Geo-spatial site selection for solar power plants using Geographic Information System (GIS) in Kermanshah Province, Iran

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ڕێکەوتی وەرگرتن: 16 نیسان ٢٠١٩، پەسەندکردن: 15 مایس ٢٠١٩، بڵاوکردنەوە: ٢٥ کانونی یەکەم ٢٠١٩

JZSB p-ISSN: 1813-0852, e-ISSN: 2617-3034

Abstract

In this study, integration of multi-criteria decision analysis and geographical information system (GIS) are used together to select the best solar farm sites in Kermanshah Province, Iran. For this aim, first, different criteria were identified, and maps were built in a GIS environment. Since the criteria have different scales and nature, the prepared maps were divided into layers. After that, the relative weights of these layers were determined, and weighted information layers were combined using the overlay method. The final index maps were grouped into four categories ranging from “no suitability” to “high suitability” with an equal interval classification method. The results reveal that 23 % of the area has high suitability for solar farms, mostly found in the southern parts, while the unsuitable sites represent 5%.

In conclusion, considering different criteria and technical requirements to select the appropriate solar farm site, is an effective approach which leads to a more efficient solar farm with minimum social and environmental issues. This approach can be replicated in any location providing availability of information and geographical data. The results of this study are particularly useful for investors and governments in developing countries such as Iran, Iraq and Saudi Arabia who are planning to build renewable energy sites. It is also recommended that in the future studies other decision criteria such as population growth, heritage sites, proximity to line power, and proximity to the location of the main power generation station would be considered to enhance the precision of the optimal sites and enrich proposed model.

Introduction

Energy has become an essential concern in today's world. The need for more sustainable energy production/consumption systems has significantly increased global attention toward energy-related analysis. Global warming and energy consumption/production related environmental issues are threatening humankind's existence on the Earth. According to British Petroleum statistical review, the world's total energy consumption has increased almost 70% between 1990 and 2016, and it will rise 1.3% annually till 2040 [1]. Growing energy demand in developing countries, population growth, urbanization and higher standards of living are among the main factors that will drive the increase in global energy demands in the coming decades [2].

One way to respond to the increasing demand for energy is to utilize renewable energies. Renewable energy is originated from natural sources such as sun and wind. The importance of renewable energies, as its name implies, is that they are replenished at a rate that is equal or faster than the rate at which they are consumed. In the last decades, renewable energy power capacity has increased, its cost has decreased, and investment and advances in enabling technologies have increased. Renewable energies have been used in power, transportation, and buildings sectors. Despite their advantages, estimated renewable energies share of total final energy consumption in 2016, was less than 18%, suggesting further attention and investment (see Figure 1) [3]. Figure 2 presents the share of renewable energy in total final energy consumption by sector [3]. According to this figure, renewable energies (traditional biomass and modern renewable energies combined) make up 27%, 3% and 25% of total energy consumption in buildings, transportation and power sector, respectively. Solar energy is available almost everywhere. It can be utilized to produce electricity and thermal energy.

Not only are renewable energies vital for decreasing dependence on fossil fuels, but also it will help to reduce the pressure on other important factors for development such as water. For example, non-renewable power generation technologies consume considerable amount of water in their production process for producing steam or cooling purposes. Promoting renewable energies will help to release that pressure on water resources. Water resources and electricity are inevitable for a sustainable future. In Figure 3, the photovoltaic power potential in the world is presented. According to this figure, the the Middle East and Africa have significant solar energy potential. Surprisingly, the top 20 water-stressed countries are in these regions, the Middle East and South Africa [4]. Therefore, further investment and attention toward promoting renewable energy, especially in the form of solar energy, will help to make a better picture of the future ahead of us in the world. However, developing locations for harvesting renewable energies is a complex task because it involves considering not only technical and economic requirements but also several environmental and social factors. Therefore, site selection for renewable energy requires a systematic and precise approach to consider a comprehensive set of parameters and requirements.

Iran mostly has on the fossil fuels while it has a high potential for renewable energy sources that can cover a portion of its needs and export a part to neighbor countries. For these reasons, Iran has launched strategic plans to develop renewable energy through the country and produce the country's electricity from renewable sources. Therefore, the primary objective of the current study is to examine the applicability of multi-criteria decision analysis and geographical information system in locating the best possible sites for solar energy in Iran. Kermanshah province, as a case study, is considered here to evaluate the optimal locations for solar power plant considering environmental and socio-economic criteria using GIS. The results of this study provide detailed information on solar energy land suitability for investor and government. The suggested suitable sites are those in which environmental effects are minimized and economic benefits are maximized.

