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Utilizing GIS and RS to determine suitable areas for installing wind power stations: Case study, Erbil governorate, Kurdistan Region, Iraq

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Abstract

Determining suitable locations for wind energy installation is essential for the use of renewable energy. In order to identify the ideal locations for wind turbine installations in Erbil province, Iraqi Kurdistan Region, this study utilizes a geographic information system and remote sensing technologies. The assessment was based on three parameters: elevation, slope, and wind speed, using SRTM and Global Wind Atlas data. We worked out the weights for each of the criteria using the Analytical Hierarchy Process (AHP). The results show that the northern, central, and western parts of the governorate account for 58.91% of the least suitable areas for wind generation. 39.33% of the governorate's total area consists of less suitable areas, with moderately suitable areas accounting for 1.70% and primarily located in the north. The northeastern region offers the majority of highly suitable areas, comprising only 0.06%. Consequently, while the northern and northeastern regions have the greatest capability for wind energy, the middle, southern, and western regions represent significant challenges to wind energy development.

Keywords: wind speed, GIS, MCDA, AHP, Erbil Governorate.

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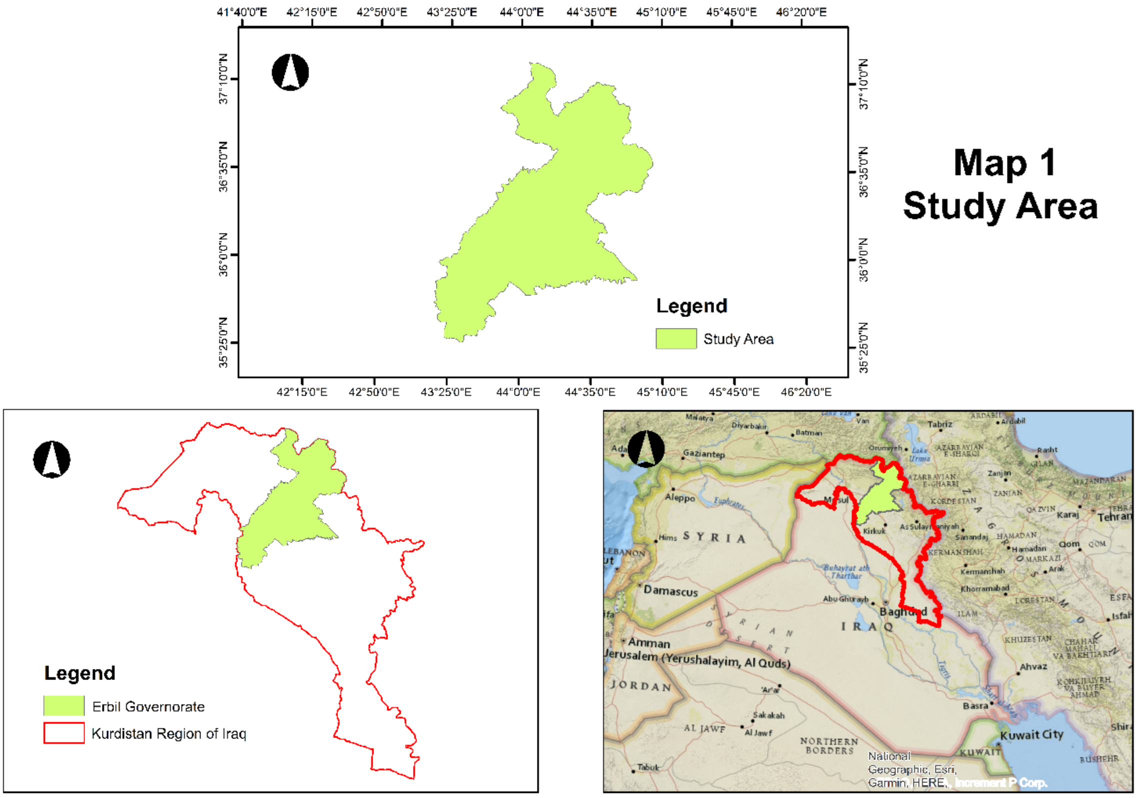
introduction

