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Site selection for wind farms using geographic information system with best-worst method: A case study Amhara Region of Ethiopia

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Abstract

Finding a wind potential site that is ideal for energy production and planning for sustainable land use, environmental management, and protection all depend on the analysis of suitability for wind farms. This study's objective was to locate potential sites for wind farms using a Geographic Information System (GIS) and the Best-Worst Method (BWM). In order to determine the weights of the eight criteria, BWM was utilized. The most crucial factor in choosing where to put wind farms was determined to be wind speed, which was then followed by slope, power grid lines, land cover, aspect, airports, major roads, and protected regions. Weighted Overlay analysis in a GIS environment was used to illustrate the wind farm's suitability map. According to the study, the Amhara region's eastern and western regions have good potential for producing wind-based renewable energy. The suitability of the area for wind farms is indicated on a scale of 0 to 5 as unsuitable, very low, low, moderate, high, and very high potential.

1. Introduction

Energy is a crucial component of developing countries' plans for economic development since it contributes significantly to national advancement, increased competitiveness, and societal welfare [1]. The energy supply policies of several nations throughout the world have undergone fundamental changes as a result of the demand for adequate, secure, continuous, and clean energy. The development of renewable energy in the world is increasing as a result of population growth and industrialization [2, 3].

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. Even though Ethiopia has a vast amount of renewable energy sources, including solar, hydro, wind, and geothermal, only a small amount of its potential hydropower is now used. Because of this, traditional fuels including charcoal, fuel wood, dung cakes, and agricultural waste are the majority of the energy used in Ethiopia's rural areas, which provides significant health and environmental risks [4]. Up to 45,000 MW of hydropower, 10,000 MW of wind, 5000 MW of geothermal, and an average of 5.26 kWh per square meter per day of solar energy that hasn't yet been fully utilized make up its renewable energy potential [5].

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. Wind turbines create energy without emitting any pollutants, in contrast to conventional energy sources (i.e., coal, gas, and petroleum-based fuel). As a result, emissions especially those of carbon dioxide, nitrogen oxide, and sulfur dioxide can be reduce. Wind turbines have a variety of environmental and societal impacts such as sound noise to the vicinity, wildlife mortality from collision of wind turbines, habitat disruption and displacement that must be properly investigated and evaluated [6, 7].

Since wind energy is clean, renewable, and has no influence on people or the environment, it is one of the newest and fastest-developing renewable energy sources [7, 8]. Additionally, wind turbines are simple to build and have low operating and maintenance expenses. There are a variety of aspects that must be taken into account while developing wind energy projects [9]. Finding a good investment location for a wind power plant (WPP) is important, taking into account the preliminary evaluation for economic, technical, environmental, and land-use implementation circumstances [10].

The best locations for wind can be identified using a combination of a GIS and multi-criteria decision-making (MCDM). In order to manage the decision-making process in accordance with criteria, MCDM techniques focus on an analysis process that enhances the decision benefit of the decision maker by choosing the most important criteria among competing alternatives [11]. MCDM can be implemented using a variety of techniques, some of which can be combined with the GIS environment, including the rating method, weighted sum method (WSM), ranking method, analytical hierarchy process (AHP), weighted linear combination (WLC), Boolean overlay operation, analytic network process (ANP), trade-off analysis method, trade-off analysis method, Order Weighted Average (OWA), and Technique for Order Preference by Similar to Ideal Solution (TOPSIS), Best-Worst Method (BWM) [12]. BWM approaches attempt to evaluate several criteria simultaneously and provide an optimal solution [13, 14]. Different real-world problem-solving researches in different research themes have been used BWM for criteria weight evaluation such as Land valuation, transportation, communication and tourism [15-17].

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

2. Material and 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 to organize and manage the data downloaded from multiple sources 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, weight of each criterion was determined by using multicriteria decision making method (Best-Worst Method) and weighted overlay analysis were done to identify suitable wind farm's location. In this study, the general workflow is illustrated in Figure 1.

2.1. Study area

The study was conducted in the Amhara region in the northern part of Ethiopia, shown in Figure 2. The region is dominated by a chain of mountains, hills, and valleys ranging in elevation from 505 to 4529 meters above MSL [18] and has more than 6.8 m/s wind speed; Such geographical characteristics are suitable places for energy development from the wind.

