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IDENTIFYING THE OPTIMAL PLACEMENT OF SPATIAL WIND ENERGY FARMS IN SELANGOR, MALAYSIA

Muhammad Ashrul Mohd Zubir[1], Saiful Anuar Jaafar@Ibrahim[2], Abdul Rauf Abdul Rasam[3], Zaharah Mohd Yusoff[4], Izrahayu Che Hashim[5]

[1,2,3,4] *Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying*
UNIVERSITI TEKNOLOGI MARA, SHAH ALAM, MALAYSIA.
[5]*Department of Built Environment Studies and Technology, Faculty of Architecture, Planning and Surveying*
UNIVERSITI TEKNOLOGI MARA, PERAK BRANCH, MALAYSIA

Abstract

Electrical energy is indispensable for the economic growth and well-being of humanity. However, there is a growing concern with the conventional method of generating electricity which is by burning coal and other fossil fuels. In the coming decades, the world will experience a transition to cleaner energy, away from the use of fossil fuels. One of the clean and renewable energies that is getting more popular and advancing in technology is wind energy. Wind energy requires a proper location to operate in order to be profitable and have the desired impact on society. In search of a suitable location for wind energy, a Geographical Information System based Multi-Criteria Decision Making (GIS-MCDM) approach was utilized in this paper to explore the suitable areas for wind energy development in Selangor. Eight parameters were chosen to address this concern, including terrain elevation, terrain slope, road network, airport locations, forests, settlements, water bodies and average wind speed. All of these criteria were weighted using the pairwise comparison approach in MCDM, and the decision-making process was facilitated by the criteria utilizing the ArcGIS-weighted overlay tool. The study has identified seven potential sites, but only four sites that are practically located the wind energy site, which are Banting, Jeram, Ijok and Kerling. GIS-MCDM can assist the decision-maker in designing the optimal placement of wind farms in real scenarios.

Keywords: Wind Energy, Site Selection, Suitability Index Map, GIS, MCDM

[3] Senior Lecturer at Universiti Teknologi MARA, Shah Alam. Email: rauf@uitm.edu.my

INTRODUCTION

Electricity is essential for the economic growth and well-being of human populations. Nowadays, the majority of electrical power is generated with the burning of fossil fuels such as oil, coal, and nuclear reaction. Increased environmental concern and issues surrounding the security of supply have led to a global drive to develop renewable energy systems (Harper et al., 2017). Many energy sources are renewable and safer than fossil fuels. One of such resources is the energy obtained from wind (Szurek et al., 2014)

Building a new infrastructure such as a wind turbine to serve as an active long-term investment requires careful planning in terms of the site selection. Site selection of wind farms producing electricity requires careful and combined analysis of numerous criteria such as technical requirements, as well as environmental, social, and spatial constraints (Szurek et al., 2014). Wind turbines would probably operate profitably at a speed of 4.5m/s - 5.0 m/s. (Csikós & Szilassi, 2015). A suitable site should also consider the slope, aspect surface of the area, location of nature protection areas and their buffer zones, built-up areas and their buffer zones, location and distance from power lines, location and distance from rivers and surface waters, location and buffer zones from forests, location and distance from telecommunication lines and location, technical standards and distance from roads and railways (Szurek et al., 2014).

A multi-criteria decision making (MCDM) model for calculating wind speed and slipstream topography is used in this study, as an integrated calculation model in GIS implementation. Therefore, a Digital Elevation Model (DEM), wind data from the nearest weather station, geology data for determining appropriate soil, the distance to power lines and land use data sets are used to identify a suitable location for power generating wind turbine (Arcidiacono, 2012). The study's main aim is to identify suitable locations to place power-generating wind turbines in Selangor using the GIS-MCDM approach with influential parameters. The specific objectives are i) to determine the criteria of profitable wind turbine location in Selangor ii) to estimate the weight of the criteria and sub-criteria for a profitable wind turbine in Selangor, and iii) to create a suitability index map of wind energy locations in Selangor.