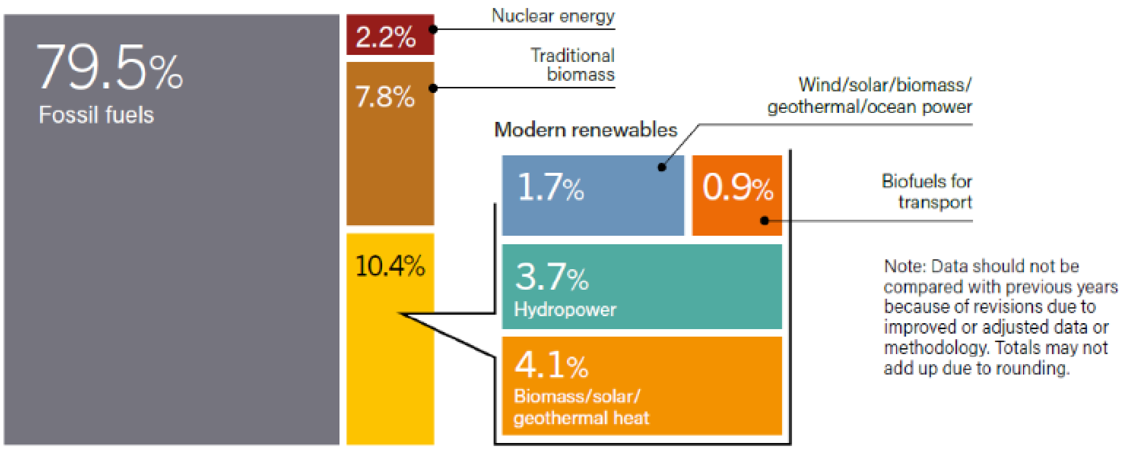

Figure 1. Estimated renewable energy share of total final energy consumption, 2016 [3].

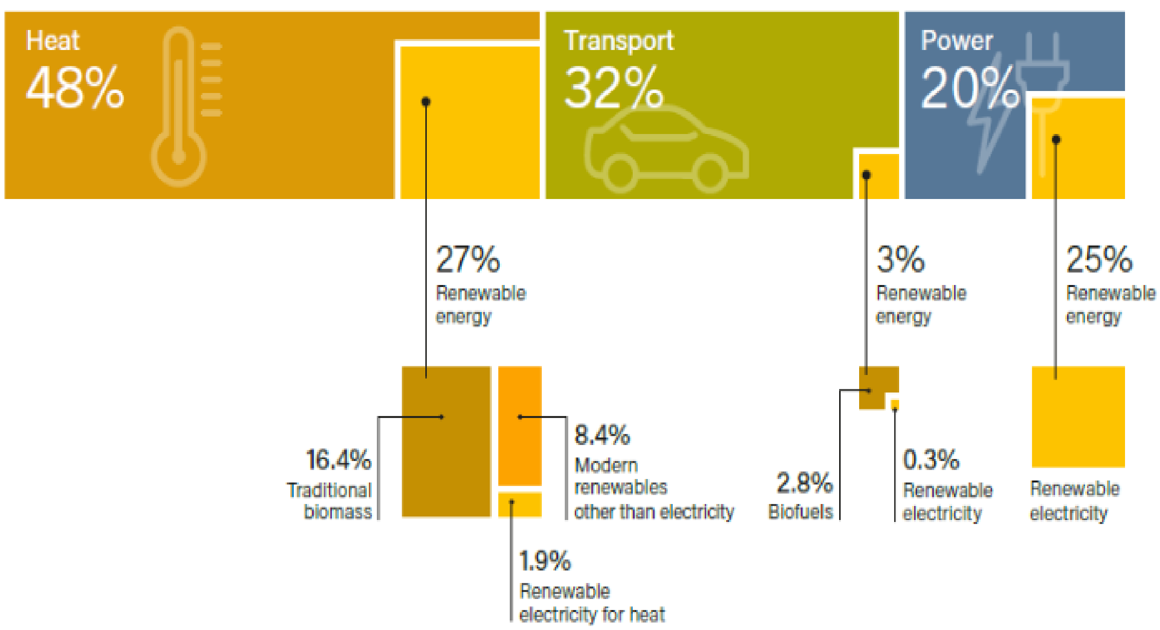

Figure 2. Renewable energy share in total energy consumption by sector, 2016 [3]

