LOCATION OF SUITABLE SITES FOR WIND FARMS USING TOOLS OF SPATIAL INFORMATION

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Abstract:

The rapid increase in the global population and fast depleting reserves of fossils fuel and increasing environmental pollution have encouraged the search for alternative source of environmental friendly renewable energy. One such possible source of energy is wind. The potential of harnessing wind energy has been realized for long but due to the high cost of generating electricity, this resource was slow to receive practical acceptance. In spite of the high costs of generating power from wind, presently it is becoming the fast growing technology. To harness the energy from the wind efficiently without polluting our environment there is a need to develop methods to locate the suitable sites for wind farms. This study attempts to locate preliminary sites for wind farms by using geographic information system (GIS). The criteria for wind farm suitability have been identified. Based on the criteria, different spatial data layers such as for slope, roads, urban centers, railways, rivers water bodies and transmission lines, etc. are created. Three different approaches have been used to discriminate the suitable areas for wind farm. In the first approach it is assumed that all the maps are equally important. The second approach incorporates the criteria maps with weights assigned to individual map according to their importance. In the third approach, besides the weights of individual maps, the input maps have been divided into four classes. The output consists of classes varying from highly suitable location to not suitable sites. These maps can help the decision makers to locate the final wind farm sites.

INTRODUCTION

The demand of energy is increasing in Malaysia due to a lot of industrial growth and the change in the life style. The total projected average primary energy supply in Malaysia is about 7.2% per annum while Malaysia has to cater for the 7.8% yearly increase in final energy demand to keep pace with the economic growth in the year 2001-2005 (Jaafar et al., 2003). The domestic fossils fuel resources are limited and exhaustible. The generation of electricity using wind farm can reduce the need to use oil, gas and coal which have a lot of negative impact on our environment and are the main causes of green house effects and global warming. Unlike nuclear power, the wind power will not produce any harmful waste products for the future generation.

The government of Malaysia is encouraging the electricity generation using renewable energy resources and has set a target of 5 % from such sources (Jaafar et al., 2003). However, wind energy is not included in the list of renewable energy sources. Globally there was an increase of 31% in power generated by the wind in the year of 2001 and it has reached a level of 23,000 MW. Germany is the country which is taking the lead in generation of wind power (Carver, 2003) with 11,500 wind turbines and provides jobs to about 35,000 people in the wind power industry.

Although the wind speed in Malaysia is not very high, small or medium size wind turbines are recommended at a few places in Malaysia like Mersing (Sophian, 1995). There is a need to establish wind farm site selection criteria in Malaysia to produce economically viable energy from the wind.

The GIS has the capability to locate suitable sites for wind farms as it has the potential to manage and analyze the large amount of data from different disciplinary sources required for the wind farm siting.

Further, the availability of functions to generate scenarios which are useful to determine the effects of planning policies of the region and to find the best from amongst the various alternative options makes GIS more relevant for wind farm analysis.

The aim of this paper is to select the suitable site for wind farm using GIS as a tool and considering the various factors in order to win the support of the local people. Relevant criteria for wind farms suitability level were defined. This information was used to obtain the criteria map.

RELATED STUDIES

Geographic information systems (GIS) have been either used or their importance is highlighted more frequently for various site selection studies such as for recreational activities, residential areas, hazardous and solid waste disposal areas as well as habitat suitable areas. Siddiqui (1995) discussed spatial- analytical hierarchy (AHP) to identify and rank potential landfill areas for preliminary site assessment. He integrated the analytical environment provided by GIS and a decision-making method provided by (AHP). The habitat suitability maps were produced using GIS (Store and Kangasn, 2001). Ceballos-Silva and Lopez-Blanco (2003) presented Multi-Criteria Evaluation (MCE) approach to identify suitable areas for the production of maize and potato crops in Central Mexico. Relevant criteria for crops and suitability levels were defined, and this information was used to obtain the criteria maps. These maps were used as input to MCE algorithm.

However, GIS has not been used extensively for the selection of suitable sites for wind farm. Baban and Parry (2001) developed a GIS–assisted wind farm location criteria for the UK. Two different methods were used to combine different information layers of the criteria. In the first method all the layers were considered equally important and the second one, the layers were graded according to the perceived importance.

STUDY AREA

The study area consists of a part of Mersing in Malaysia (latitude 2° 16′ - 2° 26′, departure 103° 48′ - 103° 56′) facing the South China Sea. Average wind speed in Mersing is about 3.03 m/s which is the highest wind speed area in Malaysia. The highest wind speed frequency in the area is in south-west direction. (Bawadi et al, 2003). The land use map of the area is shown in Figure 1. The area mainly has oil palm plantation, primary forest, secondary jungles, swamp areas etc. The average elevation of the area is about 50m (Figure 2).

