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Wind farm suitability analysis using Geographic Information System with Best-Worst Method in Amhara region of Ethiopia

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Abstract

The analysis of suitability for wind farms is important not only for finding a suitable wind potential site for energy production but also for a sustainable land use planning, environmental management and protection. The objective of this study was to identify a suitable locations for wind farms using the Geographic Information System (GIS) with Best-Worst Method (BWM). Eight criteria were used, and BWM was implemented to calculate the criteria weights. The wind speed was chosen as the most important criterion for locating wind farms, followed by slope, Power grid lines, land cover, aspect, airports, main roads, and protected areas. The suitability map of the wind farm was presented using Weighted Overlay analysis in a GIS environment. The findings indicate that the eastern and western parts of the Amhara region have good potential for generating renewable energy from the wind. The result is presented with a scale of 0 to 5 to represent the degree of suitability such as unsuitable, very low, low, moderate, high, and very high potential for wind farms.

1. Introduction

The development of renewable energy in the world is increasing as a result of population growth and industrialization (Adams, Klobodu, & Apio, 2018; DLA PIPER, 2021).

Ethiopia is one of the fastest-growing countries in the eastern part of Africa, and its' energy demand is increasing at an alarming rate due to the fast-growing economy and flourishing infrastructures. Despite the fact that Ethiopia has an enormous amount of renewable energy resources such as solar, hydro, wind, and geothermal, only a few amounts of its total hydropower potential is now utilized. As a result, traditional fuels (charcoal, fuel wood, dung cakes, and agricultural residues) account for the majority of energy consumption in the rural parts of Ethiopia, which brings significant health and environmental risks (Tiruye et al., 2021). It has a renewable energy potential of up to 45,000 MW from hydropower, 10,000 MW from wind, 5000 MW from geothermal, and an average of 5.26 kWh per square meter per day from solar energy that has yet to be completely exploited (Asress, Simonovic, Komarov, & Stupar, 2013).

Exploiting renewable energy alternatives boosts energy supply by shifting away from the usage of fossil fuels to fill the gap in electricity consumption in rural and urban areas. Renewable energy sources such as wind and solar produce little to no global warming emissions, reducing the use of fossil fuels and their adverse environmental effects. As a result, it is a viable option for generating electricity. Wind turbines and farms, have a variety of environmental and societal implications that must be properly investigated and evaluated (Kotb, Elkadeem, Elmorshedy, & Dán, 2020; Nasery, Matci, & Avdan, 2021).

A Combination of Geographic Information System (GIS) and Multi-criteria Decision Making (MCDM) can help as a decision support tool to identify the most suitable places for wind. MCDM such as Best-Worst Method (BWM) approaches attempt to evaluate several criteria simultaneously and provide an optimal solution (Ecer, 2021; Tercan, 2021).

The objective of the study is to identify a suitable locations for the wind farms using GIS with BWM in the Amhara region of Ethiopia.

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2. Method

In this study, the data such as wind speed, DEM, Land cover, administrative boundary, power grid line and protected areas were downloaded from different sources as indicated in Table 1.

Table 1. Data and sources

Data	Sources
Wind speed	https://globalwindatlas)
Digital Elevation Model (DEM)	https://earthexplorer.usgs.gov/
Land cover	https://livingatlas.arcgis.com/landcover/
Administrative boundaries	https://ethiopia.africageoportal.com/
Power grid lines	https://energydata.info/
Protected Areas	https://data.apps.fao.org/

The database was constructed and the data downloaded from different sources were organized and managed in the GIS environment. Extraction of all the parametrical data within the intended area of interest, buffering, resampling, rasterization, surface analysis, reclassification at a given scale, and weighted overlay analysis were done to identify suitable wind farms location. In this study, the general workflow is illustrated in Figure 1.