Currently, most countries in the world, especially those that care about the environment, are trying to gradually reduce energy production from fossil fuels and switch to renewable energy. Sustainable alternatives safeguard the environment and ensure the availability of human necessities for both present and future generations. Renewable energies are generally environmentally friendly, and wind energy, one of these clean energies, has the potential to generate significant amounts of energy. Wind turbines harness wind energy by using mechanical power to generate electricity. Not only does wind provide an abundant and uninterrupted resource, it also provides electricity without burning any fuel or polluting the air. Wind energy in the U.S., for example, helps avoid 336 million tons of carbon dioxide per year—the equivalent of 73 million vehicle emissions (EERE, 2024). In the current technological era, Geographic Information System (GIS) and Remote Sensing (RS) technologies are powerful tools in spatial data analysis, so they have a very effective role in identifying areas suitable for wind farms (Janke, 2010). Geographic information systems and remote sensing, with their diverse capabilities, have demonstrated their importance in analyzing various locations (Goodchild, 1991) (Jensen, 2009). By integrating a variety of data, including meteorological, topographic, and land use data, any study can consider these as criteria for determining the optimal location for wind turbine installation (J.F. Manwell, J.G. McGowan, A.L. Rogers, 2010).

Fortunately, the Iraqi Kurdistan Region in general is a good place for wind energy production because it has different topography and climatic conditions that are quite favorable for wind energy production. However, identifying suitable locations without modern technology may not help in selecting the most suitable location. Through the use of modern technologies such as GIS and RS, the most suitable areas can be identified considering important factors (Serwan M.J Baban, Tim Parry, 2001). This study aims to identify the most suitable locations for installing wind power plants in Erbil province, using GIS and RS technology to generate electricity. While there are numerous criteria to consider, this study solely considers three: elevation, slope, and wind speed. We analyze and identify suitable sites based on four categories. The article also talks about the Multi-Criteria Decision Analysis (MCDA) and Analytical Hierarchy Process (AHP) methods. These use elevation, slope, and wind speed as the three main criteria to evaluate possible sites. The objectives are to extract spatial datasets in terms of information-related elevation, slope, and wind speed within Erbil. We will identify and categorize wind farm deployment sites using GIS-based suitability maps that have been assigned specific categories. Validate the adaptation map with field data and recommendations on where to engage most promising areas for wind energy investment in Erbil governorate.

1.1. Description of the study area

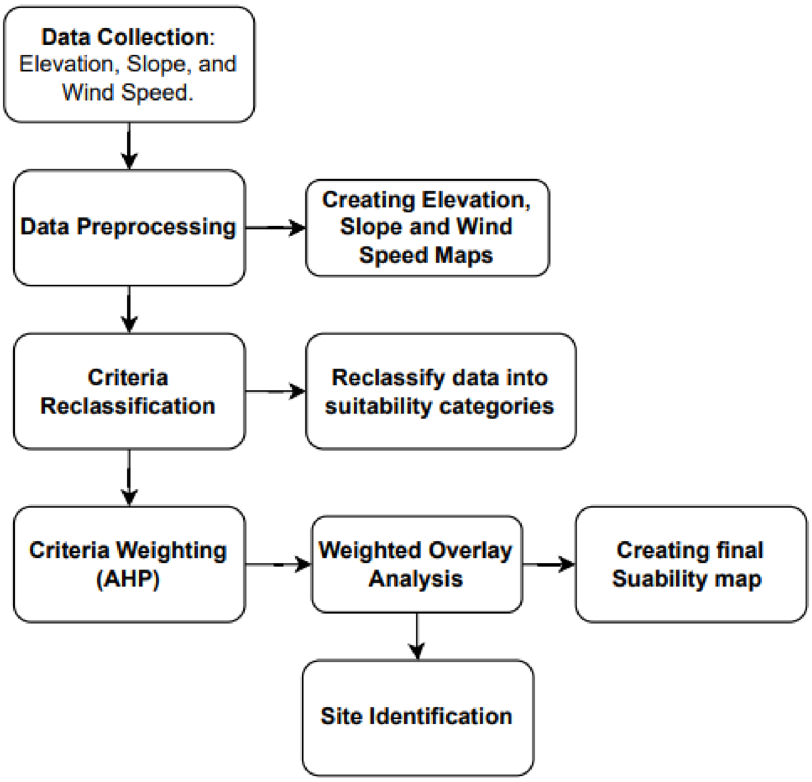
Erbil is one of the governorates of the Kurdistan Region of Iraq, located in the center of the Kurdistan Region and the capital of the region. The province and the entire Kurdistan Region are located in northern Iraq (as shown in maps 1). The governorate covers an area 14,636 square kilometers which is 3.3% of the area of Iraq. The population of Erbil province in 2020 – (2,254,422) people (Srwa S. Nooruldeen, Ahmed J. Ismael, 2023).It has different elevations, such as several mountainous areas in the north and east, and several flat plains in the south and west (Erbil Goverorate). The governorate has hot and dry summer temperatures that rise to more than 40 degrees Celsius, and winter temperatures vary from region to region, for example, temperatures drop below zero in the mountainous areas. The average annual rainfall is about 600 mm (Erbil Goverorate). These geographical conditions play an important role in determining the wind patterns required for wind energy production (Younes Noorollahi, Hossein Yousefi, Mohammad Mohammadi, 2016).



