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DEVELOPING A GEOSPATIAL BASED APPROACH TO LOCATE WIND FARMS IN POLLACHI TALUK, TAMIL NADU, INDIA

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Abstact -Selecting the location for wind farm is a complex process involving not only technical feasibility, but also physical, economic, and environmental requirements that may result in conflicting objectives. Such complexities necessitate the simultaneous use of Geographical Information System (GIS), Boolean Logic and Fuzzy logic. GIS was applied based on a set of criteria derived from the spatial aspects, physical, environment and economical.Multi-criteria evaluation (MCE) is perhaps the most fundamental of decision support operations in geospatial technology. This paper reviews two main MCE approaches employed in GIS, namely Boolean and Fuzzy logic.Aintegrated model was developed to evaluate the potential locations of wind in PollachiTaluk, Tamil Nadu. This integration could benefit investors and decision makers. The key idea of this paper is to explicate the procedure of getting a prototype GIS application to offer a scheme for supporting location decisions with regard to the carrying out of wind energy developers.

Keywords- Site selection; Wind energy; Wind farm; GIS; Multi-criteria analysis.

I. INTRODUCTION

Wind energy technologies transform the kinetic energy of the wind into useful electrical power. Wind power have been used by human since ancient times.Wind energy is renewable, inexhaustible and it generates clean and climate-friendly energy, which can cut down fossil fuel dependency [1][2].Among the renewable energy resources, wind energy has been the most popular for the investors. In India, Tamil Nadu has a very large potential for wind power. In India, Tamil Nadu has a very large potential for wind power[3].

Based on the Indian wind atlas of Centre for Wind Energy Technology (CWET), installable wind power potential has been estimated as 49 GW at 50 m above ground level with the assumption of 2% land availability[4]. Wind Atlasshows that the regions of Coimbatore district have high wind energy potential. However, CWET was not assessed the actual land available for wind energy development or wind turbine installation. Identification of potential location for wind farm is a complex problem. This study focus on the land suitability analysis to identify potential location.

The methodology consists of data preparation and then analyzing in open source Geographical Information System (GIS). The required data include different factors such as physical, economic, technical and environmental[5][6][7]. For data analysis to evaluate the potential locations, different parameters are considered , namely wind velocity, terrain slope, distance to road, railway, settlement, power line, water body and turbulence intensity. These parameters are first normalized and then processed according to multi-criteria with equal weights.

II. METHODOLOGY

The methodology of the study is explained comprehensively for the site selection procedures proposed for wind turbines. The entire process of this methodology is summarized pictorially in the flow chart in Figure 2. First, feasibility criteria for wind farm location are identified. Then, morphological features of the study area which are spatial distribution of wind energy potentials, vector data (i.e. boundaries, settlements, Lakes, Rivers, streams, roads, railways, transmission lines, etc.), and raster data (i.e. slope) are collected and processed in order to obtain spatial data layers. The next step is representation of environmental objectives as Boolean sets for vector layers and fuzzy sets for raster layers. At the end of the Multi-criteria Decision making process, an overall index for wind energy potential was calculated by raster multiplication.

A. *Study Area*

The study area lies between 10°27'14"N to 10°44'06"N latitude and 76°48'33"E and 77°10'59"E longitude (Figure 1) and runs southwest to northeast. It is part of the Coimbatore District of the Tamil Nadu state, India. PollachiTaluk covers a land area of approximately 721.7 km^2. At the 2011 census, the Taluk's population was 575478. The mean elevation is 295 m.

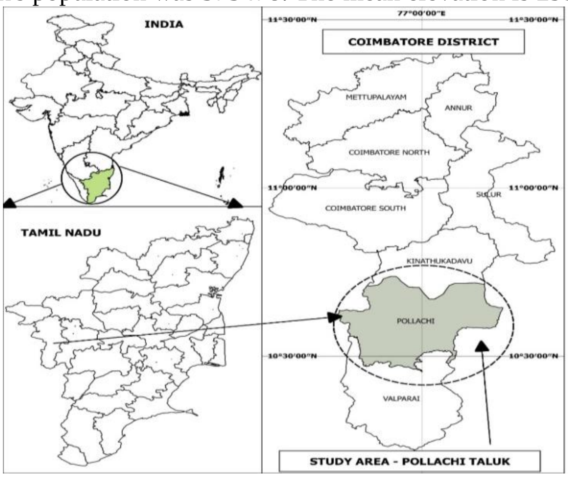

Figure 1: Position of study area in India, Tamil Nadu State, and Coimbatore District

The average elevation of the taluk is about 295 meters above mean sea level. The difference of height between the highest (554 m) and lowest elevation point (155 m) is about 399 m. The data layers of scale 1:50,000 were used in this study by considering the available spatial data in the study area.