WIND ENERGY AND SITE SUITABILITY

In the context of geographical suitability, identifying a good location is vital for the success of wind farms (Eichhorn et al., 2019; Becker and Thran, 2018). There are three key factors influencing the location of wind farms which are wind energy output, grid availability and construction conditions. On the other hand, there are limiting factors such as the technical requirements, economic, social and environmental considerations, which present a sitting difficulty of the wind farms (Musa et al., 2012). In Malaysia based on MCDM method, there are four criteria considered including wind energy density, wind speed, terrain condition and noise restriction (Hwang et al., 2011).

Meanwhile, a study in Thailand found that to select a suitable site for the wind farm, the criteria of urban areas, community zones, important places, scenic areas, airport areas, highways, wind energy potential, surface roughness, elevation, river/canal are suggested to be considered (Bennui et al., 2007). In finding a suitable location for the wind farm in Nebraska, there are seven probable criteria that are taken into consideration such as the potential of wind energy potential, land use, population density, distance to major roads, slope, distance to transmission lines, and exclusionary areas (i.e., areas where cities and towns, wetlands, airports and roads are located) (Miller & Li, 2014).

According to Szurek et al.(2014) and (Saleous and Issa, 2016) , the criteria that should be put into considerations when determining the suitable location to establish power-generating wind turbines are the location of nature protection areas and their buffer zones Hence, this study has considered a widened selections of factors influencing the suitable wind energy area that have been discussed by previous studies (Eichhorn et al., 2019; Hwang et al., 2011; Musa et al., 2012; Bennui et al., 2007). Eichhorn et al. (2019) addressed that wind power provides an important role in shaping sustainable energy system, such as reducing carbon emissions and ensuring the health of residents and the environment.

GIS-MCDM AND REMOTE IMAGERY APPROACH FOR WIND ENERGY LOCATION

GIS-MCDM incorporated explicit statements of preferences of decision-makers and such preferences are represented by various quantities, weighting scheme, constraints, goal, utilities, and other parameters used. This is to analyse and support decision through formal analysis of alternative options, their attribute, evaluation criteria, goals or objectives, and constraints (Bennui et al., 2007).

Some functional operations are implemented in the GIS-MCDM approach, such as Analytical Hierarchy Process (AHP) and weighting. AHP method is a flexible and simple Multi-criteria Analysis (MCA) and it has been largely explored in the literature related to location identification as conducted in several studies in Malaysia (Saad et al., 2021; Mohd Zaini., 2021; Rasam et al., 2017; Abdul Rasam et al., 2016; Mamat et al., 2014; Othman et al., 2021). AHP is recognized for its ability to consider tangible and intangible criteria in giving solutions to a multi-criteria problem. There are two distinct characters of AHP; the ability to assign a hierarchy structure and conducting pairwise comparisons between different criteria (Musa et al., 2012; Kaluthanthri & Osmadi, 2020).

Weighting scores for each criterion is derived from AHP, by directly comparing the importance of one criterion to another criterion. Rules for defining the score are; “1” when the criteria in columns are less significant than those in a row, “2” when the criteria in columns have the same significance as those in a row, and “3” when the criteria in columns are more significant than those in a row. When criteria in columns are the same as those in a row, the score is equal to “0” (Bennui et al., 2007).

MODIS is the Moderate Resolution Imaging Satellite built by Santa Barbara Remote Sensing. It maps the earth at 500-meter spatial resolution for six different Land Cover types. The maps were derived from the classification of spectro-temporal features. Identifying proper locations for onshore wind turbines requires consideration to a lot of spatial characteristics; hence, GIS is widely used to carry out such studies (Abdel-Basset et al., 2021; Tercan et al., 2020; Díaz-Cuevas, 2018; Harper et al., 2017).