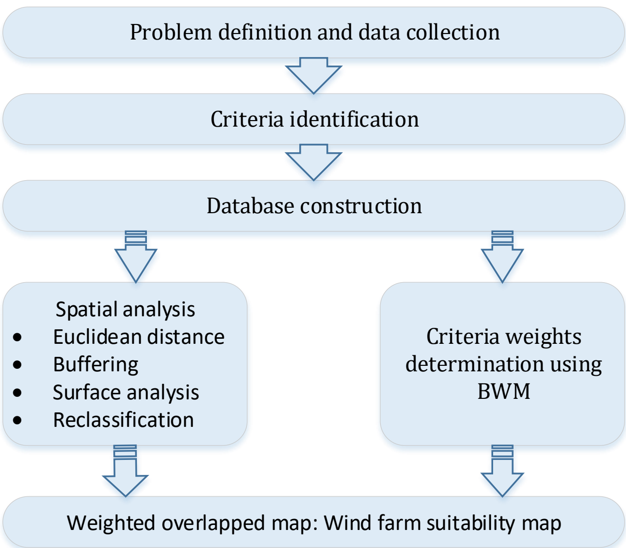

Figure 1. General workflow of the study

2.1. Location of the study area

The study was conducted in the Amhara region in the northern part of Ethiopia Figure 2. The region is dominated by a chain of mountains, hills, and valleys ranging in elevation from 505 to 4529 meters above MSL (Abera & Abegaz, 2020) and has more than 6.8 m/s wind speed; Such geographical characteristics are suitable places for energy development from the wind.

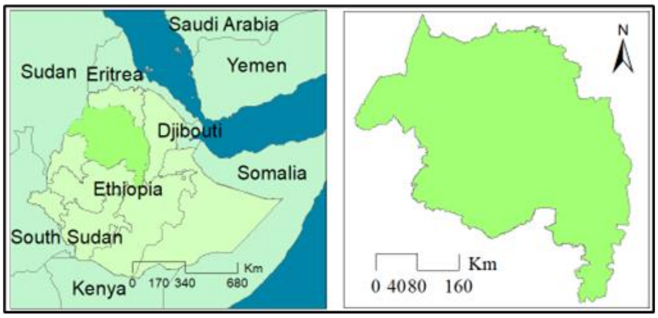

Figure 2. Location of the study area

2.2. Criteria Determination

The criteria for wind farm suitability analysis were determined based on recent literature (Ayodele, Ogunjuyigbe, Odigie, & Munda, 2018; Nasery et al., 2021; Pamucar, Gigovic, Bajic, & Janoševic, 2017; Szurek, Blachowski, & Nowacka, 2014; Tercan, 2021; Xu et al., 2020; Zalhaf et al., 2022) and considering opinions of experts who dealt with similar problems. Based on literature and experts opinions eight criteria were determined and categorized as unsuitable, very low, low, moderate, high and very high as described in Table 2.

Vector and raster datasets were clipped and masked with the area of interest respectively. Multi-buffer and Euclidean distance were used for proximity analysis. Based on the scale mentioned for each criterion in Table 2, the criteria were reclassified and criteria reclassified maps were produced. The reclassified maps of the criteria are shown in Figure 3.

2.3. Determination of weight of the Criteria

Many criteria affect the location of a suitable wind farms. However, each has a different weight that has significant to determine a suitable location for the wind farm. In this study, BWM has been used to determine the weights of criteria. In multi-criteria decision-making (MCDM) problems, BWM is one of the most successful approaches for determining the weights of criteria (Rezaei, 2016). The expert first determines the best (e.g., most desirable, most important) and worst (e.g., least desirable, least important) criteria, then compares the best criterion to the other criteria, and the other criteria to the worst criterion. The weights of the criteria can be computed using equation (1).

Min ξ^L such that

$$\begin{gathered} \left|W_B - a_{Bj}W_j\right| \le \xi^L, for\ all\ j \\ \left|W_j - a_{jW}W_W\right| \le \xi^L, for\ all\ j \\ \textstyle\sum_j W_j = 1 \\ W_j \ge 0, for\ all\ j \end{gathered} \tag{1}$$

