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Applying Geographic Information System (GIS) for Solar Power Plants Site Selection Support in Makkah

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Abstract

Solar energy is one of the most important components of renewable energy, which constitutes an important source of clean energy in many fields, especially water desalination and electricity generation. With the increase in electricity consumption in the Kingdom of Saudi Arabia at an annual rate of 5%, the National Initiative for the production of water and electricity was launched. The current study aims to apply a multi-standard GIS method to determine the most appropriate spatial sites for solar energy collection in the Makkah Administrative District. A set of conditions and criteria have been relied upon, whether planning criteria, environmental criteria, or an environmental criterion, to obtain a digital appropriate model that shows the best sites for constructing solar power plants. The study determined the required criteria by relying on literary studies and creating a digital geographic database for these requirements, and then integrating these requirements into an integrated geographic information system in order to obtain a spatial fit model. The results of the suitability indicate that all areas of Makkah Al-Mukarramah are suitable for the solar energy project with an appropriate percentage ranging between 30% and 80%. These results are promising for the renewable energy sector in Makkah Al-Mukarramah and should be taken into consideration. By analyzing these spatial sites and their degrees of suitability to standards, it was found that the lands that are characterized by an adequate share of more than 80% have an area of about 4000 square kilometers with a percentage of 3% of the total suitable lands. These highly suitable areas are concentrated on the governorates of the Makkah Al-Mukarramah Administrative Region, where the Taif governorate comes in the first place with 35% of the total area, followed by the two governorates of Turbah with 24%, and the Rania governorate with 14%. A digital map was made showing the spatial distribution of suitable lands for solar energy projects in the Makkah Al-Mukarramah Administrative Region. The study recommended applying the obtained results in the national plan for renewable energy sources in the Kingdom of Saudi Arabia.

Keywords

GIS, DSS, Multiple Criteria, Special Analytics, Solar Energy

1. Introduction

Electricity is one of the most important reasons for the rapid development and growth in all areas of life at the global level in the Kingdom of Saudi Arabia. In the last two decades, the actual generation capacity of electricity in the Kingdom increased from 15,212 megawatts to 51,302 megawatts, at an average rate of increase of more than 7% annually, and the share of one subscriber increased from 23,928 kilowatt-hours to 33,936 kilowatt-hours in the same time period (Chamber, 2010). Solar energy is one of the renewable energy sources that can be exploited anywhere and is a free and inexhaustible source for all needs. One of the advantages of this type of renewable energy is that it is clean energy that does not produce any pollutants, unlike the limited traditional types of energy. In the last two decades, interest has increased at the global level in the techniques, and methods of collecting solar energy and converting it into electricity. The annual growth rate of solar energy production reached 23% during the period from 1980 to 2001, while solar energy production witnessed a growth of 15% during 2007 only. It should be noted that the expansion in the production of electricity from solar energy has contributed to reducing electricity prices by 4% annually for the last fifteen years (Ministry of Water and Electricity, 2010). The Arab region and the Middle East, in general, enjoy high rates of solar radiation that can be converted into solar energy. The countries of this region have recently tended to intensify efforts to develop, innovate and invest in solar energy. The interest in solar energy in the Kingdom of Saudi Arabia began four decades ago (Nizami et al., 2015).

It should be noted that some studies in the Kingdom have indicated that the cost of electricity production from solar energy is less than its cost from oil production if the economic value of the environmental and health risks of using petroleum is taken into account (Bhutto, Bazmi, Zahedi, & Klemes, 2014). At the regional level, all the Gulf Cooperation Council countries have started in recent years to invest in renewable energy sources, especially in solar energy (Darwish & Shaaban, 2016). On the technical side, Geographic Information Systems (GIS) are the ideal choice for collecting, storing, processing, analyzing and displaying spatial and non-spatial data to devise technical solutions to multi-domain issues. The multi-parameter GIS method aims to study the possibility of a number of natural, economic and environmental criteria in a specific spatial spot, and then communicate to a set of alternatives or solutions that are placed in front of decision-makers. The application of this method is not limited to a specific range of fields, but it was used to determine the best site for several goals, including renewable energy, land use planning, sewage treatment plants, agricultural expansion, and solid waste treatment plants. In the Kingdom of Saudi Arabia, this method has been applied in several fields. For example, this method was applied to choose the best sites for the construction of rainwater harvesting dams and floods in the Qassim region. Dawod also applied a multi-criteria method in determining the best location for the establishment of tourist facilities in the Hada region. The current study is related to providing solutions that help decision-makers choose the most appropriate sites for the establishment of solar energy collection projects based on the application of the multi-calibration Geographical Information Systems (GIS) method in determining the most appropriate spatial sites for the establishment of solar energy collection projects in the Makkah Al-Mukarramah region in the Kingdom of Saudi Arabia.

Study Area:

The Makkah region is located in the middle of the western sector of the Kingdom, as it extends over a wide area between latitudes 19˚ and 24˚ north and latitudes 39˚ and 44˚ east **Figure 1**. The geographical area, where the area is about 140.1 thousand square kilometers, is equivalent to 6.4 of the total area of the Kingdom (Emirate of Makkah Al Mukarramah Region 1433 AH). Seven million people, according to the general population and housing census in 1431 AH, this number is expected to rise to 9.7 million people by 2025 AD (Wakeyama & Ehara, 2010).

2. Materials and Methods

The study relied on several sources to obtain the required initial data, and then the necessary databases were created. The data is a digital elevation model, which was obtained from the NASA website (**Figure 2**). In addition to the data of the main cities, airports, the distribution layer of the electricity network and the road network, which were obtained from the Makkah Al-Mukarramah Development Authority (**Figure 3**, **Figure 4**).

Using the digital elevation numbers of the world, it was found that the ground levels in the Makkah Al-Mukarramah Administrative Region range between 0 meters and 2586 meters, with an average of 843 meters (**Figure 2**). Examples of the region's mountains are the Al-Hadab Mountains in Maysan Belharith, which is the highest, about 2500 meters above sea level, the Mastaba Mountains in Al-Dar Al-Hamra 2400 meters, the Dhaka Mountains in Al-Shifa, south of Taif, 2400 meters, and Jabal Kara in Al-Hada to the west of Taif 2177 meters and Tuwairq Mountains is 1863 meters. The topography of the earth's surface in the Makkah Al-Mukarramah Administrative Region is also characterized by the presence of a group of hills that extend with the extension of the Sarawat-Hijaz mountains from the northwest to the southeast, including the East Al-Sarawat

