Renewable energy mapping in Maharashtra, India using GIS

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Abstract: Increasing negative effects of fossil fuel in addition to limited stock have forced many countries to switch to environmental friendly alternatives that are renewable and can sustain the increasing energy demand. In order to tap the potential of various renewable energy sources, there is a need to assess the availability of the resources spatially. Mapping potential sites for tapping renewable energy is the focus of this study. The study employs the Geographical Information System (GIS) to map various renewable energy sources. A case study of Indian state Maharashtra has been taken. Open source software, Quantum GIS (QGIS) is used to analyze the variability of renewable energy considering the spatial aspect. Maps of installed capacity have been prepared. Solar insolation data and wind speed data available for few sites in the state are mapped and then interpolated for the entire state. A macro survey is done to estimate the renewable energy potential available in the state. Spatial interpolation has been done for micro analysis to define the usefulness of such a system.

Keywords: *renewable energy, geographical information system, spatial mapping*

1. Introduction

Energy is one of the most important inputs for economic growth and human development. The sustainability of future energy systems is critical for sustainable development. Renewable energy is a key element for any sustainable solution. One of the first steps for the exploitation of any energy source is its estimation and mapping to identify the most suitable areas in terms of energy potential. To understand the current trend of the renewable energy, it is important to analyse the spatial variation of resources and their deployment.

A Geographical Information System (GIS) is a system that can handle and process location and attribute data of spatial features. Nguyen and Pearce [1] have used an open domain approach to compute insolation including temporal and spatial variation of albedo and solar photovoltaic yield. Ramachandra and Shruthi [2] have estimated the wind energy potential of Karnataka using GIS technology. Celik [3] has estimated monthly wind energy production using Weibull representative wind data for a total of 96 months from five different locations in the world (Cardiff, Canberra, Davos, Athens, Ankara). Sen [4] has used CSV (Cumulative Semi-Variogram) approach to predict the solar irradiation at any point from a given set of known data points. This paper provides a framework for analysing the status of renewable energy situation using GIS and illustrates this for Maharashtra state of India.

Maharashtra is situated in western part of India and covers the entire Deccan region. (Area 1,19,000 square miles, population 97 million as per 2001 census [5]) There are 35 districts in Maharashtra [5]. A district is an administrative division of an Indian state or territory. Maharashtra is the largest power generating state in India with an installed capacity of 22,435 MW [6]. The total renewable energy installed capacity in the State till March 2010 was 2,601 MW [7]. Open domain Quantum GIS (QGIS) is used to represent the spatial data.

2. Methodology

The general methodology for analysis of renewable energy framework using GIS approach is summarised in Fig. 1. Distribution of renewable resources; wind and solar, in terms of wind power density and hourly insolation values respectively is spatially interpolated for the state and maps are created for the same. Current installed sites of various renewable resources, viz.

wind power generation, bagasse co-generation and small hydro power plants are identified and represented on the map. Each site is linked to its corresponding database of location and installed capacity.