METHODOLOGY

There are four steps involved in the methodology of the study. The first step is the preliminary study in identifying the criteria and sub-criteria in locating the suitable location for a wind farm. Next is the geospatial data collections such as the DEM, wind speed data, land use map, and road networks. The third step is the data processing, which was carried out to map all the datasets and classify them according to the suitable criteria for wind energy generation. The weightage (pairwise comparison method) is decided based on previous study as mentioned on literature review. Finally, all the created maps were overlaid using the weighted overlay tool in ArcGIS to create the suitability index map of wind energy. Figure 1 shows the research methodology workflow.

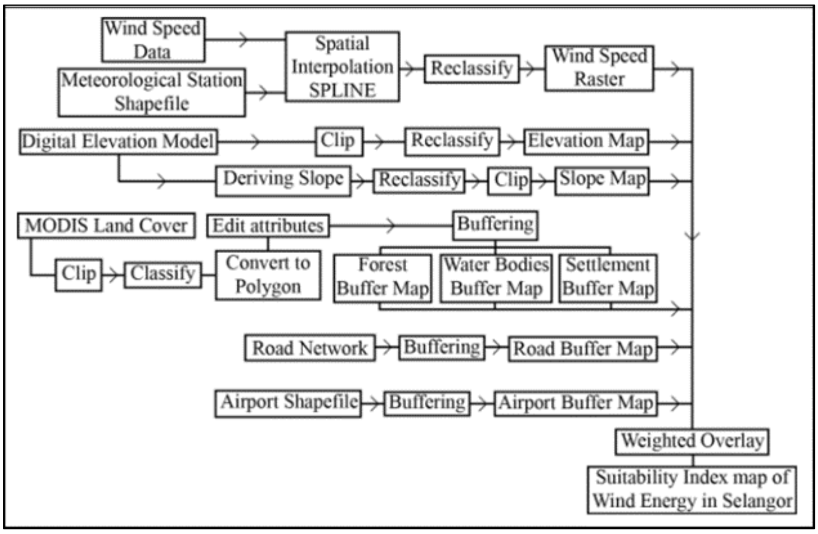


Figure 1: Research methodology

THE STUDY AREA AND CRITERIA FOR THE WIND FARM LOCATION

The study was carried out in Selangor, as shown in Figure 2. It is one of the largest states in peninsular Malaysia, with high GDP and population. Selangor is chosen since it is the most developed state in Malaysia located on the west coast of the Peninsular Malaysia and it is estimated to be 8000 square kilometres in width with a hilly and flat terrain.

Figure 2: Study area located in Selangor, Malaysia
(Google Map, 2019)

In the process of identifying suitable locations for wind farms in Selangor, several spatial characteristics are considered. The spatial characteristics and their ranking are obtained from several previous studies carried out in another country, as illustrated in Table 1 and Table 2. The criteria considered are wind speed, forest, airport location, water bodies, settlements, terrain slope, terrain elevation, and roads. Thus, the selected location will be based on the sub criteria, which are obtained from a previous study conducted by UTHM, and based on the criteria, the suitable location within the Selangor state and its districts will be selected in order to build the wind turbine.

Table 1: The sub-criteria for the wind farm location

Spatial Characteristic	**Suitability Index**					
	0	**1**	**2**	**3**	**4**	**5**
Wind Speed (m/s)	<1.0	1.0 – 1.5	1.5-2.0	2.0 – 2.5	2.5 – 3.0	>3.0
Forest (m)	<1000	-	-	-	-	> 1000
Airports (m)	<1000	-	-	-	-	> 1000
River/Water Bodies (m)	<200	201–350	351–500	501–650	651–800	>800
Settlements (Km)	>0.5	5.0 – 4.0	4.0 – 3.0	3.0 – 2.0	2.0 – 1.0	1.0 – 0.5