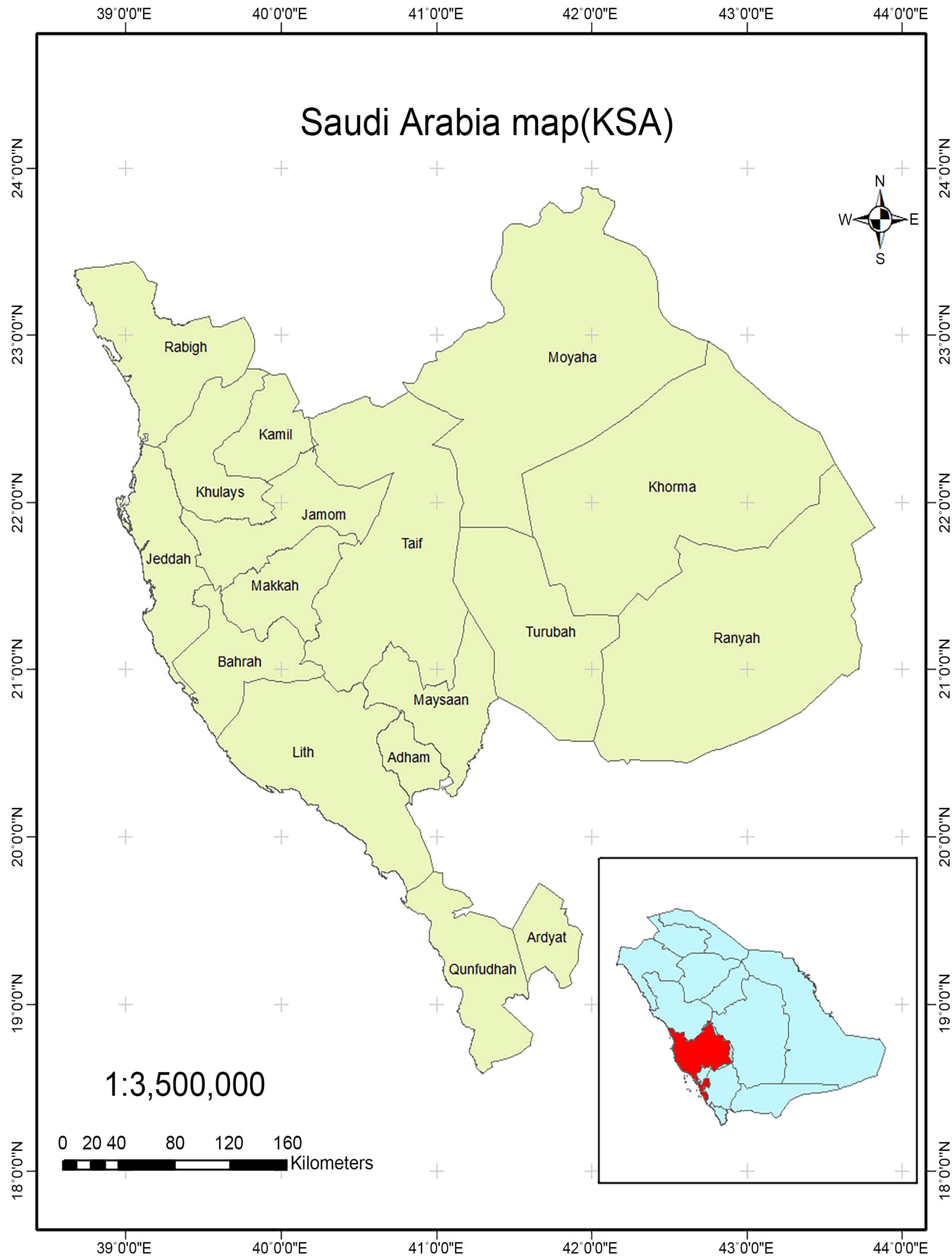

Figure 1. Makkah province map (emirate of Makkah region).

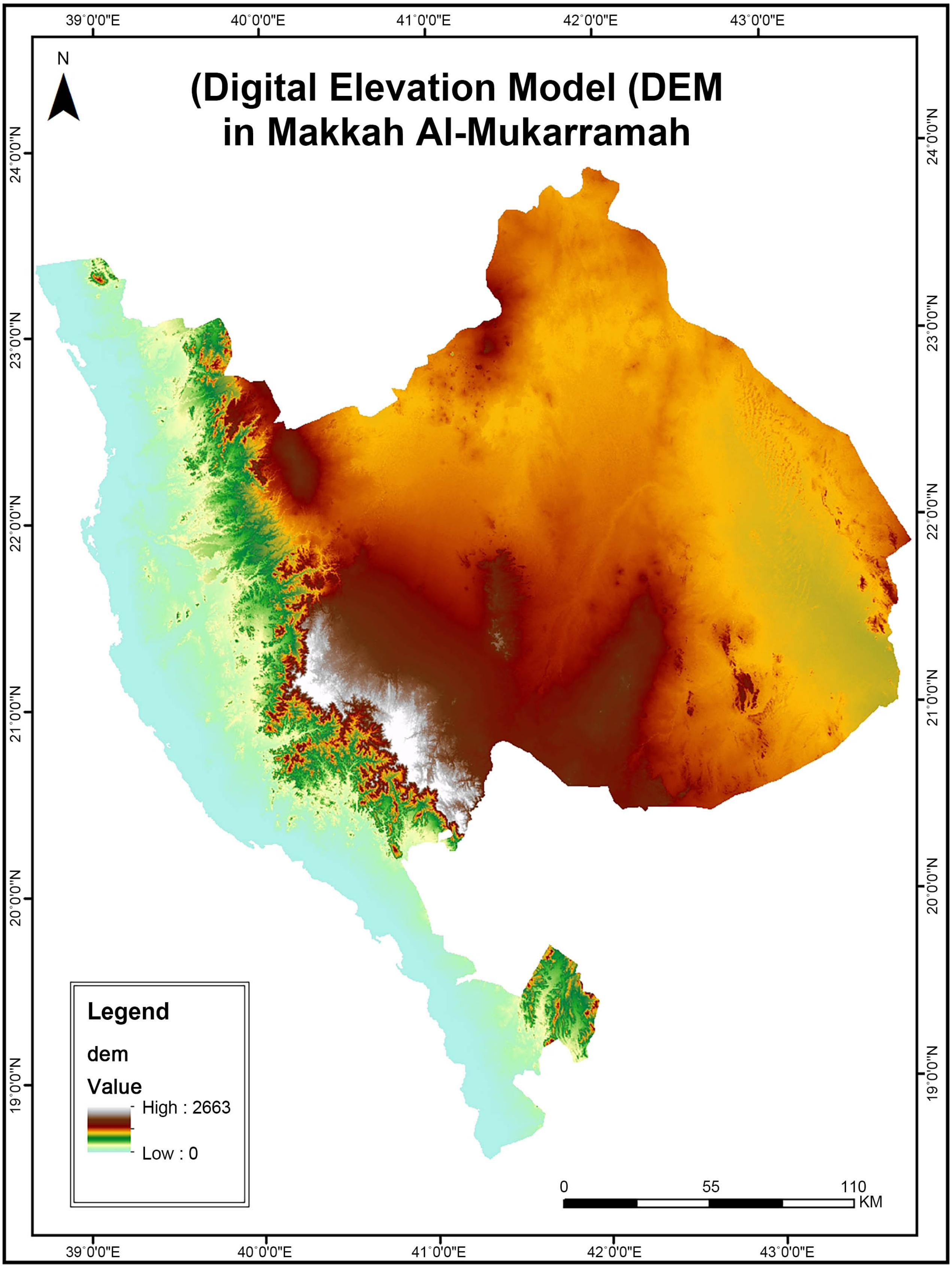

Figure 2. Digital elevation model (DEM) in Makkah Al-Mukarramah (researcher preparation).

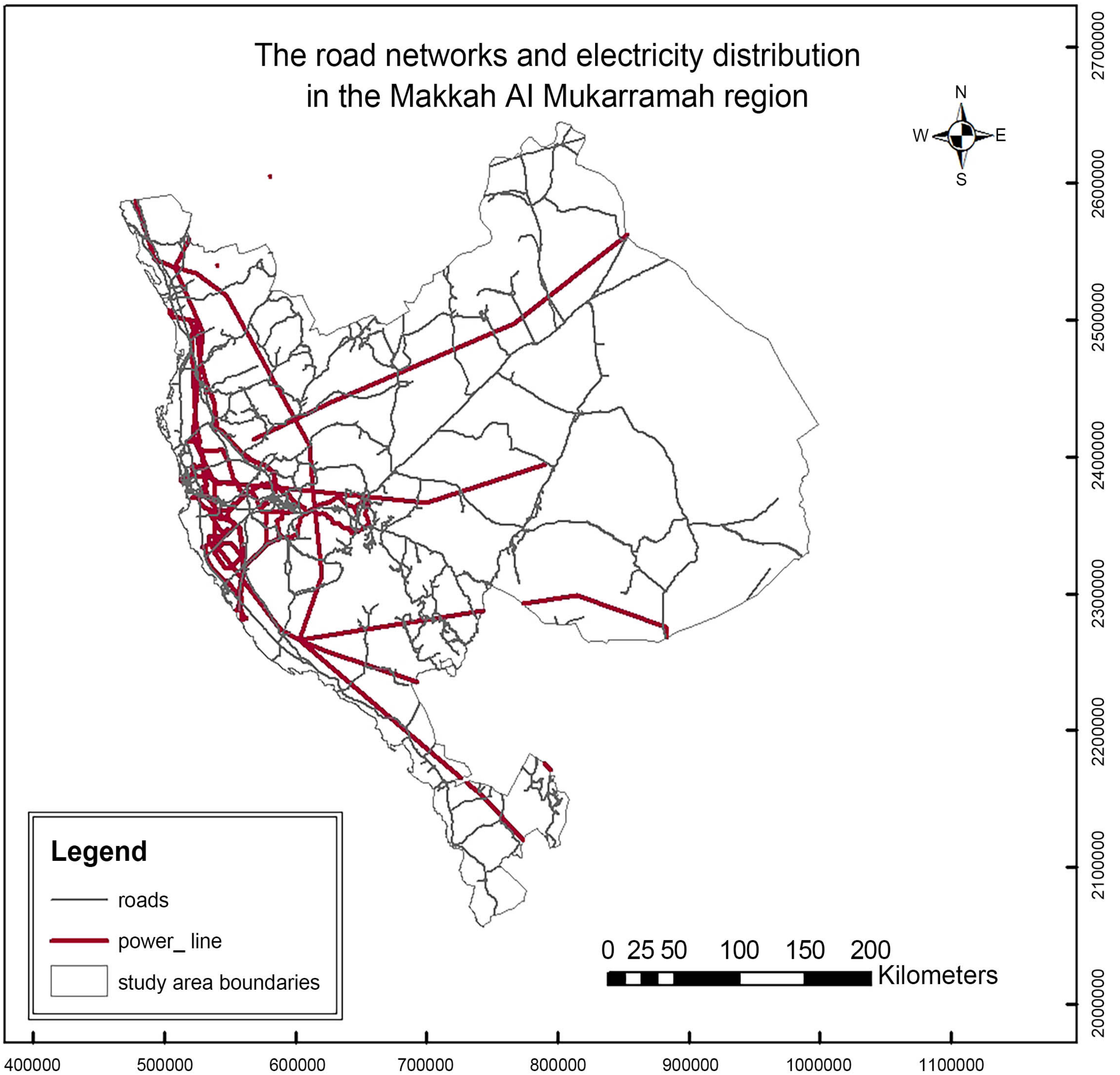

Figure 3. The road networks and electricity distribution in the Makkah Al-Mukarramah region (researcher preparation).

plateau extending from the border Al-Baha region in the south, and even the city of Taif in the north, and the plateau of the Rakba plain, which extends for about 200 km north-south and about 400 km to the north-east. The topography of the region also includes a group of coastal plains in the form of a range parallel to the coast of the Red Sea, with a width ranging between 15 and 25 km (Herrmann, 2015). Studies have indicated that the total lengths of the main road network in Makkah Al-Mukarramah are about 7000 km, while the total lengths of the main electricity distribution network are about nine hundred kilometers. It is noted that most of the cities are concentrated in the western side along the coast line.

