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Environmental Planning and Spatial Modeling for Wind Energy Farm Sites (Case Study: Najaf Secondary Region)

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ABSTRACT

The transition to renewable energy is not merely a technical option; it is a fundamental element in making and shaping policies for achieving sustainable development in the energy sector. This achieves a degree of integration among economic, environmental, and social urban policies in the secondary Najaf region. The use of renewable energy for wind farms, contributes to providing energy for human activities and various processes, by harnessing kinetic energy from wind movement to generate electrical power through the operation of wind turbines, wind energy undergoes a transformation from mechanical energy to electrical energy, meeting the energy demands of urban centers and rural areas. Therefore, this study aims to introduce a renewable energy source from wind energy, as a solution to the current and anticipated electricity deficit in the study area. In addition to contributing to urban development, agriculture, environmental conservation and related fields. This research adopts for multi-criteria decision-making (MCDM) methodology within the geographic information system (GIS) to identify the most suitable spatial location. As a result, the study has identified appropriate and efficient sites for wind farms, through establishing planning and design criteria and standards for wind farm development. The proposed design includes a well-planned wind farm covering 40.3 Km^2, equipped with 99 turbines, capable of producing 198 Mw of electrical energy to alleviate shortages and meet future energy demands.

1. INTRODUCTION

Continuous environmental pollution due to the use of traditional methods of electricity generation and insufficient electrical energy for the population has led to environmental destruction and increased pollution. This has given rise to the concept of sustainability through the utilization of natural and renewable resources to increase energy production in an environmentally safe manner [1, 2]. The conflicts and wars between countries over the control of fossil fuel resources, along with the rising costs and depletion of these resources, have led the world to consider utilizing different energy sources. Electric power has become integrated into various aspects of human life such as communications, hospitals, lighting, roads, transportation, cooling, and many other diverse fields where electric energy is indispensable [3-6]. Wind energy is one of the renewable energy sources for electricity generation, serving as an effective alternative to fossil fuels, oil, and natural gas, which are environmentally harmful due to the toxic gases they emit when burned [1, 7, 8]. Kinetic energy from wind is harnessed to generate electricity by moving wind turbines to convert wind energy into mechanical energy, which is then transformed into electrical energy to power devices [3-6].

The use of wind energy generated by turbines has increased due to the extended lifespan of wind turbines exceeding 20 years [8, 9]. Global wind energy production reached over 93.6 GW in 2021, with an expected addition of 557 GW in the next five years to reach between 10-31% by 2050 [6, 8]. In Arab countries, particularly in Iraq, there is a lack of clear application for wind energy generation due to limited studies focusing on its development and utilization, with more emphasis on solar energy generation. Historically, ancient civilizations utilized wind energy for various purposes; the ancient Egyptians used it to propel boats on the Nile, Mesopotamian civilizations used it for grinding grains, and the Chinese used it for water pumping, indicating its longstanding recognition across different civilizations [3, 5, 6].

The provision and reliance on renewable energy from wind farms will provide a less polluted environment, bridge the gap in electricity supply, and deliver power to rural areas far from conventional power plants [8, 10]. Thus, one of the key objectives of sustainable development is achieved by enhancing its role in the development of renewable energy. This is highlighted in the seventh goal of the Sustainable Development Goals, which emphasizes the importance of ensuring access to modern, safe, sustainable, and affordable energy for all. This indicates that countries, companies, and individuals are committed to promoting the development of renewable energy, such as solar, wind, and hydroelectric power. As a result, renewable energy technologies have gained significant importance in advancing sustainable development, which seeks to meet the demands of the current era without compromising the future [11]. Therefore, the importance and goal of selecting a suitable spatial location for establishing sustainable energy stations, particularly wind farms, to address the existing shortfall in electricity supply, reduce reliance on fossil fuels, and mitigate harmful emissions on the environment [7, 12, 13]. To select the best suitable location for wind energy farm placement, all necessary spatial signature criteria were considered to ensure the effectiveness of generating and utilizing this energy to bridge the existing gap in electricity supply in the secondary province of Al-Najaf Al-Ashraf.

2. CONCEPTUAL FRAMEWORK

2.1 Energy and renewable energy concept

Energy is a standard physical quantity that describes the amount of work that a force can do. There are various forms of energy, including kinetic, potential, thermal, gravitational, sound, light, elasticity, and electromagnetic energy. Forms of energy are often named after a related force. Energy can be converted from one form to another [3, 6]. The most prominent types of energy and their transformations are discussed in the generation of renewable electricity through wind kinetic energy.

Renewable energy is defined as natural, sustainable, inexhaustible sources available in nature, continuously renewable as long as life exists. By harnessing renewable energy sources, we can utilize non-renewable energies in petrochemical industries and other important industries instead of burning and wasting them as fuel. Given the environment's significance today as a component of rational resource utilization and a fundamental variable of sustainable development, it must be protected from negative effects resulting from pollution and its impacts on humans, climate, and the entire ecosystem. Hence, the need for reliance on renewable energy has emerged, characterized by being local, natural, environmentally friendly, renewable, low-cost in production, and also serving as a decentralized energy source providing users with independence from the central power grid, in addition to achieving various social, environmental, economic, and urban benefits [3, 4, 14, 15].

2.2 Wind energy concept

Winds are the horizontal movement of air above and near the Earth's surface, primarily resulting from the Earth's rotation around itself and horizontal and vertical differences in air pressure and temperature. Winds always move in an accelerating motion from areas of high air pressure to areas of low air pressure. They represent a form of solar energy due to uneven distribution of sunlight on the Earth's surface, causing some parts to be warmer than others. Warm air, being lighter than cold air, rises to higher layers while cold air descends. Varied terrains and bodies of water absorb sunlight unevenly, leading to uneven heating of the Earth's surface, resulting in the formation of winds [3, 14, 15]. Coastal winds can be generated by the temperature capacity difference between land and sea. During the day, sea breezes are created as the land heats up faster than the sea, causing the sea to be cooler, leading to the formation of cool air currents along the coast. At night, land breezes are generated as the cooler air moves from the land to the sea, moderating the sea's temperature [3, 16].

Wind movement generated by various factors drives the rotation of wind turbines or generators of electrical energy, where Wind energy is converted into electrical energy. Humans have shown significant interest in wind due to its impact on various aspects of life and activities, with every aspect of life being influenced directly or indirectly by it. The energy generated from wind is greatly influenced by wind speed and direction. The stronger and more prevalent the wind in the region, the more potential there is to harness it for generating electrical energy [12, 14, 15]. Especially when the wind speed ranges between 6 – 6.5 m/s at a turbine height of 80 M [17], Various factors such as ground roughness, obstacles, and terrain elevation also affect wind energy generation [3, 12, 18].

2.3 Wind turbines

Wind turbines are rotary machines that convert the kinetic energy from the wind into mechanical energy. This mechanical energy can be used directly in some machines to perform specific tasks such as pumping water or grinding grains, where the machine is called a windmill. If the mechanical energy is then converted into electricity, the device is called a wind turbine generator or Wind Power Unit (WPU) or Wind Energy Converter (WEC) [19, 20]. The amount of energy generated from the wind depends on the wind's power capacity to convert wind energy into a useful form of energy such as electricity. The generated power can be connected to the electrical power grid or small turbines can be used to provide electricity to remote areas [2, 3, 6, 14]. Wind turbines have a special design that helps harness wind energy through blade design and control systems [3, 6]. The electricity is produced by the wind's kinetic energy rotating the blades attached to the turbine. The blades are mounted on a rotor supported by the main rotating shaft connected to a gearbox that increases the rotational speed. The motion is then transferred to the fast-spinning shaft, cutting through a magnetic field inside the electric power generator, resulting in electricity generation [2, 3].

