# GIS-Based Multi Criteria Analysis for Solar Power Plant Site Selection Support in Mecca

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## ABSTRACT

**One of the major sources of renewable energy, particularly electricity generation and water desalination, is solar energy. The National Initiative to produce Water and Electricity started when the electricity consumption in Saudi Arabia begun to increase by about 5% per year. The current investigation aims to use a multicriteria GIS technique to identify the best spatial location for solar energy collection in the Mecca Administrative District. The best locations for solar power plant construction were determined with the use of a set of factors and criteria, including planning and environmental criteria, and terrain calibrator. These criteria were defined through a thorough literature review. This information was then used to create a digital geographic database, which was incorporated into an integrated GIS to produce a spatial fit model. According to the suitability data, most of Mecca region is ideal for solar energy projects, with an applicability percentage ranging between 30% and 80%. These findings are encouraging and promising for Mecca's renewable energy industry and they should be considered. It was discovered by examining these spatial locations and the level of suitability to the specifications that the lands with a sufficient share of more than 80% form an area of around 4000km$^2$ and makeup 3% of all suitable lands. The governorates of the Mecca Administrative Area are home to most of these exceptionally suited locations. The Taif governorate takes first place with 35% of the total area and the two governorates of Turbah are placed second and third with 24% and 14%. In the Mecca Administrative Area, the appropriate lands for solar energy projects are distributed spatially according to a digital map. The study proposes incorporating the findings into the Saudi national plan for renewable energy sources.**

***Keywords-solar power; special analytics; multiple criteria; DSS; GIS***

## I. INTRODUCTION

Over the past two decades, the Kingdom of Saudi Arabia's actual power generation capacity raised from 15,212MW to 51,302MW, with more than 7% mean annual growth. Simultaneously, the portion of one subscriber increased from 23,928kWh to 33,936kWh. Electricity is one of the most significant factors contributing to the rapid development and growth in all spheres of life on a global scale [8-11]. One renewable energy source that may be used anywhere and is free and endless, is solar energy. This form of renewable energy is clean and does not emit any pollutants, unlike the conventional energy sources. The strategies, methods, and processes for harnessing solar energy and turning it into electrical energy are becoming more and more popular on a global scale. Over the past 15 years, the development of the electricity generation from solar energy led to a reduction in electricity cost by 4% per year [13-18]. High levels of solar radiation that can be converted into energy are present throughout the Middle East, especially in the Arab world. Recently, countries in this region have tended to increase research, development, and investment efforts in solar energy. In the Kingdom of Saudi Arabia, the interest in solar energy exists for forty years [25-27]. It should be mentioned that several studies in the Kingdom have shown that, taking into consideration the economic value of the environmental and the health risks of oil use, the cost of producing power from solar energy is less than that of producing electricity from oil [13-17]. All the Gulf Cooperation Council nations have begun investing in renewable energy sources, particularly solar energy, at a regional level [18-24].

Geographic Information Systems (GIS) are the best option for gathering, storing, processing, analysing, and displaying spatial and non-spatial data to come up with technological answers to multi-domain problems. A set of alternatives or solutions are presented to decision-makers after the multi-parameter GIS approach has studied the potential of a variety of natural, economic, and environmental criteria in a particular spatial location. This approach can be utilized in a wide variety of situations and it has been used to choose the optimal location for several projects, including solid waste treatment facilities, sewage treatment plants, agricultural development, and renewable energy projects. The Kingdom of Saudi Arabia has used this approach in several different fields. This strategy, for instance, was used to determine the optimal locations in the for the construction of rainfall harvesting dams and flood control systems, to choose the optimum site for the construction of tourist facilities, and GIS with multiple calibrations was used to determine the most suitable spatial locations for setting up solar collector projects in Mecca area from Kingdom of Saudi Arabia [1-7]. This study aims to provide solutions to help policymakers choose the most suitable locations to set up solar mining projects.

## II. STUDY AREA

The Mecca region spans a sizable area and is situated in the center of the western sector of the Kingdom [29]. This region covers about 150km$^2$, or 7% of the whole area of the Kingdom. By 2025, the number of inhabitants is anticipated to reach 9.7 million [28].