Where,

a_{Bj}: preference for the best criterion over criterion j

a_{jW}: preference for criterion j over the worst criterion

Table 2. Selected criteria and description

Criterion	Description
Wind speed	One of the most important criteria for wind farming. The higher the wind speed the higher the wind power. Suitability categories; <3m/s (unsuitable), 3-4m/s (very low), 4-5m/s (low), 5-6m/s (moderate), 6 -7m/s (high) and >7m/s (very high).
Slope	Wind farm construction, maintenance and installation are affected by the high slope. The higher the slope the higher cost of construction, and maintenance of wind farms. Suitability categories; >15% (Unsuitable), 12-15% (very low), 9-12% (low), 6-9% (moderate), 3-6% (high) and 0-3% (very high).
Aspect	Slope orientation relative to the direction of the wind is an important criterion when it comes to making full use of the wind potential. Suitability categories; low (E,SE), moderate (N,NE,S,SW), and very high (W,NW,FLAT).
Landcover	Land cover is one of the critical factors for wind farm suitability analysis. Suitability categories; Water, crops, built-up area, cloud cover, and Trees as unsuitable, Flooded vegetation as moderate, Rangeland as high, and Bare ground as very high.
Power grid lines	Wind farms closed to power grid lines reduce the construction of new power grid lines. However, it has a negative effect on human health due to the electromagnetic field generated by power transmission lines. Suitability categories; <0.5km (unsuitable), 60-90km (very low), 30-60 (low), 10-30km (moderate), 5-10km (high) and 0.5-5km (very high).
Airports	Wind farm closed to airports affects aviation routes, communication system and navigations, which leads to collisions. suitability categories; <3km (unsuitable), 50–100km (very low), 20–50km (low), 10–20km (moderate), 5–10km (high), and 3–5 (very high).
Protected areas	Wind turbine noise and rotating blades influence animals' and birds' habitats. Suitability categories; <2000 (unsuitable) and >2000 (very suitable).
Main roads	Wind farms distance from the main roads has a positive and negative effect. Wind farms closed to the main roads reduce transportation cost during construction, and reduce the cost of construction and maintenance of new roads. Whereas the wind farm is closed to the main roads, the roads negatively affect road transportation because of loud noises. Categories; <3km (unsuitable), 50–100km (very low), 20–50km (low), 10–20 (moderate), 5–10km (high), and 3–5km (very high).

The weights and consistency of the criteria were computed using the BWM-Solver tool of Excel. The consistency ratio of decision-making ranges between 0 and 1; completely consistent and completely inconsistent respectively. In this study, the value for high consistency is expected to be less than or equal to 0.41. The consistency ratio of four experts while computing the weights of criteria was 0.047, 0.081, 0.146, and 0.066; which indicate the consistency ratio within the prescribed acceptance limit. During the implementation of BWM, the Best criterion was wind for all experts. However, the worst criterion was different; expert 1 selects the main roads, expert 2 and 3 select the protected areas, and expert 4 selects the airports as worst criteria. Based on the average weight of the criteria wind speed and protected areas were the best and the worst criteria respectively. Calculated weights of criteria by four experts as shown in Table 2.