Terrain Slope (°)	>40	>10	7.5 – 10	5–7.5	2.5–5	0–2.5
Terrain Elevation (m)	<200	160 – 200	120 – 160	80 -120	40-80	0-40
Roads (m)	<50	>1000	751–1000	501–750	251–500	51–250

Table 2: The GIS operations

Input	GIS Operations	Output
Elevation Raster	Clip and Reclassify	Elevation Map
Elevation Raster	Clip, Deriving Slope and Reclassify	Slope Map
Meteorological Station Points Shapefile	Spatial Interpolation	Wind Contour Map
Land Cover Raster	Clip, Classify, Edit Attributes and Buffering	Forest Buffer Map Settlement Buffer Map Water Bodies Buffer Map
Road Network Shapefile	Buffering	Road Network Buffer Map
Airport Shapefile	Buffering	Airport Buffer Map
Elevation Map Slope Map Wind Contour Map Forest Buffer Map Settlement Buffer Map Water Bodies Buffer Map Road network Map Airport Buffer Map	Weighted Overlay	Suitability Index Map of Wind Energy in Selangor

DATA COLLECTION AND PROCESSING

The dataset was collected from various open sources by referring to the previous study. The land use data were obtained from MODIS land cover data, which can be accessed through the USGS Earth Explorer server. DEM was acquired from Shuttle Radar Topography Mission, made available and accessible in opentopography.org for producing elevation and slope map. Road network data were obtained from openstreetmap.com, and wind speed data were collected from selected meteorological stations in Malaysia. Table 3 shows the GIS operation involved in the study. Each dataset undergoes several GIS operations to produce suitability maps. All the suitability maps were used in weighted overlay to produce a wind energy suitability index map in Selangor.

RESULT AND ANALYSIS

This part discusses the results that are from the data processing and analysis. It consists of GIS calculation and processes such as wind contour map, elevation map, slope map, forest, settlement and water bodies buffer map, road buffer map, and airport buffer map of Selangor. All of these maps are analysed by their area, class types, and distribution of their legends across Selangor. The final map, which is the product of the weighted overlay process from all the maps produced, is called the suitability index map of wind energy in Selangor. The results were also overlaid with Google Earth for accuracy assessment.

SPATIAL CHARACTERISTIC AND RANKING

Spatial characteristic of several studies is combined. The more frequent a spatial characteristic appeared in previous study, the higher the score ranking of the spatial characteristic. The weight is determined by calculating the percentage over the total score of the ranking. The ranking is based on the analysis in Table 3.

Table 3: Analysis of spatial characteristic used in previous studies

Study Area	**Wind Speed**	**Terrain Elevation**	**Terrain Slope**	**Distance from Forest**	**Water Bodies**	**Distance from Settlemen**	**Road Network**	**Distance from Airport**
Louisiana USA	-	-	-	-				
Tehran Iran	-	-	-	-		-	-	
Thailand	-	-	-		-	-	-	-
Malaysia	-	-	-					
United Kingdom	-					-	-	-
Serbia	-		-			-		
Ecuador	-		-	-	-	-	-	-
Zanjan, Iran	-	-	-	-	-	-		-
UAE	-		-			-	-	-
Nebraska USA	-		-	-	-	-	-	-
Prusice Poland			-	-	-	-	-	
Hungary	-			-	-	-	-	
Score	11	5	10	7	6	10	8	6

Table 4 shows the ranking of the spatial characteristic, which is determined by analysing several previous studies for determining the suitable wind farms.

Table 4: Ranking and weight

Spatial Characteristic	Score	Weight (%)
Wind Speed	11	17
Terrain Elevation	5	8
Terrain Slope	10	16
Distance to Forest	7	10
Distance to Water Bodies	6	10
Distance to Settlement	10	16
Distance to Road Network	8	13
Distance to Airport	6	10
Total	63	100

SUITABILITY MAPS OF THE CRITERIA

The suitability level of each criterion of wind energy is shown in a suitability map. All maps were combined for the analysis to produce a suitability map of energy wind. The following figures show the results of the suitability maps of the criteria.