## III. RESOURCES AND TECHNIQUES

The initial data for the study came from several sources, and the requisite databases were later built. The information which was digitized came from [29]. Development Specialist Mecca provided information on major cities, air terminals, electrical installation broadcasting classes and street organization.

The ground elevation of the Mecca specified area extends from -9m to 2586m, with a mean of 843m [29]. The highest mountains in the region are the Al-Hadab Mountains in Maysan Belharith, which are nearly 2,500m above sea level. The Sarawat-Hijaz Mountains extend from the northwest to the southeast, forming a group of hills that are characteristic of the topography of the Mecca Administrative Region. These hills include the East Al-Sarawat plateau, which stretches from the city of Taif in the north to the border of the Al-Baha region in the south, and the Rakba plain's elevation, which stretches for around 400km and nearly 200km north to south. A collection of coastal fields arranged in the form of a run parallel to the Ruddy Sea's shore and varying in width from 15 to 25km are also included in the region's topography [27]. The major energy distribution network in Mecca has a total length of about 900km while the main road network has a total length of over 7000km. The majority of the cities are grouped together in the west, near the shore.

## IV. DATA ANALYSIS

The first procedures in data handling attempt to arrive at a group of criteria that have to be available in selecting the most appropriate geological areas for the use of the geographic data framework (GIS) in order to facilitate the selection of the locations for sun-oriented energy plants [19–21], which results in choosing the best spatial sites for solar power plants. One of the most crucial factors is the amount of solar radiation [28], followed by the criterion of trends and the inclination direction, which has an impact on the setup and installation of the necessary equipment for solar power plants.

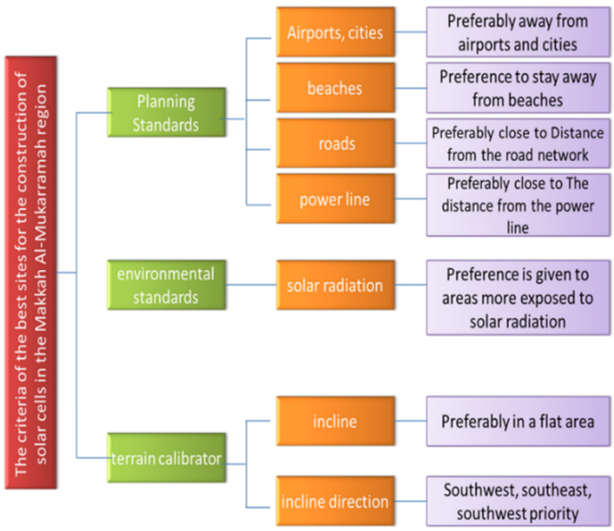


Fig. 1. Optimal site selection criteria for solar cell construction.

Regarding the environment, picking the best places for solar energy projects involves the distance from major cities, airports, roads, electrical distribution networks, and beaches. Seven criteria were chosen (see Figure 1) and their relative weights were calculated (see Table I).

TABLE I. CRITERIA TO BE CONSIDERED WHEN SELECTING THE BEST SITES FOR SOLAR POWER PLANTS

| Principle type | Principle | Result % |
|---|---|---|
| Planning | Towns and airfields | 10 |
| | Streets | 10 |
| | Shoreline | 10 |
| | Power networks | 15 |
| Environment | Solar radiation | 30 |
| Terrain calibrator | Inclination | 10 |
| | Inclination direction | 15 |

For each of the stated criteria, a network layer representing the categorization of the criteria's values was derived [20-24]. These network layers were then reclassified according to scale ranging from 1 to 10 for simplicity of presentation and analysis. The final fit model was then obtained by applying the appropriate weights [28].

## V. MODEL BUILDER

The process of creating a model involves feeding it with raw data, such as street networks, towns and airfields, digital elevation model, power system, coastline. The digital elevation model was used to extract solar radiation, inclination, and inclination orientation. The weight for each cell was determined using the Euclidean distance tool, and the street grid chart, power grid chart, town map, airfields, and shoreline map were created by reclassifying (or changing) the values in the raster, using the tool for weighted overlay [8]. The optimal location for solar power plants in Mecca was identified using specific weights for each parameter (Figure 2).