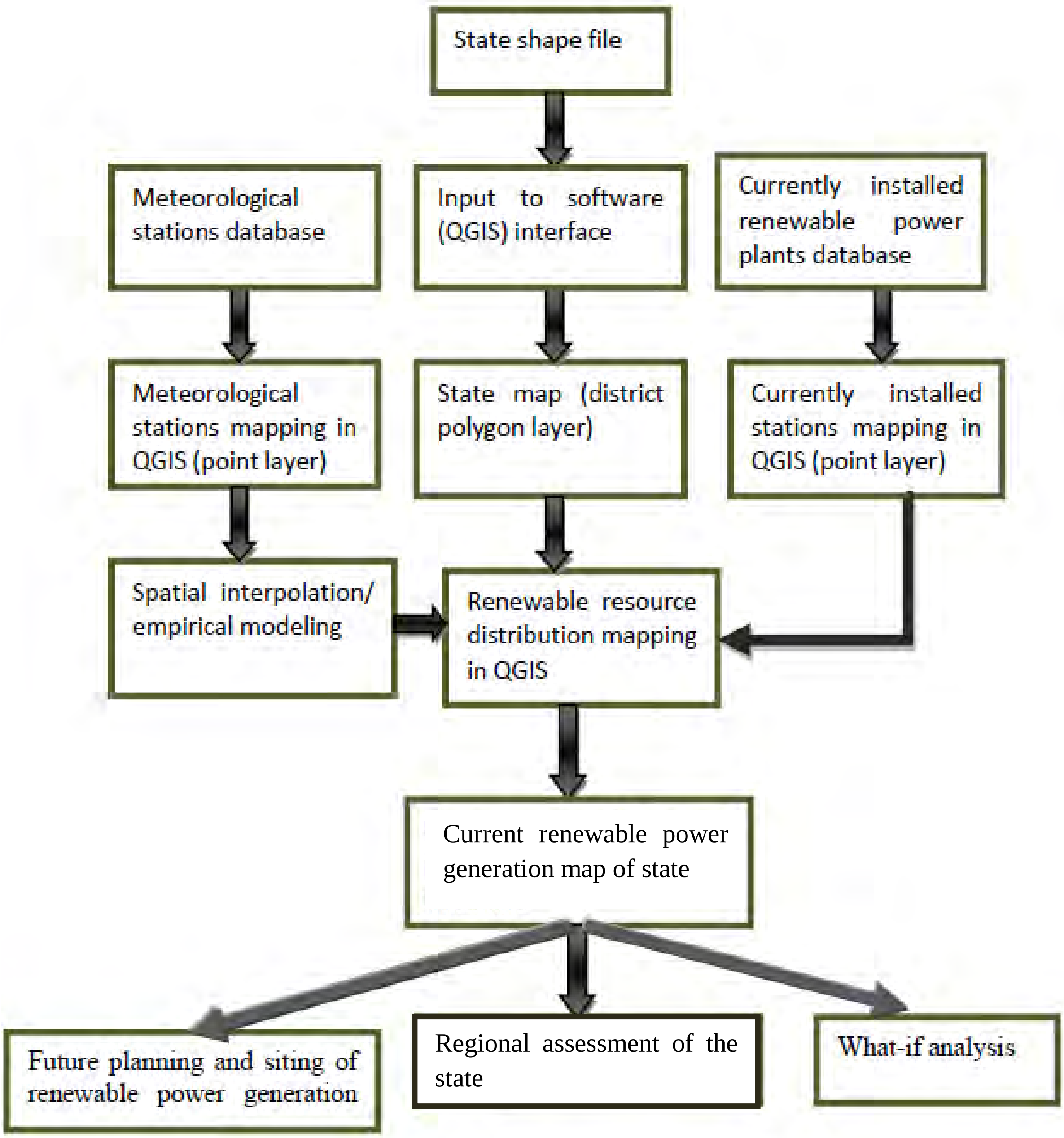

Fig. 1. General methodology to develop renewable energy framework

District shape file for Maharashtra state is taken as the first input to QGIS interface. This shape file may be created in C++ environment or may be directly downloaded. The shape file contains location attributes and area of these 35 districts. Database is obtained for currently installed renewable power generation sites, with their rated power output (MW) and location attributes. The meteorological stations for wind and solar are identified and the corresponding database of instantaneous values of parameters like wind speed, wind power density, Weibull parameters, etc. and global solar radiation are obtained. A summary of database for renewable power generation analysis in the state is organized in Table 1. Various input parameters used to create maps in reference to renewable resources and shape files are summarized in Table 2.

Table 1. Summary of database of renewable power generation in Maharashtra

Renewable energy source	Number of meteorological stations	Estimated potential (MW)	Installed capacity (GW) (2009-10+)	Number of installed power generation sites
Wind	7	4.58	2.01	31
Solar	3	-	-	-
Bagasse co-generation	-	1.25	0.35	39
Small hydro power	-	7.5	0.2	28

Table 2. Summary of input parameters used in QGIS interface

Input parameter	Information available
District shape file	35 districts; location attributes; area
Wind meteorological stations	7 stations, location attributes; hourly wind speed, hourly wind power density; Weibull parameters
Solar meteorological stations	3 stations; location attributes; hourly global, diffuse and direct solar irradiation for each month
Wind installed sites	31 sites; location attributes; installed capacity
Bagasse co generation installed sites	39 sites; location attributes; installed capacity; location of sugar factories
Small hydro power installed sites	28 sites; location attributes; installed capacity

Monthly average values of wind speed, wind power density and solar insolation for the unknown locations are predicted using interpolation techniques and empirical relations from the set of known values of meteorological stations. Predicted values are used to create raster maps in QGIS showing the distribution of wind power density and solar intensity over the state.