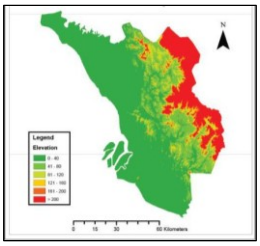


Figure 3: Elevation map

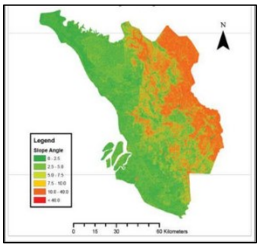


Figure 4: Slope map

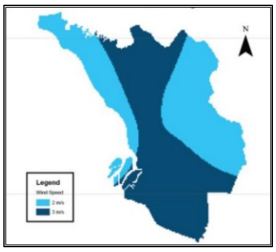


Figure 5: Wind contour map

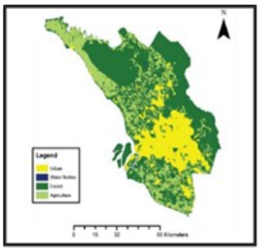


Figure 6: MODIS land map

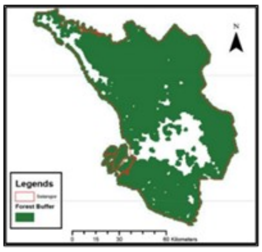


Figure 7: Forest buffer map

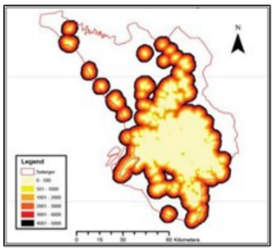


Figure 8: Settlement map

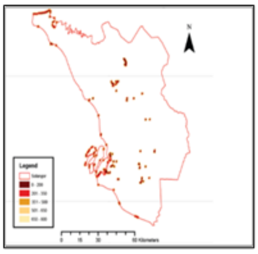


Figure 9: Water bodies map

Figure 10: Airport map

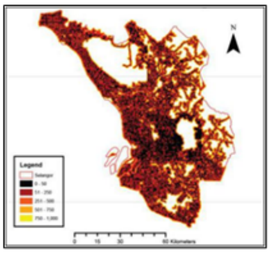


Figure 11: Road network map

The elevation map (Figure 3) shows that a lot of suitable lands are situated at the west side (green) of the Selangor state that is facing the Straits of Melaka while the unsuitable land area lies (red) at the east side of Selangor state, which is the mountainous region of Titiwangsa Mountain. The class and percentage of the suitability map is shown in Table 5.

Table 5: Suitability Map Classification

Class	0-40	40-80	80-120	120-160	200	>200
(%)	58.643	16.625	6.102	2.357	1.696	14.576

For the slope map, as shown in Figure 4, only 0.23% of Selangor land is not feasible due to its steepness. Most of this land is situated at the eastern side of Selangor, where the Titiwangsa mountain range lies. On the western and flatter side of Selangor, lies a relatively flat landscape, predominantly a class 1-3 land with a maximum steepness of 7.5°. The highest class's percentage would be class 1 with steepness ranging from 0°-2.5° angle, which is the most suitable type of land in terms of its steepness. The analysis of the slope is depicted in Table 6.

Table 6: Slope Map Classification

Class	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-40.0	>40
(%)	33.390	26.506	9.963	6.160	23.751	0.230

The wind contour map is illustrated in Figure 5, indicating 2 classes of wind 2m/s and 3m/s. The 2m/s wind class is spread along the mountain's region on the east of Selangor and the coastal area on the west of Selangor. For MODIS Land Cover, Selangor is made up of 54.02% Forest, 25.22% Farmland, 20.29% of Urban Area, and 0.47% of Water Bodies (Figure 6). Wind farm can only be established in an area without water bodies, forests and urban areas. Hence, farmland covering a quarter of Selangor's land is the only suitable location for a wind turbine farm. Farmlands are mostly located in the northwest and southern part of Selangor and are also sparsely scattered in the middle of Selangor and north of the major urban area. As shown in Figure 7 and the analysis in Table 7, forest area and its buffer cover 85.16% of the total land area in Selangor. This leaves Selangor with a measly 14.84% of the land to establish wind energy farms.