JZSB p-ISSN: 1813-0852, e-ISSN: 2617-3034

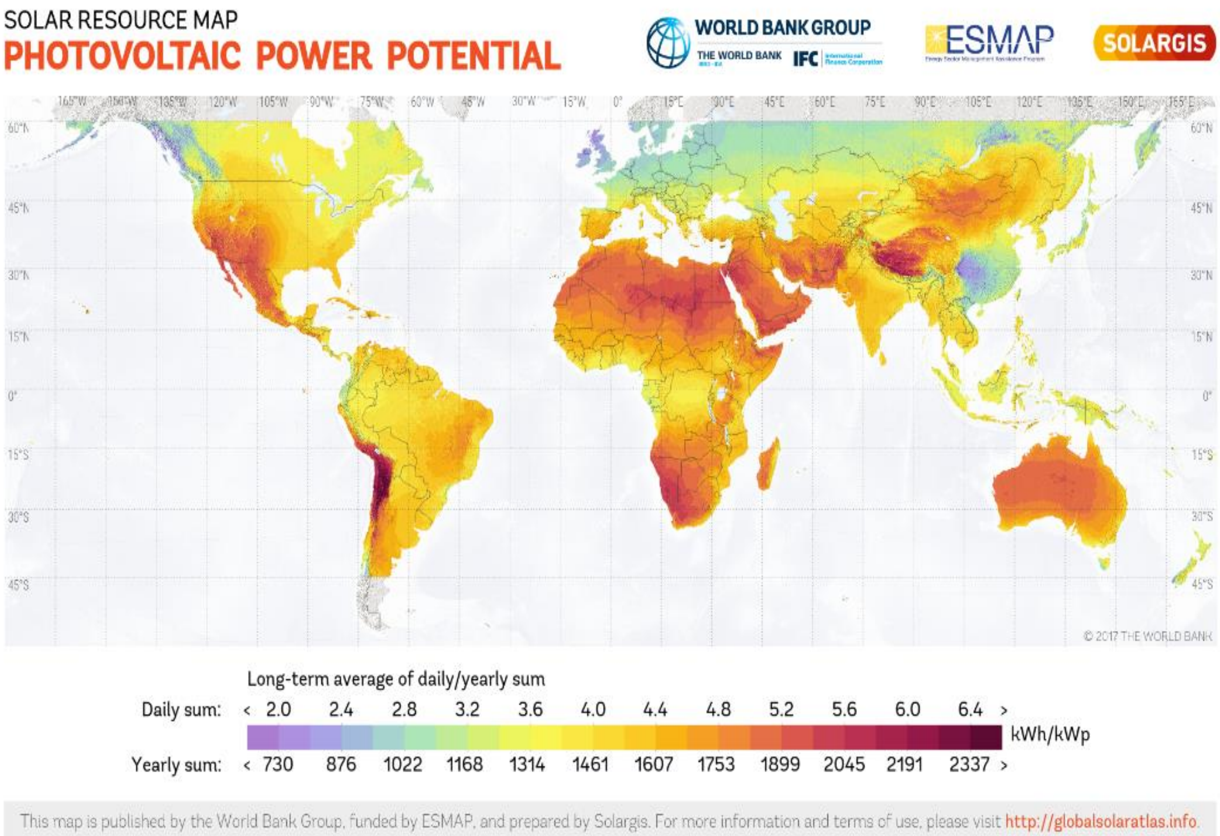

Figure 3. Photovoltaic electricity potential map across the world [5].

Study area

The study area is Kermanshah Province located at the west of Iran (Figure 4). Kermanshah Province consists of 14 districts and has a population of around 2 billion. The province covers an area of approximately 24,998 km^2. As it is situated between two cold and warm regions of Azerbaijan and Khuzestan, enjoys a moderate climate. It rains most in winter and is moderately warm in summer. The average temperature in the hottest months is above 22 °C. The annual rainfall is 450 mm and much of the precipitation falls in late autumn and early spring (Nov- Feb) where the month of January having the highest precipitation.