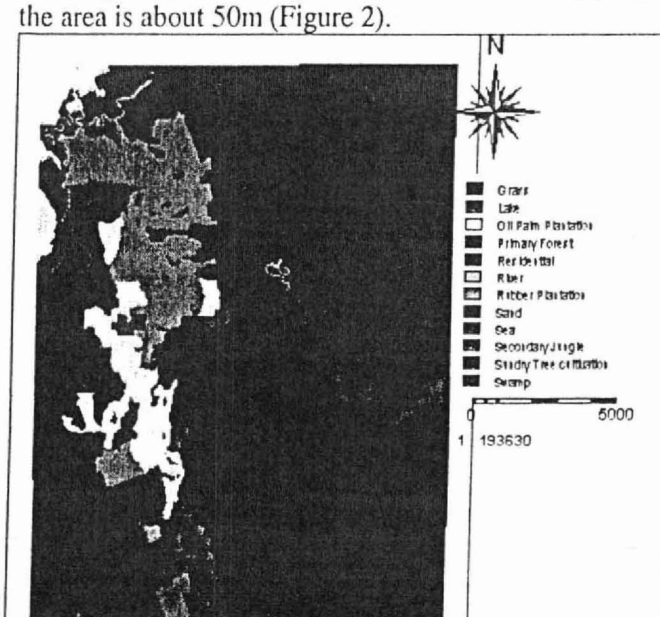

Figure 1. Landuse map of study area

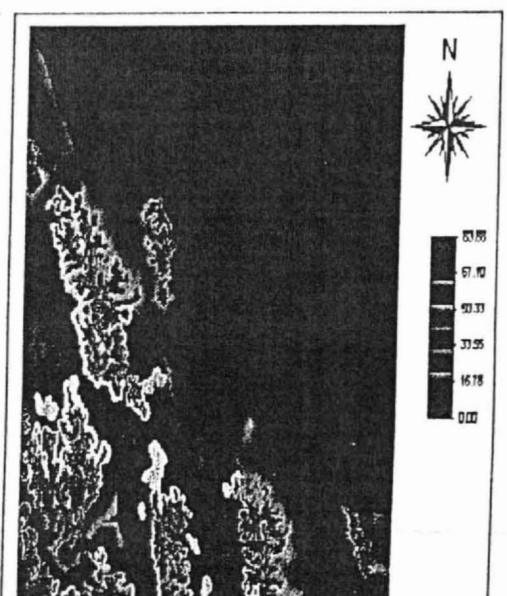

Figure2. Digital elevation model of study area

WIND FARM CRITERIA AND DATABASE

The identification of suitable sites and potential wind farm areas are essential to wind energy research and development. This must be exploited only in suitable areas from economic point of view. In this type of evaluation, many variables are involved. It is important to develop site specific criteria based on the available literature which is accepted nationally. There are a number of constraint factors which should be taken onto account. The factors that may be considered for planning of wind farms are wind speed, proximity to residential areas, noise, topography, ecology, agricultural land, conservation areas, and distance from electricity grid lines, adjacent terrain, and vegetation etc.

The study can be carried out giving equal weight to all the data layers. Since all the variables may not be equally important, they may also be weighted according to their relative importance for optimum generation of wind power.

Wind speed and the minimum distance from the residential areas are the prime factors for wind farm suitability. The safe distance from the urban controls the noise created by the turbines. It is also important to win the public support. The slope of the terrain should be less than 20%. The wind farms should be developed on suitable available sites by avoiding summits, and facing the prevailing wind directions. The average wind speed should produce the economically viable energy. The farm should be developed at a suitable distance away from the forest or from a group of high trees as these in close proximity can affect the wind speed and the direction of flow. The specific criteria used in this study are presented in Table 1.

The thematic data layers were created in GIS software ILWIS (Integrated Land and Water Information System) from the topographic map at a scale 1:50,000 to account for the criteria.

Table1. Wind Farm development Criteria

Criteria	Weight
1. Distance from large settlement should be more than 2000 m	8
2. Distance from single dwelling should be more than 500 m	5
3. Slope should be less than 10%	7
4. Top of large hills should be avoided	5
5. Distance from the roads should be less than 10,000 m	2
6. Should be located not more than 10,000 m away from the national grid	5
7. Should not be located within 400 m of water bodies	3
8. Should not be located in swamp areas	9
9. Should be located within 4000 m from the sea	8

RESULT

Simple overlaying

First of all, the vector maps have been converted to grid based raster format. After creating the various raster data layers, the individual suitable areas have been delineated for the wind farm site. Each raster cell is assigned an output score of 0 and 10 based on the criteria mentioned in Table 1. If the criterion for the suitability of wind farm site is met, the assigned output value is 10, otherwise 0. It is assumed that all the maps are equally important and therefore each map has been given equal weight.

