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Site Selection of Solar Power Plant using GIS-Fuzzy DEMATEL Model: A Case Study of Bam and Jiroft Cities of Kerman Province in Iran

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ABSTRACT

Nowadays, with the population growth, renewable energies- especially solar energy- have grown effectively among governments. These types of energies are considered to be unlimited sources of energy and have the least harmful effects on the environment. In recent years, investment in the solar energy has been rising rapidly in Iran. One of the important challenges in this field is the site selection of solar power plant which is encountered with many spatial and environmental considerations. The contribution of this research is to determine the suitable site for the creation of a solar power plant in Jiroft and Bam cities of Kerman province, using GIS and fuzzy DEMATEL. In this study, six main criteria including solar radiation potential, surface temperature, access to urban areas, access to transportation lines, slope and aspect, were used. Finally, the study area is classified into four categories as “low suitable”, “moderate”, “best suitable” and “not suitable” with an equal interval classification method. The results showed that 8% (1218.282km2) of the study area has low suitable, 14.23% (2406.903 km2) has moderate suitable and 12% (1996.311 km2) has best suitable for solar power plant area. 66% (11291.03 km2) of the study area is not suitable for solar power plant.

1. Introduction

1. In the modern societies, energy is one of the key parameters of the country's prosperity and sustainable develoment[1]. In addition to, the problem of climate change and the completion of fossil fuels are major drivers for finding alternative energy sources[2]. Recognition and use of the renewable energy is increasing worldwide, because it reduces the dependence on limited reserves of fossil fuels and reduces the effects of climate change[3-5]. The first step in the use of renewable resources in Iran was taken in 1993, and since then, the attention has grown considerably among officials and the community. Iran has a high potential for exploiting this facility because of being in the sun's radiation belt. One of the issues related to the assessment and construction of a solar power plant is the study of land or areas suitable for the installation of a solar power plant and the assessment of the transmission, accesses and geographical conditions of the area. There are several factors in choosing a suitable location for the construction of solar power plants which can be divided into economic, social, ecological factors [6]. In recent years, multi-criteria analysis and GIS have increasingly been used as a popular tool site selection procedure[7]. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) is one of the multi-criteria decision-making and evaluation method. This method was first used by Wu and Lee in a fuzzy environment[8]. Many studies have been done on site selection of

solar power plants[9-16]. Mevlut Uyan in karapinar region Konya/Turkey finding that 13.92 percent of this region best suitable for solar farm with uses AHP and GIS, he utilized two category of factors, 1- environmental factors and 2-economic factors[17]. Taheri et al. evaluated the suitable sites for the solar farm in the southern region of Morocco, using the GIS and AHP multi-criteria decision-making method[17]. In the Serbian region, Ljubomir Gigovic et al. evaluated the area in terms of ecotourism development using FDEMATEL and GIS[18]. This research emphasizes on the combination of GIS and FDEMATEL(fuzzy decision making trial and evaluation laboratory) to determine the suitable site for solar power plant construction in Bam and Jiroft cities of Kerman province.

2. Materials and Methods

2.1 The study area

The Bam and Jiroft cities(fig.1) are located in the south-eastern part of Iran's central plateau. The centre of Bam city is located at 58 degrees 21 minutes' east longitude and 29 degrees 6 minutes' northern latitude and elevation of 1050 meters and the area of it is 17755 square kilometres. The geographical position of the Jiroft city is 28 degrees 40 minutes' northern latitude and 57 degrees 44 minutes' east longitude and it is 720 meters above sea level. Figure 1 shows the location of the study area.

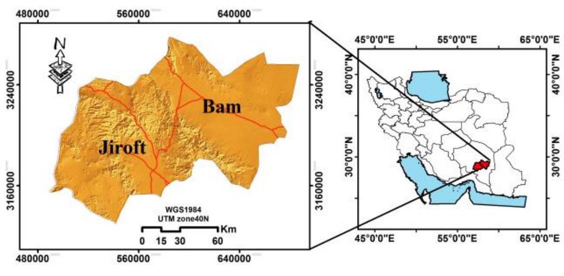


Figure 1. Location of study area

2.2 Used data (Required data)

In this study, we used Landsat 8 satellite image, the SRTM Digital Elevation Model and the MOD07 MODIS sensor. These layers are georeferenced and located in the UTM projection system in the 40 N zone. This information is available at the US Geological Survey site and NASA site. Land use maps produced by the National Forests, Range and Watershed Management Organization were prepared and used in the study.