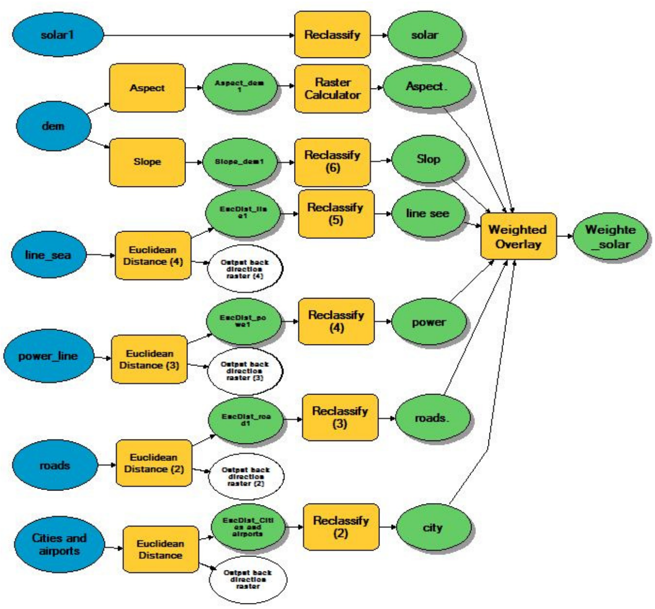


Fig. 2. The model builder will decide which locations are ideal for building solar plants.

## VI. RESULTS AND ANALYSES

Many initial models were built up matching the layers of the criteria values to the degree of spatial suitability for each criterion [8, 12]. Figures 3-11 were made with the ESRI ARC/GIS software, version 10.3. Figure 3 shows the territorial suitability for the sun powered radiation model, with the center and eastern areas having the most noteworthy esteem. Since most cities are located on the western side of coastline and in connection to basis for separate shoreline, areas of appropriate height are those that are the most remote from the shoreline, as shown in Figure 5 of the spatial appropriateness demonstrate for the cities and air terminals measure.

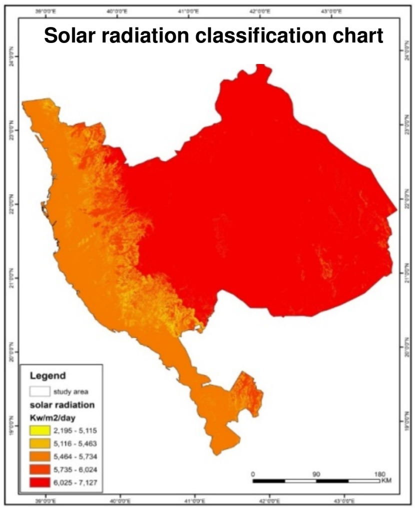


Fig. 3. Solar radiation classification chart.

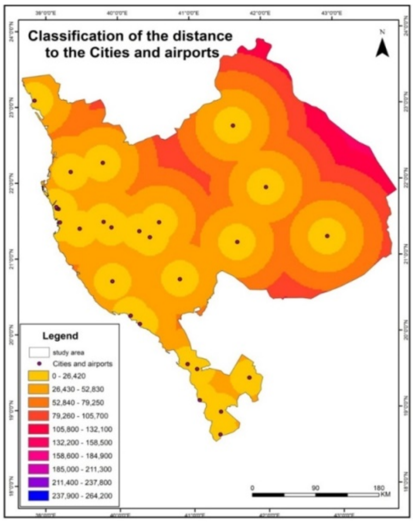


Fig. 4. Classification of the distance to cities and airports.

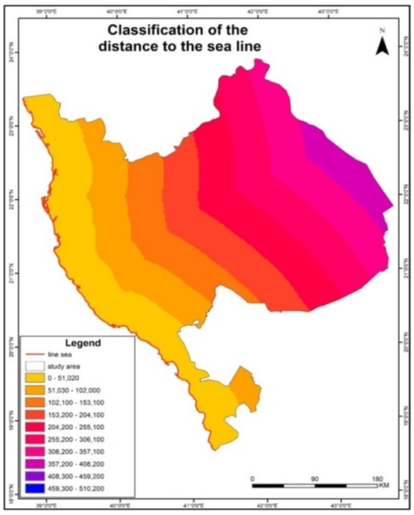


Fig. 5. Classification of the distance to the coastline.