2.2. Determination of the criteria for suitable site selection

The low production, operation, and maintenance costs of wind energy, as well as its relatively low environmental impact, make it one of the most alluring sustainable energy sources. Finding the ideal locations to build wind power plants is a challenging process that requires careful consideration of a number of criteria.

The criteria for wind farm suitability analysis were determined based on recent literature [6, 12, 13, 19-22] and considering opinions of experts who dealt with similar problems. Based on literature and experts' opinions eight criteria were selected and categorized as unsuitable, very low, low, moderate, high and very high as described in Table 2 and Table 3.

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.

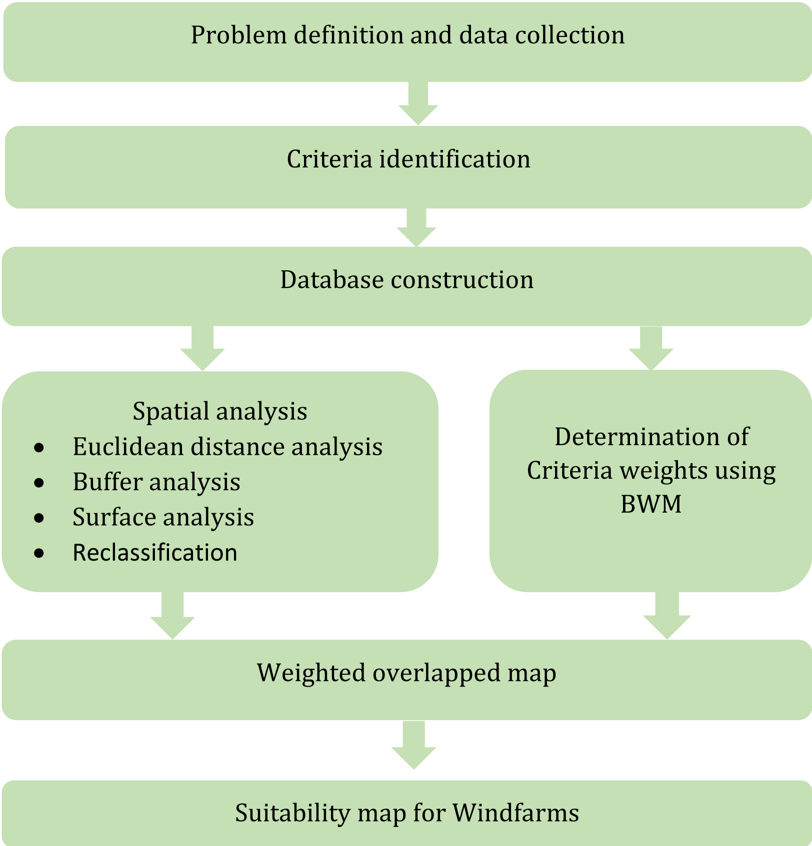


Figure 1. The flow chart of the proposed method

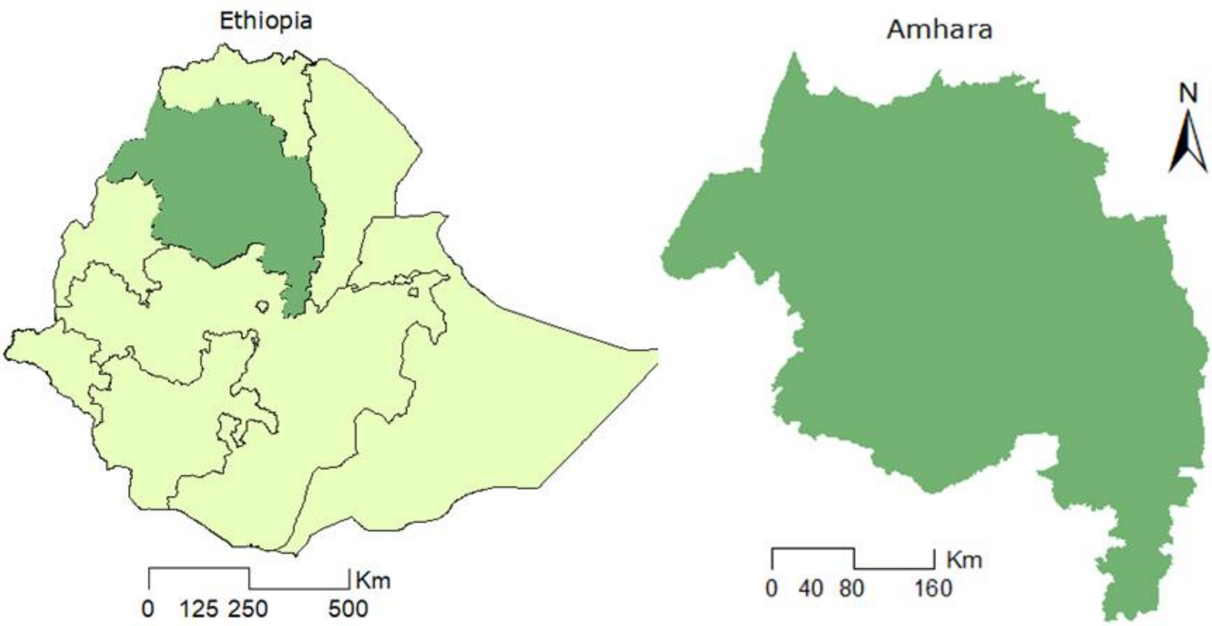


Figure 2. Study area

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.
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.
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.
Landcover	Land cover is one of the critical factors for wind farm suitability analysis.
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.
Airports	Wind farm closed to airports affects aviation routes, communication system and navigations, which leads to collisions.
