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Selecting Suitable Sites for Wind Energy Harvesting in Iraq using GIS Techniques

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Abstract

Wind energy harnesses the kinetic force of the wind through turbines to produce electricity. As a critical renewable energy source, it presents a sustainable alternative to fossil fuels. The availability of wind energy is geographically contingent. This paper aims to pinpoint optimal sites for wind energy development in Iraq and to secure future energy needs from renewable sources to achieve this, a multi-criteria analysis utilizing Geographic Information Systems (GIS) was employed to determine the prime locations for wind energy extraction. Vital climatic data incorporated into this analysis included a RASTER file of the study area's annual wind speed, temperature, precipitation, soil moisture, and NDVI (Normalized Difference Vegetation Index) roads, urban centers, terrain gradients, and land utilization patterns were instrumental in constructing a GIS-based model. This model harnessed the weighted overlay tool within ArcGIS 10.7.1's Spatial Analysis Tools to classify and integrate various raster datasets. Findings reveal that the most favorable locations for wind energy exploitation are in Iraq's southeastern sectors. These zones are not only marked by vigorous winds averaging speeds over 6.2 meters per second but also benefit from their proximity to power grids, accessible roads, and gentle slopes, making them prime candidates for wind farm installation. The research also notes that regions with a high suitability index for wind energy development constitute 5.3% of the total examined area. This is a robust indicator of Iraq's capacity for wind energy utilization. Meanwhile, 79.7% of the territory received a moderate suitability rating, 9.5% was categorized as poorly suitable, and 5.4% was considered unsuitable for wind energy projects. These insights underscore the significant potential for harvesting wind energy in Iraq and guide strategic planning for its implementation.

Keywords: Wind Energy (WE), Multi-criteria, GIS, Iraq.

اختيار المواقع المناسبة لحصاد طاقة الرياح في العراق باستخدام تقنيات نظم المعلومات الجغرافية

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الخلاصة

طاقة الرياح هي استخدام توربينات الرياح لاستخراج الطاقة من القوة الحركية للرياح لتوليد الكهرباء. تعد طاقة الرياح من أهم مصادر الطاقة المتجددة ، وقد تم استخدامها على نطاق واسع كبديل للوقود الأحفوري وتعتبر مصدر وفير للطاقة المتجددة ، لكن توافره يختلف حسب الموقع الهدف في هذا البحث هو تحديد أفضل المواقع لطاقة الرياح في العراق لإنتاج الطاقة اللازمة للمستقبل من مصادر متجددة. تم استخدام تحليل متعدد المعايير لتحديد أنسب المواقع لحصاد طاقة الرياح باستخدام نظم المعلومات الجغرافية (GIS) وكانت أهم البيانات التي تم جمعها هي البيانات المناخية والتي تتضمن ملف RASTER لسرعة الرياح السنوية ودرجات الحرارة وهطول الأمطار. رطوبة التربة ودليل الغطاء النباتي NDVI (مؤشرالفرق الطبيعي للغطاء النباتي) ، الذي يغطي منطقة الدراسة على مدار الأربعين عامًا الماضية ، بالإضافة إلى ذلك ، تم استخدام ملف شيب فايل لكل (المسافة من خطوط الكهرباء والطرق والمدن والمنحدرات واستخدام الأراضي) ، حيث تم إنتاج نموذج مناسب يعتمد على أنظمة المعلومات الجغرافية عندما تم تصنيف مجموعة من مجموعات البيانات النقطية وتراكبها بواسطة أداة التراكب الموزون في أدوات التحليل المكاني في ArcGIS 10.7.1. أشارت النتائج إلى أن أفضل المواقع المناسبة لحصاد طاقة الرياح تقع في المناطق الجنوبية الشرقية من العراق. تتميز بنشاط الرياح بسرعة تزيد عن 6.2 م / ث. من ناحية أخرى فهذه المناطق قريبة من خطوط نقل الطاقة والطرق والمنحدرات معتدلة. لذلك اعتبرت هذه المناطق مناسبة لمزارع الرياح. بالإضافة إلى ذلك ، تمثل المواقع ذات مؤشر الملاءمة المرتفع 5.3٪ من المساحة الإجمالية ، وهو مؤشر هام على إمكانات العراق في حصاد طاقة الرياح. 79.7٪ من المنطقة لديها درجة ملائمة معتدلة ، و 9.5٪ لديها مؤشر ملاءمة ضعيف ، و 5.4٪ اعتبرت غير مناسبة.