Currently installed renewable energy sites are mapped on the spatial layer of Maharashtra state to create point layer for each site in QGIS framework. Each point representing a renewable energy site is linked to its corresponding database of geographical coordinates and installed MW capacity. The Point layer of current installed renewable power generation sites is integrated with the resource distribution raster maps to get the current renewable scenario map for the state.

Usability of the system is defined in terms of future planning and siting of renewable power generation, micro modeling through regional assessment and district wise analysis of the state and what-if analysis to explore some major issues involved in integrating renewable energy framework with conventional electricity transmission network.

3. Renewable energy resource mapping

Distribution of wind power density and solar insolation is estimated for the state and represented as raster maps. Spatial interpolation technique, Kriging interpolation is used for predicting wind power density for unknown locations while Inverse Distance Weigthing (IDW) interpolation is used for predicting hourly solar insolation values for unknown locations.

3.1. Spatial interpolation for wind

Wind energy is the most explored renewable energy in Maharashtra. Out of an estimated potential of 4584 MW, almost 1990 MW has been achieved with an estimated capacity factor of 14% [7]. Seven meteorological stations are identified where actual measurement of various wind parameters (hourly wind velocity, Weibull parameters and average wind power density) are done. These stations are Lonavala, Malwan, Vijaydurga, Panchgani, Deogad, Vengurla and Chalkewadi. The database for the seven stations is obtained from the wind energy resource survey in India by Anna and Mani [8]. There are currently 31 wind power generation sites with their known installed capacities.

Map showing the distribution of wind power density over the state is created to aid in the selection of suitable region for wind turbine installation. Raster map showing the distribution of wind power density over the state is shown in Fig. 2. Current wind power generation sites are mapped to estimate the capacity target. The seven meteorological stations are also mapped and each station is linked to its corresponding data base of geographical coordinates and monthly instantaneous wind speed values. Quantum GIS (QGIS) is used to integrate the conventional database of the seven meteorological stations and 31 wind power generation sites with spatial features to get a complete pictorial representation of current wind power generation scenario.

Monthly average wind power density is predicted for all the districts in the state using the sampled values of seven meteorological stations. The seven stations are represented by and 31 installed sites are represented by in Fig. 2. Raster map of wind power density distribution are created using these predicted values. Kriging interpolation is used for predicting wind power density values.

This is done by generating the experimental semi-variogram of the data set and choosing a mathematical model which best approximates the shape of the function from sample Cumulative Semi Variance (CSV) values [9]. Weights are obtained by converting CSV values into dimensionless values and subtracting from the maximum value, i.e. 1. This appears as a non-increasing function of dimensionless distance and is known as Standard Weighing Function (SWF)[9]

Dimensionless distance of each un-sampled location from each of the seven sampled locations is estimated using the distance tool in QGIS. The distance values are based upon the centroid values of latitude and longitude of locations. For each dimensionless distance; the value of weighing function is estimated from the plot of SWF [9]. Weighted average of the corresponding value of wind power density, weights being the estimated values of weighing function, gives the predicted value of wind power density for unknown locations.

