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Site Selection For Wind Energy Farm Using GIS-Based Multi-Criteria Decision Analysis (MCDA)In Qassim Area

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ABSTRACT

One of the challenges facing the world in the 21st century is the availability of sustainable and relatively cost-effective renewable energy sources that has lower negative impacts on the environment than fossil fuels. The improvement in human living conditions and world population increase have resulted in high usage and demand of energy. Most of the energy used in the world today is produced from fossil fuels such as oil, natural gas, and coal. The drawbacks of fossil fuel energy include limited stock, environmental pollution, global warming associated with the burning of fossil fuels. The stable increases in the greenhouse's gases, in particular, CO2 and their contribution to global warming creates a serious concern about the use of fossil fuel and its impact on the environment. This study aims to select suitable sites for wind energy farms in the Qassim region using the integration of Multi-Criteria for Decision Analysis (MCDA) Multi-criteria evaluation. The data used in this study was wind speed and direction, Digital Elevation model, distance from settlements, distance from roads, railways, drainage, land slope, and land uses. The data distances from these features were ranked and weighted. By superimposing these weights, the Model Builder [1]has been built, deriving a map representing the most suitable locations for wind energy in Qassim. The results indicated that the most suitable sites with minimum impacts to the environment, society, and economy as well as conforming with the regulations and generally accepted by the public. The areas that covered with final land suitability index were 98580376.11 km^2(14,7%) for Suitable, 61344715.51 km^2 (9,1) for very Suitable, 607844.9908 km2(0.1%) for extreme Suitable and 2557421.399 km^2 (0.4) for Less Suitable. Results showed that northern part of Qassim region has potential for building wind turbine farm. It is recommended to use suitability model by decision-makers in the plans of energy development.

Keywords: *Wind energy resources, Wind power potential, (MCDA), application Water pumping.*

NOMENCLATURE

MCDA	Multi Criteria Decision Analysis
D	Density
V	Velocity
A	Area

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GWA	Global Wind Atlas
AHP	Analytic Hierarchy Process

1. Introduction

During the last decade, solar energy, biomass, and wind energy are main resources of renewable energies [1]. Due to the Increasing of global energy demand, wind turbine farms have been an integral part of the global energy landscape and a more operative issue for harvesting wind energy [2]. Wind energy is a clean and inexhaustible source of renewable energy, it has been extensively exploited worldwide due to its economic and environmental benefits [3]. Wind energy was equivalent as one of the main sources of sustainable green energy, the fastest growing renewable energy technologies, driven in part by demand for net-zero emission for reducing climate change, which causes increasing government support and public receptiveness, so wind farms are expected to increase both in number and spatial scale. [4]. The wide-reaching share of electricity produced from wind in 2018 amounted to just 4.6%, but its growth has been exponential over the past decades. Nowadays, current predictions suggest wind energy's share reaching one-quarter to one-third globally by 2050 [5]. Most previous studies on wind energy assessment focused exclusively on wind speed, where as Wind energy is the kinetic energy that is present in moving air [6]. The amount of potential energy depends mainly on wind speed but is also affected slightly by the density of the air, which is determined by the air temperature, barometric pressure, and altitude. For any wind turbine, the power and energy output increase dramatically as the wind speed increases, the most cost-effective wind turbines are located in the windiest area [7]. Wind speed is affected by the local landscape and ncreases with height above the ground, so wind turbines are usually mounted on tall towers. Application of wind energy, Mechanical application: mainly (water pumping) multi-blade windmill used for water pumping [8].

The rising concerns over global warming, environmental pollution, and energy security have increased interest in developing renewable and environmentally friendly energy sources such as wind, solar, hydropower, geothermal, hydrogen, and biomass as replacements for fossil fuels, Wind energy can provide suitable solutions for global climate change and energy crisis [9]. The utilization of wind power essentially eliminates emissions of $\mathbf{CO_2}$, $\mathbf{SO_2}$, $\mathbf{NO_X}$ and other harmful wastes as in traditional coal-fuel power plants or radioactive wastes in nuclear power plants [10]. By further diversifying the energy supply, wind energy dramatically reduces the dependence on fossil fuels that are subject to price and supply instability, thus strengthening global energy security. During the recent three decades, tremendous growth in wind power has been seen all over the world [11]. In 2009, the global annual installed wind generation capacity reached a record-breaking 37 GW, bringing the world's total wind capacity to 158 GW [12]. As the most promising renewable, clean, and reliable energy source, wind power is highly expected to take a much higher portion in power generation in the coming decades [12]. economically use of wind energy wind resources at potential sites must be investigated, for these reasons purpose, King Abdulaziz City for Science and Technology (KACST) has taken the initiative in respect to wind resource assessment in the Kingdom of Saudi Arabia [13].