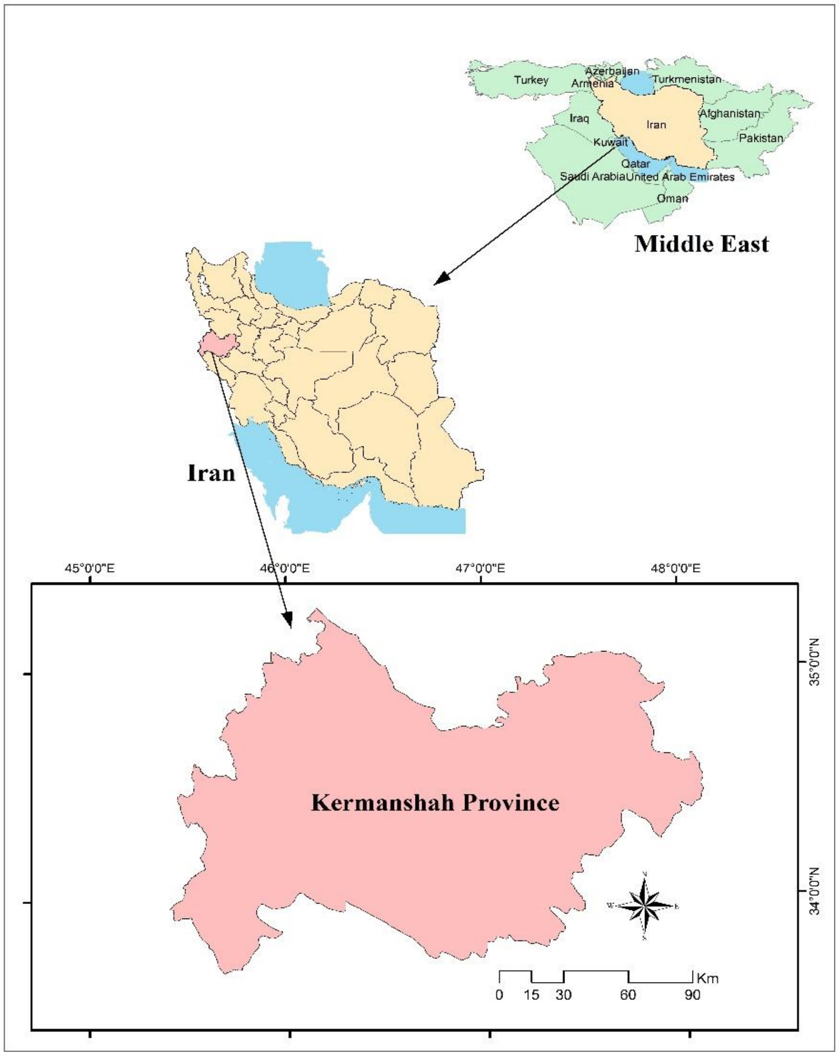

Figure 4. Location of the study area

Method

- **Data collection and classification of parameters**

Selecting suitable sites for solar farms in Kermanshah requires to determine useful spatial criteria and factors on the viability of solar power plants. There are several criteria to be considered in locating power plant establishments. The criteria factors of this research were selected based on experts' opinions and previous research studies [6, 7, 8]. The criteria used in this study are categorized into two groups: economic and environmental. The selected economic criteria are the distance to roads, slope, and daily temperature. Environmental criteria are the distance from residential areas, land use, distance from rivers, distance from protecting areas and distance from faults (Table 1).