The electrical power generated from wind energy is directly proportional to the amount of wind blowing and moving the turbines. When the wind is calm, the electrical power decreases, which is considered in generating electrical energy [6, 14]. Different types of wind turbines exist based on their characteristics, such as their connection to the power grid, axis of rotation, speed regulation, installation location, number of blades, wind-facing angle, blade position, and usage. A prominent classification of wind turbines is based on their installation location, categorized as offshore or onshore turbines, depending on the features of the studied area, including the presence of seas [3].

2.4 Wind farm

2.4.1 Wind farm concept

It is a group of wind turbines in the same location used to generate electricity. It consists of several tens to several hundreds of individual wind turbines, covering an extensive area of hundreds of square kilometers. The wind turbines are connected to each other through a medium voltage energy collection system in a substation. The average electrical current voltage is increased using a transformer to connect it to the high voltage power transmission system [3, 6]. What distinguishes these wind farms is the ability to use the land between the wind turbines for agricultural purposes or other uses [21]. Wind farms can be located on land or in seas and oceans away from the shore to take advantage of the strong winds blowing over them. Marine winds tend to flow faster and stronger than winds on land because the surface roughness of the sea is less than that on land, and there are no obstacles or barriers to hinder the wind flow. Consequently, this allows the turbines to generate more electrical energy [16].

2.4.2 Planning and design of wind farms

Several planning and design criteria must be considered when planning wind farms, including determining the distance between turbines. Factors such as prevailing wind direction within the farm, turbine quantity, turbine layout pattern, and turbine characteristics play a crucial role. To economically harness energy efficiently, turbines should be positioned in a natural distribution pattern, arranged in staggered rows perpendicular to the wind direction. The distance between turbines within the farm is preferably 3-6 times the turbine diameter, while the distance between rows ranges from 5-10 times the diameter. Leaving adequate spacing between turbine arrays allows sufficient room for wind to compensate for speed reduction due to turbine collision, reducing wake turbulence, noise, and sunlight reflection caused by turbine blade rotation [8, 21, 22]. Each array is connected by cables to gather electrical energy produced, which is then collected and converted by transformers before being integrated into the existing power grid in the studied area. All turbines within the wind farm are linked to monitoring and control systems through computer programs to detect and identify issues, enabling individual turbine control without the need for specific fault diagnosis and maintenance [3]. Table 1 shows a set of criteria and indicators for designing and planning wind farms, which will be applied in the study as inputs using geographic information systems (GIS) to analyze the earth's layers and find elevations, slope ratios, wind speeds, the spread of urban agglomerations, and other analyses related to environmental planning. As a result, after advanced stages of analysis, geographic information systems will support the decision maker in choosing the best decision, or what is called (Optimal Decision) [23].

3. MATERIALS AND METHODS

3.1 Study area

The province of Najaf Al-Ashraf covers an area of 29567.47 Km^2, with the secondary region of the province covering 3592.13 Km^2. The study area represents 12.15% of the total area of Najaf Al-Ashraf province. Geographically, the study area is located between longitudinal lines $43°36'37.13"E - 44°37'43"E$ and latitudinal lines $31°37'5.3"N - 32°22'13.9"N$. The secondary region of Najaf Province is situated west of Iraq, bordered by Karbala Province to the north, Babil Province to the east, and Qadisiyah Province to the southeast. The study area extends westward until it reaches the lowlands of Najaf Sea to meet its borders with Al-Shabaka district. The secondary region serves as a transitional area between two natural regions, the alluvial plain and the western plateau. Administratively, Najaf city serves as the center of Najaf Al-Ashraf province, which includes 4 districts and 7 sub-districts, as shown in Table 2. The study area (the secondary region of Najaf Al-Ashraf province) encompasses all mentioned sub-districts except for Al-Shabaka sub-district in Najaf district, which was excluded from the study due to being a vast desert area devoid of dense and regular human settlement.

Table 1. Indicators and criteria for designing and planning wind farms for electricity production

N	Index	Schematic Indicator	Design Indicator
1	**Winds**	A site with wind speeds of 6-6.5 m/s or more [17]. A site with a wind energy density ranging between **200-400 W/m^2** [1, 6, 7]	Distribute the turbines stacked in opposite rows and perpendicular to the direction of the prevailing winds, which is in the study area (northwest and north direction) [8, 14, 21]
2	**Connection to the electrical network**	The wind farm should be close to high pressure lines at a distance of **100-1000 m** [8, 22, 24]	The closer the wind farm is to the electrical transmission network, the better to reduce the costs required to connect to the main electrical network (high-pressure lines) [8, 18]
3	**Distance from current and future residential areas**	The distance from residential areas ranges between **1000-2000 m** to avoid noise resulting from air friction with turbine fans and sunlight reflections resulting from the rotation of turbine blades [1, 7, 8, 13, 22]	When wind farms are located away from current and future residential areas, it becomes more advantageous due to the noise and visual impact they produce on cities. However, maintaining a certain distance is essential to avoid the costs of electricity supply and loss of energy to housing [7, 22]
4	**Proximity to transportation routes / main roads**	The wind farm must be at a distance of **> 500 m** from the main roads and not far away from them [1, 8, 22, 25, 26]	The closer the wind farm to the main roads, the greater the preference, due to the noise and simple visual impact caused by wind farms on the one hand, and the need for easy access on the other hand to transport and maintain the turbines [7, 22]
5	**Distance from areas of importance**	Wind farms should be **> 2000 m** away from areas of interest [10, 22, 26]	The further away the wind farm from areas of interest, whether environmental, economic, tourist or other, the greater the preference [10, 22, 26]
6	**Distance from airports**	The wind farm should be **> 3000** m away from airports [1, 7, 10]	The further away the wind farm from airports of all kinds, the greater the preference, to avoid the risk of aircraft colliding with wind turbines when taking off

			and landing [1, 7, 10]
7	**Obstructions**	Terrain: The change in elevations of the Earth's surface around the site affects the speed and direction of the wind and this effect may be positive or negative [3, 18]. Slope: Wind farms sign on flat land with little slope in areas with a slope **< 15%** [1, 8, 25, 27], with a maximum slope of 30% [18, 22]	Land roughness: that is, the quality of the land such as seas, oceans, valleys, sandy and agricultural areas, cities and every surface has a different impact on wind speed, as it has the highest impact in dense forests and the least impact on water bodies [18]. Obstacle: Affects wind speed like residential buildings, so stay away from obstructions to avoid their impact [3, 18]
8	**Soil**	Clay and erodible soils are unsuitable for wind farm signatures [8]	The optimal location for a wind farm is on rocky or sandy clay soil [8]
9	**Bodies of water, Rivers and Springs**	Wind farm sites should be **> 2500 m** away from water bodies [1, 7], and the construction is prepared on a 5 m strip around all water bodies [22]	The further away the wind farm from areas of water bodies, the greater the preference, and the reason for that is the damage that can be caused to the water environment and its edges, noise and visual impact on the population [22]
10	**Distance from Birding trails and areas**	Wind farm locations should be **> 500 m** away from bird trails [1, 7, 8, 22, 25]	The more the avoidance of birds movement paths, the greater the preference, and the reason for this is that the signature of wind farms on the paths of birds may cause birds to abandon their environment and extinction
11	**Land Cover**	Agricultural land, built-up area, water, and wetlands are not suitable for the signature of wind farms [8]	The further away the wind farm from orchards, farmland, and forests, the greater the preference [8]
12	**Turbine Height**	The height of the tower is determined according to the wind speed in the area for many reasons, as well as the increase in the height of the tower increases its effectiveness, and the average height ranges between **50-100 m**. A turbine model with a height of **80 m** has been approved [12, 18, 19]	Adopt 78 m tower axis height, which is suitable for optimizing energy utilization with study area characteristics [8, 18]
13	**Size and capability**	The capacity of the small turbine is 10 KW, which generates 16,000 KW/h, and the large turbine generates about 1.8 MW, and the study suggested relying on the latest model of wind turbines is Vestas V80 or Gamesa G87, which has a capacity of **2 MW** [8, 18]	Approving the diameter of the rotation fan in the wind turbine 87 m [8, 18]
14	**After one turbine from the other**	In this study the adoption of the spacing between the wind turbines **500 m** between the columns and **700 m** between rows [8, 18]	The distance between the turbines vertically ranges between 3-6 times the diameter of the turbine, and the distance between the rows ranges between 5-10 times the diameter [8, 22]