1.2. Methodology

The study works through the integration of geographic information systems and remote sensing technologies to identify suitable areas for wind turbine farms, based on three criteria: Elevation, slope and wind speed. For this purpose, the Analytical Hierarchy Process (AHP), which is a Multi-Criteria Decision Analysis (MCDA) technique, is used to weight these criteria to identify the most suitable areas for the installation of wind turbine farms in Erbil province. AHP is an effective approach for evaluating and prioritizing multiple criteria, making it ideal for complex decision-making scenarios where all different factors must be considered at the same time (Mendoza, G.A. and Martins, H. , 2006) Thomas Saaty developed AHP in 1970-1975 (Saaty, 1987), which is a structured approach for organizing complex decision problems into a hierarchy. This hierarchy is often composed of, Goal, Criteria, Alternatives. AHP is based on pairwise comparisons, with the decision-maker determining the relative relevance of each set of criteria or alternatives (Saaty, Decision making with the analytic hierarchy process, 2008). The combination of AHP and MCDA has a substantial impact on the process of decision making, where AHP can be used to structure decision-making problems and determine the weight of criterion, while MCDA can be used to evaluate alternatives and determine appropriate solutions (Malczewski, 2008). The following flowchart (figures 1) explains the methodology of this article:

Figures 1: Study Methodology



1.3. Data Collection

Elevation received from the Shuttle Radar Topography Mission (SRTM) (NASA, n.d.) Digital Elevation Model (DEM) with a dimension of 30 meters. This dataset provides correct topographical statistics vital for figuring out the land suitability for wind power stations. Higher elevations are normally desired for wind strength because of accelerated wind speeds and decreased obstructions. Slope was derived from the elevation dataset the usage of GIS tools. The slope is an important aspect for wind electricity installations, Steeper slopes can pose production challenges, while flatter areas are usually extra appropriate. The slope turned into calculated in ranges and labeled accordingly. Wind speed data received from the Global Wind Atlas (globalwindatlas, 2024), which offers high-decision wind useful resource maps. This dataset offers crucial facts at the common wind speeds throughout special regions. Higher wind speeds are immediately correlated with more energy manufacturing capacity from wind turbines. The data covers the range of wind speeds across the Erbil Governorate, with a high of 14.642 m/s and a low of 0.84923 m/s. From the map, it is obvious that the northern and northeastern parts of the study area show the highest speeds, however there are also various sites in the southern region of the county with high speeds. The average speed is equally spread across the entire region. When classifying wind speed into four suitable areas, the northeast is considered as the most suitable area based only on wind data. These three datasets had been processed and analyzed the use of a Multi-Criteria Decision Analysis (MCDA) method to decide the maximum suitable areas for wind power installations inside the Erbil Governorate.

1.4. Data Processing and Analysis

After collecting elevation, slope and wind speed data, then each of these criteria were classified to into four different suitability categories (as shown in the maps 2,3 and 4 below), classified records used then analyzed using multi-criteria decision analysis (MCDA) technique to decide overall suitability for wind energy facilities. The Analytical Hierarchy Process (AHP) was used to assign weights to every criterion mainly based on relative importance. The weights assigned to the parameters (elevation, slope and wind speed) through the AHP method played an important role in determining the suitability classes. The high weight assigned to elevation (27%) reflects its effect on suitability for wind energy installations, followed by slope (6%) and wind speed (67%). And also, the Consistency Ratio (CR) is 3.0%. Thus, the CR is a measure of consistency that is utilized within the Analytic Hierarchy Process to describe how much consistency exists in judgments that were made in a pairwise comparison matrix as shown in the table below (table 1). It helps determine whether the judgments are consistent enough to be reliable.