B. *Software used*

The remote sensing and GIS software used in this study were Quantum GIS (QGIS) 2.4, System for Automated Geo-scientific Analyses (SAGA) GIS and Geographic Resources Analysis Support System (GRASS). Data processing and modeling were performed mainly with QGIS, while SAGA and GRASS were used for satellite image processing. QGIS, SAGA and GRASS are free and open source Geographic

Information System (GIS) software suite used for geospatial data management and spatial analysis, image analysis, graphical representation,spatial modeling, and visualization.

C. Data Collection and Preparation

According to constraints or criteria, the Datasets were obtained from several establishments, such as the International Renewable Energy Agency (wind speed), Survey of India (topographic sheets), and U.S. Geological Survey (satellite imagery and elevation information). The vector layers (Figure 3a and 3b) of the PollachiTaluk was digitized by using survey of India topographic sheets (Sheet Number 58B14, 58B15, 58F2 and 58F3) and updated by using Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) satellite imagery with 15 m spatial resolution[8]. The amount of electricity that can be generated by a wind turbine is directly influenced by wind velocity. Wind speed data (Figure 3c) with 3.5km resolution was collected from 'Global Atlas for renewable energy' of International Renewable Energy Agency (IRENA) web portal (http://irena.masdar.ac.ae/?map=178). Global Wind Atlas of IRENA was sponsored by 3TIER organization, and which data is the most suitable to use. The slope map (Figure 3d) was prepared by using digital elevation model (DEM) of the NASA Shuttle Radar Topographic Mission[9]. The DEM data was collected free of charge from the National Map Seamless Data Distribution System, or the USGS glovis website.

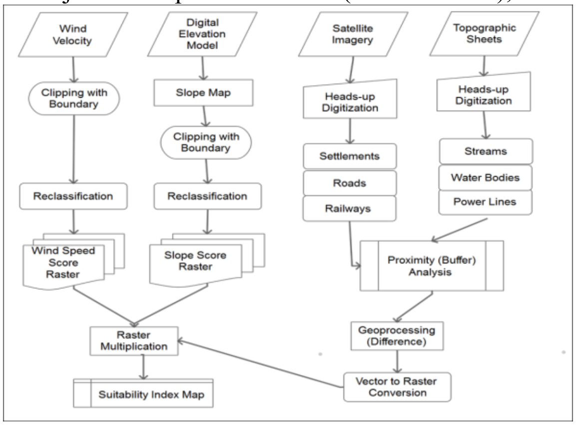

Figure 2. Comprehensive work flow-chart of the methodology

D. Identification of criteria

The developed criteria consisted of a bit of constraint factors including; wind velocity, Terrain slope, settlements, Power line access, road access, hydrography and environmental science[10]. So, these parameters were used for identifying suitable sites for wind farms in PollachiTaluk (Table 1). The constraint factors and their corresponding criteria were highlighted as being a physical, planning, environmental and economic (Table 1).Areas containing settlements were excluded because of environmental concerns such as noise that might disturb of humans. Other excluded areas are streams, lakes, and rivers.

Table 1: Criteria: excluded areas

Sl.No	Criteria	Constraints Factor	Consideration
	The Wind farm location must:		
1 2	have slope angles less than 15% [11][6][12] have a wind speed greater than 5 m/s [6][13][14]	Topography Wind Speed	Physical
3 4 5 6	not be located within 500 m of Settlements [15] not be located further than 150 m from roads [16] not be located further than 150 m from railways [16] not be located further than 200 m of Power Line [15][16]	Population Safety Safety Safety	Planning
7 8	not be located within 400 m of lakes and rivers [17][13] not be located within 30 m of Streams [18]	Hydrology Hydrology	Environmental
9 10	not be located further than 10000 m from roads [19][17] not be located further than 10000 m of Power Line [19][17]	Access Economic	Economy