Table 2. Administrative units and area of Al-Najaf Al-Ashraf Governorate and the secondary Najaf region

N.	Name	Governorate Area (Km^2)	Percentage (%)	City Area (Km^2)
1	Al-Najaf	186.23	0.63	169.62
2	Al-Hiadaria	1324.93	4.48	13.32
3	Al-Radawia	233.84	0.79	10.63
4	Baniqia	913.61	3.09	21.74
5	Al-Shabaka	25,975.35	87.85	2.15
6	Al-Kufa	97.09	0.33	49.88
7	Al-Abasia	219.03	0.74	8.67
8	Al-Heria	103.58	0.35	6.01
9	Al-Manadra	51.22	0.17	24.68
10	Al-Hirah	126.17	0.43	5.39
11	Al-Meshkhab	111.91	0.38	11.65
12	Al-Qadisia	224.51	0.76	4.07
	29,567.47	**100%**	**327.80**	
	3592.13	**12.15%**	**325.65**	

Studying the secondary region of Najaf is important, especially with the concentration of all human activities in it, including large urban areas, water resources that sustain the inhabitants, agricultural and desert lands, industrial areas, and other natural and human resources. With the global trend towards using renewable, clean, and highly efficient energy, the establishment of a wind farm is proposed in this research to address the shortage of electricity, especially with the emergence of the new Najaf city north of the current Najaf city as shown in Figure 1.

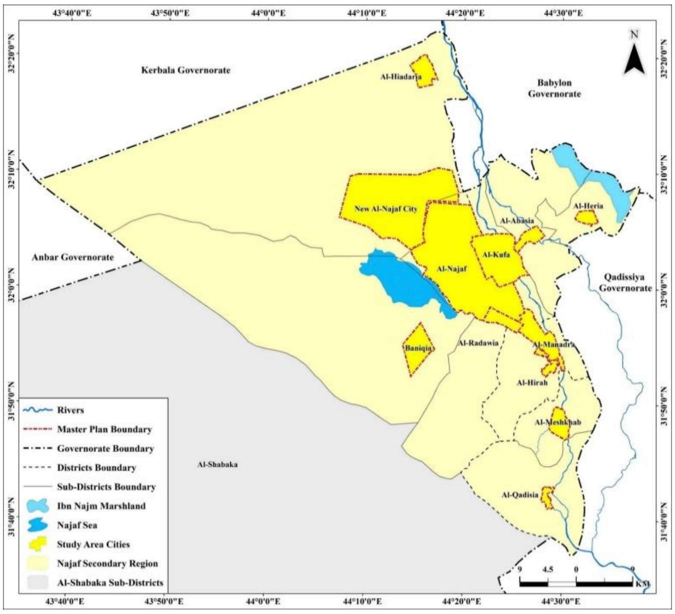

Figure 1. Secondary region of Najaf Governorate
Source: Researcher using Arc GIS 10.8, and based on the Iraqi Ministry of Planning, Directorate of Regional Planning and Development, Najaf Planning Directorate, 2024.

3.2 Data collection and methods

3.2.1 Data sources

A dataset was adapted from various sources, including the internet, government departments, previous studies, Arabic and foreign books, as well as the visual of Al-Najaf Al-Ashraf Governorate for the year 2023, the global wind atlas visual, and the digital elevation model for the year 2023. These sources included numerous indicators and criteria that define and illustrate the process of selecting and designing wind farms. Arc GIS 10.8 software was utilized to implement work on the secondary region of Al-Najaf Al-Ashraf Governorate.

A survey was conducted by a group of experts to determine the indicators and weights of the criteria before applying them to the study area for establishing wind farms. These experts included managers and employees of government departments (the Planning Directorate of Najaf, the Electricity Directorate of Najaf, and the Urban Planning Department in Najaf Governorate), as well as specialized professors. The wind farm site was identified using geographic information systems by matching the weights of the adopted indicators with the percentage and significance of each weight. The necessary data for the study was collected from December 2023 to February 2024.

3.2.2 Research methods

There are several specific criteria for locating wind farms in any region, and the use of these criteria varies according to the natural and physical environment of the studied area. Therefore, the research included adopting a set of important criteria and indicators for the location of wind farms, which were derived from the conceptual framework and previous studies [1, 7, 8, 22, 28-30]. Eleven spatial criteria were adopted to determine the suitable spatial location for wind farms, applied to the secondary region of Al-Najaf Al-Ashraf Governorate. The proposal to establish a wind farm aims to address the shortage in providing electricity from traditional sources, as well as the potential use of these farms to promote the shift towards renewable energy and establish farms between turbines for recreational, agricultural, economic, and touristic purposes, generating energy using solar panels and other benefits of wind farm establishment [21].

The research presented a set of criteria and factors. Each criterion will be divided into weights according to its degree of importance and priority, assigning a specific weight to each criterion based on its importance as determined in the spatial signature process of the wind farm site and the specific environmental conditions of the region and its components for wind farm establishment. The weights were established based on input from a group of experts, the region's specificity, and logic. The suitability process is implemented to determine the most suitable sites and their required area for signing wind farms using the geographic information systems program (Arc GIS 10.8) based on multi-criteria decision making (MCDM). Geographic information systems are an effective and efficient tool that is of great importance in analyzing spatial data and evaluating multiple options to achieve effective visualization, which contributes to supporting planning decision-making to achieve integration between spatial and descriptive data for any region, especially the study area, in order to reach the most efficient and priority scenarios within the effective planning decision [23], and based on Figure 2 that defines the study stages and Table 3 that shows the criteria adopted in signing wind farms in the secondary Najaf region.