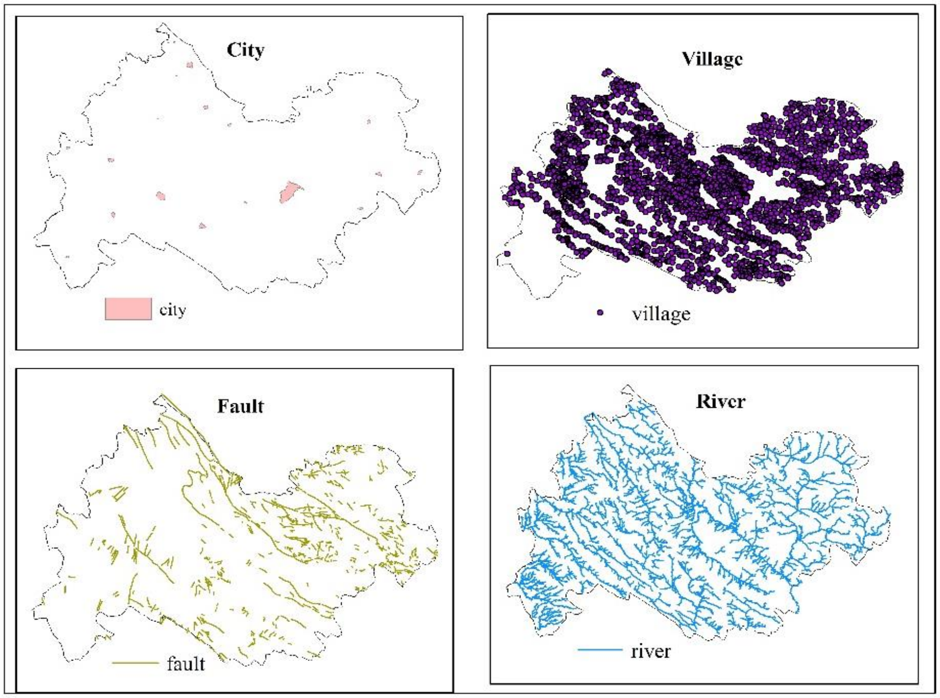

Figure 5. City, village, fault and river of the study area

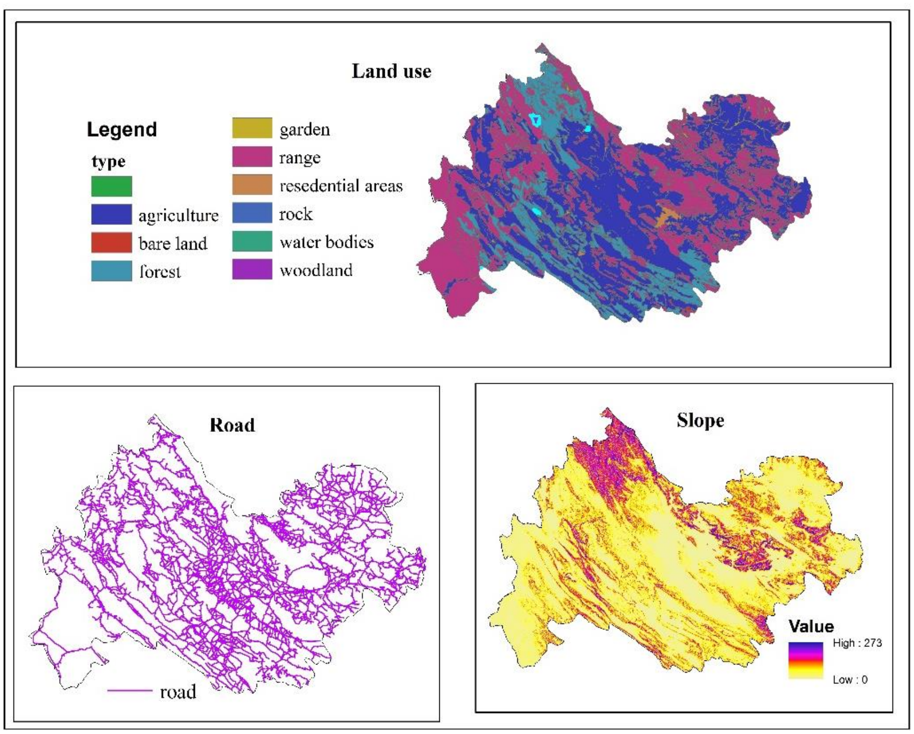

Figure 6. Slope, road and land use of the study area

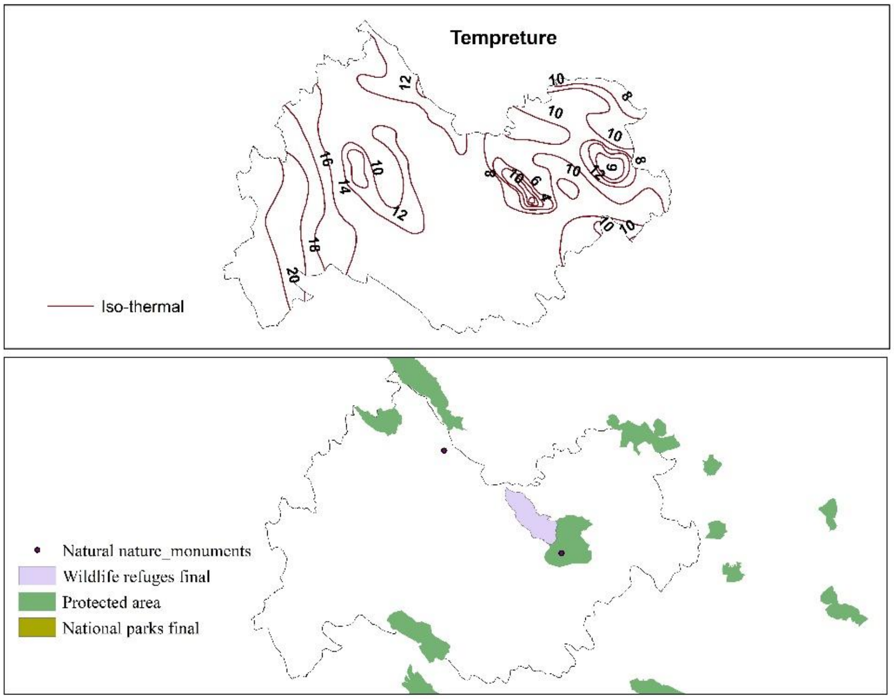

Figure 7. Protected areas and annual average temperature of the study area

The utilized spatial data were 1:25,000 topographic maps obtained from National Cartographic Center, 1:100,000 maps of the Geological Survey of Iran, ASTER and Landsat satellite image, GPS survey and synoptic meteorological data. The information layers of criteria are prepared in ArcGIS 10.3 environment (Figure 5 and 6).

- **Data integration and selection of suitable sites**

Since the importance of different criteria in site selection are not usually equal, the value and importance of each criterion should be evaluated before aggregation. Analytical Hierarchy Processes (AHP) Method is used in this study to rank the importance of criteria based on experts' suggestions. AHP is one of the most efficient multi-criteria decision analysis techniques that were presented by Saaty for the first time (Saaty, 2008). To do so, the questionnaire is spread out among eight experts to receive their input on the importance of criteria. Then all experts' opinions were imported into Expert Choice software, and the final weight of each criterion was obtained. The results are presented in Table 1. The computed weights and the prepared layers maps were aggregated using raster calculator function, to yield the final suitability map for the solar power plant.

Table 1. Selected criteria and their weights base on the analysis of expert's opinion

Aim	Category	Criteria	Weight
Solar power plant site selection	Environmental factors	Land use	0.17
		Distance from urban areas	0.10
		Distance from villages	0.08
		Distance from rivers	0.08
		Distance from faults	0.07