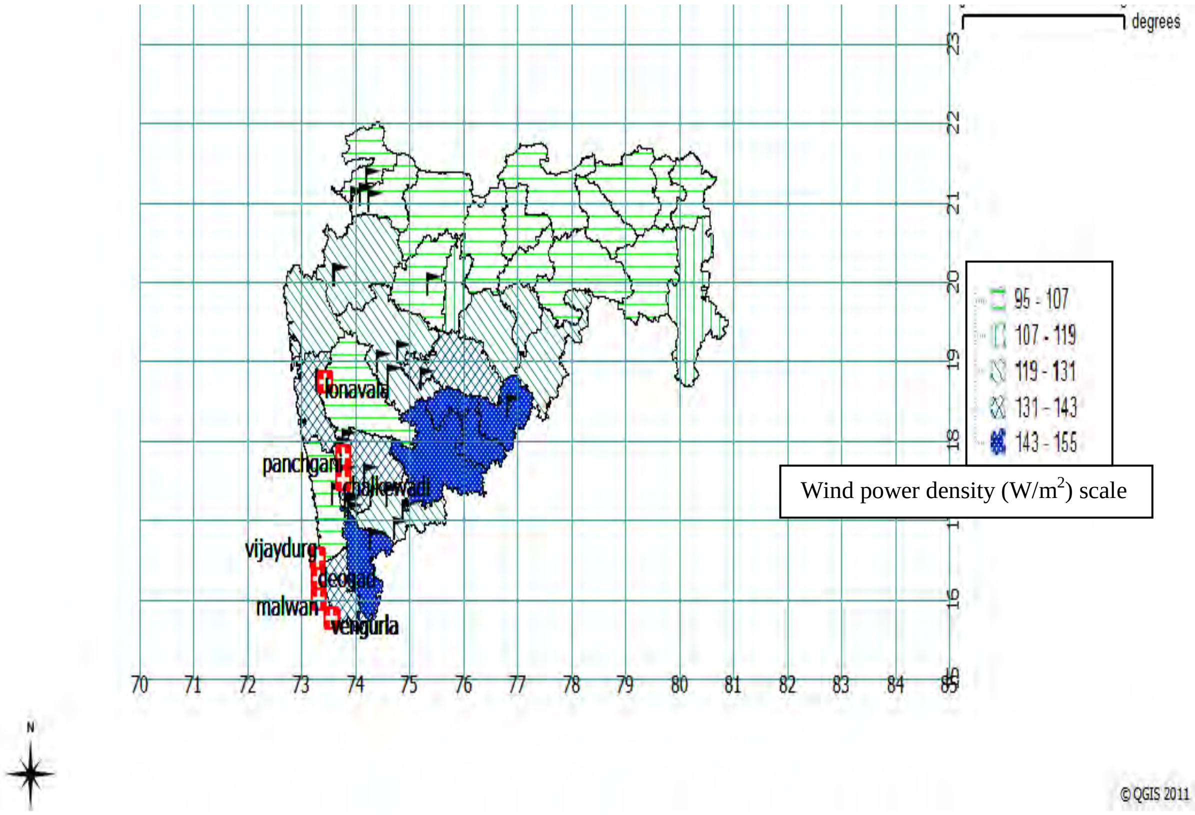

Fig. 2. Wind power density distribution over Maharashtra state

3.2. Spatial interpolation for solar resource mapping

For solar energy, three meteorological stations are identified, viz. Pune, Nagpur and Mumbai. Hourly values of global and diffuse solar radiation for the three stations are taken from solar energy resource survey in India by Anna and Mani [8]. Inverse Distance Weighting (IDW) interpolation [10] technique is used to predict hourly insolation values for un-sampled locations.

In IDW interpolation, weights are proportional to the inverse distance value between un-sampled location and sampled location. This proportionality varies with the power to which the distance is raised and is known as distance coefficient. Distance coefficient of two is taken here.

Raster map showing the distribution of solar energy resource is created using the IDW interpolation plugin in QGIS platform. Hourly global solar radiation estimated for the state are in the order of magnitude of 2000 kWh/m^{2}year which signifies a relatively low value. The variation of solar intensity over the state is also low. Variation of global solar insolation over a year for Mumbai station is shown in Fig. 3. The raster map showing the distribution of solar energy resource is not shown here although the three meteorological stations are represented by ⊞ in Fig. 4.

Since the IDW interpolation technique is based on the distance value between the un-sampled location and the sampled location, the uncertainty in the predicted value increases with the increasing distance value. The three sampled locations for solar energy are at a considerable distance from each other. Therefore using local correlations model for estimating the hourly insolation values would give better accuracy.