1. Introduction

Renewable energy, set apart by its sustainability and non-polluting nature, contrasts sharply with traditional energy sources. Wind energy is emblematic of this distinction, having witnessed unprecedented growth and becoming integral to the global energy portfolio [1,2]. This surge in wind energy aligns with an expanding recognition of its role as a large-scale, endless energy source. GIS technology offers comprehensive, detailed analysis and visualization capabilities, providing actionable insights for policymakers. Researchers have made significant efforts to identify optimal locations for wind farms. They have employed different criteria, such as the average wind speed, to evaluate the feasibility and cost of building wind turbines [3]. Additionally, GIS-based studies have been instrumental in locating regions with high wind potential to mitigate pollution and combat global warming [4,5,6]. In these studies, GIS is not merely incidental but central to identifying high-wind areas conducive to reducing pollution and addressing global warming [7,8].

Furthermore, a hybrid approach that combines GIS with solar and wind energy data has been spotlighted in research, highlighting an effective and rigorous method for “multi-criteria decision-making” [9,10,11]. The success of wind farms depends on specific location planning, considering factors such as wind speed and proximity to critical infrastructure such as roads and power lines. [12,13]. Internationally, multiple studies have applied GIS alongside “multi-criteria decision” analysis, specifically the AHP, to ascertain the most appropriate sites for wind power facilities, emphasizing GIS's role in supporting decision-making for power station construction [14,15,16,17]. With the growing imperative for renewable energy, experts have performed field analyses to evaluate environmental impacts, acknowledging wind speed as a reliable indicator for site suitability [18].

Integrating AHP with GIS to determine the best wind farm location has been extensively studied in international scientific studies. Researchers examined wind energy development factors and how to use analytical models (GIS) to display land suitability to find the best wind farm layout [19,20, 21]. Recent global studies focus on energy harvesting. Meysam Asadi and colleagues used an (AHP) to find Iran's best wind farm sites in 2023 [22]. This research found an endless supply of clean energy in large areas, especially eastern Iran, which has flat terrain and high wind power density. Kama Aladdin and colleagues (2023) suggested a GIS-based Fuzzy Logic Method for Bangladesh site selection. Chittagong was the best location because 11% were acceptable and 25% were suitable for installation [23]. Djalili Messaoudi et al. (2024) examined turbine hub height in Algerian wind energy. Algeria has an estimated annual wind energy capacity of 1.093 Gt (without constraints) and 1.066 Gt (with constraints) [24]. Jayant Jangid (2016) employed GIS and spatial multi-criteria decision analysis for wind farm development projects. The results indicate that 11.06% of the research area is classified as having low suitability, while a more significant amount, precisely 17.06%, is categorized as moderately suitable. Furthermore, a significant proportion (12.20%) is highly suitable. The northwestern region of India, which includes Osian, Shergargh, Dechu, Shaitrawa, and Phalodi, has been identified as a highly advantageous area [25]. In 2023, Meysam Asadi created a program to choose optimal locations for wind power plants. The categorization utilized in this study provides a customized method precisely targeted to the national situation, as opposed to the broader classifications found in the global model [26]. Al-Ani and Altimimi used GIS to find Iraq's best solar energy extraction sites. The findings showed that southern Iraq is best for solar energy collection. [27]. In 2017, a multi-criteria analysis was employed to identify the most advantageous site for using solar PV and wind farms in the Sinai Peninsula. The study suggests that the northwest, southwest, and center regions of Sinai have significant potential for producing solar power [28]. Throughout the research conducted in Egypt, multiple aspects were considered to determine the most advantageous sites for energy extraction within the country. Notably, nearly all of Egypt's territory holds excellent potential for collecting solar energy, with varied levels of appropriateness. In 2017, a study identified the most favorable sites for harnessing solar energy in the Makkah metropolitan region. A multi-criteria GIS was employed for this objective. A multitude of physical and environmental geographic databases have been compiled. Based on the data obtained from the conclusive adequacy model [29], it can be concluded that all regions in Makkah are exceptionally suited for solar energy collection initiatives, exhibiting an average suitability rating of 80%.

The purpose of this paper is to choose appropriate wind farm sites based on several climatic, economic and environmental criteria in Iraq by analyzing 40-year GIS data. by applying a multifaceted set of climatic, economic, and environmental criteria to discern the most suitable locations for wind farm development in Iraq.