2.3 Methodology

In fact, there are many factors that influence on the site selection challenges; the geographic information system is very suitable for these problems. The effective factors in this research are determined by the expert's opinion, the review of the past studies and their availability. These factors are divided into two groups: economic factor and environmental factor. The former includes distance from the city and the distance from the transmission lines. The latter consists of radiation potential, land surface temperature, slope, and aspect. After collecting data from different sources, all layers are converted to raster format and are normalized using linear functions. in the site selection issues, factors have not same effect. in this research, FDEMATEL has been used to obtain the importance of each factor, and weighted overlays have been used to prepare a suitability map. Finally, Exclusionary areas have been removed from the suitability map to get the final map. The flowchart of the research methodology is shown in Figure 2.

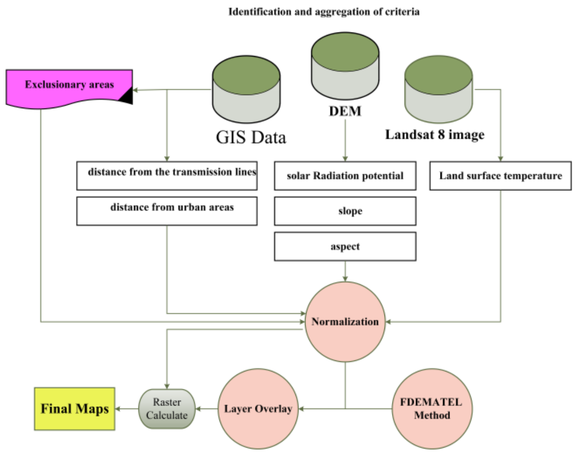


Figure 2. The flowchart of the research methodology

2.4 Definition of criteria

2.4.1 Solar Radiation potential

The solar radiation map represents the potential of solar energy in a particular area and provides useful information for selecting the suitable location for solar power plant. to obtain the solar radiation map we used a digital elevation model and spatial analysis tools in the ArcGIS software.

2.4.2 Land surface temperature

Mono-Window algorithms was used to retrieve the land surface temperature (equations 1)[19].

$$\mathrm{T}_{s} = \left\{ \begin{matrix} a_6(1-\mathrm{C}_6-\mathrm{D}_6)+ \\ [\mathrm{b}_6(1-\mathrm{C}_6-\mathrm{D}_6)+\mathrm{C}_6+\mathrm{D}_6] \\ \times \mathrm{T}_{\mathrm{sensor}} - \mathrm{D}_6\mathrm{T}_{\mathrm{a}} \end{matrix} \right\} / \mathrm{C}_6 \qquad (1)$$

In this Equation, the Ts is the land surface temperature, a6 and b6 are the coefficients that equal to 67.355351 and 0.458606, respectively, b6 is thermal band, C and D are internal parameters for the algorithm calculated from equations (2) and (3). To:

$$\mathrm{C}_6 = \varepsilon_6 \tau_6 \qquad (2)$$

$$\mathrm{D}_6 = (1-\tau_6)\big(1+(1-\varepsilon_6)\big)\tau_6 \qquad (3)$$

Where; Tsensor is the brightness temperature at the sensor in Kelvin scale, τ6 is the transmittance capacity of the atmosphere, and Ta is mean atmospheric temperature.

2.4.3 Slope and aspect

The Slope and aspect are extracted from the digital elevation model.

2.4.4 The distance from the transmission lines and urban areas

The proximity of a solar power plant to the urban areas and transmission lines is one of the economic factors, in fact, proximity to the road and urban area reduce the cost of construction infrastructure and the environmental damage.

2.4.5 Exclusive areas

The regions that are restricted ecologically, location, personal estate, etc. and not given in the site selection process.