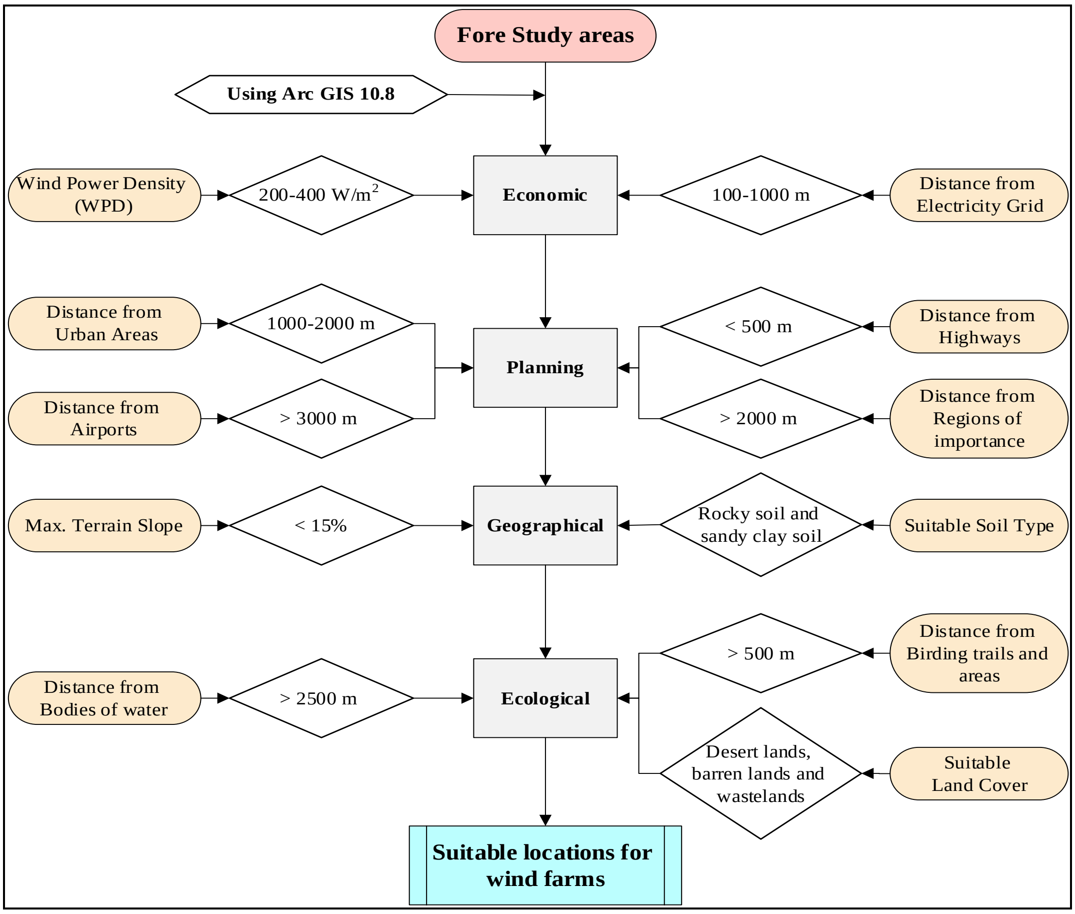

Figure 2. Study criteria to select a location for wind farm

Table 3. Criteria for selecting an appropriate location for a wind farm

N.	Criteria	Criteria Type	Preference	Criteria Value	Percentage Importance
1	**Wind Power Density (WPD)**	Economic	Proximity to areas with high wind power density	The WPD should range between **200-400 W/m²** [1, 6, 7]	21.6%
2	**Electricity Grid**		Proximity to electrical power transmission lines (high voltage lines)	The electricity network must be, within **100-1000 m** [8, 22, 24]	16%
3	**Urban Areas**	Planning	Distance from current and future housing	The Urban Areas must be, within **1000-2000 m** [1, 7, 8, 13, 22]	18.5%
4	**Roads/ Highways**		Proximity to Main transportation roads (Highways)	Distance of **< 500 m** from main roads is not suitable [1, 8, 22, 25, 26]	9.5%
5	**Regions of importance**		Distance from Regions of importance	Distance from Regions of importance > **2000 m** [22, 26]	5%
6	**Airports**		Distance from Airports	Distance from Airports **> 3000 m** [1, 7]	3.5%
7	**Terrain Slope**	Geographical	Flat land	Areas with a Slope **< 15%** are suitable [1, 8, 25, 27], and the maximum Slope **30%** [18, 22]	4.6%
8	**Soil**		Rocky soil and sandy clay soil	Clay and erodible soil are not suitable [8]	5.3%
9	**Bodies of water, Rivers and Springs**	Ecological	Distance from Bodies of water, Rivers and Springs	Distance from Bodies of water **> 2500 m** [1, 7], and it is prohibited to build on < **5 m** strip around them [22]	4%
10	**Birding trails and areas**		Distance from Birding trails and areas	Distance from Birding trails and areas > **500 m** [1, 7, 8, 22, 25]	5%
11	**Land Cover**		Desert lands, barren lands and wastelands	Agricultural land, orchards, forests, built-up area, water, and wetlands are unsuitable [8]	7%
				SUM	**100%**

Source: The researcher based on the indicators of the conceptual framework and previous studies.

4. RESULTS

After identifying the key planning and design indicators for applying spatial suitability standards for wind farm locations as determined by the research, we arrive at the following:

4.1 Spatial suitability of wind farm location

The study identified eleven criteria for wind farm siting that will be applied to the study area.

4.1.1 Wind Power Density (WPD)

Wind Power Density (WPD) is a measure that determines the amount of wind energy that can be accessed in a specific area by relating wind speed to its density. The available wind energy is linked to air density, with energy increasing as air density rises. Air density is determined by air pressure and temperature, increasing with higher air pressure or lower temperatures. WPD is measured in watts per square meter (W/m²), where higher WPD values indicate greater energy potential that can be harnessed by wind turbines at that location.

Wind energy density is an effective indicator to identify which locations in the study area contain the necessary energy to rotate a wind turbine. A wind energy density of 200-400 watts/m^2 or more is sufficient, especially when wind turbines are directed towards the prevailing northwesterly and northerly winds in the study area. The Global Wind Atlas (GWA) was utilized to assess the available wind energy at a height of 80 M, using the latest model of wind turbines such as the Gamesa G87 with a capacity of 2 MW for generating electricity in wind farms. Figure 3 shows that the lowest wind energy density is in the southern and southwestern parts, reaching 143 watts/m^2 due to lower ground elevation, agricultural land, and orchards hindering wind movement. In the northern areas, the wind energy density increases across all parts, reaching 410 watts/m^2, especially in the Al-Haidariya district. Overall, all lands in the study area are suitable for wind energy generation, categorized based on wind energy density with higher ratings given to areas with high wind energy density (10) and lower ratings (1) for areas with low density.

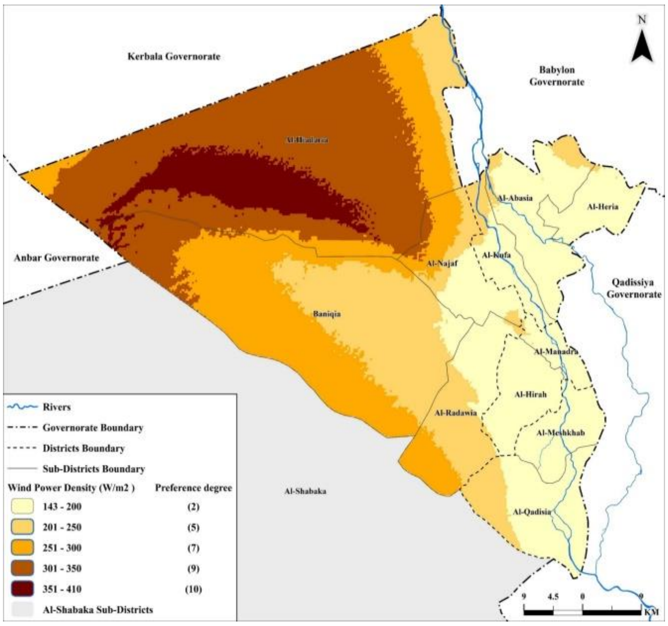

Figure 3. Wind energy density in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 [6].

4.1.2 Electricity grid

The proximity between high-pressure power lines and wind farms is crucial to reduce the costs of connecting the wind farm to the main power grid and minimize energy loss during long-distance transmission. The longer the energy transmission distance, the higher the costs of cable supplies and the greater the loss of electrical energy [8]. Wind farms should be located near the power grid and connected either to the 110 kV high-pressure network or to the very high voltage network of 220 and 380 kV, depending on the number of wind turbines and the size of the planned farm. Wind farms generating large amounts of energy exceeding 10-15 Mw are connected to the high-pressure network with the construction of a substation [22].

Therefore, wind farm developers should expect to be located near power supplies within a range of 100-1000 M. The costs increase and the priority decreases as we move further away. The distance from the high-pressure power lines intended for connection has been categorized into classes using the Euclidean Distance tool, assigning a higher rating to closer distances (10) and a lower rating (1) to distant areas, as shown in Figure 4. This demonstrates the suitable spread of high-pressure lines in the study area for wind farm placement.