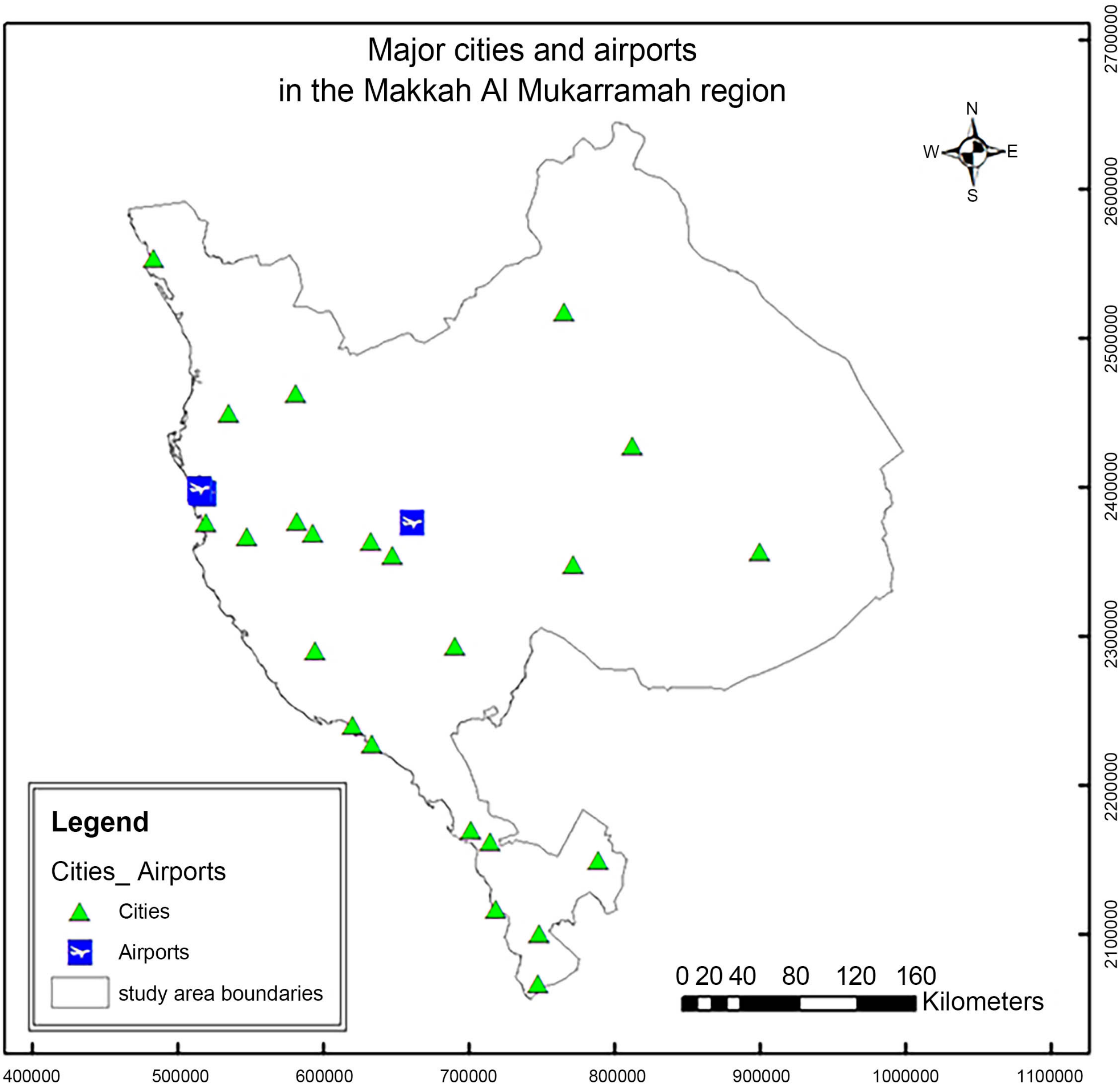

Figure 4. Major cities and airports in the Makkah Al-Mukarramah region (researcher preparation).

3. Data Processing

The first steps of data processing were to reach a set of criteria required to be available in choosing the most appropriate spatial locations for the application of the Geographic Information System (GIS) (Liu, Xu, & Lin, 2017; Saaty, 1980) to support the selection of the locations of solar energy plants (Forman & Selly, 2001; Al-Rasheed, 2021), which leads to the selection of the most appropriate spatial locations for solar power plants.

The value of solar radiation is one of the most important criteria (Arnette & Zobel, 2011; Nguyen & Pearce, 2010), then comes the criterion of tendencies and incline direction of the earth's surface, which affects the equipment and installation of the necessary devices designated for solar power plants

As for the environment, the distance from the main cities, airports, roads, electricity distribution networks, and beaches are also important factors in choosing the most suitable locations for solar energy projects. Also, seven criteria were selected Figure 5 and the relative weights of each of these criteria were determined as shown Table 1.

The data processing steps consisted of deriving a network layer for each of the specified criteria (Asakereh et al., 2014; Choudhary & Shankar, 2012; Ruiz et al., 2020) representing the classification of the criteria's values into categories and then re-classifying them into degrees on a scale ranging from 1 to 10 for ease of presentation and analysis. Then apply the specified weights to reach the final fit model (Freitas, Catita, Redweik, & Brito, 2015).

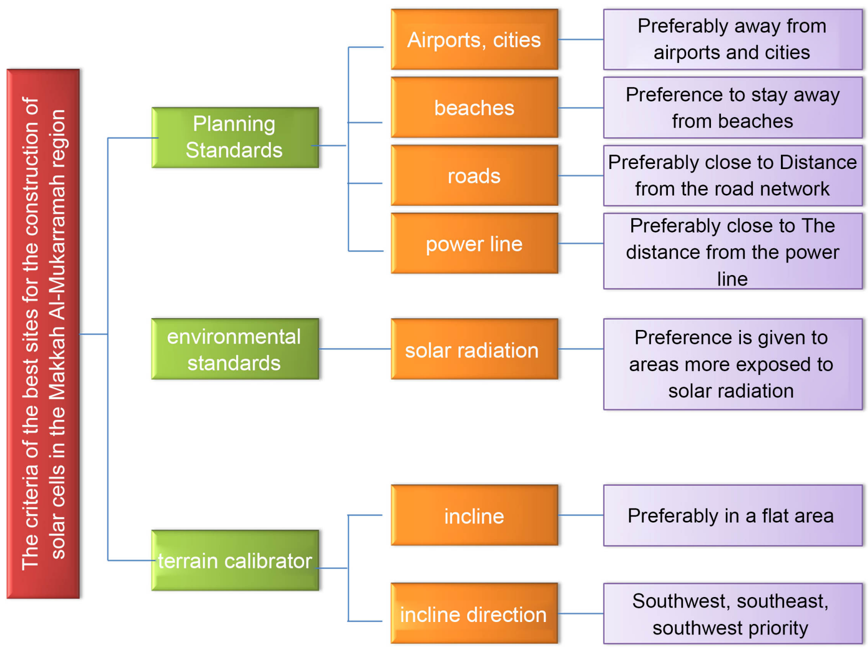

Figure 5. The criteria of the best sites for the construction of solar cells (researcher preparation).

Table 1. Criteria for the most suitable locations for solar gatherings.

Criterion type	Criterion	Effect %
Planning	Cities & airports	10
	Beach line	10
	Roads	10
	Electricity networks	15
Environment	Solar radiation	30
Terrain calibrator	Incline	10
	Incline direction	15

4. Model Builder

The model building steps consist of relying on basic data as input into the model (digital elevation model, road network, energy network, cities and airports, shore line).

The solar radiation, the side direction of the Earth and the slope of the Earth were extracted from the digital elevation model.