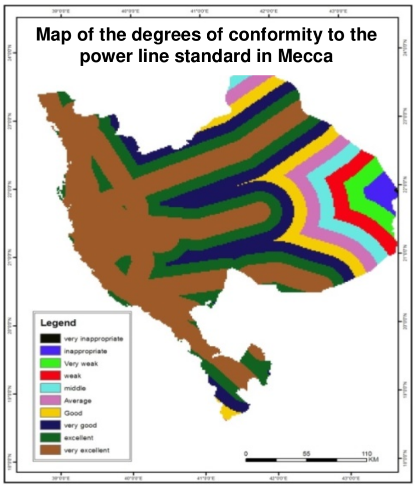


Fig. 6. Degrees of conformity to the power line standard in locations in Mecca.

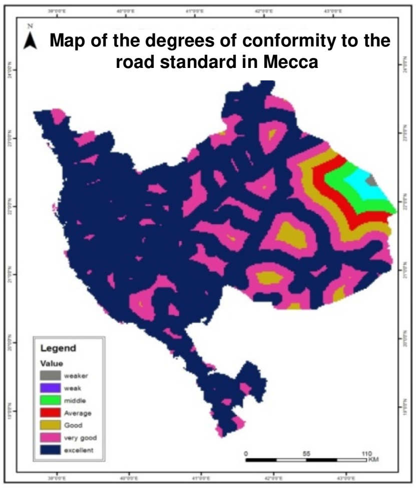


Fig. 7. Degrees of contormity to the road standard in in Mecca.

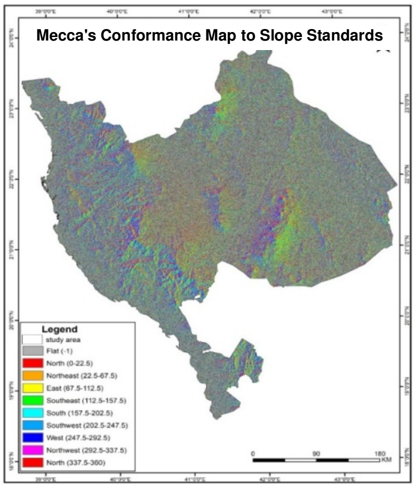


Fig. 8. Mecca's conformance map to slope standards.

Figure 6 outlines the spatial ampleness from the power dispersion. It should be noted that high altitude areas are those that are not distant from the control conveyance line. This model pertains to the criterion of distance from the electricity distribution network. Additionally, the chart shows that the optimal areas are concentrated on the western portion of the research region for this criterion. Figure 7 portrays the area suitability with regard to the proximity to the road network.

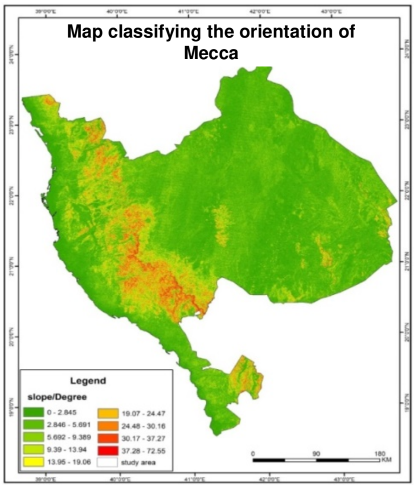


Fig. 9. Map classifying orientation.

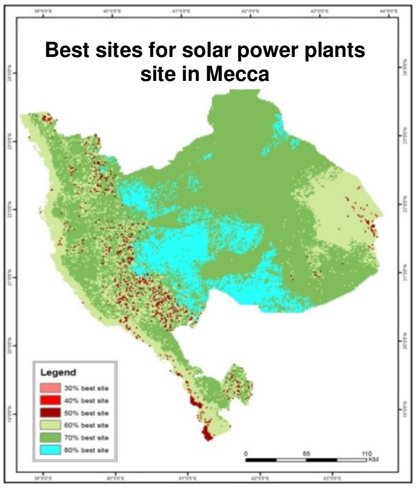


Fig. 10. Best sites for solar power plants in Mecca.