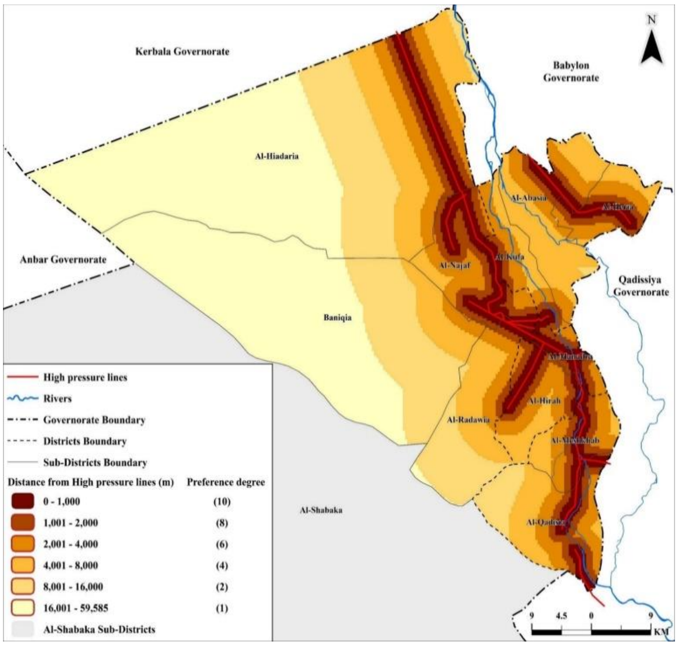

Figure 4. Distance from high pressure lines in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and on the Najaf Electricity Directorate.

4.1.3 Urban areas

Signing wind farms in urban areas or near them may cause disturbance to residents due to the noise generated by wind turbines as a result of air friction with turbine blades, and the minimal visual pollution resulting from sunlight reflections caused by the rotating turbine blades. The maximum allowable sound level in residential areas has been set at less than 30 dB [22]. These issues can be avoided by signing wind farms at a distance from residential areas ranging from 1000-2000 M without straying too far from cities. The further we relatively move away from current and future residential areas, the more advantageous it becomes to avoid costs of electrical power supplies, energy losses reaching homes, support urban expansion, and provide energy for them. The study area has been divided based on Euclidean Distance tool into categories, giving the highest rating to relatively close areas (10) within the range of 1000-2000 M, and the lowest rating (1) to distant areas and areas within less than 1000 M, as shown in Figure 5 illustrating the spread of cities to determine suitable locations for signing wind farms from cities.

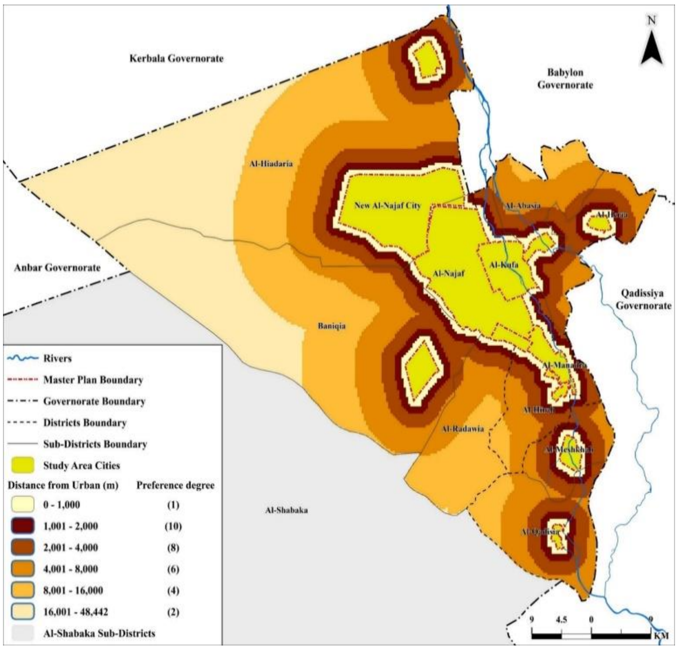

Figure 5. Distance from urban areas in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and on the Directorate of Urban Planning in Najaf.

4.1.4 Roads/ highways

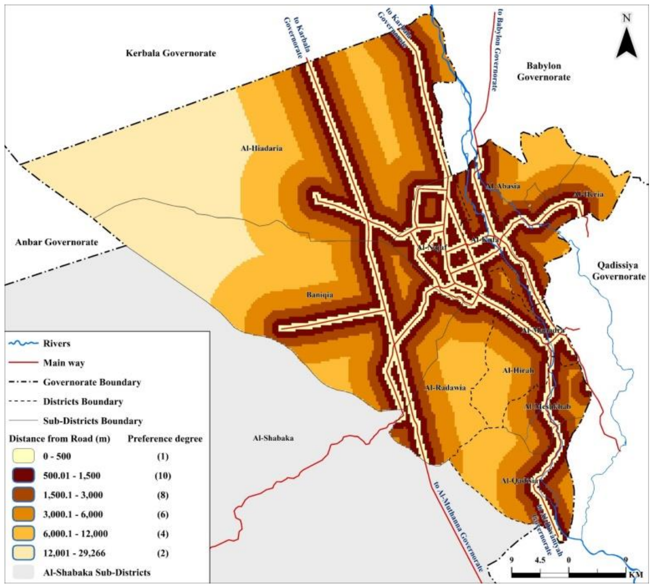

Figure 6. Distance from the main transportation routes in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and on the Directorate of Urban Planning in Najaf.

The relationship between the road network and the accessibility to wind farm sites is crucial. The transportation routes play a significant role in determining the location of a wind farm due to the importance of delivering large wind turbine components to the site. The connection between them also contributes to attracting people for various purposes, as the spaces between the turbines can be utilized for recreation, tourism, agriculture, and more. The proximity to main roads increases the advantage to avoid the costs of building new roads. Wind farms should be located at a distance of over 500 M from main roads but not too far, considering the noise and visual impact of the wind farms on one hand, and the need for easy access for turbine transportation and maintenance on the other hand. Therefore, wind farms should be situated near main roads. The presence of numerous main roads in the study area will greatly facilitate the construction of wind farms at lower costs. The study area has been divided based on the Euclidean Distance tool into categories, giving the highest rating (10) to relatively close areas exceeding 500 M, and the lowest rating (1) to distant areas and those within a distance of less than 500 M, as shown in Figure 6, indicating the appropriate distribution of main transportation routes for locating wind farms.

4.1.5 Regions of importance

The study area contains many significant sites, including natural and human-related sites. The natural sites include wetlands, natural reserves, and forests, while the human-related sites include archaeological and industrial areas, natural resources, and important service locations. Therefore, wind farms should be kept at a distance of more than 2000 M from these significant sites to ensure their protection and prevent damage. The further we move away from these significant areas, whether environmental, economic, touristic, or otherwise, the more advantageous it becomes. The study area has been divided using the Euclidean Distance tool into two ranges, giving the highest rating (10) to the distant areas exceeding 2000 M, and the lowest rating (1) to the nearby areas within less than 2000 M, as shown in Figure 7. This map illustrates the distribution of significant sites affecting the placement of wind farms, including the Wadi Al-Salam cemetery, the model Wadi Al-Salam cemetery, the Najaf Tire Factory, the Haidar Factory, and other important sites.