In ILWIS it has been attained by combining the maps using Boolean logic model. For the maps to be more logical and meaningful, the map score had to add 100%. To achieve this each map was assigned a weight of 11.11% and then they were combined. The pixel score of the output map was equal to the total of the corresponding pixel scores from each of the input map. The highly suitable areas for wind farm have been shown in Figure 3.

Overlaying with weighted maps

However, all the maps may not be of equal importance for selecting the suitable site for the wind farm. For example, the criteria of distance from the main settlement, is more important than the distance from the roads in determining the suitability for a Wind farm. It is better to have a different method in which the weight can be assigned proportional to the importance of each criterion.

This type of analysis can be carried out using method of index overlaying. In this method, different weights are assigned to different maps depending upon the importance of the pattern to the model under consideration. All the binary maps are multiplied by their weight factors; a combined map is obtained by summing up all the maps and normalized by the sum of the weights. The score at any pixel of output image is given by

$$\bar{s} = \frac{\sum_{i=1}^{n} w_i (CLmap)_i}{\sum_{i=1}^{n} w_i}$$

where w_i is the weight of the i^{th} map, and *CLmap* is either 10 or 0 for presence or absence of binary condition. The output score p is between 0 (extremely unsuitable) to 10 (highly suitable). The map in Figure 4 shows the highly suitable areas for wind farm siting using this method.

Index overlay with Multi-class Maps

In this approach the various map classes are assigned different scores and the maps are also assigned the weights as in the second approach. The classes of each input maps have been given in Table 2. Depending upon the importance of each class, the scores have been assigned (Table 3) from 0 (totally unsuitable to 10 (very suitable). The individual class maps have been created using these scores. For example, some of these classified maps for national grid, single dwelling, sea, slope, urban area, water bodies have been shown in figures 5-10.

The weighted score of the output image were computed as:

$$\bar{s} = \frac{\sum_{i=1}^{n} w_i S_{ij}}{\sum_{i=1}^{n} w_i}$$

where w_i is the weight of the i^{th} input map, and S_{ij} is the score for the j^{th} class of the i^{th} input map. The value of j depends on the type of class at the current location.

The wind farm suitability map has been shown in Figure 11. It was classified in three categories, namely, highly suitable, suitable and not suitable.

Table 2. Classes of criteria maps

	Class I	Class II	Class III	Class IV
Settlement	0-3000 m	3000-6000m	6000-9000 m	>9000m
Single dwellings	>2000 m	1000-2000 m	500-1000 m	0-500
Slope (%)	0-20	20-30	30-40	>40
Hill (elevation)	0-20 m	20-40 m	40-60 m	>60 m
Roads	100-500 m	500-1000 m	1000-5000 m	>5000 m
National grid				
Water bodies	0-100 m	100-300 m	300-500 m	>500 m
Sea	0-2000 m	2000-4000 m	4000-6000 m	>6000 m

Table3. Scores assigned to individual classes

	Class I	Class II	Class III	Class IV
Settlement	10	5	3	0
Single dwellings	10	7	3	0
Slope (%)	10	7	5	0
Hill (elevation)	10	7	5	1
Roads	10	7	5	3
National grid	10	7	5	3
Water bodies	10	7	5	3
Sea	10	7	5	3

Summary

The highly suitable site map for wind farm by assigning same weights satisfying the criteria mentioned in Table 1 has been depicted in Figure 3. While figure 4 shows the highly suitable areas using the second approach in which the weights were assigned to the data layers depending upon their importance. The comparison of areas of the two output suitability maps shows that there is no significant changes in the areas of the highly suitable sites. The wind farm suitability map (Figure 11) based on index overlay with multi-class map has been classified in three categories, highly suitable, suitable and not suitable areas.

The highly suitable areas are near the sea where the slope is less than 20%. The spatial patterns on the suitability map show the influence of urban areas, single dwellings and the electric grid lines. The suitability maps created based on using assigning different weights and with multi-class maps are not very much different from the first one and show the similar patterns from all aspects discussed above.

GIS can help the wind farm developers, landuse planners and politicians for selecting the suitable sites. For this purpose, the systems have been developed within ILWIS which illustrates the potential of the analytical tools. However, the study is still in its infancy with respect to producing optimal solutions. Since the study of wind farm site selection is quite subjective, a decision support system should be integrated to achieve better results. The various maps which are developed here along with the suitability map can help the decision makers in final selection of the wind farm location and to carry out the detailed analysis for the performance of the wind turbines.