Figures 8 and 9 indicate that most of the authoritative locales have great suitability degrees with regard to slope and slope orientation, with the exemption of the centre fragment of the area, which has extraordinary slants. At the highest places the degree of suitability was medium and occasionally weak.

To ensure that the sun's rays fall directly on the solar cells, it is ideal for the gradient to face south, southeast, or southwest. As a result, these restrictions were used in the final fit process, which can be seen in Figure 10.

Mecca as a whole is ideal for the solar energy harvesting, with a reasonable rate between 30% and 80%. The findings of the current study are important for Mecca's renewable energy sector. A detailed examination of the spatial zones and their level of compliance with the regulations shows that a 3% of the qualified lands that are defined by a satisfactory extent of more than 80% and cover a total area of about 4000km$^2$.

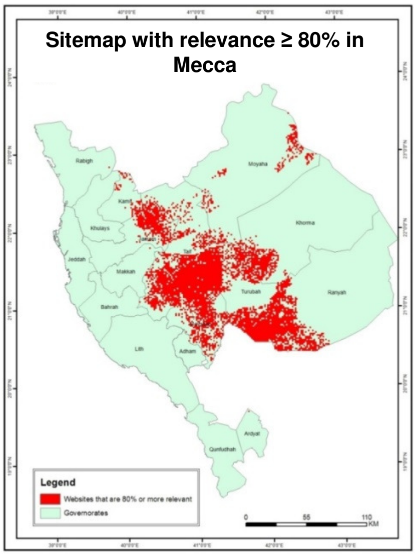


Fig. 11. Sitemap with relevance ≥ 80% in Mecca.

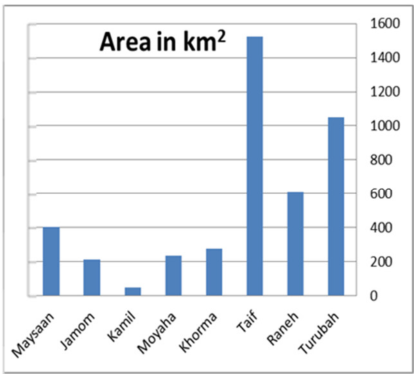


Fig. 12. Areas with at least 80% compliance.

TABLE II. DISTRIBUTION OF LOCATIONS WITH SPATIAL SUITABILITY GREATER THAN 80%

| Percentage % | Area in km$^2$ | Governorate |
|---|---|---|
| 24 | 1051 | Turubah |
| 14 | 608 | Raneh |
| 35 | 1521 | Taif |
| 6 | 278 | Khorma |
| 5 | 236 | Moyaha |
| 1 | 48 | Kamil |
| 5 | 211 | Jamom |
| 9 | 403 | Maysaan |
| 100 | 4356 | Total |

Table II and Figures 11 and 12 show how these appropriate locations are distributed throughout the governorates of the Mecca Authoritative Locale. The Taif governorate has the most suitable areas, with 35% of the overall zones, followed by the two Turbah governorates with 24% and the Rania governorate with 14%. The governorates of Maysan and Al-Khumra follow, each with 14%, and none of the other governorates have any place with a degree of compliance more than 80%.

## VII. CONCLUSION

The current research focuses on the Mecca region of Saudi Arabia, mainly due to the promising prospects for international energy interconnection. The distribution of spatial phenomena varies between natural and human phenomena that spread on the lands of Mecca Governorate, such as road networks, electricity network, cities and airports, solar radiation, and tendencies. Combined, these are criteria that the study relied on to design a model that determines the suitability for the application of solar energy projects. Based on the investigation and analysis conducted in this study, it was found that the degree of spatial appropriateness varies, and the land area with a fit coefficient greater than 80% is about 5,000km$^2$. Mecca Governorate's center region contains the majority of these areas. To evaluate the best locations for the deployment of photovoltaic power stations in the Mecca region, this study considered various criteria (planning standards, environmental standards, terrain calibrator). The results showed that, with varying degrees ranging between 30% and 80%, the larger part of the Mecca Regulatory Locale is suitable for establishing solar power plants. The conclusions of this investigation are more accurate than those obtained from previous studies, which conclude that the whole area of Mecca is suitable for solar power plant placement. This study's outcome can help decision-makers to specify the most suitable locations to set up solar harvesting projects in the Governorate of Mecca.

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