2. **“Material and Methods”**

2.2. Source of data

Data was collected from various sources to influence the criteria for selecting wind power farms. Climate data were the most significant data that were gathered. It contains a yearly wind speed RASTER dataset, temperatures, precipitation, soil moisture, and NDVI, covering the research region for the past 40 years. The (DEM) is one of the most required data for the study Using DEM, Typical morphological parameters of height and slope can be generated. In addition, after implementing the structure, GIS layers of economic parameters and protected area limits were combined with the approved geographic database. LULC (land Use/Land Cover) data as a server was utilized to download and extract the Iraq map. The last step of these processes was the collection of the above reclassified raster data. The weighted overlay tool works by grouping all raster layers based on weight. Table 1, determines the suitable area for wind harvesting, which is calculated based on merging the exclusion zone and the classified area into one map based on the calculated values to Identify suitable areas for wind farms.

Table 1: "Criteria used in wind speed suitability of weight overly"

No	Criteria	Weight%	factors	Suitability
1	Annual Wind Speed (50 m) high[5]	0.40	<4.2 m/s 4.2-5.2 5.2-6.2 >6.2	“Unsuitable Low Suitable Moderate Suitable High Suitable”
2	Slope, degree	0.20	1-3 % 3-7 7-10 10-82	“High Suitable Moderate Suitable Low Suitable Unsuitable”
3	Land cover/use	0.10	Water Bodies Other	Restructure “Suitable”
4	Distance from Cities	0.10	0-2 km 2-5 5-20 >20	“Unsuitable Low Suitable Moderate Suitable High Suitable”
5	Distance from Roads	0.10	0-0.5 km 0.5-5 5-20 >20	“Low Suitable High Suitable Moderate Suitable Unsuitable”
6	Distance from power line	0.10	0-0.5 km 0.5-5 5-20 >20	“Low Suitable High Suitable Moderate Suitable Unsuitable”

2.1 Statistical analysis

GIS includes a complex combination of software, hardware, and data designed to handle location-based information. GIS lets users input, process, analyze, and present geographical data [30,31]. In this study, GIS was used to identify optimal wind farm sites while excluding unsuitable areas like water, dense tree cover, and forests using weighted overlay analysis [33]. This model is needed to standardize values across diverse inputs for a cohesive analysis. It uses multi-criteria evaluation with multiple objective layers, so the analysis components are non-uniform. Units are assigned to grid cells, weighted, and aggregated to get the final weighted value. “Eq. (1)” shows how this process weights each criterion for each map location [34].

$$\mathbf{SI} = \sum_{i=1}^{n} v_i * w_i \qquad \dots\dots..(1)$$

where,
i is indicator,
n is the number of indicators,
vi is the normalized value of indicator i, and
wi is the weight of indicator i

The flowchart in Figure 1 provides a comprehensive overview of the GIS-based Multi-Criteria Decision-Making (GIS-MCDM) process employed to ascertain the most viable sites for wind energy installations in Iraq .

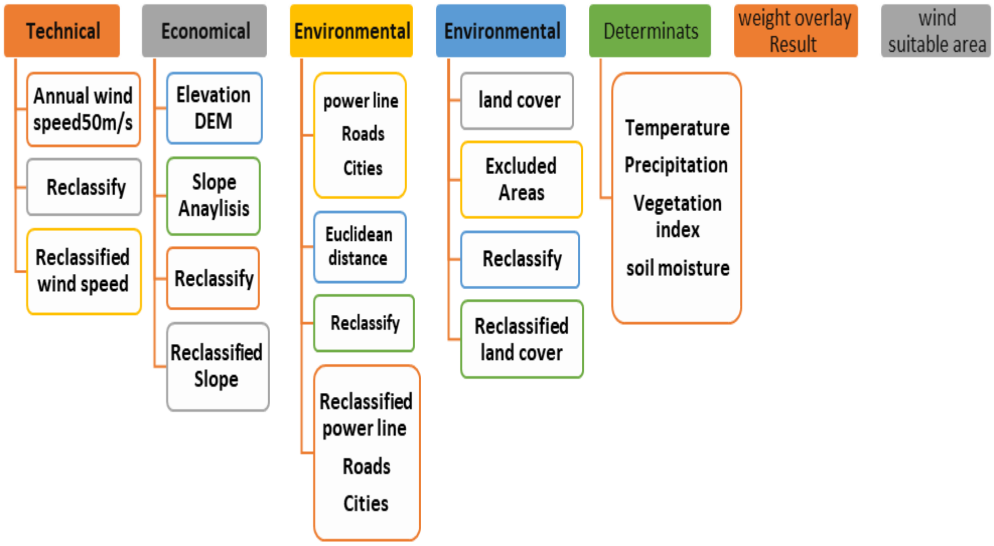


Figure 1: Framework for Identifying Suitable Wind Farm Locations using GIS.