There have been numerous studies on installing wind energy in different terrains, including urban environments, wind farms, and offshore. However, power is also associated with several environmental issues, including ecological disturbance, wildlife safety, noise, electromagnetic interference, and local climate change [14]. Wind energy has made significant advances in recent years. Wind energy is a dependable and promising renewable energy. Wind energy becomes more and more attractive as one of the clean renewable energy resources and this trend is widespread throughout the world [15]. Wind energy, selecting a location for a wind farm is a crucial phase in developing wind plans. Conducting a site suitability analysis will reduce the cost of establishing wind energy projects [16]. Thus, before installing wind energy projects, research should be conducted to evaluate the capacity of wind energy available in various regions. Additionally, the site location must meet all ecological, topological, and structural constraints such as land use/cover, important bird areas (IBAs), distance to airports, and distance to water bodies [17]. It is, so, not necessary to select the sites with the highest wind velocity. Instead, a trade-off must be made between numerous technical, economic, environmental, and social aspects to select the most suitable sites [18].

wind turbine represents the ability of a wind turbine to transfer the kinetic energy carried by wind into electricity [19] as showing in equation below.

The Power Coefficient ($\mathbf{C_P}$) of the turbine is well-defined as, $\mathbf{C_P} = \frac{\mathbf{P}}{\mathbf{0.5\rho V_i A}}$ Equation (1)

were, P ≡ Power. ρ≡ Density. v ≡Velocity. A ≡Area.

Wind energy is one of the main sources of green energy today, being produced in many countries by wind energy companies, but also by consumers in certain lands in the last few years on a small scale [20]. wind energy was the main source of domestic electricity production [21]. Wind technology was commercially adopted in the 1970s, which has been made more efficient in the current times through periodic modifications over the decades. However, the turbine's basic working concept remains the same, with a horizontal axis generator placed on the top of a vertical tower and three blades rotating on a vertical plane. Several wind turbine machines, usually hundreds, are located in the most feasible location, known as a wind energy farm, to produce enough power that can be converted into commercial electricity also, wind towers' size varies according to the economic and landscape limitations, although they can sometimes be over 150m in height [22]. One of the alternative routes for reducing oil consumption is to rely more on renewable energy. Saudi Arabia generates the majority of its power using oil, making it the largest oil consumer to produce electricity, Wind power to produce electricity has economic and environmental advantages, wind energy cost-effective. wind speed resources, efficiency of the wind farm equipment, quality of operation of wind turbines with the wind and other aspects of control [23]. The country generates 42% of the power using oil, while natural comprises 57.8% using natural gas [24]. Saudi Arabia has committed to reducing the massive use of oil by 2030 under its Vision 2030 program, The Kingdom goals to make 50% of its production from natural gas, while the rest from renewable energy. The country has already installed 397MW of renewable energy facilities by the end of the year 2019 and targets 6GW of power generation using renewables by 2030[25]. Hence, there is a noticeable difference between the number of facilities that need to be installed to fulfill the commitment. Related to the current studies, Saudi Arabia could be a net oil importer by 2038, if oil consumption in the energy sector is not reduced significantly, hence it is of utmost importance to reduce the dependency on crude oil and to tap more power from the abundant renewable energy resources of the Kingdom [26]. wind power is a recognized, sustainable energy source, siting can be challenging. Detecting potential sites for wind turbines is a important step in renewable energy resource planning [26]. The aim of this paper is to choose the best area in Qassim in order to established and fundamentals wind farm using GIS-based Multi-criteria Decision Analysis (MCDA) and modern wind turbine design, as well as some insights concerning wind power generation.

2. **Previous Works**:

Depended on survey and study in order to selection suitable location based on wind resources and future values is so difficult. GIS is used to distinguish potential areas by integrating digital thematic maps and conceptual models for data. Baffoe and Sarpong, 2016 are used, GIS has been used to choose wind farm sites as a decision support system, using applied the GIS-AHP methodology to detect suitable sites for wind farms in Ghana. weighted criteria and constraints criteria, was used in process of site selection such as wind speed, slope, proximity to towns, proximity to the electricity grid, proximity to airports, proximity to roads, and land use restrictions. Lamya Albraheem, Lama AlAwlaqi presents a wind farm site suitability analysis based on the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS)techniques, which consider technical, economic, environmental, and social considerations, reflecting five criteria. First, a Multi-Criteria Decision-Making (MCDM) analysis using the AHP approach is applied to give suitable weights to the addressed criteria based on their relative importance [27]. A GIS is utilized to behavior a geospatial analysis and integrate multiple criteria throughout the suggested index to produce the final suitability map and indicate unsuitable locations[28].GIS combined with multi-criteria analysis have been reported in the literature to have been applied to several renewable energy applications, for example, Sánchez-Lozano et al] have used Fuzzy Analytic Hierarchy Process (FAHP) approaches of different Multi-Criteria Decision Making (MCDM) techniques to deal with onshore wind farm site selection. The authors applied Geographic Information System (GIS) to obtain the database of the alternatives and the criteria were transformed into a fuzzy [29] multi-criteria evaluation methods are commonly used for site selection. to select suitable sites for solar farm and wind turbine using GIS and AHP in Tehran [30]. Geographical Information System (GIS)-assisted wind farm location criteria were established for the UK. A GIS (IDRISI) was employed to apply these criteria using two different methods to combine information layers for a site in Lancashire. The first considered all the layers as being equally important and gave them equal weight [31]. In Saudi Arabia, there are five locations in coastal areas where meteorological data are being collected since 1970. The details of the locations at all of these locations, the meteorological measurements were made at 10 m height except at Gizan, where data were recorded at 8 m height above ground level. So the data were normalized to 10 m height for Gizan using the 1/7th wind power law. The data used in this analysis cover 14 years of measurements, extending from [32].