Protected areas	Wind turbine noise and rotating blades influence animals' and birds' habitats. Wind turbine collisions with birds and bats frequently result in serious injuries and deaths. Additionally, wind farms have a detrimental effect on wildlife because spinning turbines alter air pressure. By creating buffer zones and choosing better wind turbine locations in regions with lower wildlife populations, the effect of wind turbines on wildlife could be reduced.
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.

Table 3. Suitability categories of criteria

Criteria	Suitability class	Range	Score/scale
Wind speed	Unsuitable	<3m/s	0
	Very low	3-4m/s	1
	Low	4-5m/s	2
	Moderate	5-6m/s	3
	High	6-7m/s	4
	Very high	>7m/s	5
Slope	Unsuitable	>15%	0
	Very low	12-15%	1
	Low	9-12%	2
	Moderate	6-9%	3
	High	3-6%	4
	Very high	0-3%	5
Aspect	Low	E, SE	2
	Moderate	N, NE, S, SW	3
	Very high	W, NW, FlAT	5
Landcover		(Water, crops, built-up area, cloud cover, and Trees as)	
		(Flooded and vegetation)	
	Unsuitable	Rangeland	0
		Bare ground	
	Moderate		3
	High		4
	Very high		5
Power grid lines	Unsuitable	<0.5km	0
	Very low	60-90km	1
	Low	30-60km	2
	Moderate	10-30km	3
	High	5-10km	4
	Very high	0.5-5km	5
Airports	Unsuitable	<3km	0
	Very low	50–100km	1
	Low	20–50km	2
	Moderate	10–20km	3
	High	5–10km	4
	Very high	3–5km	5
Protected areas	Unsuitable	<2000	0
	Very suitable	>2000	5
Main roads	Unsuitable	<3km	0
	Very low	50–100km	1
	Low	20–50km	2
	Moderate	10–20km	3
	High	5–10km	4
	Very high	3–5km	5

2.3. Determination of criteria weights

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 was used to determine the weights of criteria. In MCDM problems, BWM is one of the most successful approaches for determining the weights of criteria [23]. 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).