Table 7: Forest buffer map class

Class	Ranking	Buffer Area(m^2)	Percentage of Cover
0	Restricted	7035100728	85.16
1	5	-	14.84

The urban area in Selangor is focused on the centre of Selangor, which also happens to be the capital city of Malaysia, Kuala Lumpur. This is shown in Figure 8 and the settlement buffer map in Table 8.

Table 8: Settlement buffer map class

Class	Ranking	Buffer (m)	Percentage Area Cover (%)
0	Restricted	500	26.98
1	5	1000	5.72
2	4	2000	9.50
3	3	3000	7.94
4	2	4000	7.12
5	1	5000	6.74
No Data	Restricted	>5000	36.01
Total Percentage Area Cover			63.99

The water bodies in MODIS Land Cover data only cover water bodies that are bigger or wider than 500m due to MODIS spatial resolution Figure 9. By referring to the Table 9, water bodies and their buffers cover only 3.29% of the total land area in Selangor, and only 0.51% falls under the restricted area in terms of nearness to water bodies. This means that 99.49% of land in Selangor is available for wind energy farms in this context. About 96.71% of the area not affected by the buffer falls under the rank 5 in terms of distance to water bodies, making it the most suitable land in this context.

Table 9: Water bodies buffer map

Class	Ranking	Buffer (m)	Percentage Area Cover (%)
0	Restricted	200	0.51
1	1	350	0.57
2	2	500	0.63
3	3	650	0.67
4	4	800	0.92
5	5	>800	96.71
Total Percentage Area Cover			3.29

As shown in Figure 10 and Table 10, Selangor is sprawled with roads, and its buffer cover 79.63% of the total land area in Selangor. about 22.81% of the area is restricted due to being too close to the road network, leaving 77.9% of the land in Selangor available for wind energy farms in this context.

Table 10: Road network buffer map class

Class	Ranking	Buffer (m)	Area Cover (%)
0	Restricted	50	22.81
1	1	250	34.82
2	2	500	11.69
3	3	750	6.09
4	4	1000	4.21
5	5	>1000	20.38

Airport and its buffer only account for 1% of the total land area in Selangor. the buffered area is restricted for wind energy farms due to take-offs and landings of the airplane. the result is displayed in Figure 11 and Table 11.

Table 11: Airport buffer map area cover

Airport Buffer	Percentage Area Cover (%)
KLIA	0.70
SAAS Airport	0.24
Bernam River Airfield	0.06
Total Area Cover	1.00

SUITABILITY INDEX MAP OF WIND ENERGY

After producing the suitability map of each criterion according to its sub-criteria, all the suitability maps were overlaid according to their assigned weightage to produce a suitability index map of wind energy in Selangor, as shown in Figure 12. From the map, it can be observed that there are seven potential sites for wind energy around Selangor. Four out of seven potential sites are located in Banting, Selangor, and the rest is located at Ijok, Kerling, and Jeram.

All the potential sites are located on agricultural land. Based on the analysis depicted in Table 12, site number 4 has the largest area while site number 6 has the smallest area. There is only one site with a suitability ranking of 5, which is site number 2, and the rest of the potential sites have a suitability ranking of number 4. These sites have suitable terrain conditions, and away from roads and is in suitable proximity to the major settlement to which it can then supply the power generated.