The study employed a systematic framework incorporating a comprehensive, sequential mulit-criteria evaluation approach to pinpoint and identify the optimal sites for utilization of wind energy. The selection process began with a thorough assessment of technical factors, specifically emphasizing the annual wind speed at a standardized height of about 50 meters above the Earth's surface. This metric is crucial as it strongly connects with the potential energy output. Afterward, the raw wind speed data was classified to group regions into different categories based on their suitability for wind energy production. The economic criteria were examined next, with the elevation data obtained from the Digital Elevation Model playing a crucial role in assessing the topographical suitability for wind farm installations. The importance of elevation and slope in impacting wind speed and associated costs of building and running wind energy installations is well acknowledged. After conducting a thorough analysis of the slope data, the information was methodically classified, which played a crucial role in identifying the most suitable areas for wind farm development.

The site selection process considered critical environmental concerns. The proximity of candidate sites to existing infrastructure, such as electricity lines, roads, and urban areas, was estimated using Euclidean distance computations. Afterward, these distances were carefully categorized to emphasize areas that achieved a perfect balance between accessibility to infrastructure and the efficient use of development and maintenance resources. The selection process continued with a meticulous analysis of land cover. At this stage, certain regions were intentionally left out of the assessment for wind energy initiatives. These locations included various aquatic ecosystems, abundant vegetation cover, and specific conservation zones. The remaining land parcels were later categorized based on their suitability for wind energy infrastructure, resulting in a decrease in the number of potential locations.

The potential wind farm sites were carefully chosen after thoroughly assessing various factors, such as climate conditions and vegetation measurements. These factors included temperature, rainfall patterns, soil wetness, and the normalized difference in vegetation index. These factors play a crucial role in shaping the prevailing wind patterns, ultimately impacting the effectiveness of wind turbines. A thorough analysis was carried out using the GIS to complete the site selection process. This allowed for a detailed evaluation of various factors, identifying the ideal locations for wind energy projects.

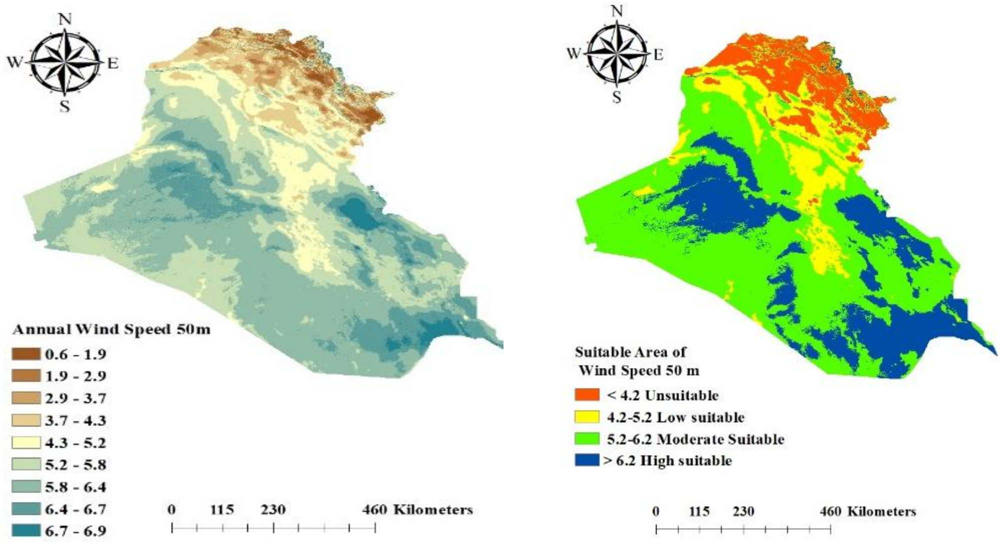
A suitability index map was created from the reclassified layers, weighting each criterion by its importance in determining wind farm site suitability. A thorough weighted overlay analysis completed the methodology. The chart showed zones in the study with the most wind energy potential. The interpretative phase turned the meticulous analysis into a site selection guide, providing a solid foundation for wind energy project development decisions.

3. Results and Discussion

Figure 2 presents the average wind speed (WS) at 50 meters above ground level, adjusted for surface roughness (SR) and based on the collected data. Economic feasibility is compromised for wind speeds below 4.2 m/s, therefore regions where the wind speed is less than 3 m/s were excluded from consideration (as illustrated in Figure 2a). Figure 2b depicts the reclassified average wind speeds tailored to the specific requirements of wind energy projects and the characteristics of the study area. Consequently, the mean wind speed data layer was categorized into four principal classes, detailed in Table 2. These range from regions of high suitability with WS exceeding 6.2 m/s, to medium suitability (5.2-6.2 m/s), to low suitability (4.2-5.2 m/s), and finally to the exclusion zones where wind speeds fall below 4.2 m/s.