2.5 Fuzzy DEMATEL method

DEMATEL'S technique was presented by Fonetla and Gabus in 1971. This technique is based on a pairwise comparisons of decision making methods[20]. The fuzzified Likert scale was used for comparing the criteria in FDEMATEL method. In FDEMATEL method, the fuzzy direct relation matrix$(\tilde{Z}^{(k)}\ \forall K = 1.2 \dots P)$, where $\tilde{Z}^{(k)}$is a matrix $n \times n$, n denotes the number of criteria, P is the number of experts. After normalizing the fuzzy direct relation matrix, the weight of each criterion is obtained using equations (4 and 5)[8].

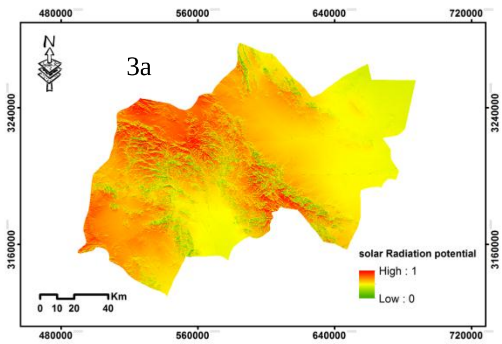
$$\tilde{T} = \lim_{w\to\infty}(\tilde{x} + \tilde{x}^2 + \cdots + \tilde{x}^w) = \tilde{x} \times (I - \tilde{x})^{-1} \quad (4)$$

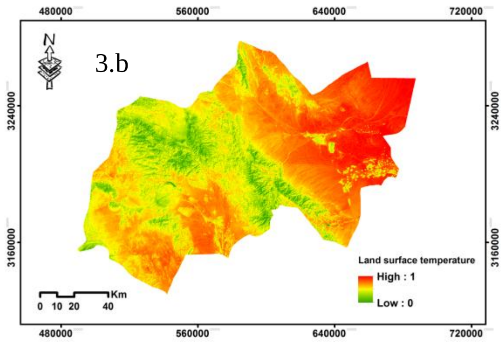
$$w_i = \sqrt{(\tilde{D}_i^{def} + \tilde{R}_i^{def})^2 + (\tilde{D}_i^{def} - \tilde{R}_i^{def})^2} \quad (5)$$

Where w_i is the weight of the criteria i , $\tilde{D}_i^{def}$, $\tilde{R}_i^{def}$ are the sum of the column and the sum of the rows of the final matrix.

3. Results & Discussion

This study clearly demonstrates the combination of GIS and multi-criteria decision making. The FDEMATEL approach is a very useful way to determining the weight of each criterion and its application in fuzzy environments has increased the capabilities of this method.