The Euclidean distance tool was used to calculate the weight for each cell, and then reclassification: was used to reclassify (or change) the values in the raster in order to derive the road network map, power grid map, city map, airports, and beach line map. Relying on the weighted overlay tool (Hepbasli & Alsuhaibani, 2011), specific weights were determined for each criterion and the best location for solar power plants in Makkah was extracted (**Figure 6**).

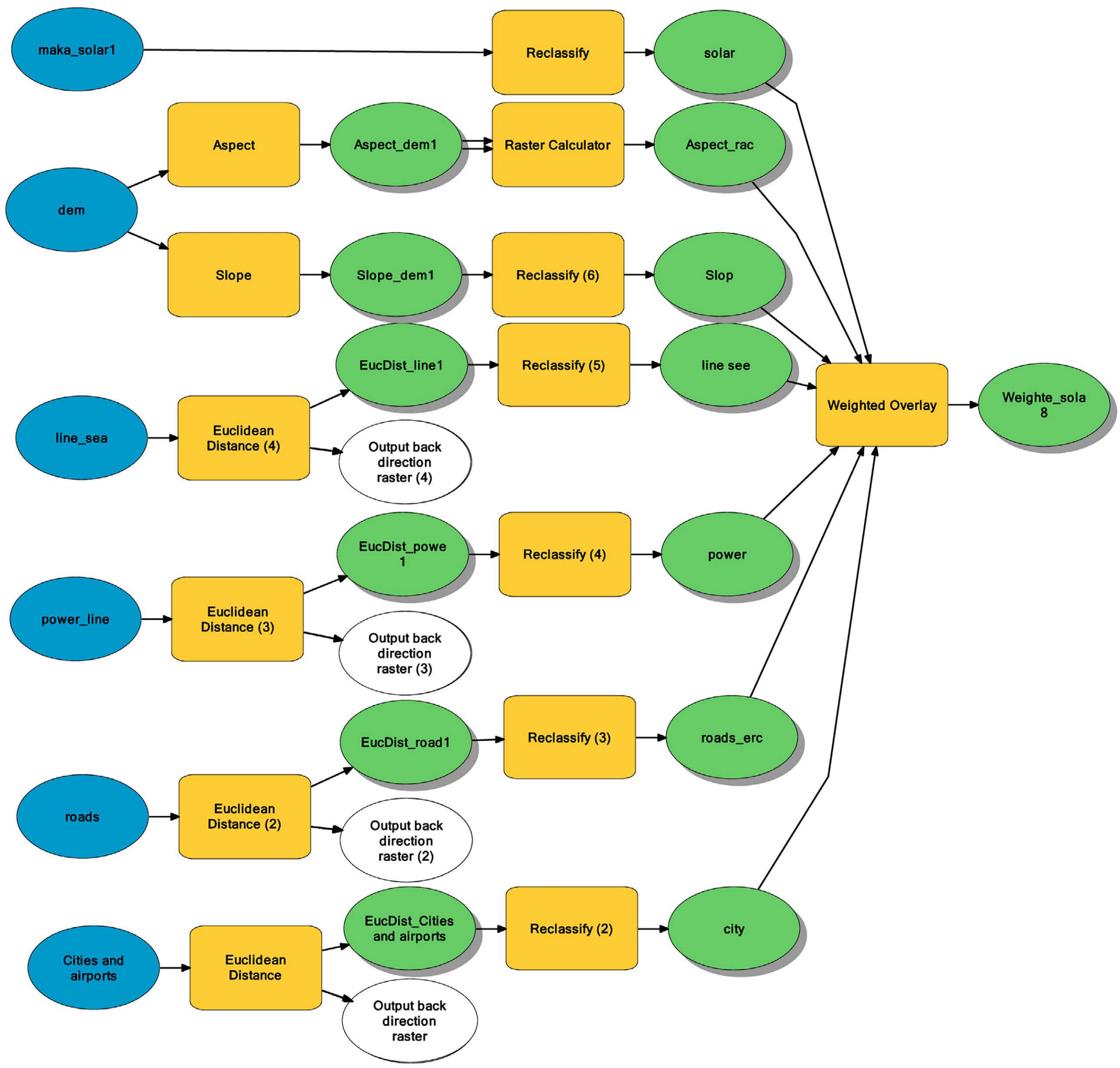

Figure 6. The model builder to select the best sites for the construction of solar cells (researcher preparation).

5. Results and Discussion

The layers of the values of each criterion were transformed into layers that represent the extent of spatial appropriateness for each criterion individually, meaning that several initial appropriate models were reached (Hepbasli & Alsuhaibani, 2011; Nizami et al., 2015). For example, **Figure 7** presents the spatial suitability model for the solar radiation criterion, and its highest value is in the central and eastern regions. The spatial suitability model for the cities and airports criterion, **Figure 8** shows that most cities are concentrated in the western side along the coast line and in proportion to the criterion of distance from the beach, so it appears that suitable high sites are those that are farthest from the beach (**Figure 9**).

As for the criterion of distance from the electricity distribution network, for example, **Figure 10** presents a model of spatial adequacy for the criterion of distance from the electricity distribution network, where we note that high appropriate sites are those that are not far from the power distribution line. The figure also indicates that these appropriate sites. For this criterion, it is focused on the western part of the study area. As for the appropriateness model for the criterion of distance from the road network, **Figure 11** shows more spatial locations, as the road network extends almost throughout the administrative region.

As for the slope of the earth's surface and the direction of regression (**Figure 12**), the initial adequacy model for this criterion figure (Sánchez-Lozano et al., 2013; Juma'a Muhammad et al., 2017) showed that most parts of the administrative regions have good appropriateness degrees, except for the middle segment of the region, which has great inclinations, and then the degree of suitability was medium and sometimes weak at the tops of the heights.

It is preferable that the direction of the gradient be south, southeast or southwest, so that the angle of the sun's rays is directly on the solar cells. Hence, these constraints were applied during the final fit process (**Figure 13**).

Al-Mallana results indicate that all areas of Makkah Al-Mukarramah are suitable for the solar energy project with an appropriate percentage ranging between 30% and 80% (**Figure 14**). These results are promising for the renewable energy sector in Makkah Al-Mukarramah and should be taken into consideration. By carefully analyzing these spatial sites and their degree of suitability to standards, it was found that the lands that are characterized by an appropriate share of more than 80% have an area of about 4000 square kilometers with a percentage of 3% of the total suitable lands. **Table 2** and **Figure 15**, **Figure 16** show the distribution of these highly suitable areas over the governorates of the Makkah Al-Mukarramah Administrative Region, where the Taif governorate comes in the first place with 35% of the total area, followed by the two governorates of Turbah with 24%, and the Rania governorate with 14%. It is followed by the governorate of Maysan and Al-Khumra with 14% of each and On the other hand, the governorates of Makkah, Jeddah and the rest of the governorates do not have any regions with an appropriate degree of greater than 80%.