		Distance from protected areas	0.10
	Economic factors	Slope	0.13
		Temperature	0.17
		Distance from roads	0.1

Results and Discussion

The final map was grouped into four categories of no suitability, low, moderate suitability, highly suitability. This map is produced from the overlaying our data for different criterion based on the weight from Table 1. Figure 8 shows the land suitability for solar farm sites in Kermanshah province. The figure demarcates areas that are ideal for solar farms and those that are not suitable. From this figure, one can conclude that the southern part of Kermanshah has the highest suitability for installing solar power plants. It is important to mention that this part of Kermanshah has a higher temperature during the whole year compared to another part of the province. Very close to the urban area is also demonstrated as being not suitable. The west, northern part of the Province is also not much suitable because it is primarily high mountains area.

Figure 9 shows the suitability of the total area of the province in four main classes. From this figure, 23 % of the area has high suitability for solar farms. The portions of low and moderate suitability are 25% and 47% respectively. The other 5% of the study area is not suitable for solar farms — the regions that have high suitability found in the southeast and northwest of the study area as discussed earlier.

The method can be used to evaluate suitability of any places for developing renewable energies. The method can be broaden by considering several other important factors, including the distance from the electricity grid, availability of potential customers and market, human force factors such as professional engineers, to name a few. This study demonstrates the applicability of this method and further considerations to develop of this approach are left for future studies.