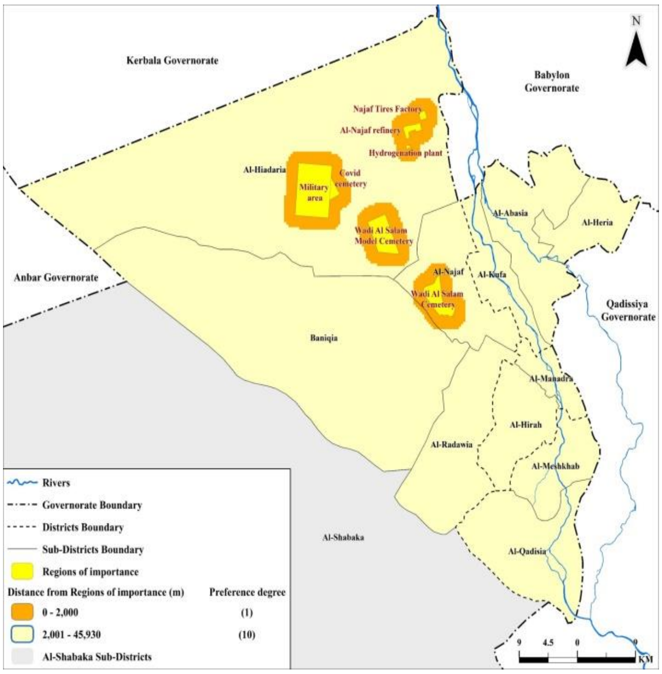

Figure 7. Distance from important sites in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and on the Directorate of Urban Planning in Najaf.

4.1.6 Airports

Proximity to airports of all types (civilian and military) is a crucial factor in determining the location of wind farms to avoid the risk of aircraft colliding with wind turbines during takeoff and landing, as well as the noise generated by aircraft on wind farms, which can hinder their recreational, agricultural, or other uses. Wind farms should be located at a distance of over 3000 meters from airports to maximize safety. The distance from Al-Najaf International Airport has been divided into two categories using Euclidean Distance, giving a highest rating of (10) to areas located over 3000 M away, and a lowest rating of (1) to nearby areas, as shown in Figure 8, indicating the sole airport location in the study area.

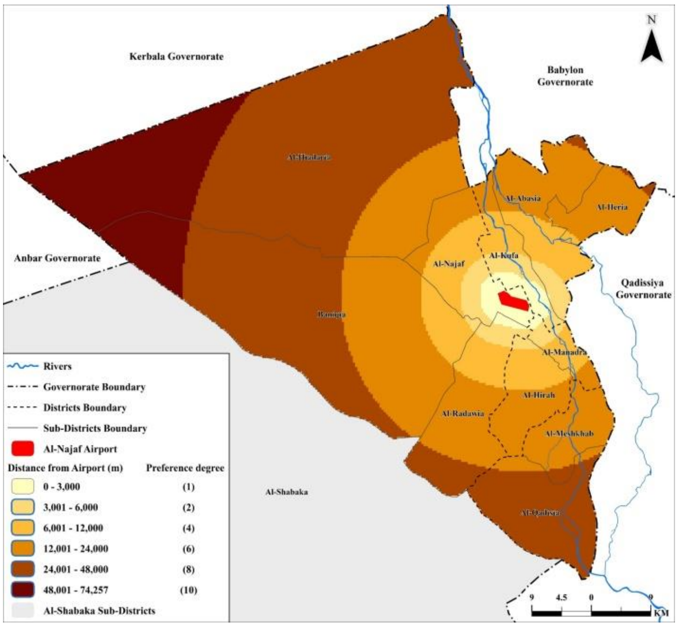

Figure 8. Distance from airports in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and on the Directorate of Urban Planning in Najaf.

4.1.7 Terrain slope

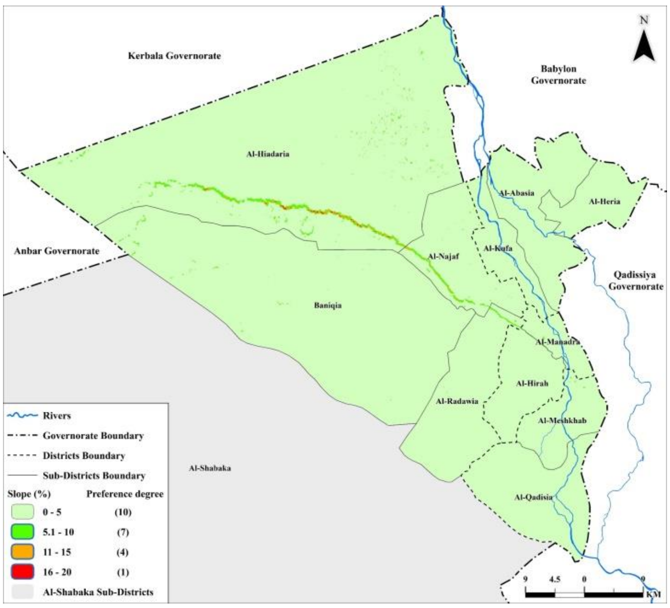

Figure 9. Slope of the land in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and on the digital elevation model (DEM).

The slope of the land and the variations in elevations in the study area significantly affect the speed, direction, and density of the wind. Wind speed increases on flat and gently sloping terrains, facilitating the establishment of a wind farm. Various obstacles hinder the generation of wind power, including the terrain and the impact of ground elevation changes on wind energy, the land slope which should be relatively flat, not exceeding a 15% incline, and the land roughness (soil type) differs between marine and desert areas with high wind speeds and low roughness compared to agricultural lands, forests, and heavily rough urban areas. Therefore, the study area was divided based on land slope using the Digital Elevation Model (DEM) and the Slope tool into categories, giving the highest rating (10) to flat and gently sloping areas and the lowest rating (1) to steeply sloping lands, as shown in Figure 9, indicating the suitability of establishing a wind farm in the study area due to its gentle slope and few obstacles.

4.1.8 Soil

Wind farm sites are affected by the type of soil they are built on in terms of soil's ability to withstand wind turbines, the stability of their construction on the ground, and the potential damage turbines may cause to sensitive land. Therefore, wind farms should not be established on unstable clay soils or highly erodible soils. Instead, rocky, desert, sandy loam, and wildlife habitat soils are suitable for wind farm development. After studying the soil types in the study area, the best soil types for wind farm establishment were identified and ranked accordingly: soil of Mixed gypsum desert (10) was rated the highest, followed by soil of river basin (7), soils of marshes and swamps (5), soil of sand dune (3), and the lowest rating was for river shoulders, soils of lakes, and marshes (2) (1) respectively. This is illustrated in Figure 10, showing the soil types in the study area according to Buringh's soil classification.

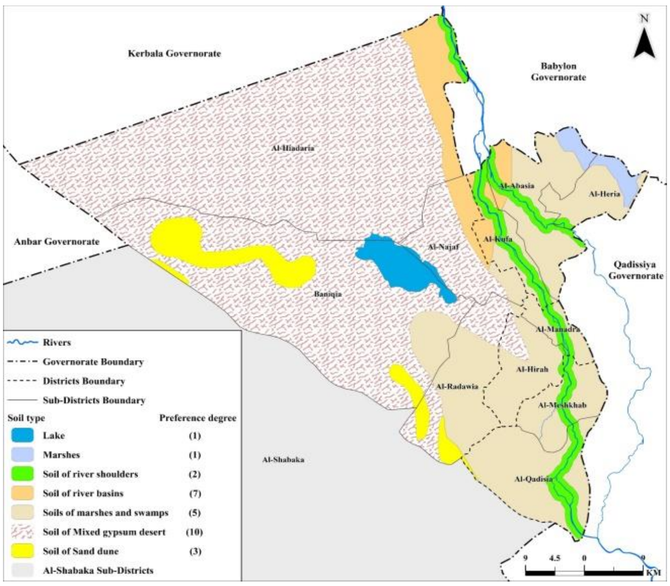

Figure 10. Types of soil in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and Buringh's soil classification map.