3.MATERIALS AND METHODS

3.1 Study Area:

The Qassim region is in the area between latitudes 24º.27-28.18 North and longitudes 41º.27-44.46 East. One of the administrative regions in the Kingdom of Saudi Arabia. It is noted that the Qassim region is bordered to the east by the Eastern Region, to the east and south by the Riyadh region, to the north by the Hail region, and to the west by the Medina region. We find that it is distinguished by its central location in the northern direction of the Kingdom of Saudi Arabia, as its western and eastern borders are some distance away. It is approximately equal, estimated at about 500 kilometers from the coast of the Red Sea and the Arabian Gulf, and its area represents about 73 thousand square kilometers, which represents about 3.2% of the total area of the Kingdom. The maximum width is about 480 kilometers from north to south, and 400 kilometers from East to west.

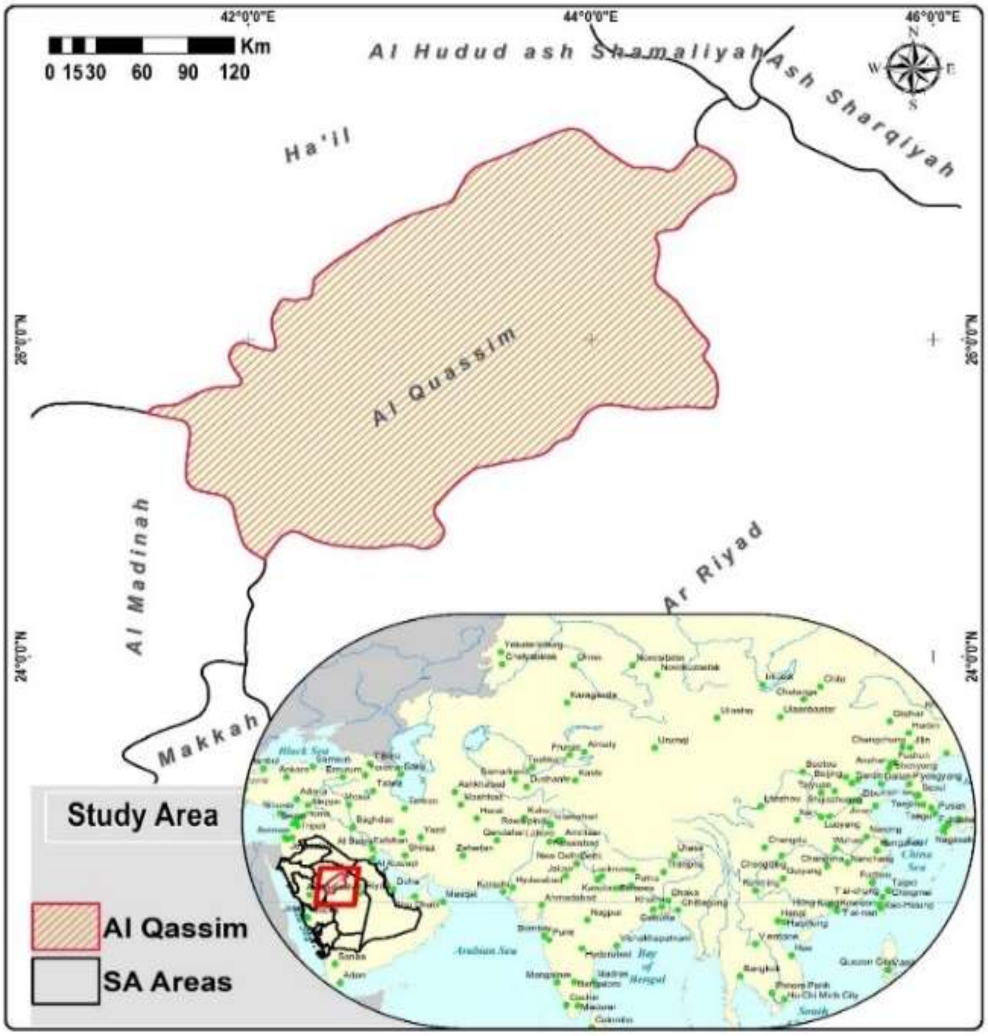


Fig (1) Location of the Study Area

3.2. Define Criteria.

This section describes how the site selection of wind energy in Qassim region was carried out. The analysis was applied using a combination of GIS and MCDM methodologies because site suitability is a complex problem that depends on various factors. Following is a discussion of the steps following the proposed flowchart illustrated in Fig (2). The main steps in the methodology are. Two types of criteria were identified during the planning process: evaluation criteria for the site suitability analysis and constraints for excluding unsuitable locations. Criteria factors include average wind speed (C1), distance to power lines (C2), distance to roads (C3), distance to settlement areas (C4), and slope (C5), whereas constraints criteria applied in this study are the exclusion of the following factors criteria: airports, land use, water bodies, and Important Bird Areas (IBA) [33].