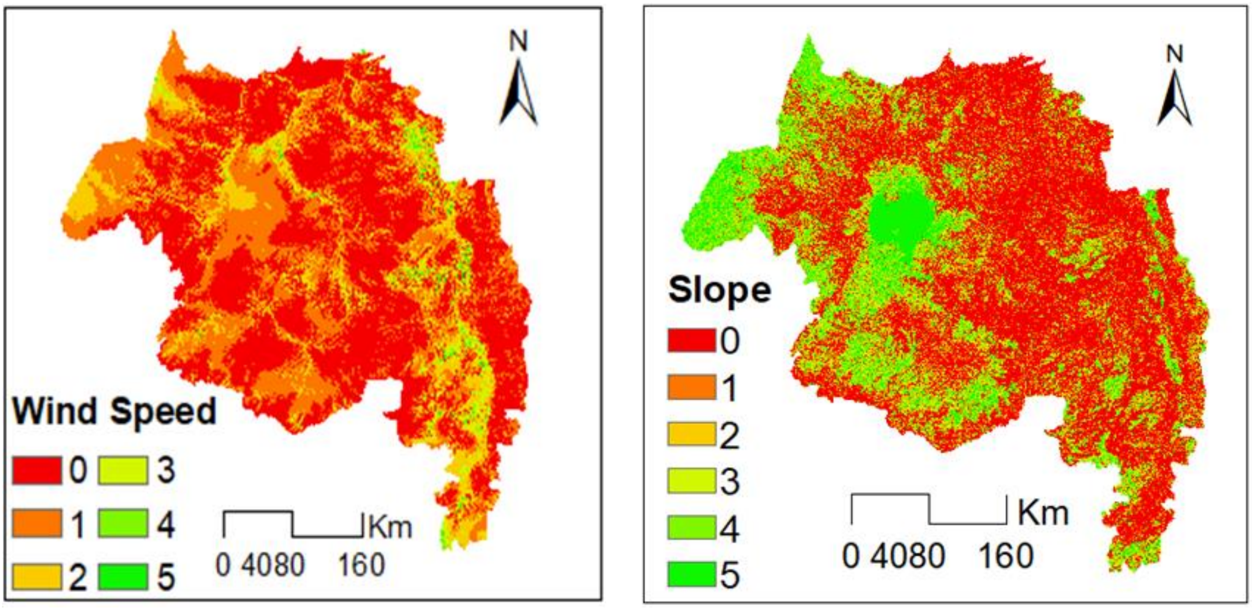
Min ξ^L such that

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

Where,
ξ^L ; Consistency ratio
W_B: weight of best criteria
W_W: weight of worst criteria
W_j: weight of criterion

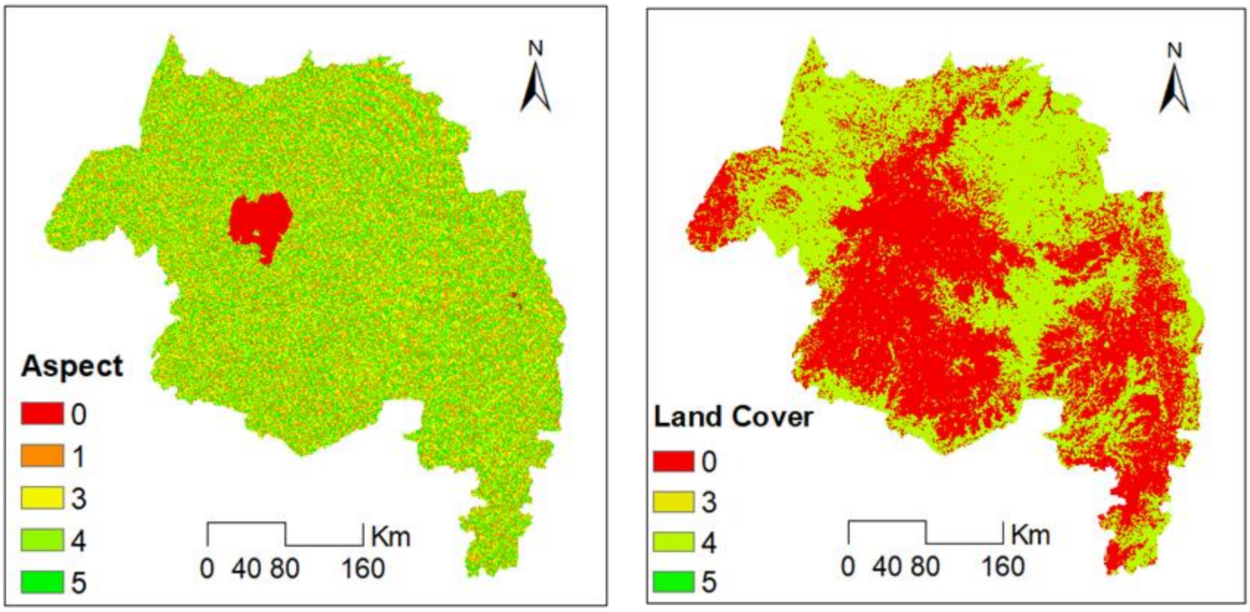
A Bj: preference for the best criterion over criterion j
a_jW: preference for criterion j over the worst criterion