Table 1: Pairwise Comparison Matrix for Elevation, Slope, and Wind Speed

Criteria	Elevation	Slope	Wind speed
Elevation	1	5.00	0.33
Slope	0.20	1	0.11
Wind speed	3.00	9.00	1

The CR works in this formula below:

$$C1 = \frac{\lambda max - n}{n - 1}$$

Where:

$\lambda max\lambda max$ is the maximum eigenvalue of the pairwise comparison matrix.

nn is the number of criteria.

calculate the Consistency Ratio (CR):

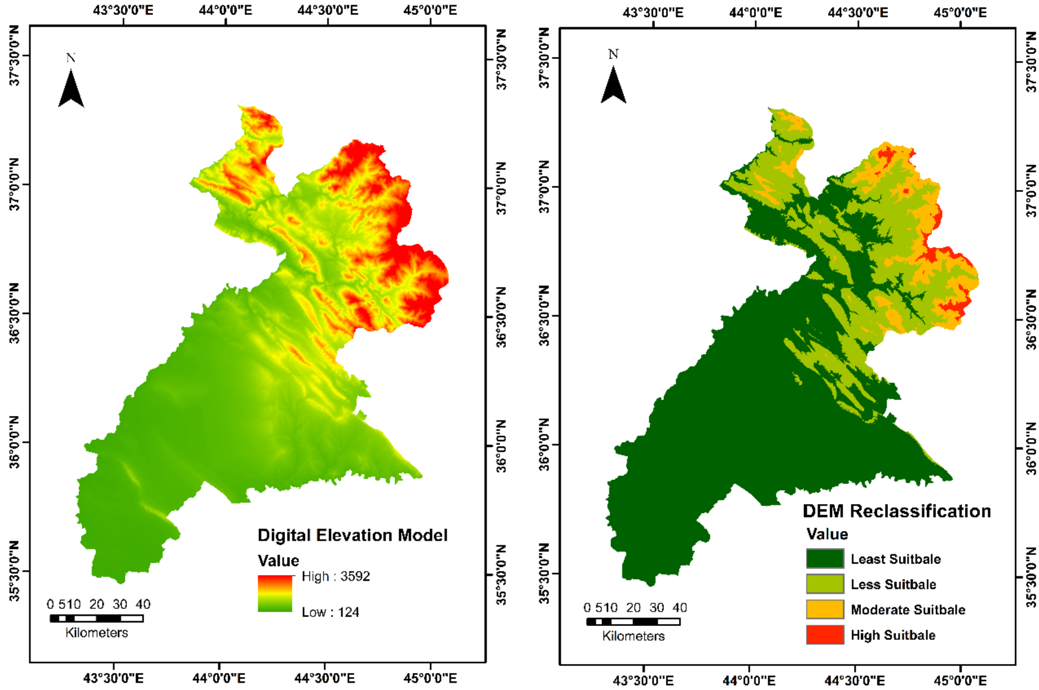
$$CR\frac{C1}{C2}$$

Interpreting the CR

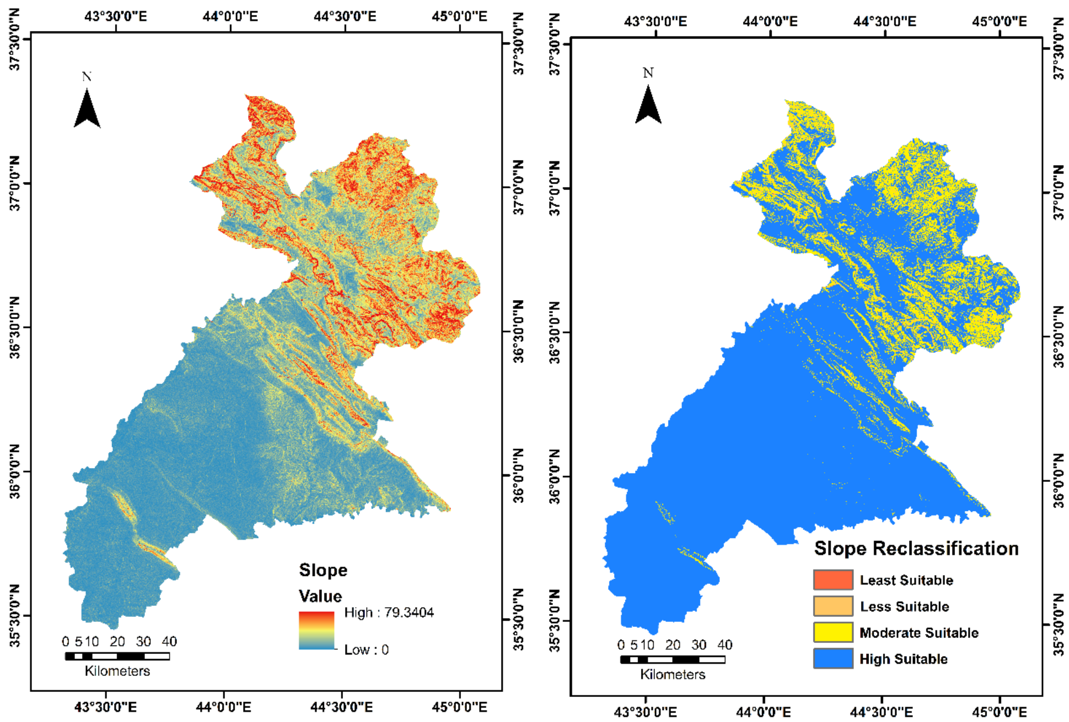
- **CR ≤ 0.1** (10%): The level of inconsistency is acceptable, and the results can be considered reliable.
- **CR > 0.1** (10%): The level of inconsistency is too high, suggesting that the pairwise comparisons may need to be revised to improve consistency (Enrique Mu , Milagros Pereyra-Rojas, 2017)

These weights emphasize the importance of topographic factors in the site selection process for wind energy projects in the region. After using weighted overlay tool in the program in ArcMap using the weights that were taken from AHP, the final map was created.