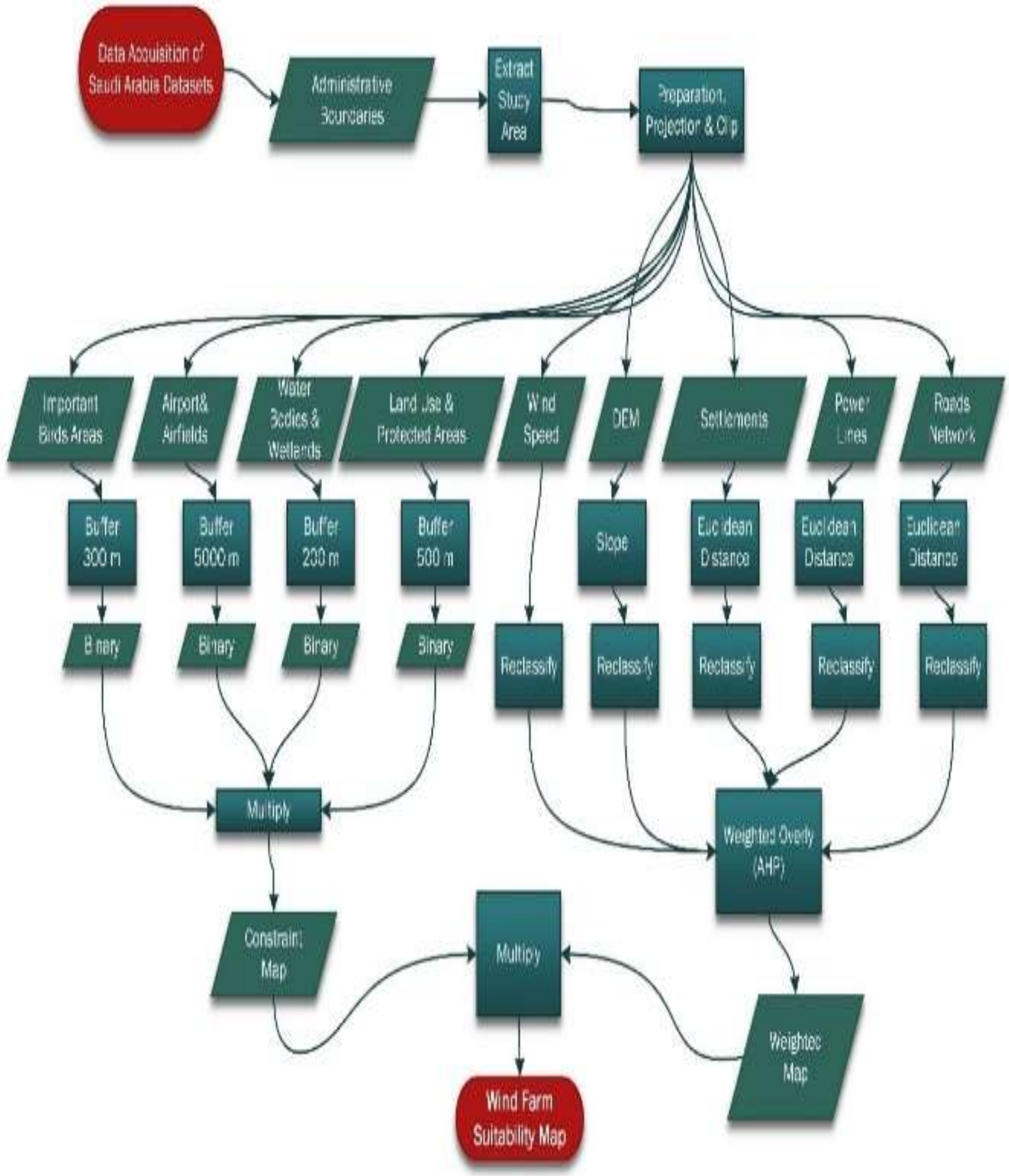


Fig (2) flow chart of the Data used.