Figure 3. Highly suitable wind farm sites by simple overlaying

Figure 4. Highly suitable wind farm sites by assigning different weights to individual maps

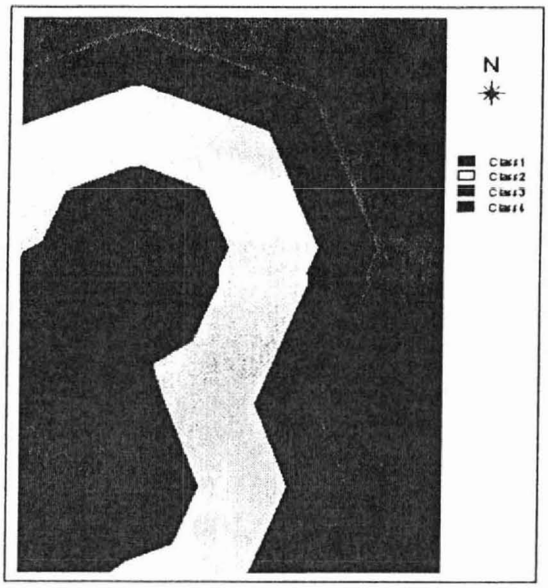

Figure 5. Classes of distance from national grid

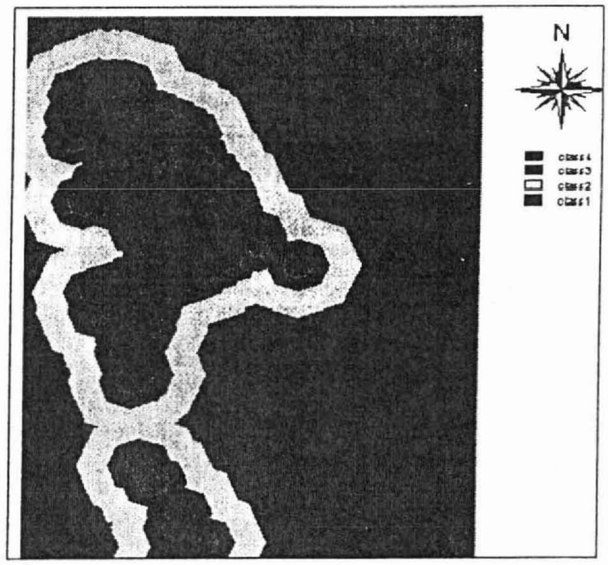

Figure 6. Classes of distance from single dwelling

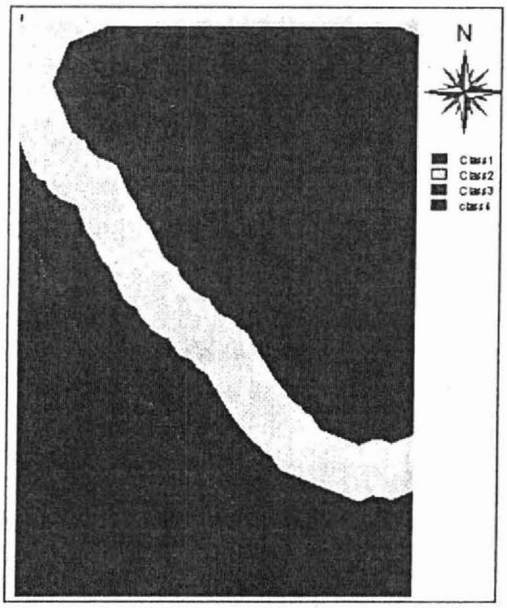

Figure 7. Classes of distance from the sea