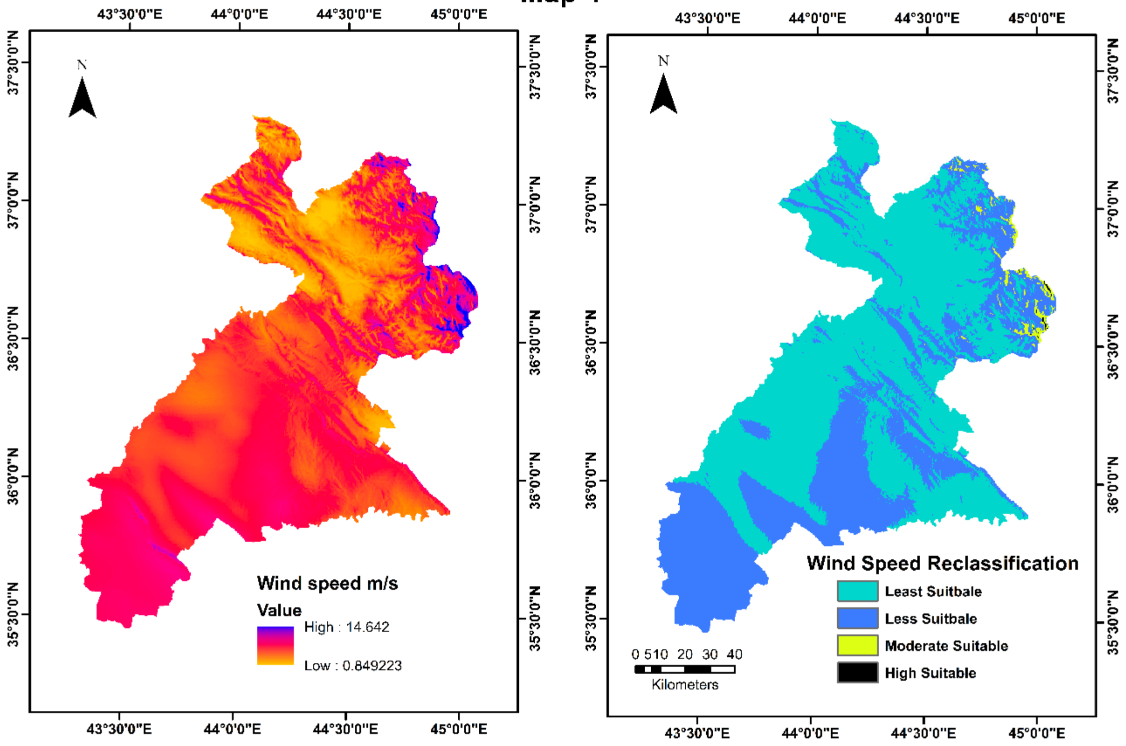
Map 2



Map 3



Map 4

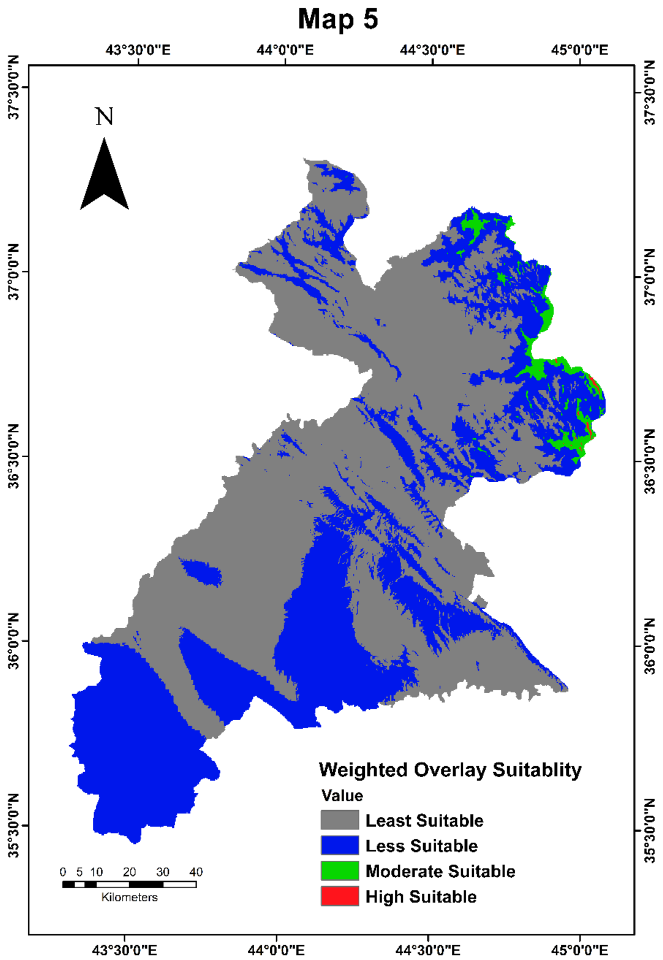


1. Results

Based on the final map (Map 5) and the schedule 1, the area of each suitability category was calculated. The least suitable areas, which comprise the largest land coverage, account for approximately 140,368 square kilometers (58.91%) of total area. These areas are predominantly located in the northern, northwestern, central, and western parts of the governorate, as well as in the eastern region. The second category, less suitable areas, covers a total of 93,723 square kilometers (39.33%) of total area, making it the second largest. These areas are scattered throughout the governorate, particularly in the northeast, central, and southernmost regions. Moderately suitable areas, classified as the third category, encompass 4,044 square kilometers (1.70%) of total area and are primarily concentrated in the northern and northeastern parts of the study area. Finally, the most suitable areas, the smallest category, cover just 137 square kilometers (0.06%) of total area and are sporadically distributed in the northeastern region of the study area.

Table 2

Suitability Category	Area/Km Square	Percentage %
Least Suitable	140,368	58.91
Less Suitable	93,723	39.33
Moderately Suitable	4,044	1.70
Highly Suitable	137	0.06



1.1. Discussion of results

1.1.1 Spatial Analysis:

Least Suitable Areas (Gray): These places, primarily found in the province's center and western districts, are distinguished by a combination of elevation, slope, and wind speed conditions that are unsuitable for efficient wind power generation. The broad spread of these least suitable zones indicates that much of the land has either low wind speeds, unsuitable slopes, or an elevation that are insufficient for wind energy development.

Less Suitable Areas (Blue): These areas are broadly distributed throughout the governorate, with concentrations in the south, northeast, and center. While less suitable areas may have moderate wind speeds or slightly better elevation and slope types than the first category. However, they fall short of the ideal conditions for wind energy generation. The scattered distribution of these locations indicates changes in topography and wind conditions.