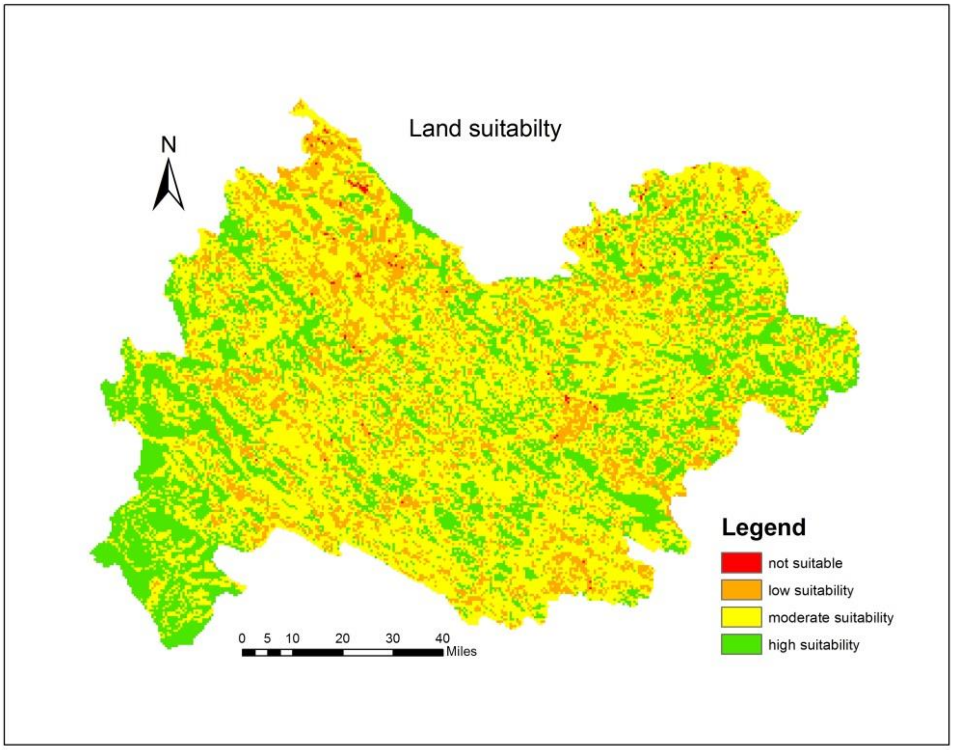

Figure 8. Land suitability map for establishing solar power plant in the study area, Kermanshah.

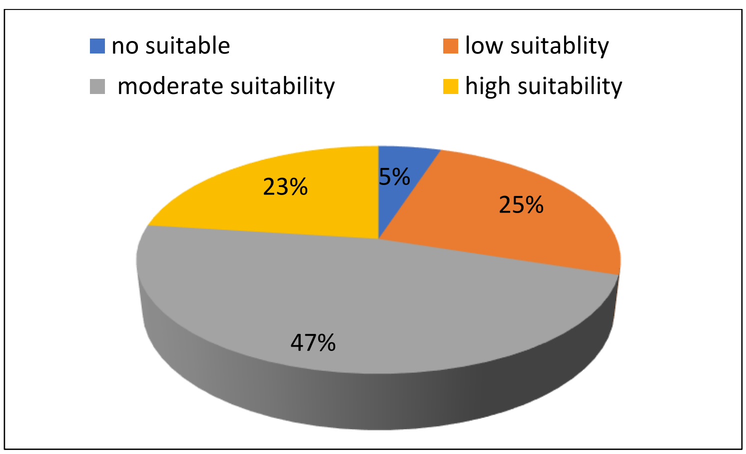

Figure 9. Percentage suitability of total area of Kermanshah for establishing a solar power plant

JZSB p-ISSN: 1813-0852, e-ISSN: 2617-3034

Conclusion

This paper presents an application of GIS in the land suitability evaluation for solar power plants. The GIS has the capability of storing, analyzing and displaying spatially referenced data with integrated spatial data for the large geographic area. Moreover, using GIS reduce both the errors and the time needed for the analysis of criteria, thus decreasing the overall cost of the selection process. The integration of GIS and overlay approach shows that this combination can be successfully used to select feasible sites, assess their economic value and give a preliminary impact assessment on environment consideration.

In future research, considering other decision criteria such as population growth, heritage sites, proximity to line power, proximity to the location of main power generation station and sunshine hours could potentially enhance the precision of the optimal places and enrich proposed model. Moreover, taking hybrid systems such as solar solar-wind and solar-biomass could lead to cost-effective and technically feasible sites.

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