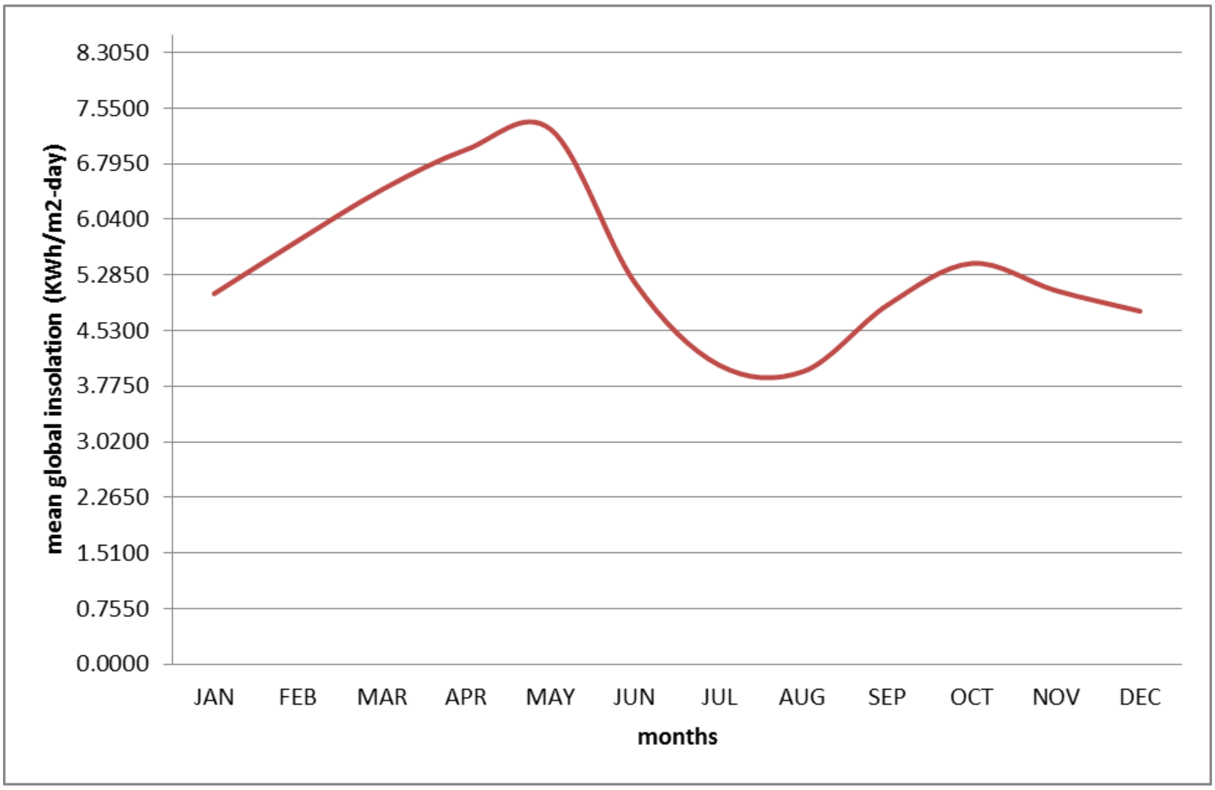

Fig. 3 Variation of global solar insolation for Mumbai

4. Renewable installed capacity mapping

In the field of green energy, the major renewable energy sources in Maharashtra are wind energy, small hydro power plants and bagasse co-generation plants with a small contribution of waste to energy power plants and biomass [6]. 31 sites of wind power generation, 39 sites of bagasse co-generation plants and 28 sites of small hydro power plants are identified and represented spatially [7]. A vector map showing the current installed sites of renewable power generation in Maharashtra is shown in Fig. 4.

Each station mapped is linked to its corresponding data base of geographical coordinates and monthly instantaneous parametric values. A complete database of hourly wind speed data of each month for seven wind meteorological stations (Lonavala, Malwan, Vijaydurga, Panchgani, Deogad, Vengurla and Chalkewadi) is linked with the corresponding location. Similarly database of hourly global solar radiation data of each month for three solar energy meteorological stations (Mumbai, Pune and Nagpur) is linked with the corresponding location. Maps are created representing the spatial data of current installed sites of wind power, bagasse co-generation and small hydro power plants (Fig. 4). Each site is linked with its corresponding database. Every district in the state is also linked to the database of district name, location attributes, i.e. longitude and latitude of the location and predicted values of monthly average wind power density, and monthly average solar insolation. One such database for Satara district in Maharashtra state is shown in Fig. 4.

Monthly average wind power density of seven wind sampled locations and monthly average solar insolation data of three solar sampled locations is used to predicts wind power density distribution and solar intensity distribution over the state respectively.