Table 2: Reclassified wind speed in Iraq

Old Values Average wind speed in m/s	New values
< 4.2	1
4.2-5.2	2
5.2-6.2	3
>6.2	4



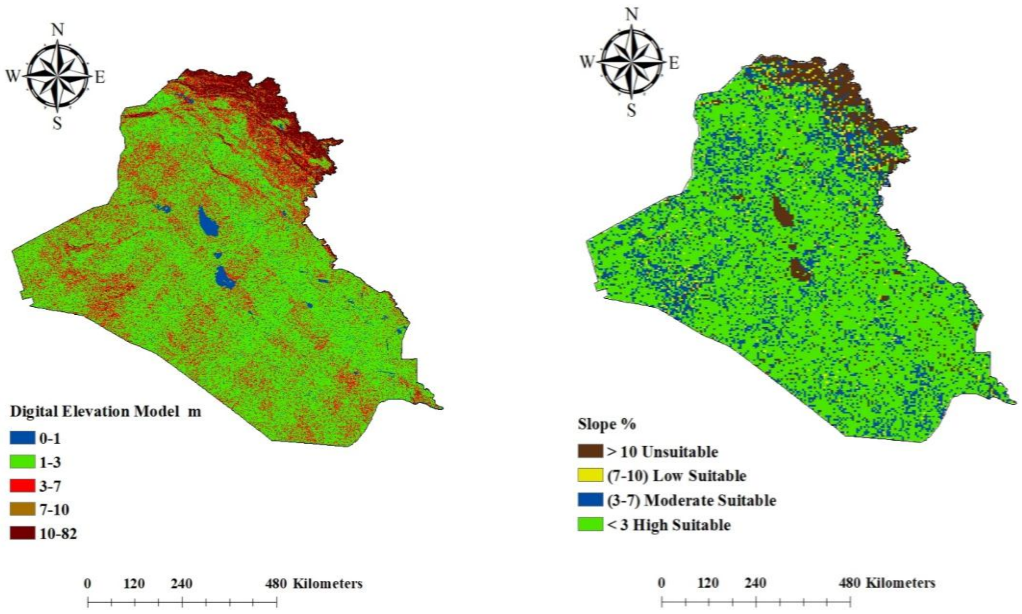
(a) (b)

Figure 2: The mean wind Speed at 50 M over Iraq (a)Annual wind speed, and (b) Reclassified wind speed

The second analysis criterion is the terrain slope plotted in Figure 3. Aslope layer was obtained from the Digital Elevation Model after using slope management until this map was obtained. The aim purpose is to look at the areas whose slope value is in the range (0-10) degrees, as shown in Figure 3a, where the areas with slopes less than 10 degrees are considered suitable for wind farms. While those ,with slopes more than 5 degrees create more turbulent wind patterns that interfere with the stability of turbines. The reclassified slope is shown in Figure3b From an economic point of view, building on high slopes increases project costs, so the terrain must be flat because it is exposed to more winds of constant speed. The inclination was classified into four categories: high degrees suitable (1-3 degrees), medium, low degrees (3 -10 degrees) and unsuitable degrees (> 10 degrees) See Table3.

Table 3: Reclassified Slope in Iraq"

Old Values Slope	New values
1-3	4
3-7	3
7-10	2
10-82	1



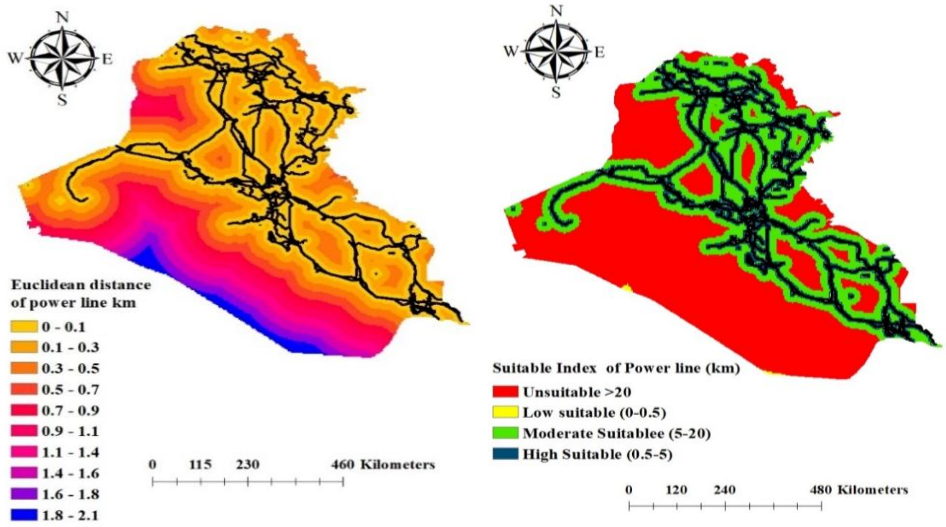
(a) (b)

Figure -3 "Suitability of Slope of Iraq (a) Elevation after using slope tool, and b) Reclassified of Slope " .