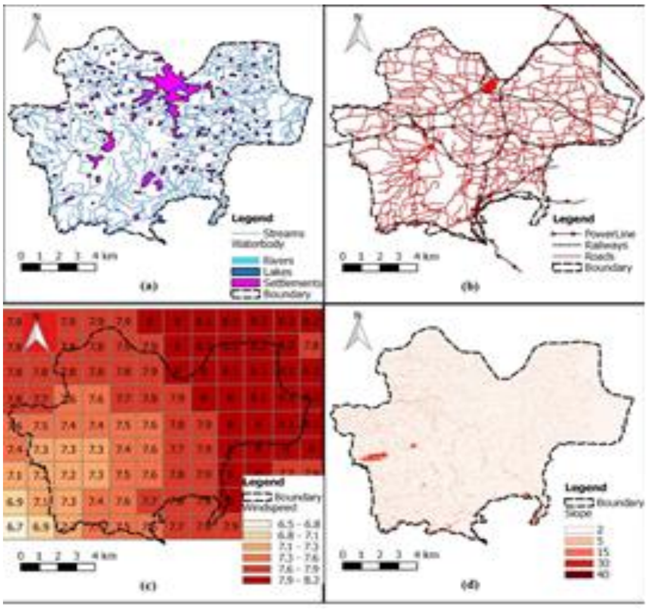

Figure 3: a. Landuse map of study area; b. Transportation and Power line map; c. Wind speed data (Speed is in m/s): d. Slope Map (slope is in percentage)

E. Boolean Logic

In the case of single-objective, a decision set contains two subsets: suitable (for allocation), and not suitable (for allocation). For that, the vector layers were geo-processed by Boolean operators (AND, OR, NOR), in order to perform such functions as, Buffer, intersection, union, difference and clip within the QGIS software environment. Buffer zones were created and the distance scores (assigned '1' for suitable and '0' not suitable) then added in the attribute table, thereby creating layers for each of the constraint criteria is shown in figure 4a, 4b and 4c. Then, the buffer layers were integrated by OR operator or UNION tool of QGIS software environment. The integrated buffer layeris shown in figure 4d. The vector suitability layer was created by NOT operator or Difference tool applied between boundary layer and integrated buffer layer. Then, the product of the Boolean operations was used to convert the resultant layer into a binary raster format of 0 (excluded) and 1 (not excluded) (Figure 5a) [20].

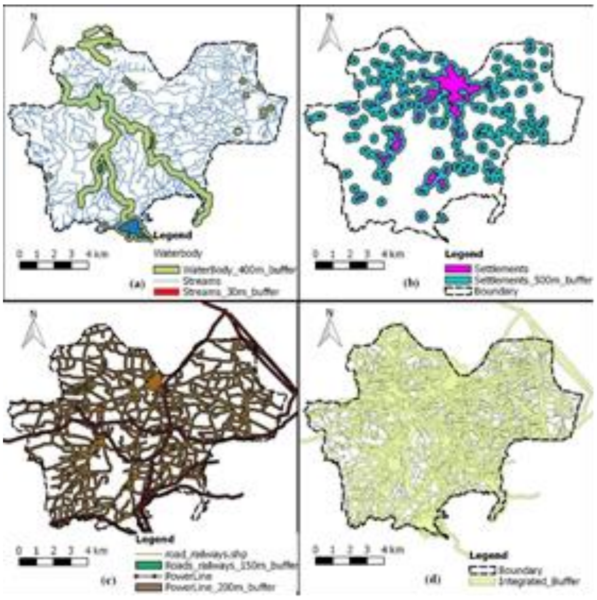

Figure 4: a. Water body Buffer Layers; b. Settlement Buffer layer; c. Transportation Buffer Layer; d. Integrated Buffer Layer.Fuzzy Logic and index overlay

A decision is then derived from an assessment of suitability, the level to which a land location belongs to the set `suitable' (in most cases, fuzzy membership in the set `not suitable' is assumed to be the complement of `suitable' set membership). In most decision making processes, Fuzzy multi-criteria are considered to assess the degree of suitability each location bears to the allocation under consideration[21]. Thus, suitability is commonly not Boolean in character (suitable or not suitable), but expresses varying degrees of set membership, i.e. a fuzzy set (not suitable, least suitable, moderately suitable, highly suitable). The latter is a special case of fuzzy sets. Given the constraints for siting a wind farm, the accuracy in finding the most and the least suitable locations is dependent on how the information from all the constraint layers is combined to produce a single index of evaluation[10] . Single Index of evaluation map was produced by combining the constraints for siting a wind farm. This can be realized by assuming that all the layers are of equal importance and therefore carry the same weight or Overall Average Weighting procedure. This is achieved by multiplying the attribute scores(Table 2), by map layer weights, on a cell by cell basis. In QGIS, this is attained using the RECLASS and RASTER CALCULATOR function of the RASTER module. In order for the resultant map to be meaningful and consistent, map weights had to add up to 100% and the attribute scores had to be chosen using a scheme that was the same for each map as shown in figure 5. Following this procedure, each of the 10 constraint maps was considered to be of equal importance.