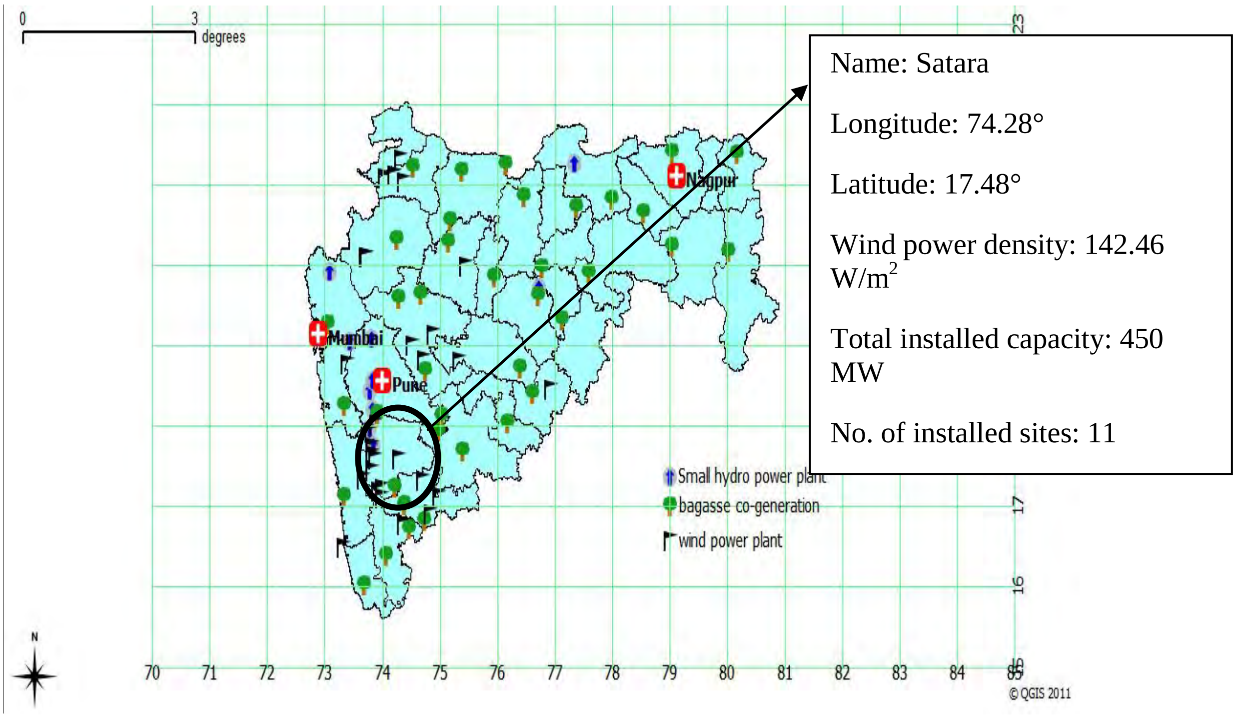

Fig. 4 Current status of major renewable power generation sources in Maharashtra and sample database for Satara district

The GIS approach used is helpful in estimating the renewable energy potential available in the state. Such a system could be useful in future planning and siting of wind power and solar power generation. It helps in analysing the potential areas where wind and solar energy resources can be used exhaustively. Regional assessment of state is also possible as can be seen from Fig. 4 that central region of the state is the major site of wind turbines installation and also the region of high wind capacity (Fig. 2). Satara district in the central region of the state is the site of maximum wind turbine installation with total installed capacity of approximately 450 MW. Eastern part of central region also has high wind potential and hence can be explored more. Similarly southern part of the state was found to be the region of high solar intensity. Bagasse co-generation power plants are distributed all over the state which is in accordance with the distribution of sugar factories in the state [11].

5. Conclusion

A framework is developed for mapping renewable energy resources using an open domain GIS (QGIS) and linking this with the databases for individual stations. Using this framework, it is possible to determine average wind and solar energy densities in selected regions. This is illustrated for Maharashtra state in India.

The QGIS platform is also used to represent the spatial distribution of installed capacities of different renewables. This permits determination of installed capacities for selected regions and renewable energy generation based on estimated capacity factors using the renewable energy resource data for the region.

The framework developed can be used to assist siting decisions. For any site selected, it is possible to determine through Kriging interpolation or empirical correlations the availability (and monthly variation) of wind and solar resource. This can enable determination of the annual capacity factor and the cost-effectiveness of new installed capacities.

Since the method is simple it will be useful, in general, for engineers, architects and solar system designers. The system is also helpful in what-if analysis: if certain percentage of electricity to be achieved through renewable only, is fixed, then what would it imply in terms of capacity of different renewable required to be installed, hybrid scenario of renewable power system, impact on conventional power system, operational and economic implications and capacity savings achieved with penetration of renewable power in the grid.

QGIS being open domain software, the framework can be extended to other states and countries as well and hence can be used extensively for renewable power generation siting and planning for any region.

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