Figure 4 shows the distance between the transmission lines where the pattern was changed from a vector to a raster, using spatial analysis, which reclassifies the tool for these layers using the Euclidean distance tool to convert from a vector to a raster, as in Figure 4a. To evaluate the available areas that are considered essential economic factors in increasing costs or reducing production costs, the proximity to power stations must be considered when choosing suitable sites for building renewable energy stations to reduce production costs. Then, the transmission lines' separation distance was reclassified, as shown in Figure 4b, where the distance is necessary to transfer the energy generated from wind energy. At the same time, to reduce construction and maintenance costs. Therefore, the most appropriate locations are near the power lines and away from wind energy. Areas as appropriate for power stations as in Table 4 between the proposed distance of power lines, where the standards are set, and the distance of 0.5-20 km, accordingly. Finally, areas of less than 0.5 km from low-power lines are considered appropriate.

Table 4:"Reclassified distance power line in Iraq"

Old values distance power line (km)	New values
0-0.5	2
0.5-5	4
5-20	3
20-21.9375	1



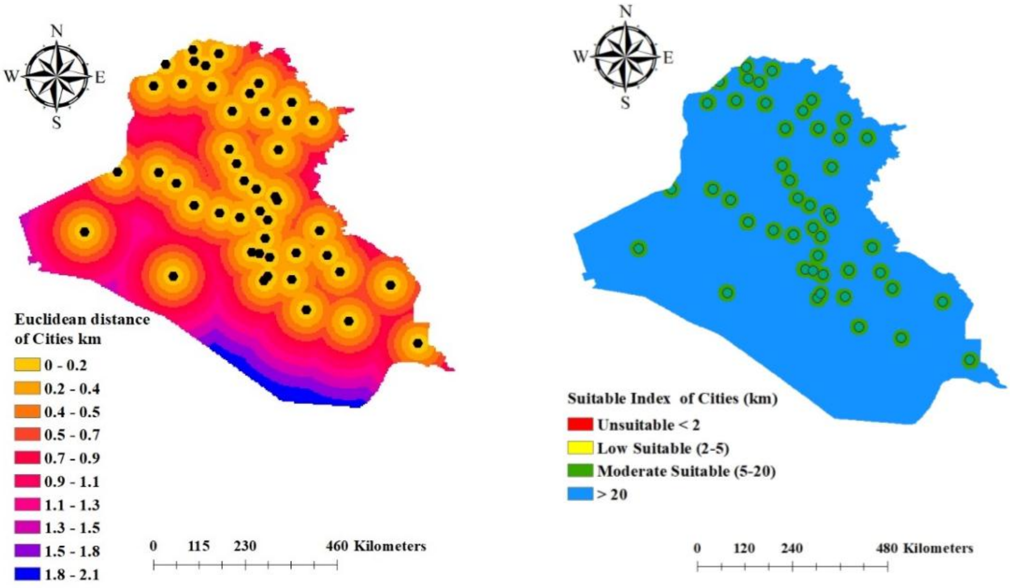
(a) (b)

Figure 4: Assessment of the appropriateness for distances from power lines : (a) The Euclidean distance of the power line, and (b) The power lines that have been reclassified

For cities ,it was also used the Euclidean distance tool, as seen in Figure (5a).The insulating layer has been reclassified into four classes as in Table (5) with a suitable high score greater than 5 km and not suitable When the distance is less than 2 km, it belongs to marginal fitting, and the middle fitting value is between (5-20), as shown in Figure (5b).