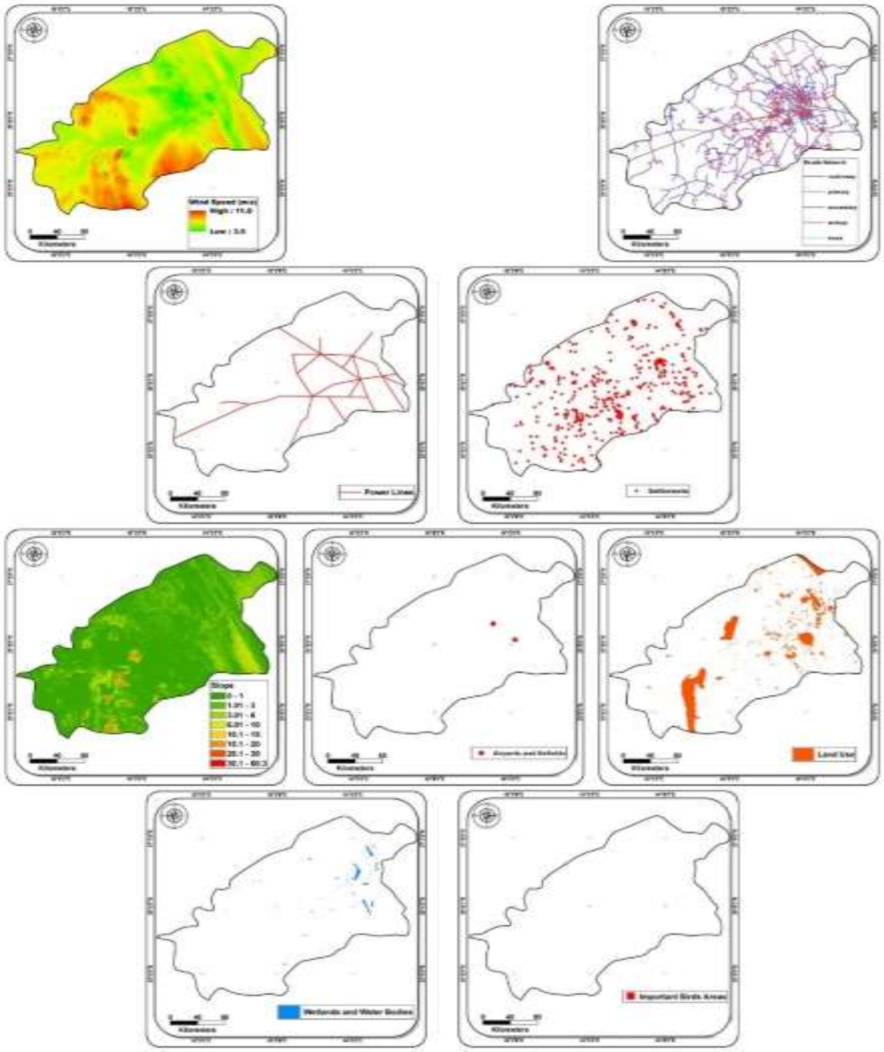


Fig (3) criteria data of the study.

In figure (3) the criteria data include Average wind speed at 50-m AGL high 11.0 m/s low 3.5 m/s; Road including primary, secondary, tertiary, motorway, and trunk; Electricity power lines; Settlements; Slope network generated from DEM layer; Land use and protected areas; Wetlands and water bodies; Airports and airfields; and Important bird areas.

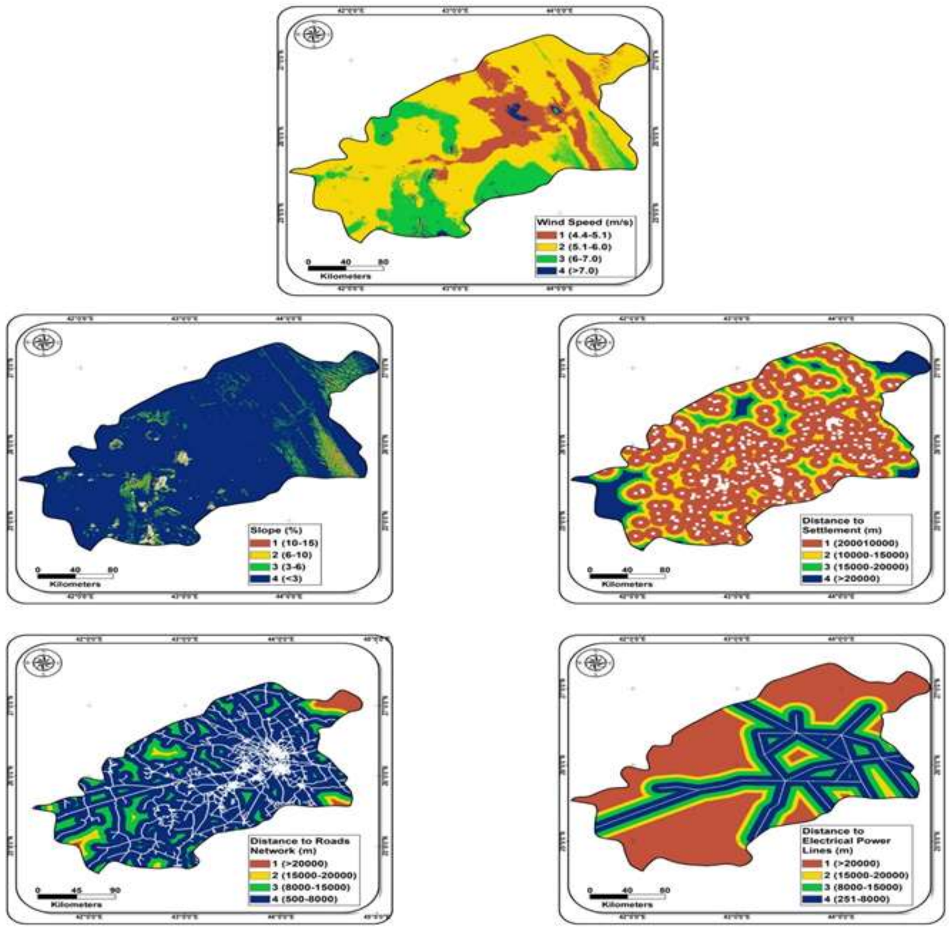


Fig (4) Criteria Map of the study

3.2.1. Wind energy farm criteria (factors)

Wind speed (m/s): this is the most important factor. The average wind speed of the region should meet the wind speed needed for moving the small wind turbines that are used in the region driven from global winds Atlas, average wind speed of Qassim region about 11.0. Distance to power lines categories as >20000m Less suitable**,** 8000**-**251 m as Extremely suitable**.** Distance to road network: the Euclidean distance is calculated 2000-10000 **m.** Less suitable as >20000 m as Extremely suitable. Distance to Settlements, building a wind turbine near the city causes pollution, 2000-10000 m. Less suitable as >20000 m, as Extremely suitable buffer forms the region.