The weights and consistency of the criteria were computed using the BWM-Solver tool of Excel following the general steps; (1) Select required decision criteria, (2) Determine the best (most significant) and the worst (least significant) criteria by expert's form identified criteria, (3) Pairwise Comparison best to others and others to worst by assigning preference value between 1 and 9 and (4) Computing the optimal weights of selected criteria.



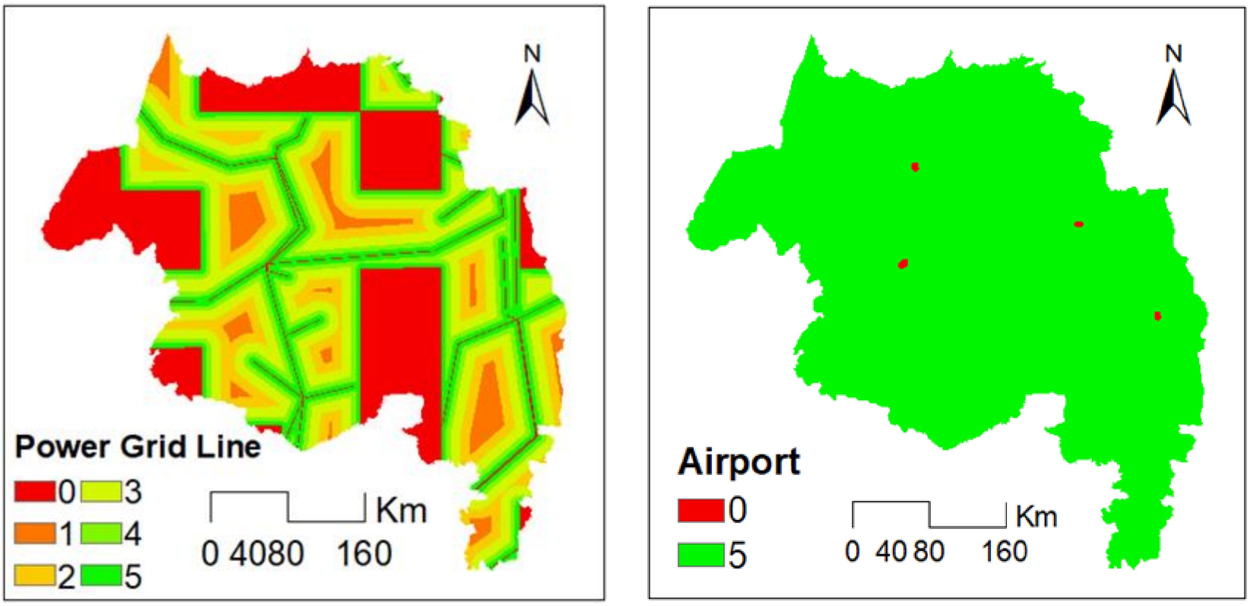
(a) (b)

Figure 3. Criteria reclassified map; (a) wind speed (b) slope



(c) (d)