Sl.No	Implemented layer	Criteria	Scale	
1	Slope	< 15% ≤ 15% - < 30% ≥ 30%	2 1 0	Highly suitable Moderately Suitable Not Suitable
2	Wind Speed	< 7.0 m/s[22] ≥ 7.0 m/s - < 7.5 m/s ≥ 7.5 m/s - < 8.0 m/s	1 2 3	Least Suitable Moderately Suitable Highly Suitable
3	Settlements	Distance from ≤ 500 m Distance from > 500 m	0 1	Not Suitable Highly Suitable
4	Roads	Distance from ≤ 150 m Distance from > 150 m Distance from > 10000 m	0 1 0	Not Suitable Highly Suitable Not Suitable
5	Railways	Distance from ≤ 150 m Distance from > 150 m	0 1	Not Suitable Highly Suitable
6	Transmission Lines	Distance from ≤ 200 m, Distance from >200 ≤ 10000 m Distance from > 10000 m	0 1 0	Not Suitable Highly Suitable Not Suitable
7	Lakes and Ponds	Distance from ≤ 400 m Distance from > 400 m	0 1	Not Suitable Highly Suitable
8	Streams	Distance from ≤ 30 m Distance from > 30 m	0 1	Not Suitable Highly Suitable
9	Transmission Lines	Distance from ≤ 200 m, Distance from >200 ≤ 10000 m	0 1	Not Suitable Highly Suitable

Table 2: Attribute scores for the maps used in the wind farm site selection

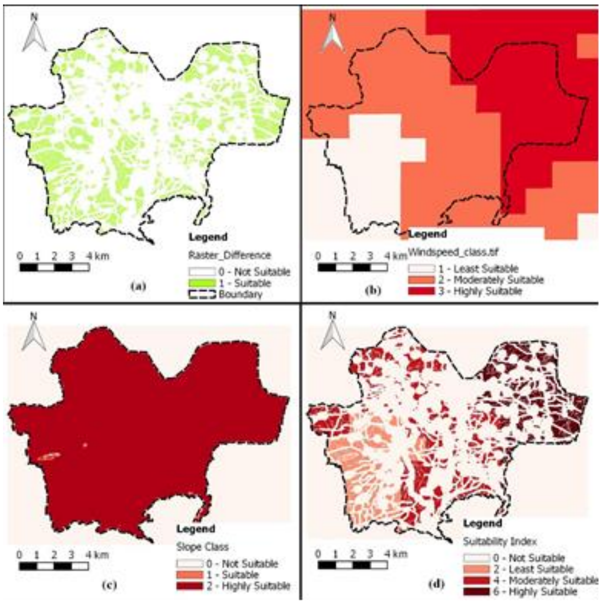

Figure 5: Suitability maps of different submodels generated for wind farm location in PollachiTaluk, Tamil Nadu, India. (a) Vector submodel and (b) Wind speed submodel c Terrain slope sub model d Suitability index map

III. RESULTS AND DISCUSSION

The nine criteria used in this study are input to the Multi-criteria decision making in the open source GIS software environment, whichcomputes the suitability index. Figure5d shows the calculation results of the land suitability index at 80mabove the ground. The results are then reclassified with equal intervals into four classes namely “not suitable,” “least suitable,” “moderately suitable” and “highly or mostly suitable” as shown in Figure 5d.The suitability index map (figure 5d) shows the varying ranges of suitability for locating a wind farm throughout the study area. The suitability scale ranges from “not suitable” (class 0) to “highly suitable” (class 3), where scores of 0 and 6 were attained respectively. The most suitable areas are occupying 8.29% of the total study area while the not suitable sites cover 71.55% of the area. It shows that most of the land of PollachiTaluk is not suitable for wind energy development. The area of “mostly suitable” lands represents 8.29% of the total country’s area (59.81 km^2) at 80 m above the ground as shown in Table 3

Table 3. Land percentage available area for different suitability classification

Score	Class	Area in sq.km	Area in percentage
0	not suitable	516.2	71.55%
2	least suitable	56.57	7.84%
4	moderately suitable	89.22	12.37%
6	highly suitable	59.81	8.29%

IV. CONCLUSION

The study established to determine the efficiency of geographic analysis tools in QGIS to identify the suitable sites for wind farm development in PollachiTaluk, Tamil Nadu. This paper adopts the concept of Boolean Logic and Fuzzy logic to Multi-criteria Decision making process. It has been demonstrated here, the standardized criteria of multi-criteria evaluation belong to the general class of fuzzy measures. Thus, consolidation of multiple criteria follows the broad approaches in fuzzy logic integration with Boolean Logic. In this study, the suitability index map will be technical support to the investors of wind farm development. This study indicates that 8.29% of the study area is identified as most suitable for wind farm establishments, 12.37 % is found to be moderately suitable and 7.84% is the least suitable while only 71.55% is permanently not suitable sites.

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