3.2.2. Wind energy constraints:

Wind energy farm constraints are explained as distance from Land use= 500m, distance from Airport=5 000 m. distance from water bodies 200m = distance from Important Birds area 300m.

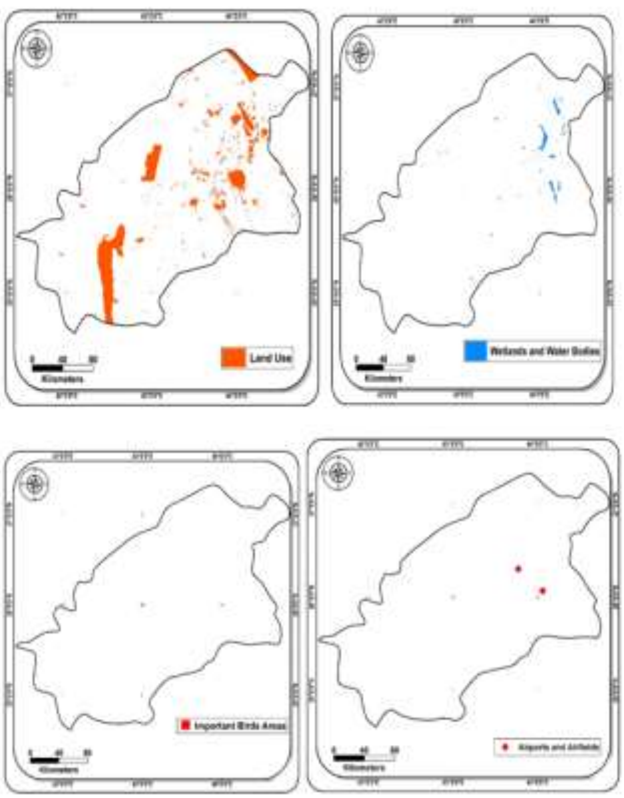
Table (1): Reclassification of weighted criteria map

category	Distance(m)to	Settlements	Road network	Wind speed (m/s)	Slope %	score	suitability

	electric power						
1	>20000	2000-10000	2000-10000	4.4-5.1	10-15	1	Less suitable
2	-15000 20000	10000-15000	10000-15000	5.1-6.0	6-10	2	suitable
3	-8000 15000	15000-20000	15000-20000	6-7.0	3-6	3	Very suitable
4	8000-251	>20000	>20000	>7.1	<3	4	Extremely suitable

Table (2): Reclassification of constrain criteria map

Constrain Criteria	Conditions	Score	classification
Land use.	Within500 m buffer	0 1	Exclude area Non-exclude area
Water bodies	200 m buffer	0 1	Exclude area. Non-exclude area
Airports	5000 m buffer	0 1	Exclude area. Non-exclude area



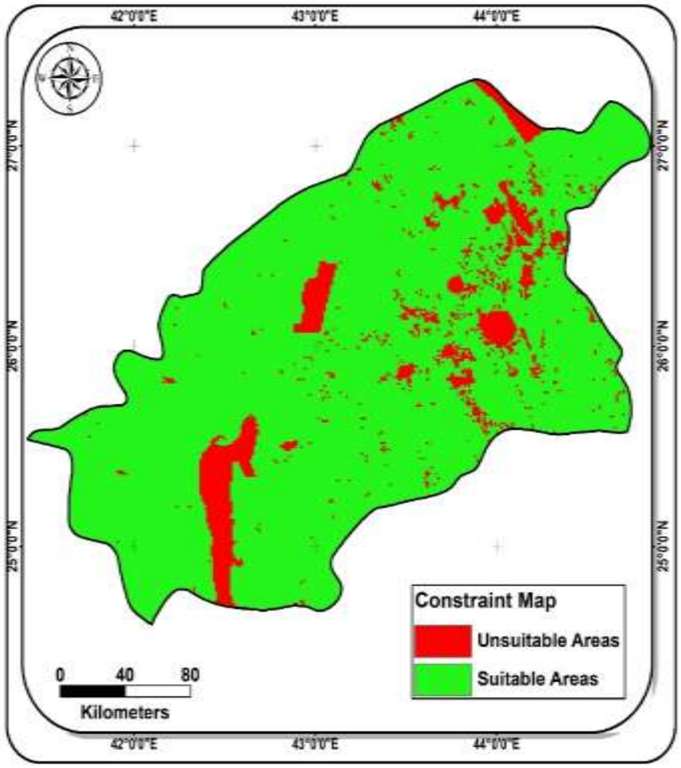


Fig. (5) constrain criteria.

Fig. (6) constrain map

3.3. Methodology

3.3.1 Multi Criteria Decision Making (MCDM):

The techniques adopted in the various approaches of decision analysis are called (MCDM).These methods incorporate explicit statements of preferences of decision- makers. Such preferences are represented by various quantities, weighting scheme, constraints, goal, utilities, and other parameters. They analyze and support decision through formal analysis of alternative options, their attribute, evaluation criteria, goals or objectives, and constraints. MCDM used to solve various site selection problems. MCDA results can be mapped to display the spatial extent of the best areas or index of land suitability using GIS for wind farm site selection is a complex process as it combines multiple and conflicting objectives and integrates numerous data types. For this purpose, several criteria have been accounted in this study.