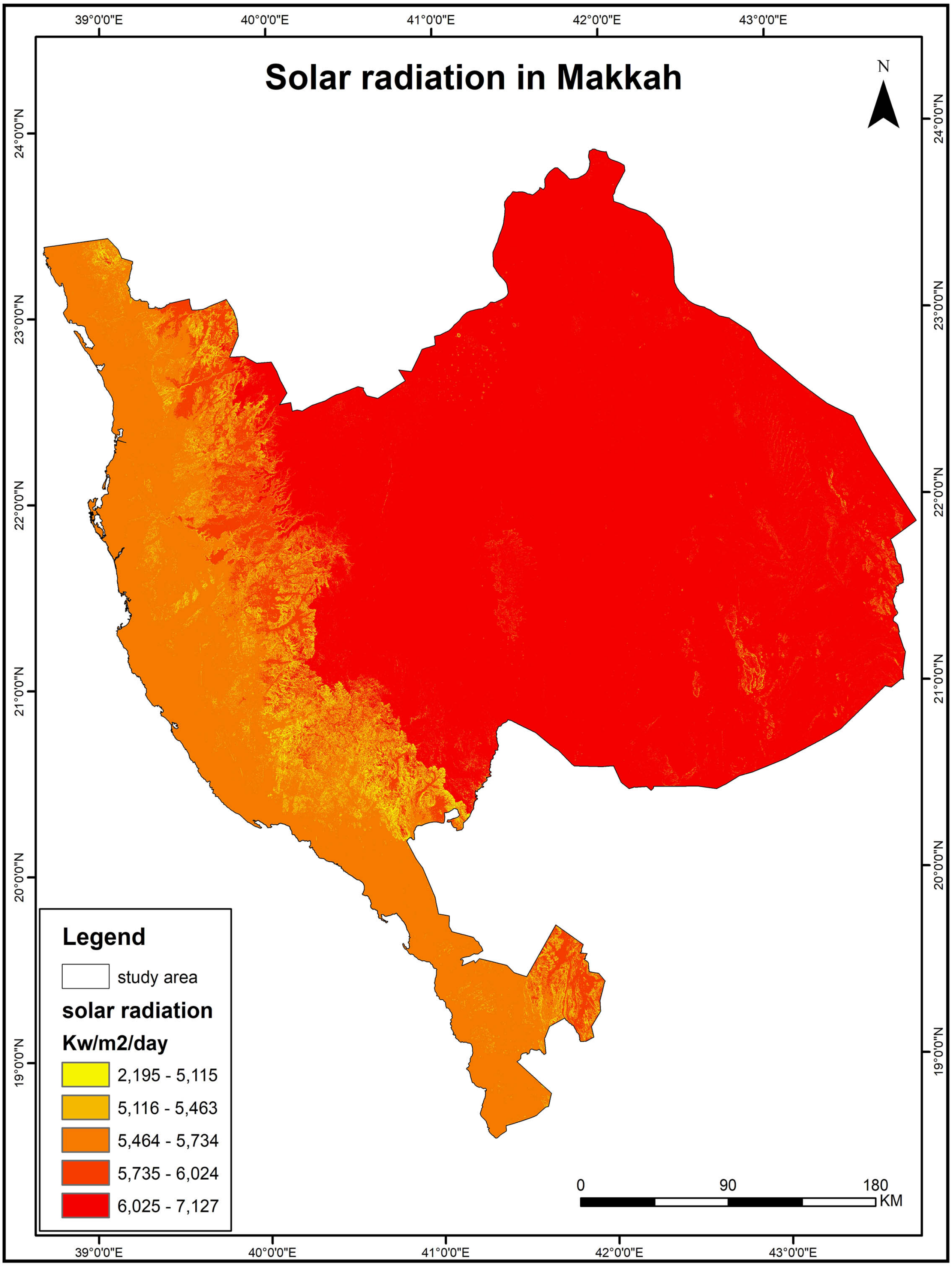

Figure 7. Map showing classify for solar radiation (researcher preparation).

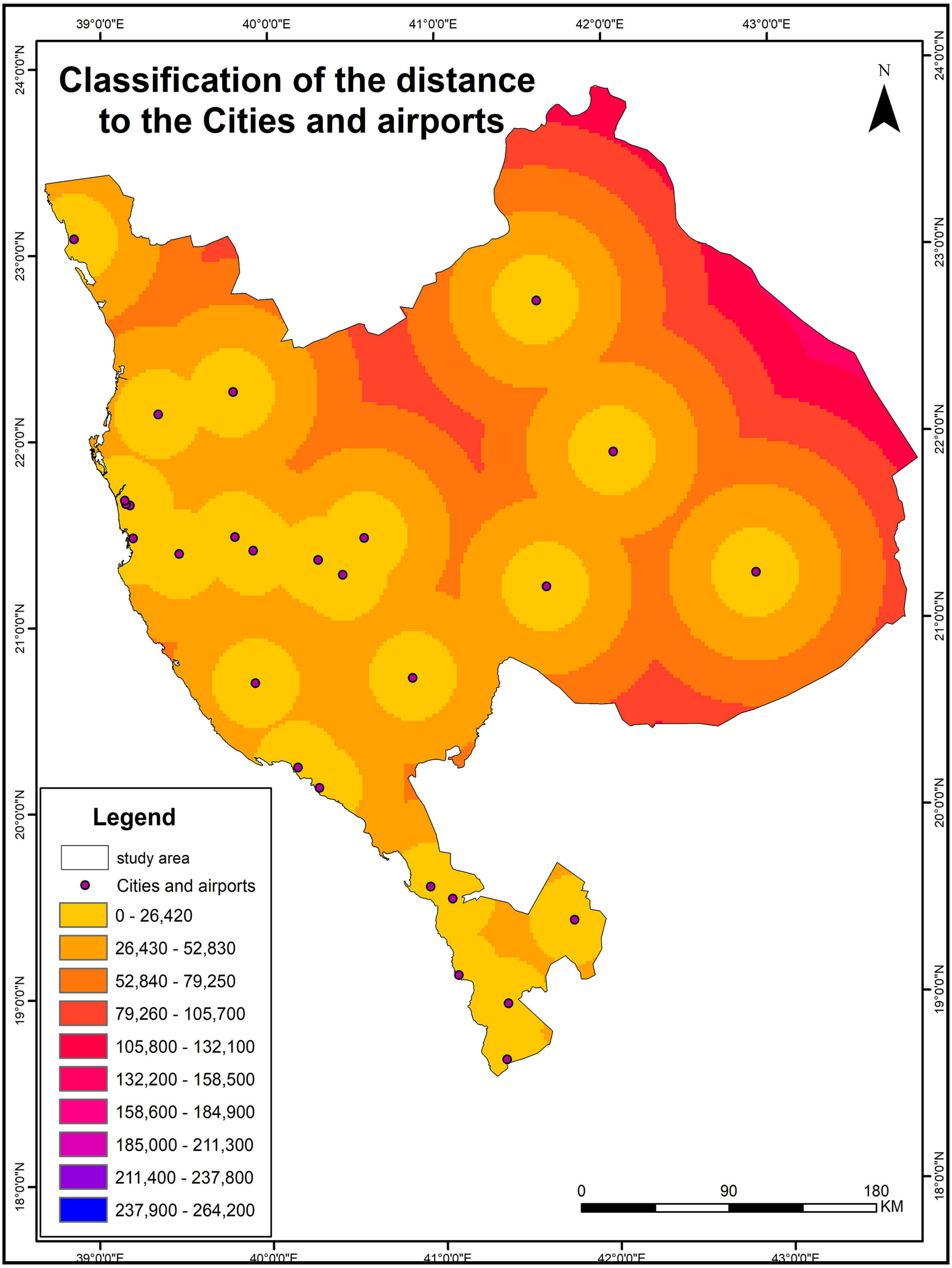

Figure 8. Map showing classify for cities & airports (researcher preparation).

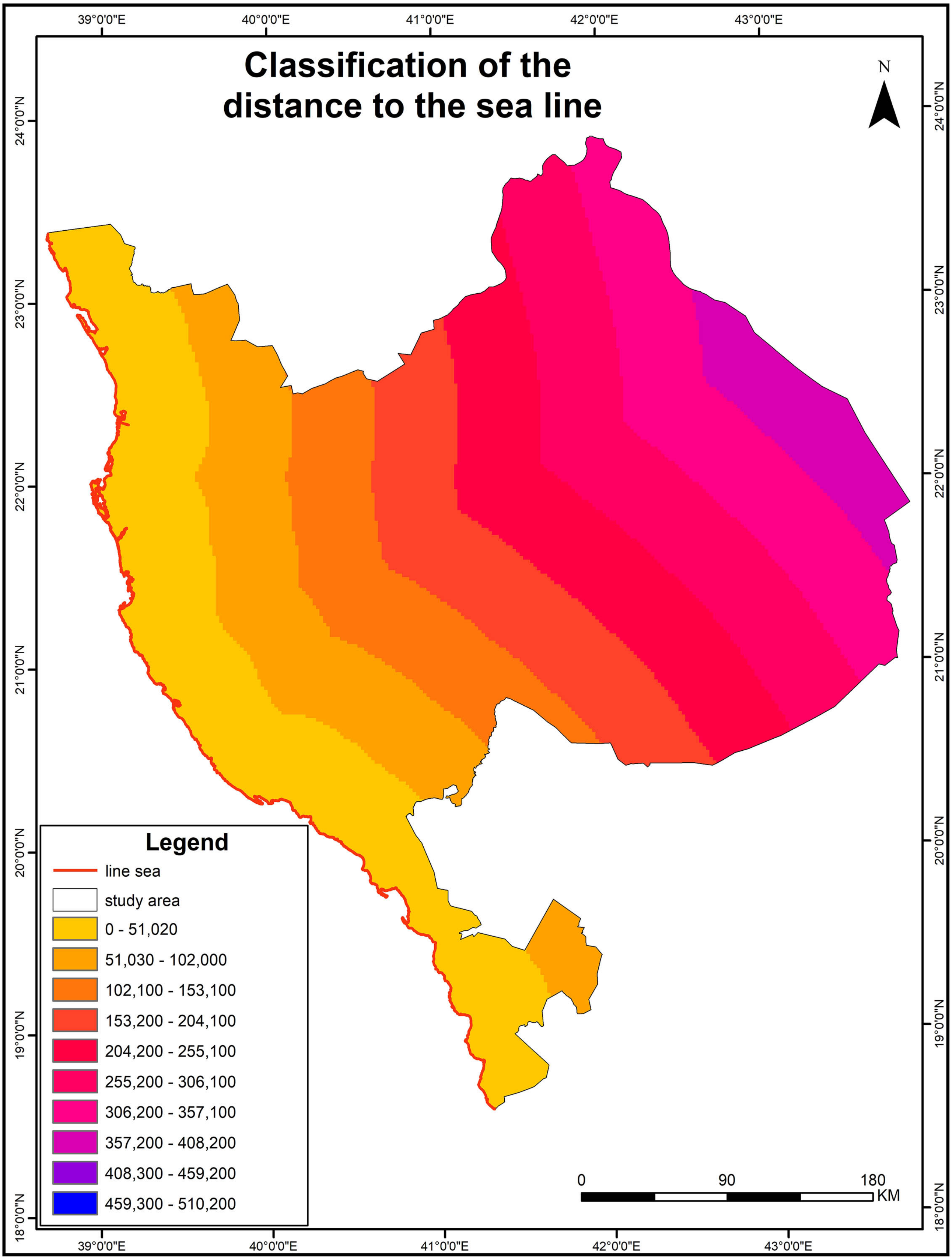

Figure 9. Map showing classify for sea line (researcher preparation).