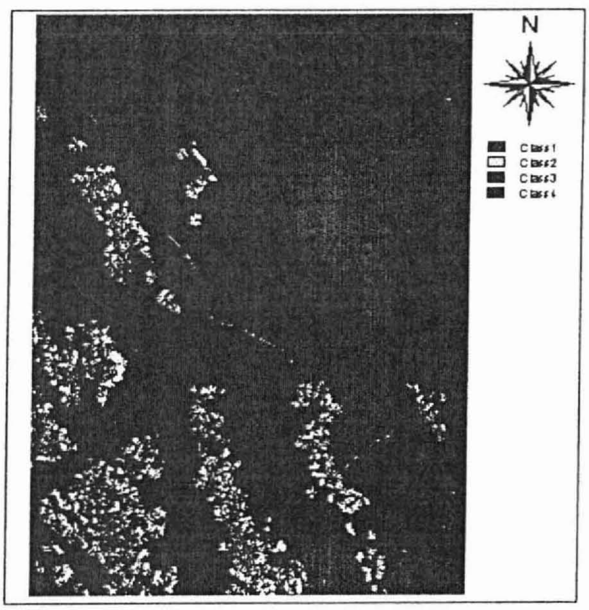

Figure 8. Slope classified Map

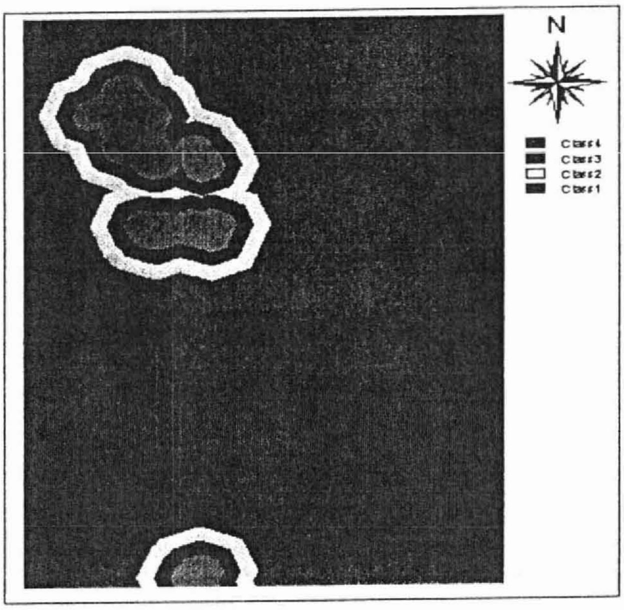

Figure 9. Classes of distance from urban areas

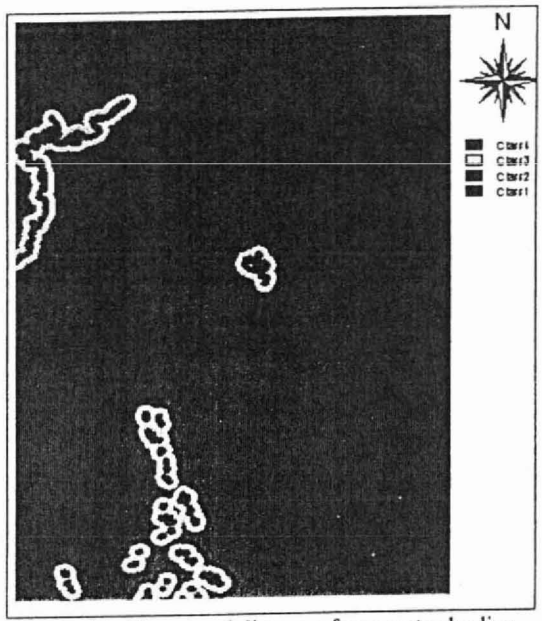

Figure 10. Classes of distance from water bodies

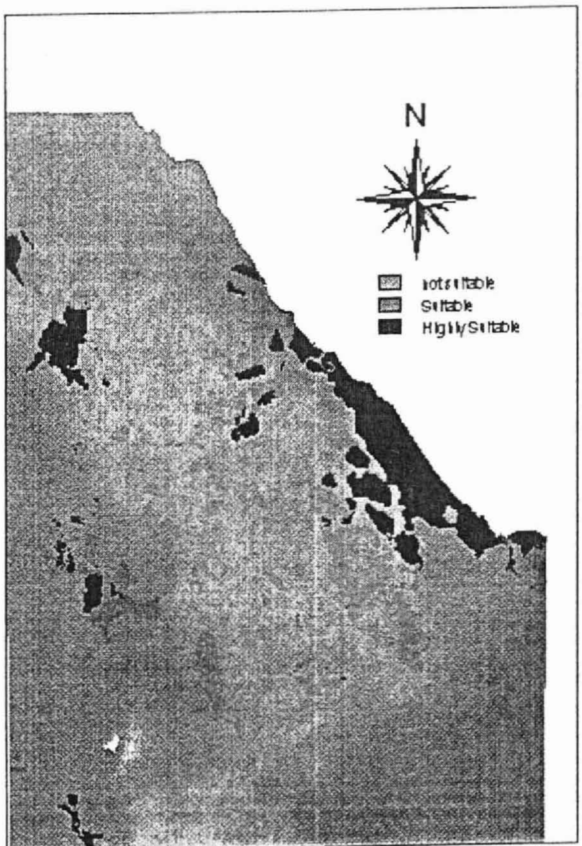

Figure 11: Wind arm site selection suitability map by Index overlay with multi-class maps

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