3.3.2 Analytical Hierarchy Process (AHP))

The most important factor in MCDM is how to establish “weights” for a set of criteria according to importance. Location decisions such as the ranking of alternative communities are representative multi-criteria decisions that require prioritizing multiple criteria. The analytic hierarchy process (AHP) is a comprehensive, logical, and structural framework, which allows analyzer to improve the understanding of complex decisions by decomposing the problem in a hierarchical structure. The incorporation of all relevant decision criteria, and their pairwise comparison allows the decision maker to determine the trade-offs among objectives. Such multicriteria decision problems are typical for housing sites selection. The AHP allows decision-makers to model a complex problem in a hierarchical structure showing the relationship of the goal, objectives, criteria, and alternatives.

4. RESULTS AND DISCUSSION:

To calculate the suitability selection index, the selection criteria relative weights has been done with the Analytical Hierarchy Process (AHP) proposed by Saaty (34), has three phases: analysis, comparison, and priority composition. In the first phase the criteria and constrain criteria determined, the second phase the comparison matrix is made, and the criteria are compared 2-by-2 and they are scored, from 1-9 based on the scale of Saaty (35). The comparison matrix (Equation.) for criteria is composed as follow. A land suitability index was determined for site of wind energy farm. The final index was then categorized in “Less Suitable”, “suitable”, “very suitable” and “Extreme Suitable” Figure (8).

Table (3) Pairwise comparison scale (data adopted from Saaty 1987)

Intensity of importance	Description
1	Equally important factors
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extremely more important factors
2,4,6,8	Intermediate values,

$$A = \begin{matrix} A_1 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

Equation (2)

Where λmax = Eigen value of the matrix n = number of criteria

Table(4) Random index values, according to Saaty (1987)

n	1	2	3	4	5	6	7	8	9	10
R1	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The next step is to calculate the consistency ratio (C R) (Equation 3.)

$CR = \frac{CI}{RI}$ Equation 3

Where RI = random consistency index for different values of n (Table 1.) If CR≥0.1, the consistency degree is satisfactory but if the CR R<0.1 the matrix is inconsistent If not, the decision-makers must review their judgments (Saaty, 1987)

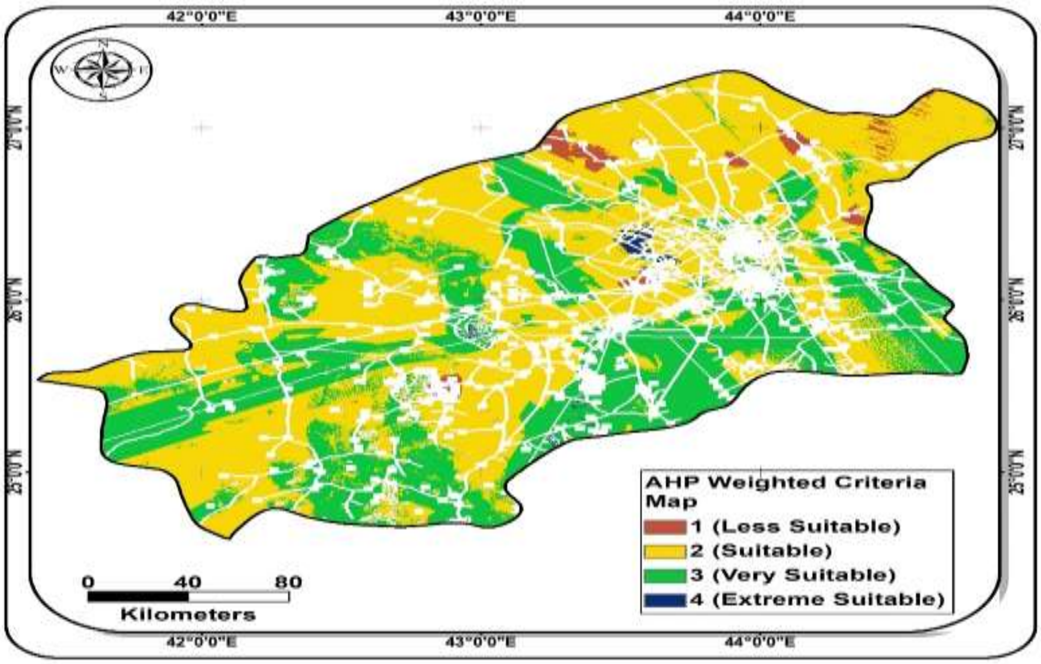


Fig. (7) AHP Weighted Criteria Map

Criteria has been defined and weighted fig (7) according to the methodology described above. Four factors are constraints (Figure 5 ,6) and five factors (Figure 4) are defined here in as design criteria based on the current national legislation framework and they are combined to assess the degree of suitability for wind farm installation in the regional of Qassim area. Initially, all constraints are transformed into (AHP) maps (raster datasets) to represent the following rules: a. Exclusion of areas demarcated for absolute nature protection that belong to the Natura 2000 network in accordance with Directive 2006/613/EC of the European Parliament: The shapefile regarding the margins of these areas is transformed into a raster file, for the other factors combined and weighted. In this study, AHP was used to combine criteria and calculate the overall score and land suitability of the study area.