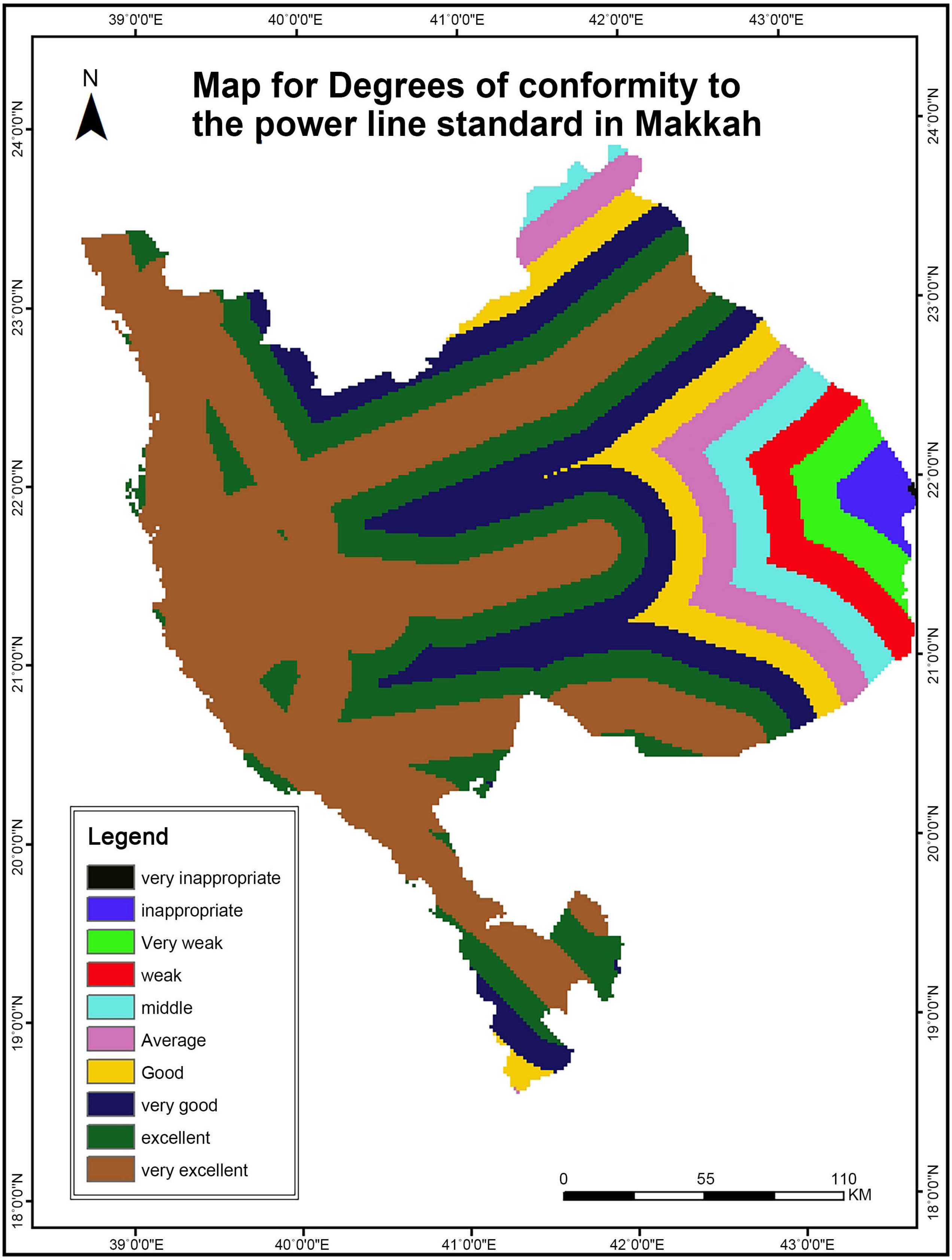

Figure 10. Map showing classify for distance from the electricity distribution network in MAKKAH (researcher preparation).

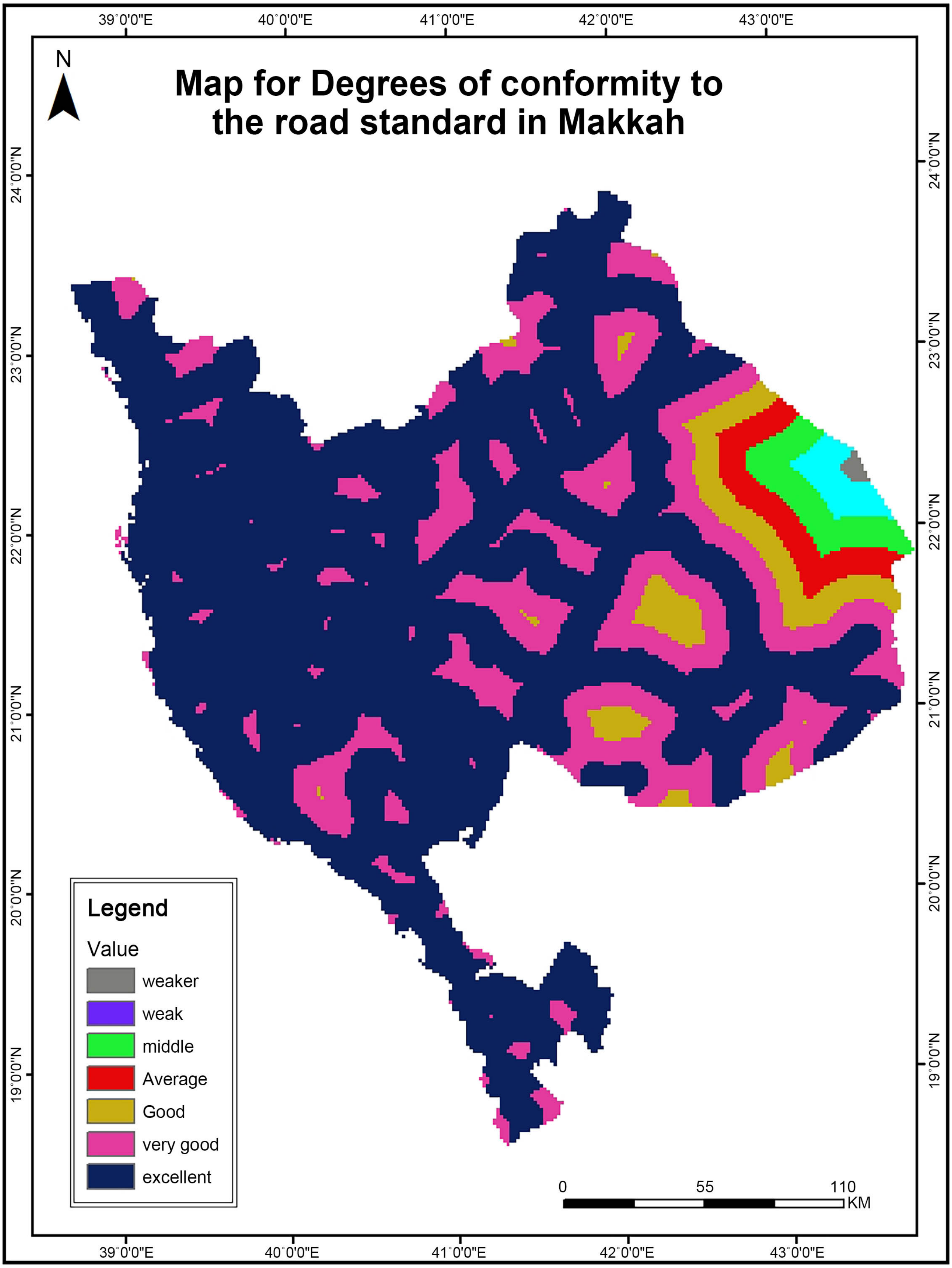

Figure 11. Map showing classify for distance from the road network in MAKKAH (researcher preparation).