4.1.9 Bodies of water, rivers and springs

Wind farm construction and turbine installation are prohibited in protected water reserves, stagnant and flowing waters, marshes, swamps, rivers, and valleys due to their sensitivity as habitats for various living organisms that may face extinction or displacement from their environment. It is also prohibited to place wind turbines near the edges of water bodies, with a mandatory 5-meter "construction exclusion zone" around all water bodies [22]. Wind farms must be located at a distance of more than 2500 M from sensitive water bodies, with increasing preference as the distance grows, to prevent potential harm to the aquatic environment and its surroundings, noise disturbances, and visual impacts on residents. The study area was divided using Euclidean Distance into categories, giving higher ratings to areas further away from water bodies (10) exceeding 2500 M, and lower ratings (1) to closer areas, as shown in Figure 11, illustrating the distribution of various water sources like flowing rivers (Euphrates River), stagnant waters (Hawr Ibn Najim), lakes (Lake Najaf), and others.

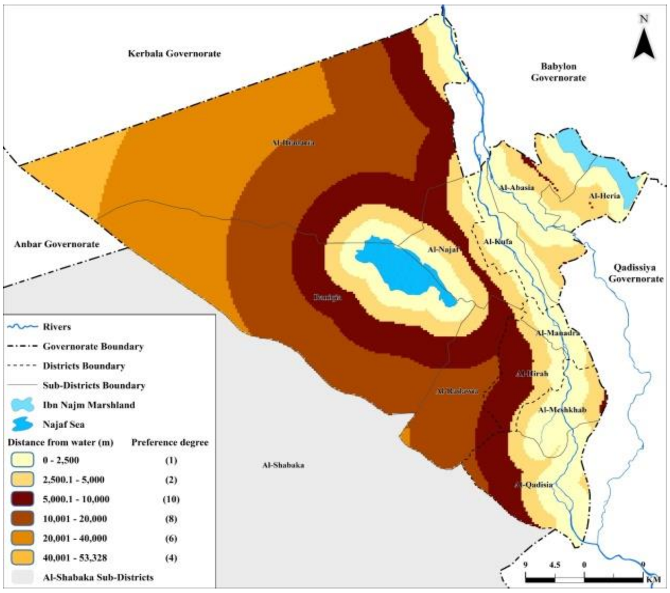

Figure 11. Distance from water resources in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and Water Resources Directorate in the Najaf Governorate.

4.1.10 Birding trails and areas

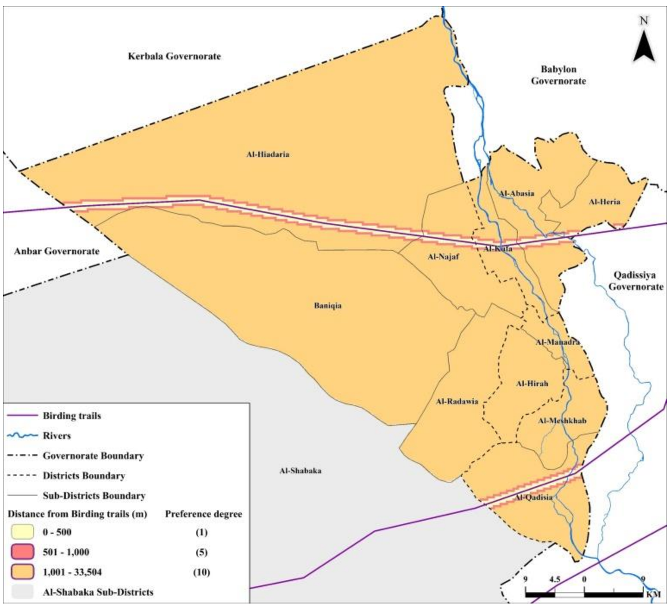

Figure 12. Distance from bird migration routes in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3.

Wind farms affect the lives of wildlife, especially the movement of birds, their environment, migration routes, and nesting. Avoiding bird movement routes increases the advantage. The reason is that the placement of wind farms on bird migration routes may lead to the displacement, extinction, or killing of birds. Therefore, wind farm sites should be located at a distance of more than 500 M from bird movement routes and their environment. The study area was divided using the Euclidean Distance tool into categories, giving the highest rating to areas far from bird movement routes (10) and the lowest rating (1) to nearby areas, as shown in Figure 12, which illustrates the presence of two main migration routes for birds in the study area.

4.1.11 Land cover

The ground cover directly and indirectly affects the establishment of wind farms positively or negatively. Wind farms contribute to land reclamation, improvement, and soil stabilization when located spatially in desert and barren lands. Conversely, they may have a negative impact on land excavation when situated in orchards and agricultural lands, which could reduce the efficiency of the wind farm. Orchards, depending on their type, can act as obstacles and wind barriers to the turbines. Therefore, agricultural lands, built-up areas, water bodies, and wetlands are not suitable for wind farm establishment. Hence, wetlands, agricultural lands, and orchards are assigned the lowest values (1) (4) consecutively when establishing wind farms, while barren and desert lands are assigned the highest values (8) (10) consecutively to ensure wind farms are placed on lands unsuitable for agriculture for reclamation purposes and to avoid land excavation. The ground cover of the study area is illustrated in Figure 13.

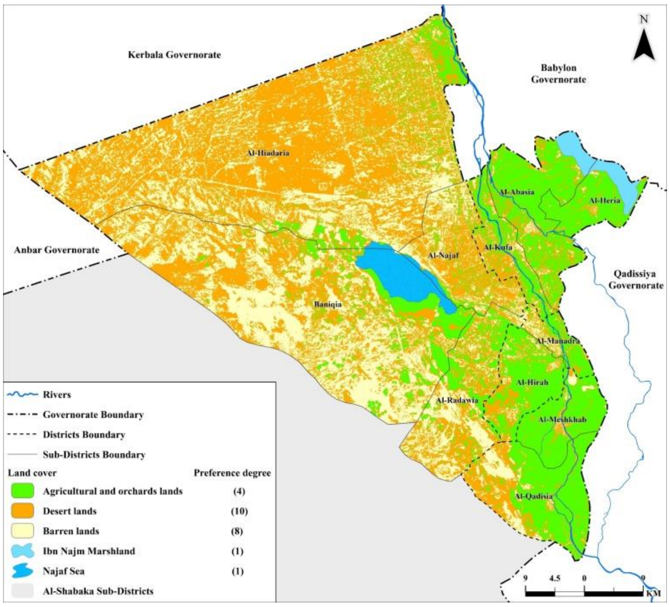

Figure 13. Land cover in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3 and classification directed to the visibility of Najaf Al-Ashraf for the year 2023.

4.2 Determine the suitable location for wind farms

After stating the impact of each indicator and determinant on the wind farm signature in the study area, the spatial suitability of wind farms will be evaluated using ArcGIS 10.8 software. This evaluation will be based on the relative importance assigned to each indicator in Table 3, as determined by the survey of experts. By considering the justifications given for each factor in terms of its mentioned importance during the classification process, 11 layers of criteria were introduced. These criteria were derived and each layer was reclassified using the Reclassify tool to reclassify the visuals resulting from the analysis of the criteria layers. Subsequently, these layers will be placed, and spatial analysis will be conducted in the Geographic Information System (GIS) environment within the Spatial Analyst application, assigning weight to each criterion based on its relative importance using the Raster Calculator tool. The results of these processes in the GIS environment led to the classification of the study area lands according to importance from 1-10 in the wind farm signature for electricity production. They were classified into five categories showing the degree of priority for determining the optimal location for the wind farm, as depicted in Figure 14.