Table 5 :"Reclassified Cities in Iraq"

Old values distance of Cities (km)	New values
0-2	1
2-5	2
5-20	3
>20	4



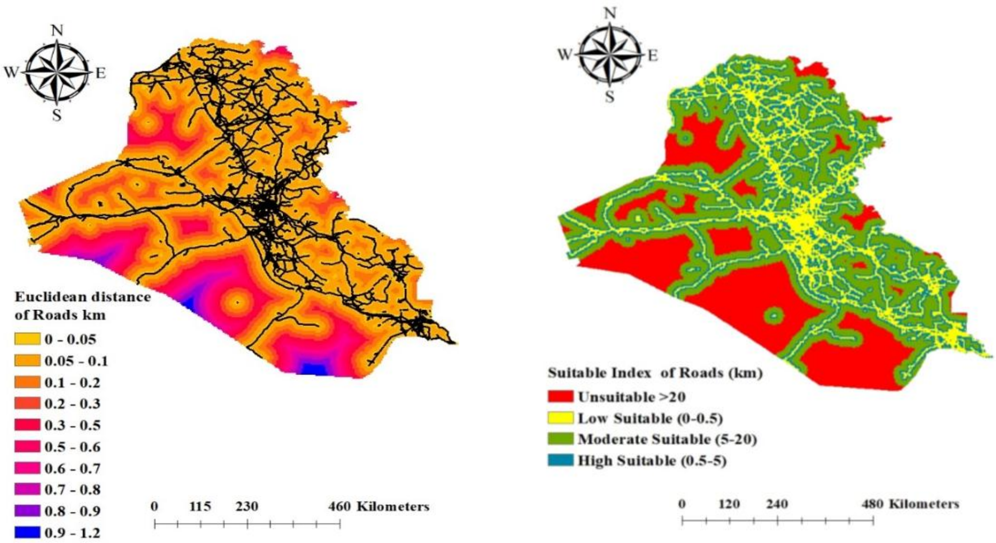
(a) (b)

Figure 5: Suitability of distances from Iraqi cities (a) Euclidean distance of Cities, and(b) Reclassified Cities**.**

Figure 6 shows the distance between the roads, which is considered one of the important criteria associated with renewable energy projects. The Euclidean distance was used (Figure 6a). The point layer of the main roads was reclassified into four categories (Figure 6b – Table

Table 6: Reclassified roads in Iraq

Old values distance of roads (km)	New values
0-2	1
2-5	2
5-20	3
>20	4



(a) (b)

Figure 6: Suitability of distances from the road of Iraq (a)Euclidean distance of Roads, and (b) Reclassified of Road"

The Classification of land cover raster layers is shown in Figure7. The agricultural areas were excluded in his analysis to choose the optimal locations for wind farms. Dry areas and soils are considered the best areas for wind activities, where the wind speed is high and essential for wind turbines within the permissible rate. As for the unsuitable sites, they are represented by mountains which are unsuitable sites to establish wind energy projects. Not only that, but water bodies, wetlands, and forests within the classification of areas are considered unsuitable. For this reason ,water bodies and trees were excluded and removed when using the weight overlay tool .

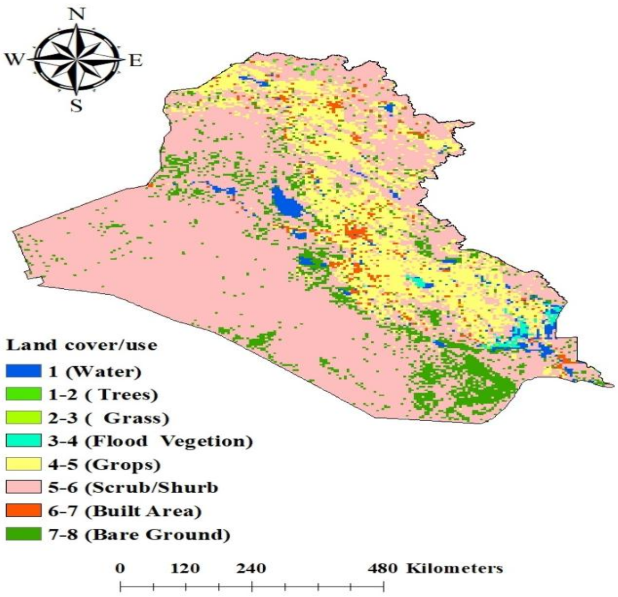
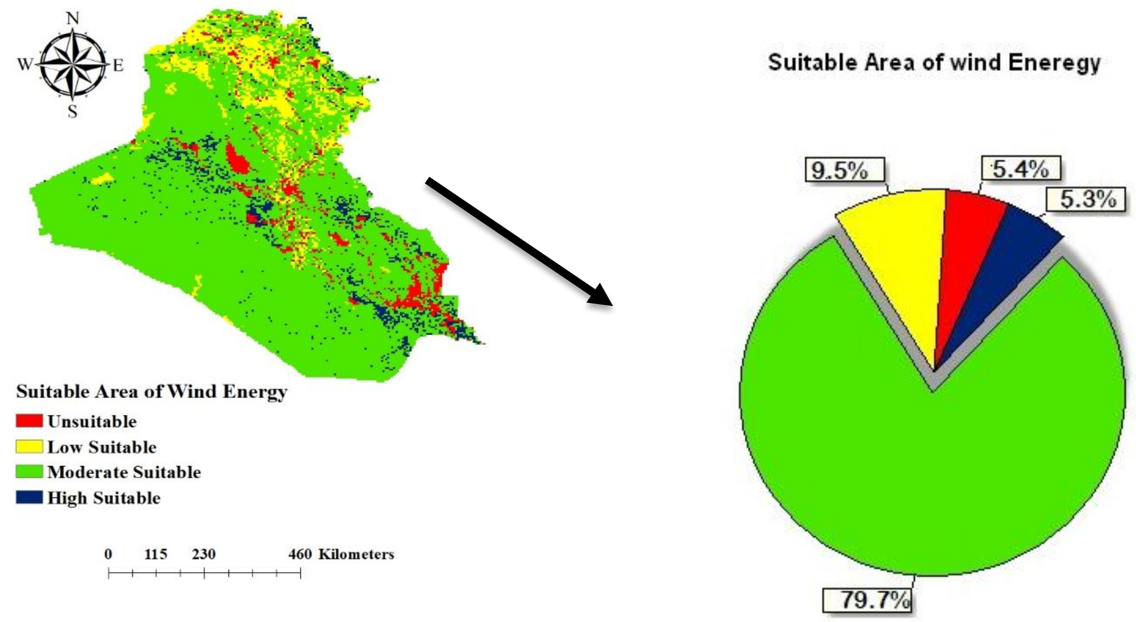