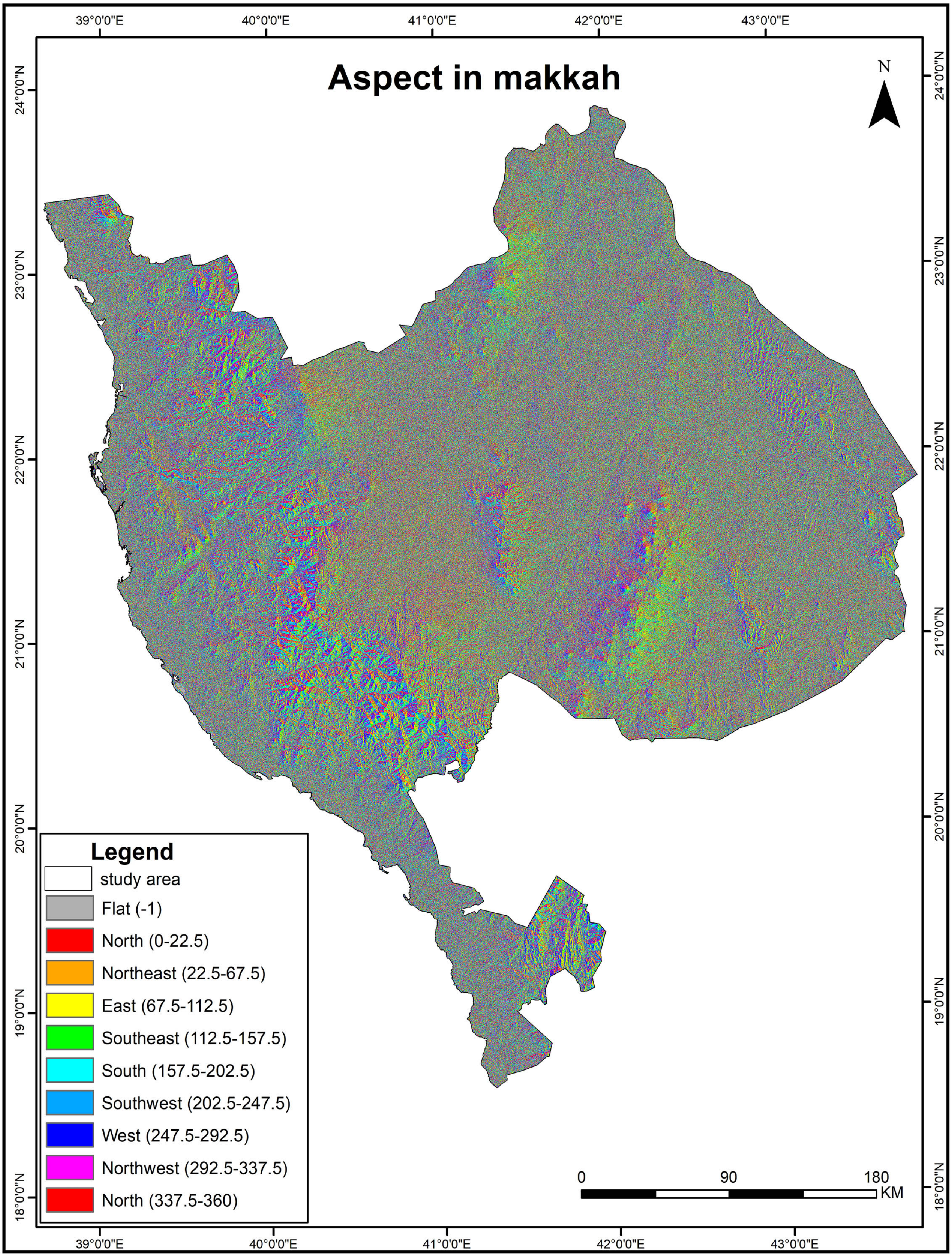

Figure 12. Map for degrees of conformity to the slop standard in Makkah (researcher preparation).

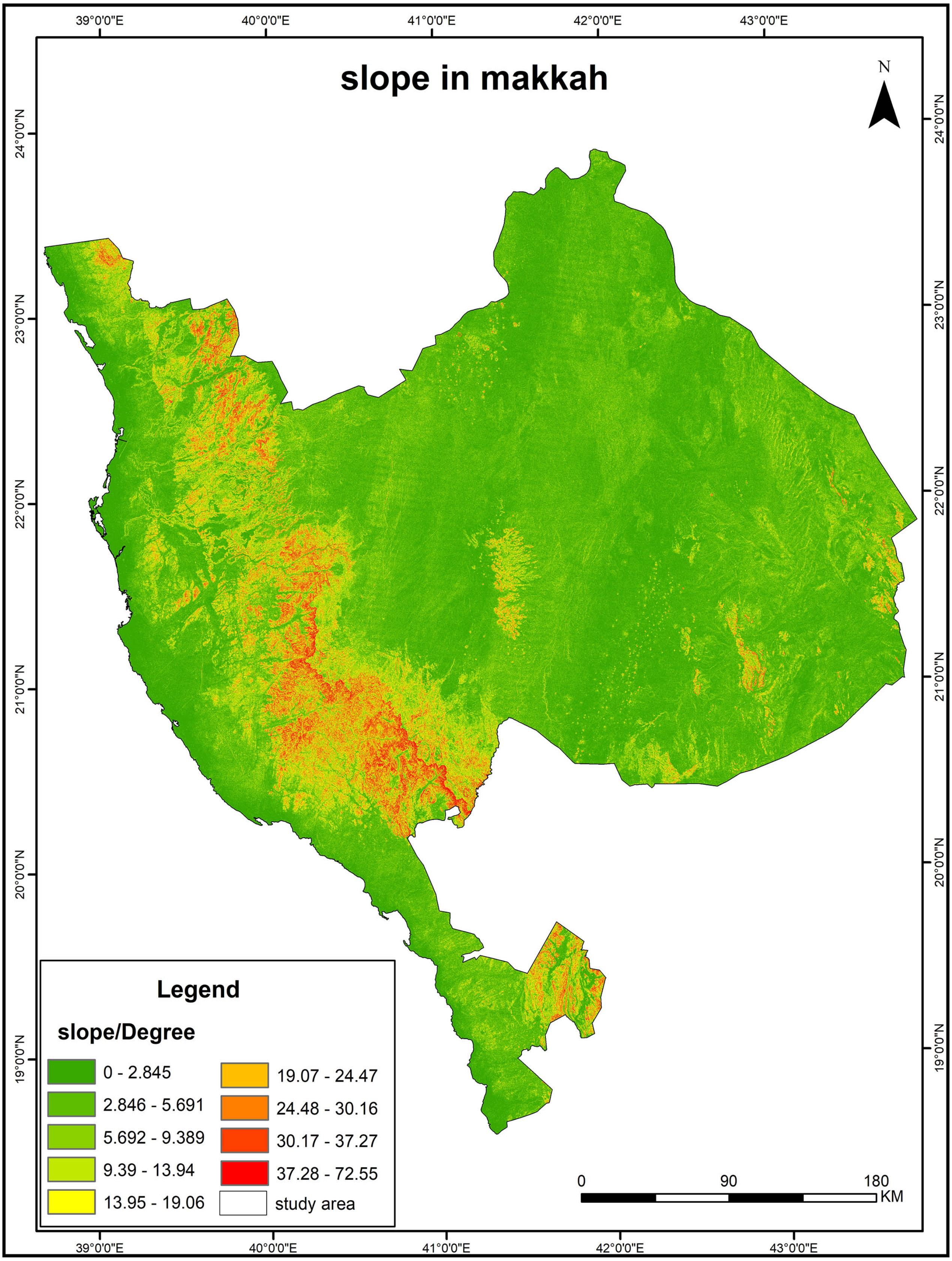

Figure 13. Map showing classify for aspect direction of the Earth (researcher preparation).