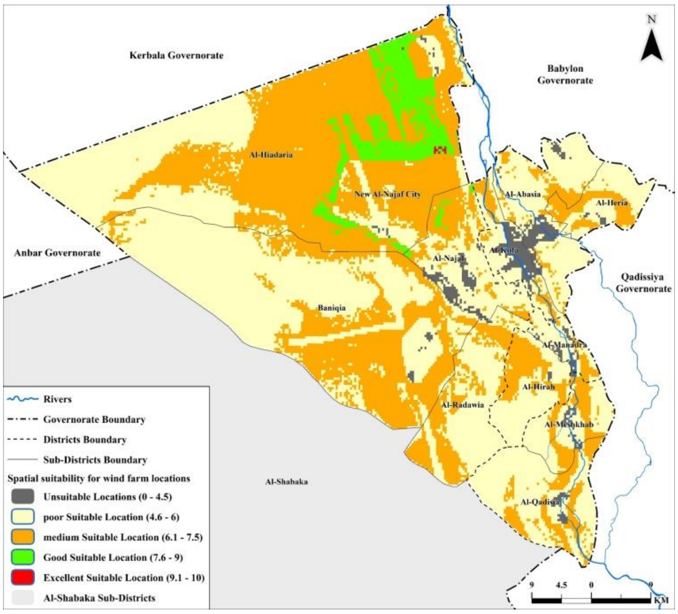

Figure 14. Spatial suitability for wind farms in study area
Source: Researcher using Arc GIS 10.8, and based on Table 3.

Table 4. Spatial suitability for wind farm locations

Suitability Sections	Area (Km^2)
Unsuitable Locations (0 - 4.5)	86.32
Poor Suitable Location (4.6 - 6)	1883.47
Medium Suitable Location (6.1 - 7.5)	1465.35
Good Suitable Location (7.6 - 9)	154.76
Excellent Suitable Location (9.1 - 10)	2.23
SUM	3592.13

Source: Researcher based Arc GIS 10.8 and Figure 14 and Table 3.

From Figure 14 and Table 4, the study area is divided into five categories to demonstrate the suitability resulting from the application of the Multi-Criteria Analysis process. It is evident that the excellent sites suitable for wind farms are located in the northern part of the study area with an area of 2.23 Km^2 and good sites with similar suitability which cover an area of 154.76 Km^2. These two categories represent the best locations for establishing wind farms. However, moderately and poorly suitable sites are widely spread throughout the study area. Unsuitable areas are concentrated in the central part of the study area in the cities of Najaf and Kufa. Consequently, the excellent and good suitable areas are sufficient for establishing a current wind farm, and the remaining good suitable areas can be utilized in the future for the expansion of the wind farm.

4.3 Calculating the amount of energy in a wind farm

The study specified, according to the criteria in Tables 1 and 3, that the size of a wind farm is related to the desired energy output and the number of wind turbines to be installed. Several design criteria have been identified for establishing a wind farm with a production capacity of 198 Mw in the secondary Najaf region within suitable excellent and good areas. The tower height for the turbines has been determined based on the wind speed in the area using a turbine model with a height of 80 M and a rotor diameter of 87 M, of the Gamesa G87 type, with a capacity of 2 Mw. The spacing between the wind turbines has been set at 500 M between columns and 700 M between rows, with a prohibited area around the wind farm extending 300 M.

By applying the specified standards, the appropriate design for the wind farm in Al-Najaf Secondary Province has been reached. The farm will consist of 99 turbines, with each turbine generating 2 Mw of power, resulting in a wind farm with a total production capacity of 198 Mw. The wind turbines have been distributed into 9 rows with a spacing of 700 M between them, and 11 columns with a spacing of 500 M. This arrangement provides 99 turbines for electricity production. Adding a buffer zone around the wind turbines at a distance of 300 M, the wind farm will be 6500 M long and 6200 M wide, making the total area of the wind farm 40.3 Km^2. This is illustrated in Figure 15.

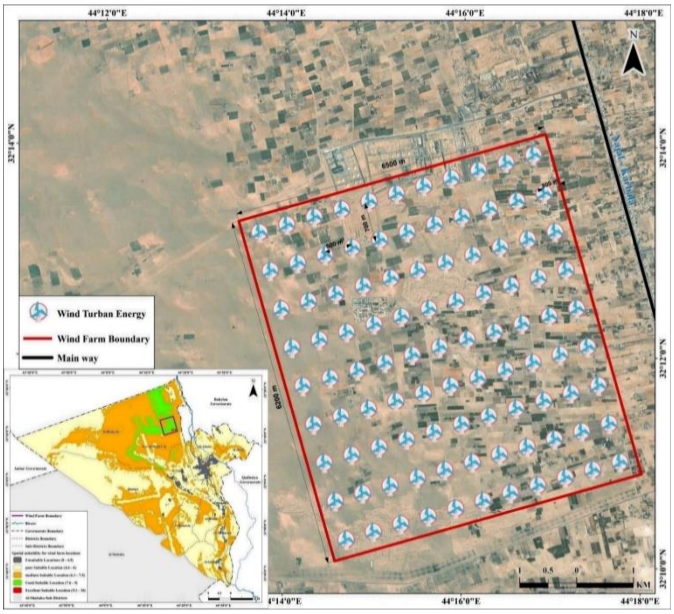

Figure 15. Designing a wind farm in study area
Source: Researcher using Arc GIS 10.8, and based on Table 1.

5. DISCUSSION

The importance of establishing wind farms, particularly relying on renewable energy in general, is evident from the above. Wind farms represent a source of environmentally friendly renewable energy, in addition to providing economic, environmental, social, and urban benefits to the study area. By relying on a set of planning and design criteria, suitable areas for establishing wind farms in the study area were identified using Arc GIS 10.8 software. By applying these criteria, a design and selection of a suitable location and area for a wind farm in the secondary Najaf province were determined to meet a set of criteria and factors influencing the spatial layout, including wind energy density, proximity to main roads, power lines, urban areas, important locations, land slope, obstacles limiting wind intensity, and many other factors.

The research has identified a number of local advantages for the wind farm, the most important of which is its location north of the new city of Najaf. Consequently, it will provide renewable energy for the city and the farm can be established during the city's development stages. Additionally, the farm is situated on the main road (Najaf - Karbala), which is 1000 M away from the farm, facilitating the transportation of wind turbines, easy access to the farm, and its maintenance. Furthermore, the farm is adjacent to important industrial sites that can supply it with energy. Moreover, the farm is located within desert lands that can be utilized for land reclamation and conversion into agricultural land, providing agricultural and touristic returns. It also serves as a belt to stabilize the soil and reduce dust storms in the study area. Wind farms can be constructed in stages, expanded in the future, and integrated into the main power grid.

6. CONCLUSIONS

The transition to renewable energy is not merely a technical option; it is a fundamental element in shaping policies and achieving sustainable development in the energy sector. The generation of renewable energy has far-reaching impacts on policy-making and sustainable development in the energy sector, through its contribution to reducing dependence on fossil fuels, enhancing energy security, creating job opportunities, encouraging innovation and technology, supporting environmental policies, improving access to energy, adapting to climate change, and promoting sustainable development. All of this achieves a degree of integration among economic, environmental, and social urban policies.

In the northern region of Al-Najaf Al-Ashraf, there is a suitable location for wind farms due to the availability of wind energy density in a suitable direction, which is the northwestern and western direction with few obstacles and the type of soil suitable for building the farm. It is also located far from airports and sensitive lands. Wind farms contribute to filling the current and future energy gap, as they have the potential for development or expansion, in addition to the possibility of using the land between turbines for multiple purposes. Wind farms also help in reclaiming and utilizing desert lands and stabilizing soil in the study area to reduce dust storms. Moreover, a set of planning and design standards and indicators for establishing wind farms have been reached, and an effective design for a wind farm with an area of 40.3 Km^2, 99 turbines, and a production capacity of 198 MW has been developed in the Al-Najaf Al-Ashraf region.

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NOMENCLATURE

GIS	Geographic Information System
MCDM	Multi Criteria Decision Making
WPD	Wind Power Density
DEM	Digital Elevation Model