Moderately suitable areas (Green): Located mostly in the northwestern part of the region, these areas are differentiated by elevations, slopes, and wind speeds, making them more ideal for wind energy installations than the least and less suitable areas.

Highly Suitable Areas (Red): The map shows only a very few suitable areas, with little areas seen in the northeastern region. These areas most likely have the best combination of wind speeds, elevations, and slopes, making them ideal locations for wind energy projects. However, the small size of these areas may cause obstacles for large-scale development.

1.1.2 Geographical Distribution

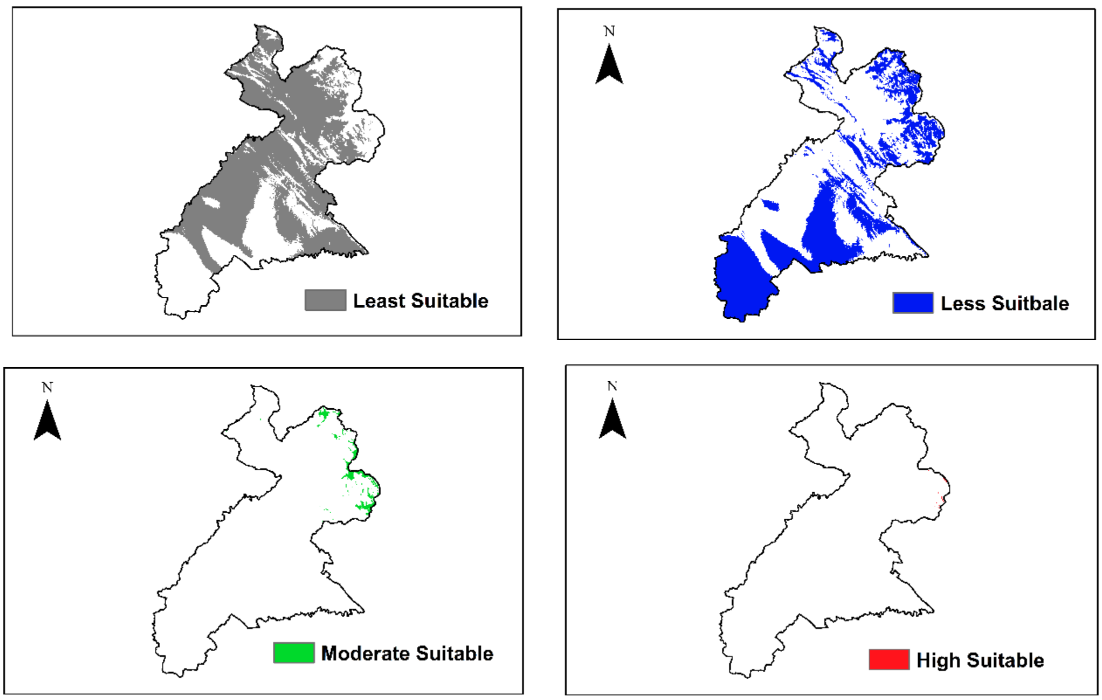
The northern and northeastern areas of the region have the greatest potential for wind power generation (map 6), with moderate to extremely favorable locations. This is due to the excellent elevation and wind speed conditions that exist in these areas. The central, southern, and western regions of the province, on the other hand, are generally less suited, implying that their elevation and wind speed make them unsuitable for construction of wind farms.

2.1.3. Implications of Renewable Energy Development:

Priority: The northeastern region of Erbil Governorate should be prioritized for extensive investigations and the development of wind energy potential. These areas, particularly those classified as highly suitable, are expected to generate significant initial investor interest.

challenges: The wide areas designated as least suitable provide significant obstacles to wind energy development. If wind energy is still pursued in certain areas, alternative technologies or hybrid solutions may be required.

Map 6



Conclusion

The spatial analysis of Erbil governorate shows that 58.91% of the land is the least suitable for wind energy, primarily in the northern, central, and western areas. The remaining 39.33% is scattered throughout the governorate. The north has the highest proportion of moderately appropriate locations (1.70%), whereas the northeast has only 0.06 %. The northern and northeastern areas have the most wind energy potential due to good conditions. However, the center, southern, and western parts face substantial problems that may require different solutions. Prioritizing the Highly Suitable areas in the Northeast is essential to the effective development of wind energy.

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