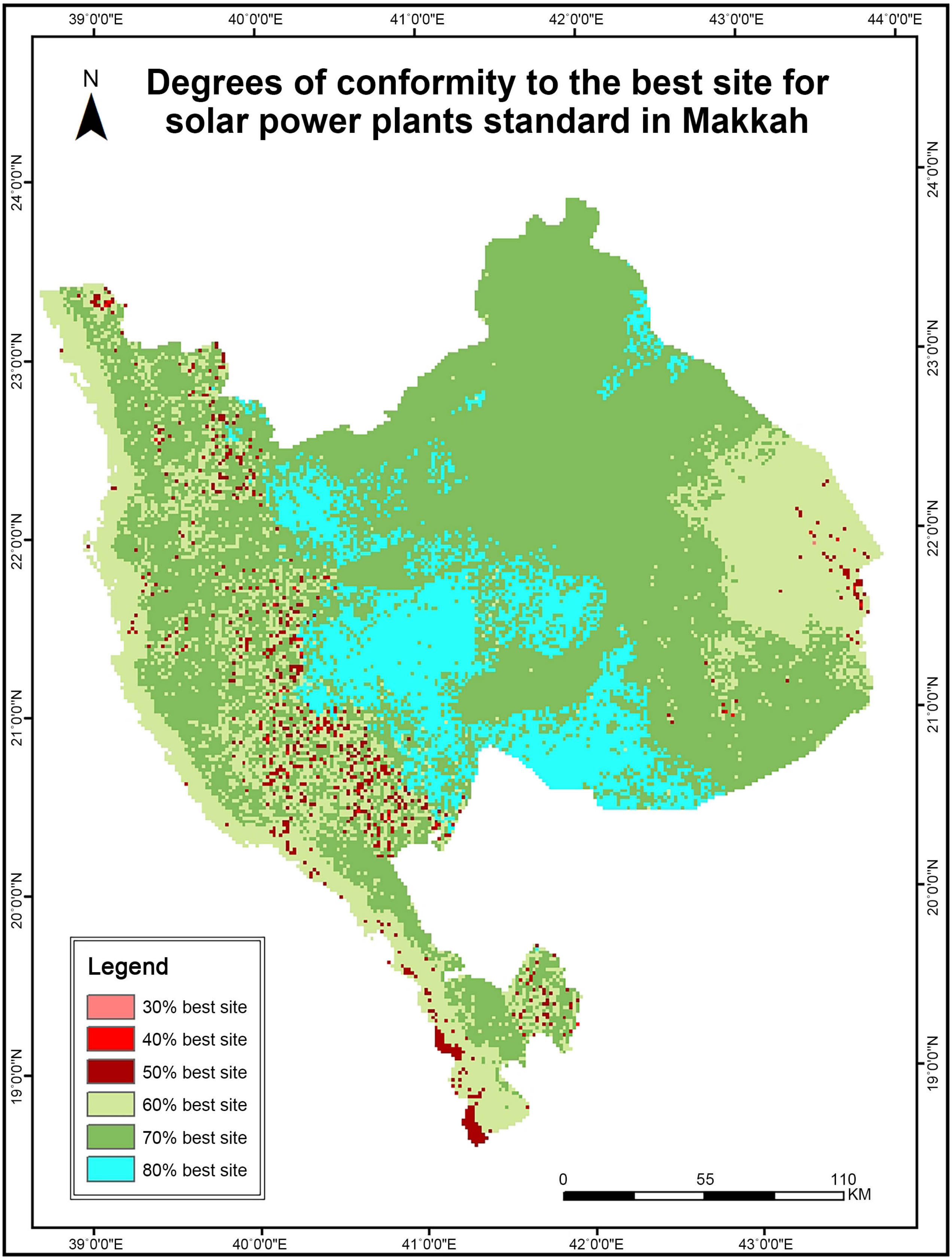

Figure 14. Map for the best site for solar power plants site in Makkah (researcher preparation).

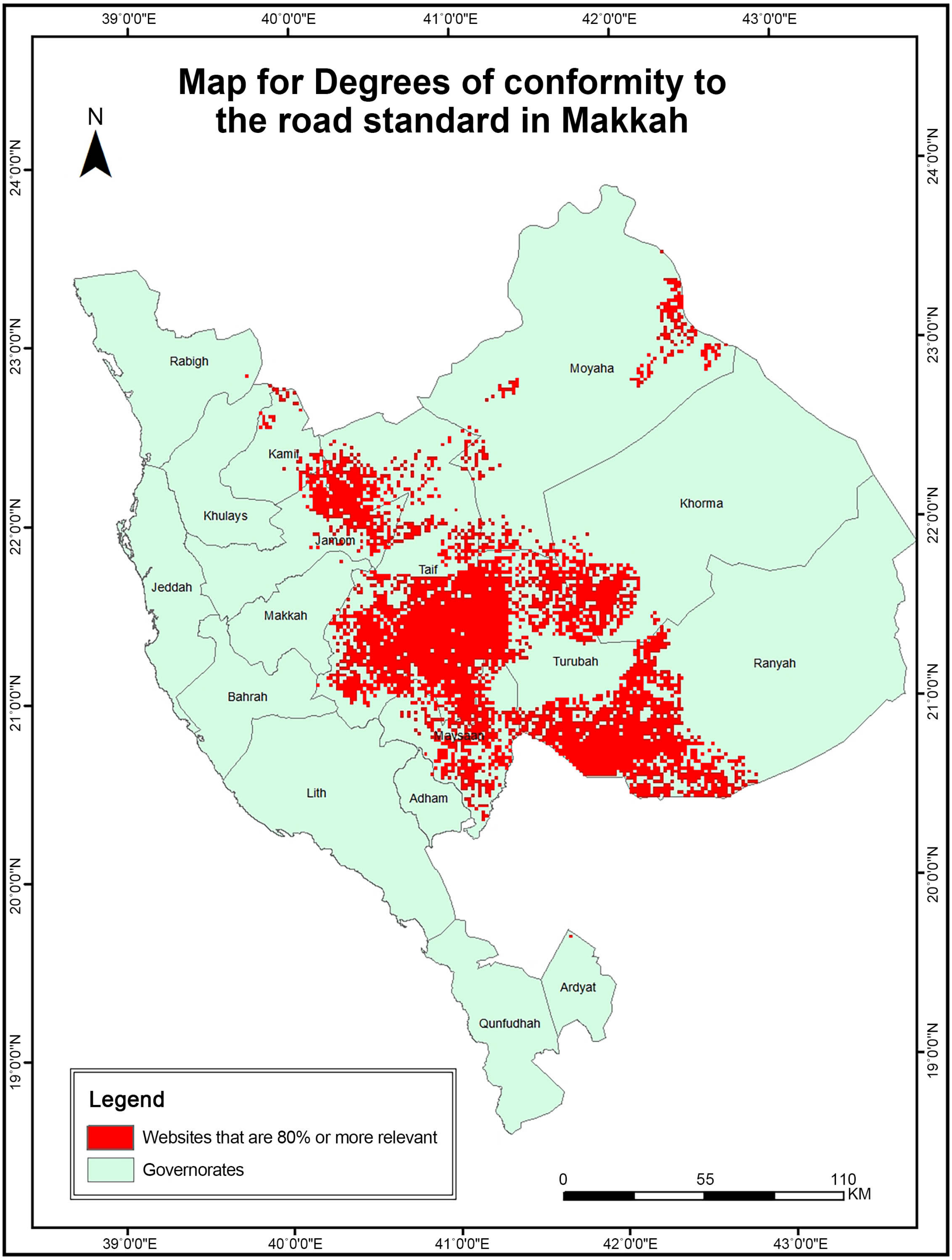

Figure 15. Sitemap with 80% or more relevance in Makkah (researcher preparation).

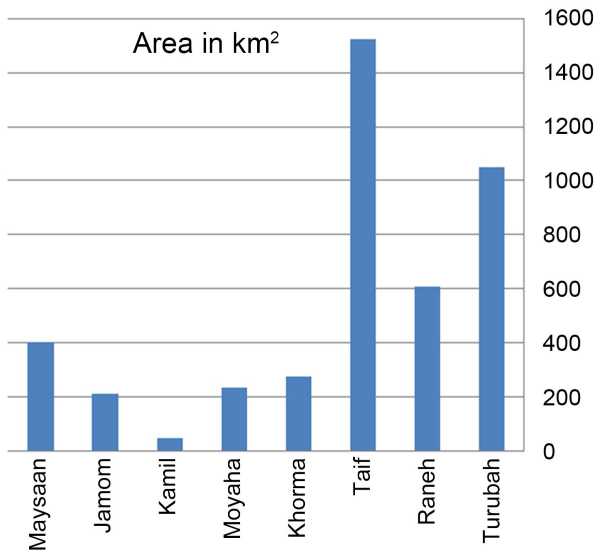

Figure 16. Statistics on the relevant site in the governorates of Makkah Al-Mukarramah (researcher preparation).

Table 2. Distribution of sites with spatial suitability more than 80% on the governorates.

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

6. Conclusion

1) The results of the final model revealed that there is variation in the extent of spatial suitability and, it was found that there are approximately 4 thousand square kilometers of land area, with a fit coefficient higher than 80%. These areas are concentrated in the central part of Makkah Mukarramah Governorate;

2) This study determined several criteria (planning standards, environmental standards, terrain calibrator) to find out the most suitable areas for the deployment of photovoltaic power stations in the Makkah region;

3) The results obtained indicated that most parts of the Makkah Al-Mukarramah Administrative Region are suitable for the solar energy collection project, but at different rates ranging between 30% and 80%.

The study also recommends the generalization of the multi-standard GIS method in all development plans in the energy sector.

7. Recommendation

The study recommends setting the appropriateness model that has been developed for decision-makers to take into account in future plans for new energy projects in the Makkah region and inclusion of geographic information systems as a basic system in any comprehensive national plan for solar cells. The study also recommends the generalization of the multi-standard GIS method in all development plans in the energy sector in the Kingdom of Saudi Arabia and projecting future energy needs and identifying possible alternatives for renewable energy use using geographic information systems.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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