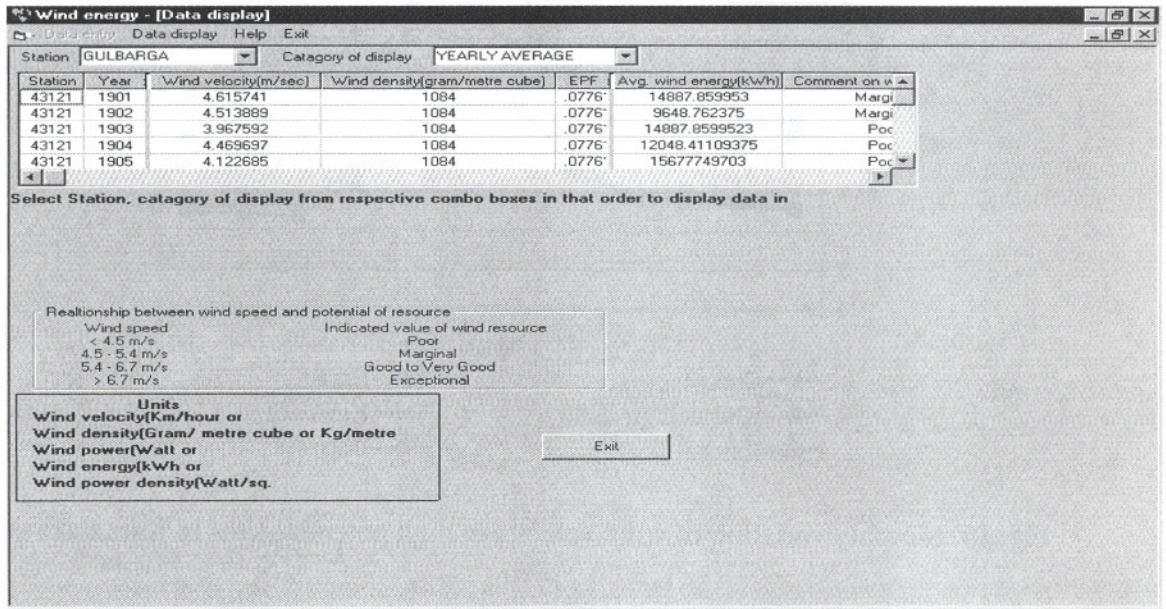| Station	Year	Wind velocity(m/sec)	Wind density(gram/metre cube)	EPF	Avg. wind energy(kWh)	Comment on w
43121	1901	4.615741	1084	.0776	14887.859953	Margi
43121	1902	4.513889	1084	.0776	9648.762375	Margi
43121	1903	3.967592	1084	.0776	14887.8599523	Poo
43121	1904	4.469697	1084	.0776	12048.41109375	Poo
43121	1905	4.122685	1084	.0776	15677749703	Poo

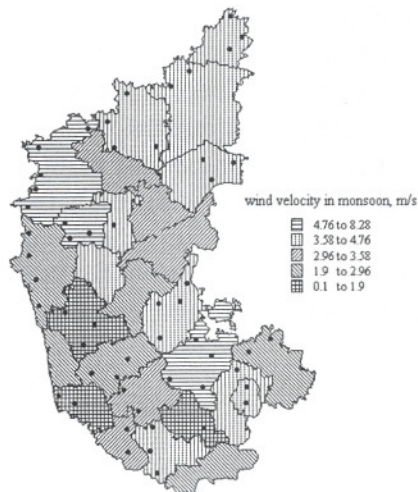Fig. 14. Display of data, station and category wise