The land suitability index for wind farm is calculated using Equation (2)

$$LSI_w = \left[A * \left(\left(\sum_{j=1}^{n} A_j\, C_{wi} * A_j SC_{wi}\right)\right)\right] + \left[B * \left(\left(\sum_{j=1}^{m} B_j\, C_{wi} * B_j SC_{wi}\right)\right)\right] (2)$$

where n = number of criteria factors, A = weighted index of criteria, $A_j C_{wi}$ = weighted index of criteria related to main factors (wind speed, slope …...) $A_j SC_{wi}$ = weighted index of sub-criteria related to criteria in the project, m= number of criteria in project B = weighted index of constrain factors $B_i C_{wi}$ = weighted index of criteria related to constrain factors (distance to power lines, distance to major roads, distance to city) $B_j SC_{wi}$ weighted index of sub-criteria related to criteria in constrain factors Calculated.

Table(5) Result of Wind Farm Suitability.

Classes	Cell Size	Number of Class Cell	Area (sq m)	Percentage %
1(Less suitable)	290.4181	8806	2557421.399	0.4%
2 (Suitable)	290.4181	339443	98580376.11	14.7%
3(Very suitable)	290.4181	211229	61344715.51	9.1%
4(Extreme Suitable)	290.4181	2093	607844.9908	0.1%
Total Suitable Area	290.4181	561571	163090358	24.2%

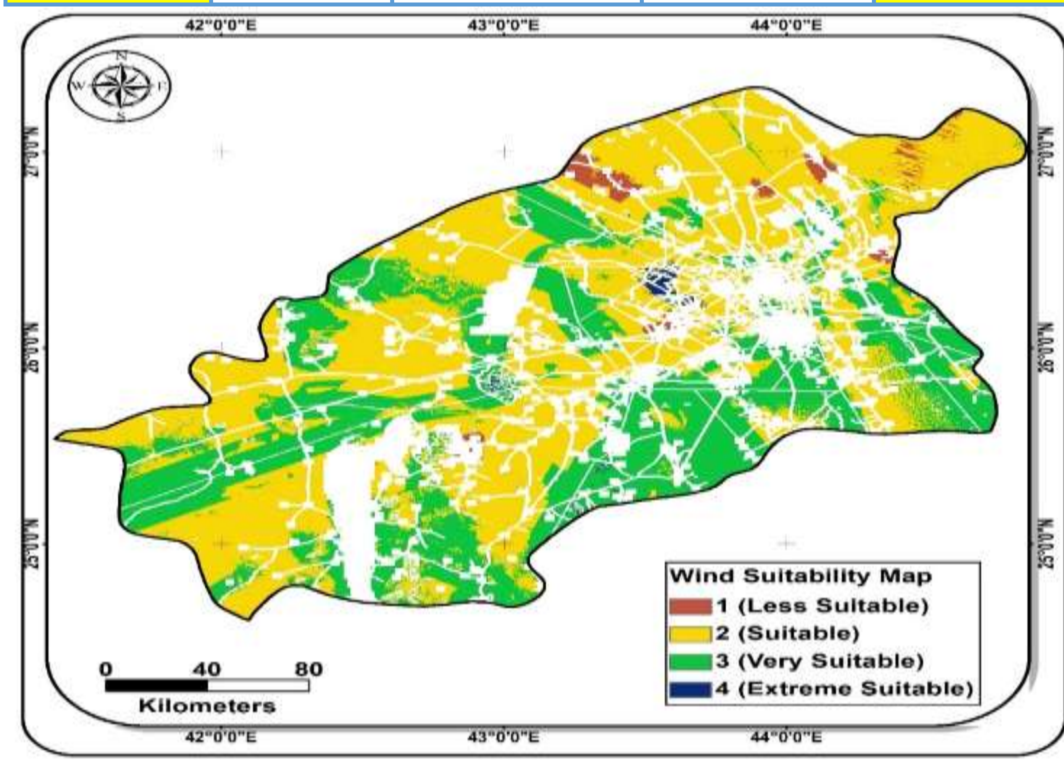


Fig.(8) Wind Suitability Map

weights with AHP for environmental objective are summarized in Table (5). The results of this study can therefore be used by decision-makers as a decision-support for further studies in the future.

4. CONCLUSIONS:

The aim of this study was to propose site suitable area a GIS-based procedure for the suitable sites for wind farm locations considering all conditions. To calculate the suitability index, Analytic Hierarchy Process method (AHP) was used. A land suitability index was determined for site of wind energy farm. The final index was then categorized in “Less Suitable”, “suitable”, “very suitable” and “Extreme Suitable” Figure 6. As a result, in table (5) fig. the total area of 98580376.11 km^2(14,7%) is Suitable, 61344715.51 km^2 (9,1) is very Suitable, 607844.9908 km^2(0.1%) is Extreme Suitable and 2557421.399 km^2 (0.4) Less Suitable for building wind energy farm. As a result, fig (8) northern part of Qassim region has potential for building wind energy farm.

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