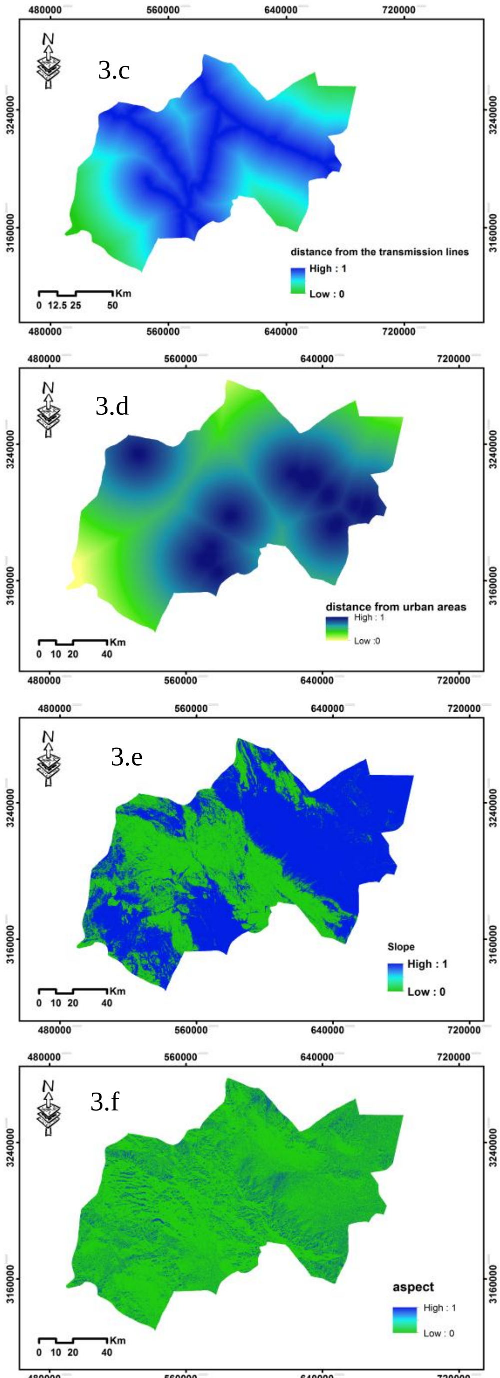


Figure 3. Physical characteristics of the study area (3.a: Potential solar; 3.b: Land surface temperature, 3.c: distance from the transmission lines3.d: distance from urban areas, 3.e Slope; 3.f: aspect).

According to Table 1, which shown the weight of the criteria obtained by the fuzzy DEMATEL method, the potential of solar radiation with a weight of 39.28% is most important among the criteria.

Table 1. Criteria weights

Criteria name	Criteria weight %
solar Radiation potential	39.28
Land surface temperature	23
distance from the transmission lines	12.44
distance from urban areas	11
slope	9.5
aspect	5

Figure 3.a shown the radiation potential in the study area, in this figure, the western, north-western and the eastern part of Bam city have the maximum radiation. land surface temperature (Fig 3.b) is also an important factor in solar energy studies, which with 23% weight is the second effective criterion. among the economic criteria, the distance from the transmission lines (Fig 3.c) with a weight of 12.44% have most important and the distance from urban areas (Fig 3.e) with a weight of 11% is the least important. Slope and aspect are least important the weight of these criterions are 9.5 % and 5 %respectively.

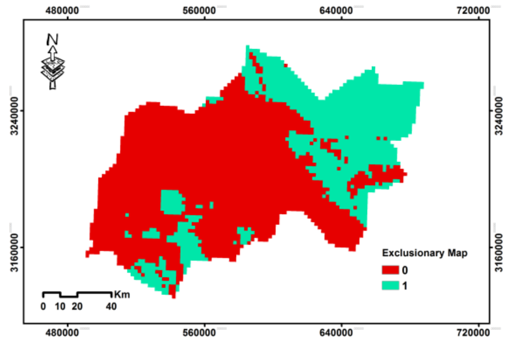


Figure 4. Map of exclusive areas

Figure 4 shown the exclusive areas in the study area. These areas include rangeland, forests, personal property, dam reservoirs and 2 km distance from the fault.

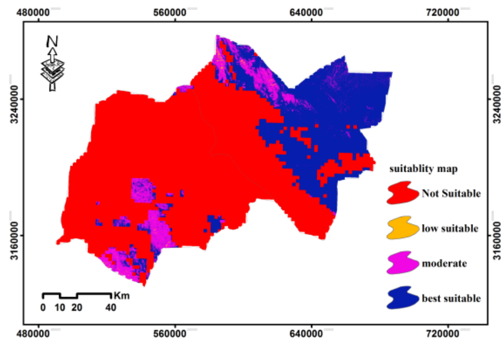


Figure 5 The map of suitability

With attention to Fig. 5, which shown the final map of the studied area, 8% of its area, which is 1218.282 Km2, is located in a “Low suitable” class. And the "Moderate" class is 14.23%, which it has area’s equivalent 2406.903 Km2. in this research 12% of studied area located on “Best suitable” class, which this class has area's equivalents 1996.311 km2. in the end 66% of the area with the most restrictions stay on the "Not suitable" category, the area is 11291.03 km2.

4. Conclusions

This paper is well indicated combination the geographic information systems and multi-criteria decision-making methods for solving site selection problems. FDEMATEL is one of the most useful methods for evaluating and obtaining effective criterion and effective weights. the final map showed that the study area has high potential for construction solar power plant. the radiation potential and land surface temperature are among the most important factors in the site selection of the solar power plant. elimination of Exclusive Areas in this study from the final map has a great impact on reducing the damage to the natural environment and increasing the accuracy of site selection process. therefore, we must be selection these areas carefully. On the other hand, the construction of its solar power plant has a great influence on the reduction of pollution caused by fossil fuels.

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