Fig. 15. Wind potential variability during monsoon across districts in Karnataka state
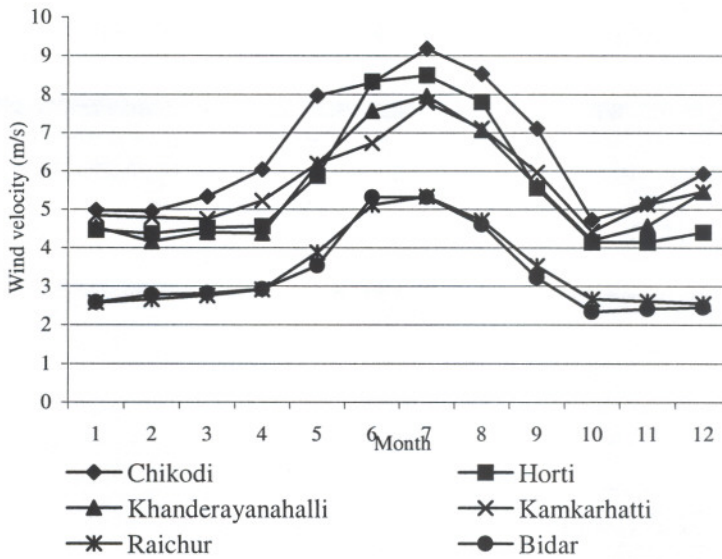
Fig. 16. Monthly variation of wind velocity at high potential sites in Karnataka state

6. 2. Wind power density

Table 2 lists locations with mean wind speed greater than 18 km per hour. Fig 16 shows monthly variation of wind velocity at high potential sites in Karnataka state. It is assumed that 2% of wastelands could be made available for harnessing wind energy (please note the extent of wasteland / barren land available district-wise in the state ranges from 15% to 45%). With this assumption, month wise wind potential has been computed at all these locations. It is found that about 0.75 to 2 MW could be generated at many locations during seasons. Human pressure on forests to meet the daily energy requirement in the form of fuel wood and fodder for domestic purposes and rural industries is quite evident from the barren hill tops in the coastal and drier belts of Karnataka. Therefore, harnessing of a renewable source like wind at feasible sites would help in the eco-development of the region. Local need for energy in a decentralized way for industrial needs, and for irrigation purposes (in the pre-monsoon period for agriculture and plantations like areca, coconut, etc.) makes the exploitation of wind energy feasible and desirable.

7. Conclusion

Human pressure on forests to meet the daily energy requirement in the form of fuel wood and fodder for domestic purposes and rural industries is quite evident from the barren hill tops of some districts of Karnataka. Therefore, harnessing of a renewable source like wind at feasible sites would help in the eco-development of the region. The exploitation of wind energy has passed the basic research stage as well as the pilot study phase and has now reached a fairly consolidated initial level of commercialization. In the future economies of scale will enable

costs to be reduced further and technological improvements to be made, thus wind energy could become more widespread on the energy market. Assessment procedures and energy planning may appear complex because of the number and diversity of the items to evaluate, the uncertainty of data. WEPA- SDSS justify its choices clearly and consistently. The availability of wind resources is quantified and characterized in this module. Local need for energy in a decentralized way for industrial needs, and for irrigation purposes (in the pre-monsoon period for agriculture and plantations like areca, coconut, etc.) makes the exploitation of wind energy feasible and desirable.

Table 2. Wind monitoring stations with annual mean wind power density (greater than 150 W/m^2)

Location	Latitude	Longitude	Wind velocity 30 m	Power density (W/m^2)
Arasinagundi	14°29'N	76°50'E	27.0	458
B.B. Hills	13°26'N	75°45'E	27.6	468
Chikodi	16°20'N	74°30'E	23.5	264
Godekere	13°20'N	76°40'E	19.9	155
Gokak	16°07'N	74°47'E	21.4	168
Gujannur	14°58'N	75°54'E	23.4	184
Hanamsagar	15°54'N	76°02'E	22.1	173
Hanumanhatti	15°55'N	74°43'E	22.1	165
Horti	17°05'N	75°40'E	20.1	173
Jogimatti	14°10'N	76°22'E	31.3	498
Jogimatti	14°11'N	76°25'E	31.0	493
Kamkarhatti	15°45'N	74°35'E	20.8	159
Khanderayanahalli	14°30'N	75°45'E	20.3	183
Madekeripura	14°13'N	76°27'E	27.1	244
Malgatti	15°52'N	75°55'E	21.9	156
Sangundi	16°15'N	75°44'E	20.4	153
Sogi A	14°55'N	75°59'E	26.6	200
Sogi B	14°54'N	75°59'E	24.5	184

Acknowledgements

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