Figure 7: Land-cover classification

To obtain the final site fit map, all datasets were combined, and the final result was calculated from a raster format so that the result could be specified pixel by pixel. The final result (Figure 8) shows that the south-eastern region of Iraq was considered more suitable for wind harvesting (Figure 8a), has high wind speed, a moderate slope, closeness to grid lines and major roads, and is far away from the city. After excluding the areas of water bodies and forests, four regions were obtained, ranging from the most suitable to the unsuitable regions for wind harvesting. Figure 8b and Table 7 show the percentage of the regions and their area where 5.3% for higher suitable, 79.7% for the moderately suitable ,9.5% for the low suitable and 5.4% for the unsuitable regions.

Table 7: "Percentage of wind harvested areas"

Area classification	Percentage %
"Unsuitable"	5.4%
"Low Suitable"	9.5%
"Moderate Suitable"	79.7%
"High Suitable"	5.3%



(a) (b)

Figure 8: The suitability for wind energy harvesting (a) the suitable areas, and (b) the percentage of suitable areas.

4. Conclusion

The presented research concludes that wind farm locations in Iraq are feasible and its methodology is reflected in the consecutive conclusions. The study identifies wind energy development hotspots using GIS analysis of multi-decadal data. To clarify the research's result, these findings are presented:

1. Utilizing the analytical strengths of Geographic Information Systems (GIS), this study has identified and characterized suitable sites for wind farm development across Iraq, anchored in a robust evaluation of data spanning four decades.
2. The systematic use of a weighted overlay tool, based on six key criteria, has been crucial in identifying the most suitable regions for wind energy projects. Special attention has been given to excluding areas with water bodies and dense tree coverage, which are not conducive to such developments.
3. The southeastern regions of Iraq have emerged as the most advantageous for wind energy management. This suitability is attributed to several factors: the consistency of wind speeds surpassing the 6.2 m/s threshold, essential for the efficient operation of wind turbines; the gentle terrain slopes that facilitate construction and minimize installation risks; and the relatively low population density, which diminishes land-use conflicts and simplifies land acquisition for development.
4. The selected regions' proximity to existing infrastructure is another significant advantage. The strategic location near power transmission lines and road networks can lead to substantial cost savings in material transport, construction, and maintenance operations. These logistical benefits are crucial for the initial setup and the ongoing upkeep of wind energy facilities.
5. As the push for a sustainable energy future gains momentum globally, the insights provided by this study serve as a strategic guide to harnessing Iraq's renewable resources. The potential for wind farm development in these areas is poised to drive economic growth, foster job creation, and propel Iraq's renewable energy ambitions forward.

This analysis represents a preliminary effort and will be associated with future works. The groundwork placed by this research prepares for subsequent, more detailed investigations that will refine our understanding and application of GIS in renewable energy development. The commitment to continuous improvement and the incorporation of additional data and advanced methodologies will enhance the robustness of our conclusions and assist in the strategic planning for Iraq's sustainable energy future.

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