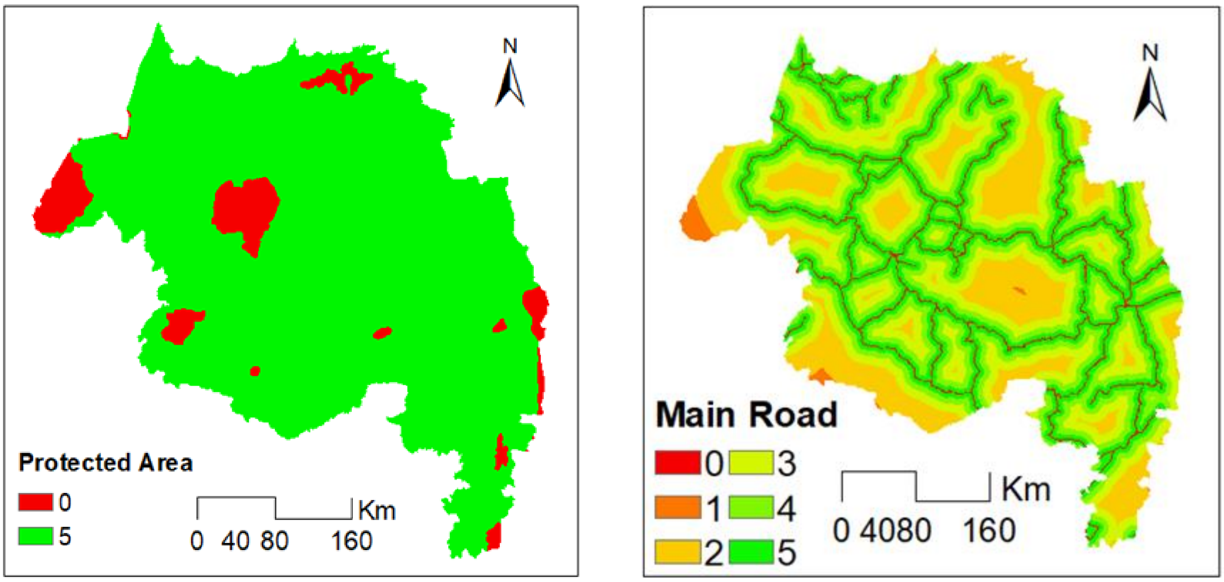
Figure 4. Criteria reclassified map; (**c**) Aspect (**d**) land cover



(e) (f)

Figure 5. Criteria reclassified map; (**e**) power grid lines (**f**) airport

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. As indicated in Table 6 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 as shown in Table 4. 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 as shown in Table 5. 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 6.



(g) (h)

Figure 5. Criteria reclassified map; (**g**) protected area and (**h**) main roads

Table 4. Pairwise comparison for assessment criteria (Best to others)

Expert	Best to others	Wind speed	Slope	Aspect	Land cover	Power transmission line	Main roads	Protected areas	Airports
1	Wind speed	1	2	3	4	5	6	7	8
2	Wind speed	1	2	3	3	4	8	7	4
3	Wind speed	1	3	4	4	4	7	7	4
4	Wind speed	1	6	9	5	3	9	9	5

Table 5. Pairwise comparison for assessment criteria (others to worst)

Expert	1	2	3	4
Others to the Worst	Airports	Main roads	Protected areas	Protected areas
Wind speed	8	8	7	9
Slope	7	6	6	1
Aspect	6	5	4	1
Land cover	5	4	4	3
Power grid lines	4	3	4	8
Main roads	3	2	3	1
Protected areas	2	1	1	1
Airports	1	3	3	1

Table 6. Determined weight of criteria

Criteria	Experts				Average
	1	2	3	4	
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
Main roads	0.033	0.060	0.059	0.066	0.055
Protected areas	0.052	0.037	0.059	0.057	0.051
Airports	0.090	0.105	0.107	0.033	0.084
ξ^L	0.066	0.047	0.081	0.146	