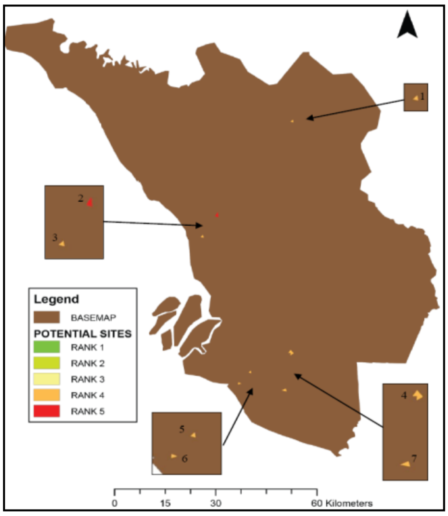


Figure 12: Spatial suitability index map

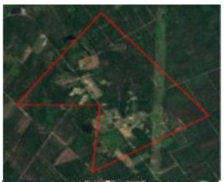
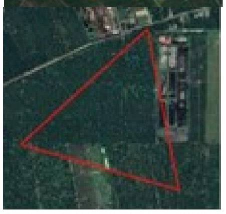
Table 12: Suitability Index Map Analysis

Number	Suitability Ranking	Area	Land Use Type
1	4	366896.67	Agriculture
2	5	731697.04	Agriculture
3	4	366897.15	Agriculture
4	4	1211132.65	Agriculture
5	4	366896.67	Agriculture
6	4	343173.81	Agriculture
7	4	723364.00	Agriculture

Table 13 describes the analysis carried out on the Google Earth platform. The site is analysed based on its terrain roughness and terrain elevation, its surrounding cultural features, and the distance of the nearest settlement that are located in Selangor.

Table 13: Suitability sites-analysis for each potential site using google earth platform

No.	Description	Sites
1	The site is located in Kerling, Selangor. It is approximately 2 km from a major settlement which is Bandar Baru Lembah Beringin. It is a sloppy area and situated at a relatively high elevation.	

2	This site is located at Ijok, Selangor and the distance is 3.5 km from the settlement of Kampung Ijok. The terrain of the site is flat and has a low elevation. It has major road passes through the side.	
3	The site is located in Jeram, Selangor. It is situated approximately 2.5 km away from the nearest major settlement, which is the town of Jeram. The terrain is flat and is at a low elevation. It is also surrounded by agriculture processing plants.	
4	The site is located at Kampung Seri Cheeding Banting Selangor. The site is nearby a school and settlements. The site is flat and has a low elevation.	
5	The site is located at Kampung Sungai Buaya Banting, Selangor. It is located around 1km from a major settlement which is Kampung Sawah and Kampung Tanah Raja. The site is flat and has a low elevation. It is also 1.6 km from the nearest river.	
6	The site is located at Kampung Sungai Arak, Banting Selangor. It is situated around 1km-1.5km from several major six settlements, namely Taman Banting Baru, Kampung Sungai Arak, and Kampung Kathong. The site has a low elevation and flat terrain	
7	The site is located at Kampung Sungai Kelambu, Banting Selangor. It is situated around 1.5km from the nearest settlement. It has a flat ground and a low elevation.	

CONCLUSION

In conclusion, the GIS-MCDM model works in trying to allocate potential wind energy locations in Selangor using the selected spatial characteristics. The ranking and weight of the spatial characteristic also work well in allocating the potential sites. Four of the potentially suitable sites are located at Banting, Jeram, Ijok, and Kerling. that are located on agricultural lands. Problematic sites are site number 4 and 6 due to close to the public school, and a major road, which is an exclusionary zone for wind turbine location. The most promising site is site number 2 because of the vastness and suitability of the area. The terrain is flat, has a low elevation and the site has a suitability ranking of 5. It is also only 1.5 km away from a major settlement. This will enable site number 2 to accommodate plenty of wind turbines as it will ease engineering works. The author suggests having a collaboration with the local experts to select the actual criteria and sub-criteria of a good wind farm location. The factors of electric grid networks, telecommunication lines, wind direction and density should be included for future spatial analysis to obtain more significant results.

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