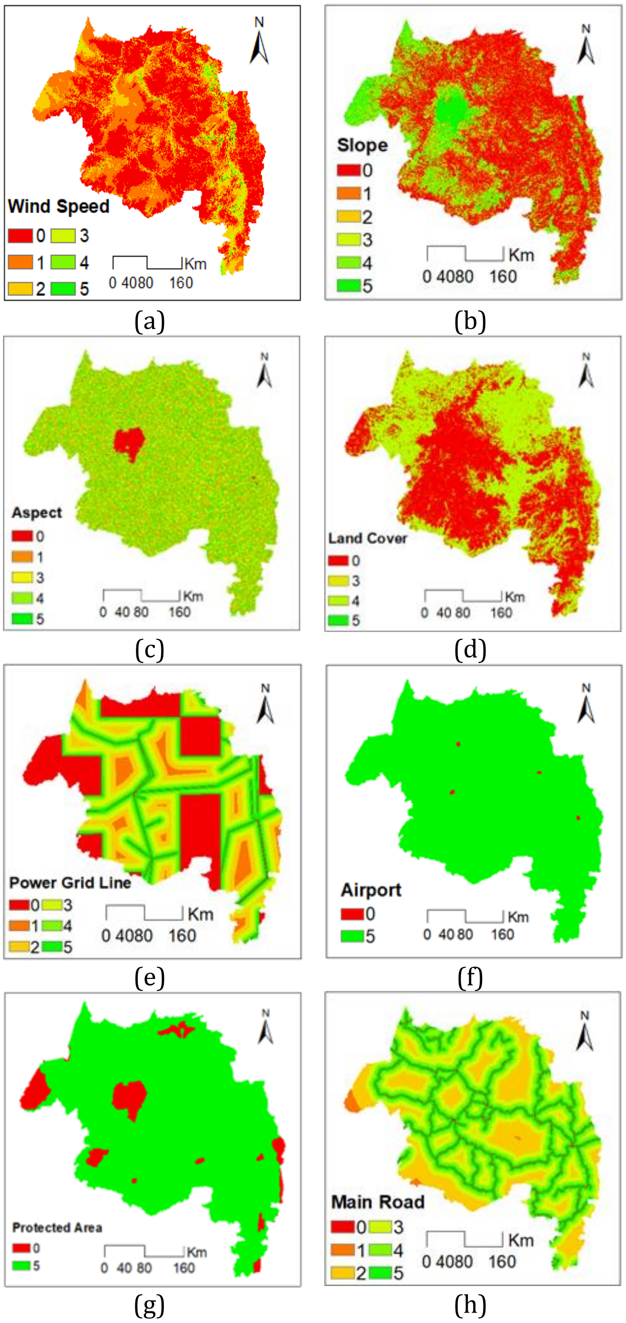

Figure 3. Criteria reclassified maps; (**a**) wind speed (**b**) slope (**c**) Aspect (**d**) land cover (**e**) power grid lines (**f**) airports (**g**) protected areas and (**h**) main roads

3. Result and Discussion

In this study, the wind speed was identified as the most important criteria for locating wind farms followed by slope, power grid lines, land cover, aspect, airports, main roads, and protected areas. The wind farm suitability map was produced based on eight criteria using a weight overlay analysis. Figure 4 shows the wind farm suitability map produced using GIS with BWM.

Table 2 Determined weight of criteria

Criterion	Exp.1	Exp.2	Exp.3	Exp.4	Average
Wind speed	0.314	0.340	0.389	0.332	0.344
Slope	0.180	0.141	0.041	0.199	0.140
Aspect	0.120	0.105	0.059	0.133	0.104
Land cover	0.120	0.105	0.107	0.100	0.108
Power grid lines	0.090	0.105	0.178	0.080	0.113
Airports	0.090	0.105	0.107	0.033	0.084
Protection area	0.052	0.037	0.059	0.057	0.051
Main roads	0.033	0.060	0.059	0.066	0.055
Total	1.000	1.000	1.000	1.000	1.000

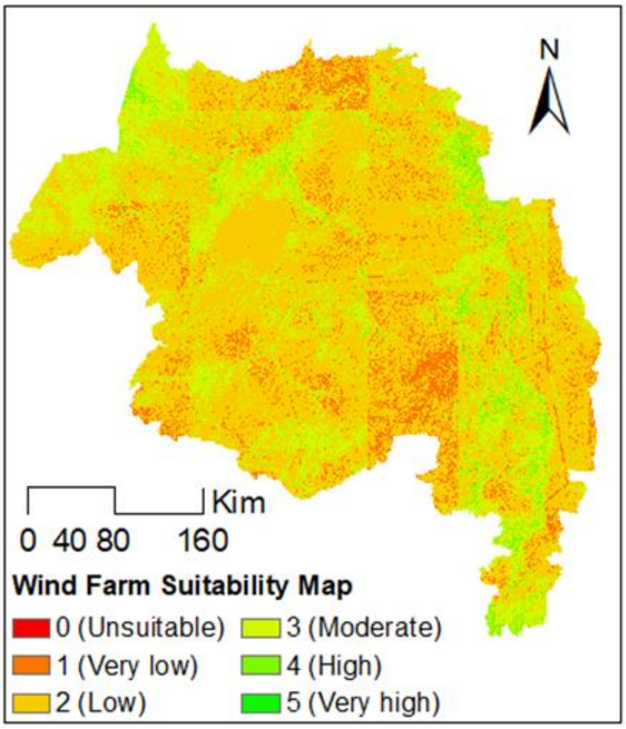

Figure 4. Wind farm suitability map

The generated wind farm suitability map using weighted overlay analysis is represented in the same value range (0 to 5) as the input reclassified criteria maps. The larger the values the more suitable the area for the location of the wind farm. The value for the criteria attributes which was considered as a constraint was 0.

In the result, the most suitable locations have been identified and presented on a suitability map. Areas that have pixel value equal to 5 (very high), 4 (high), 3 (moderate), 2 (low), 1 (very low), and 0 (unsuitable). The suitable area for the wind farms is located in the eastern and western parts of the Amhara region.

4. Conclusion

The GIS-based wind farm suitability analysis model with BWM was developed and used to analyze the suitability of wind farm locations in the Amhara region by taking into account multiple criteria. The suitability analysis was based on eight criteria; wind speed, proximity to power grid lines, slope, aspect, land cover, protected areas, airports, and proximity to main roads. Experts' opinions were used to determine the weight of the criteria. The study shows that BWM can be used in combination with GIS to determine the best location for wind farm development. In addition, the result of wind farm suitability analysis can be helpful for decision-makers during sustainable land use planning, environmental management and protection.

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