3. Results 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.

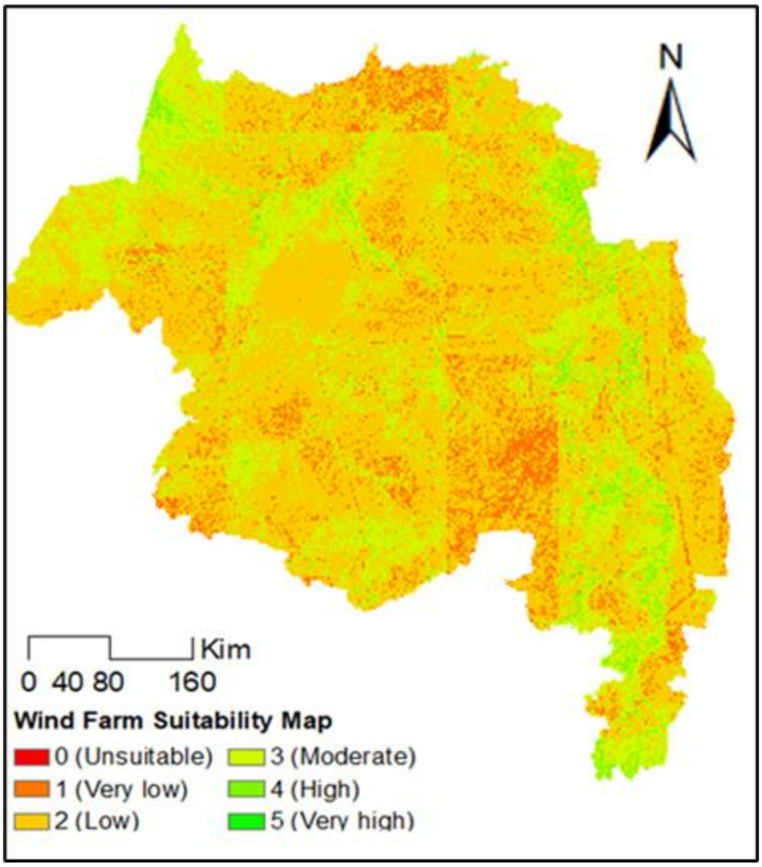


Figure 4. Wind farm suitability map

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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Author contributions

Zelalem Getachew Ayalke: Conceptualization, Methodology, Data curation, Software, Writing-Original draft preparation. **Aziz Şişman:** Visualization Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Hashemizadeh, A., Ju, Y., & Dong, P. (2020). A combined geographical information system and Best–Worst Method approach for site selection for photovoltaic power plant projects. International Journal of Environmental Science and Technology, 17(4), 2027–2042. https://doi.org/10.1007/S13762-019-02598-8.
2. Adams, S., Klobodu, E. K. M., & Apio, A. (2018). Renewable and non-renewable energy, regime type and economic growth. Renewable Energy, 125, 755–767. https://doi.org/10.1016/j.renene.2018.02.135
3. DLA PIPER. (2021). Africa Energy Futures: Horizon 2030 report. December, 1–61.
4. Tiruye, G. A., Besha, A. T., Mekonnen, Y. S., Benti, N. E., Gebreslase, G. A., & Tufa, R. A. (2021). Opportunities and challenges of renewable energy production in ethiopia. Sustainability (Switzerland), 13(18), 1–25. https://doi.org/10.3390/su131810381.
5. Asress, M. B., Simonovic, A., Komarov, D., & Stupar, S. (2013). Wind energy resource development in Ethiopia as an alternative energy future beyond the dominant hydropower. Renewable and Sustainable Energy Reviews, 23, 366–378. https://doi.org/10.1016/J.RSER.2013.02.047
6. Nasery, S., Matci, D. K., & Avdan, U. (2021). GIS-based wind farm suitability assessment using fuzzy AHP multi-criteria approach: the case of Herat, Afghanistan. Arabian Journal of Geosciences, 14(12). https://doi.org/10.1007/s12517-021-07478-5.
7. Kotb, K. M., Elkadeem, M. R., Elmorshedy, M. F., & Dán, A. (2020). Coordinated power management and optimized techno-enviro-economic design of an autonomous hybrid renewable microgrid: A case study in Egypt. Energy Conversion and Management, 221(July), 113185. https://doi.org/10.1016/j.enconman.2020.113185.
8. Rehman, S., Baseer, M. A., & Alhems, L. M. (2020). GIS-Based Multi-Criteria Wind Farm Site Selection Methodology. FME Transactions, 48(4), 855–867. https://doi.org/10.5937/fme2004855R
9. Latinopoulos, D., & Kechagia, K. (2015). A GIS-based multi-criteria evaluation for wind farm site selection. A regional scale application in Greece. Renewable Energy, 78, 550–560. https://doi.org/10.1016/J.RENENE.2015.01.041.
10. Jamshed, A., Saleem, A. A., Javed, S., & Riffat, M. (2018). Site Suitability Analysis for Developing Wind Farms in Pakistan: A GIS-Based Multi-Criteria Modeling Approach. Sci. Technol. Dev, 37(December), 195–201. https://doi.org/10.3923/std.2018.195.201.
11. Ali, S. A., Parvin, F., Al-Ansari, N., Pham, Q. B., Ahmad, A., Raj, M. S., Anh, D. T., Ba, L. H., & Thai, V. N. (2020). Sanitary landfill site selection by integrating AHP and FTOPSIS with GIS: a case study of Memari Municipality, India. Environmental Science and Pollution Research 2020 28:6, 28(6), 7528–7550. https://doi.org/10.1007/S11356-020-11004-7.
12. Zalhaf, A. S., Elboshy, B., Kotb, K. M., Han, Y., Almaliki, A. H., Aly, R. M. H., & Elkadeem, M. R. (2022). A high-resolution wind farms suitability mapping using gis and fuzzy ahp approach: A national-level case study in Sudan. Sustainability (Switzerland), 14(1), 1–21. https://doi.org/10.3390/su14010358
13. Tercan, E. (2021). Land suitability assessment for wind farms through best-worst method and GIS in Balıkesir province of Turkey. Sustainable Energy Technologies and Assessments, 47(July), 101491. https://doi.org/10.1016/j.seta.2021.101491.
14. Ecer, F. (2021). Sustainability assessment of existing onshore wind plants in the context of triple bottom line: a best-worst method (BWM) based MCDM framework. Environmental Science and Pollution Research, 28(16), 19677–19693. https://doi.org/10.1007/s11356-020-11940-4.
15. Ayalke, Z., & Sisman, A. (2022). Nominal Land Valuation with Best-Worst Method Using Geographic Information System: A Case of Atakum, Samsun. ISPRS International Journal of Geo-Information, 11(4). https://doi.org/10.3390/ijgi11040213.
16. Moslem, S., Campisi, T., Szmelter-Jarosz, A., Duleba, S., Nahiduzzaman, K. M., & Tesoriere, G. (2020). Best–Worst Method for Modelling Mobility Choice after COVID-19: Evidence from Italy. Sustainability 2020, Vol. 12, Page 6824, 12(17), 6824. https://doi.org/10.3390/SU12176824.
17. Abouhashem Abadi, F., Ghasemian Sahebi, I., Arab, A., Alavi, A., & Karachi, H. (2018). Application of best-worst method in evaluation of medical tourism development strategy. Decision Science Letters, 7(1), 77–86. https://doi.org/10.5267/j.dsl.2017.4.002.
18. Abera, E. A., & Abegaz, W. B. (2020). Seasonal and Annual Rainfall Trend Detection in Eastern Amhara, Ethiopia. J Climatol Weather Forecast, 8, 264. https://doi.org/10.35248/2332-2594.2020.8.264.
19. Ayodele, T. R., Ogunjuyigbe, A. S. O., Odigie, O., & Munda, J. L. (2018). A multi-criteria GIS-based model for wind farm site selection using interval type-2 fuzzy analytic hierarchy process: The case study of Nigeria. Applied Energy, 228(July), 1853–1869. https://doi.org/10.1016/j.apenergy.2018.07.051.
20. Szurek, M., Blachowski, J., & Nowacka, A. (2014). GIS-Based method for wind farm location multi-criteria analysis. Mining Science, 21, 65–81. https://doi.org/10.5277/ms142106.

21. Xu, Y., Li, Y., Zheng, L., Cui, L., Li, S., Li, W., & Cai, Y. (2020). Site selection of wind farms using GIS and multi-criteria decision-making method in Wafangdian, China. Energy, 207. https://doi.org/10.1016/j.energy.2020.118222.
22. Pamucar, D., Gigovic, L., Bajic, Z., & Janoševic, M. (2017). Location selection for wind farms using GIS multi-criteria hybrid model: An approach based on fuzzy and rough numbers. Sustainability (Switzerland), 9(8). https://doi.org/10.3390/su9081315.
23. Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega (United Kingdom), 64, 126–130. https://doi.org/10.1016/j.omega.2015.12.001.