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GIS-aided site selection for solar panel installation in rangeland areas of Mashhad County of Iran

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Original Research

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Abstract:

Most areas of Iran enjoy more than 300 days of good sunshine for photovoltaic energy production and the potential for wind energy production is also immense. In this study we evaluated the suitability of Mashhad County rangelands in Iran for the installation of photovoltaic panels. Mashhad is a mega city with a growing population due to its religious importance and the traveling pilgrims coming to the city to visit the Holy Shrine each year. We evaluated the rangeland areas based on several factors including topographic features (slope gradient, slope direction and height), roads and infrastructure, built-up areas, environmentally protected areas, solar photovoltaic output potential, air temperature, land cover and active fault lines using the multicriteria evaluation method. Since most of the area is flat with minor elevations, there is no limitation for energy production. The largest share of the area has slope gradient of less than 15% (3303 km^2), this factor also imposes no limitation. In terms of elevation also 42% (4335 km^2) of the area below 2000 m is suitable for solar farm construction. There are some 72 active faults in the area. In total, 7.3% of the total area is covered with protected areas accounting for $\sim$ 720 km^2 which is not suitable for solar farms. In terms of land cover, 72% of the area is available for constructing solar farms. There is also no limitation in terms of air temperature and potential PhotoVoltaic (PV) output. The final suitability map was obtained by combining these layers and then divided into five classes. Based on our results, the suitable class had the largest share of the final map. Highly suitable areas comprise 14.1% of the total area. The excluded lands from the analysis due to the limiting factors made up approximately 56% equal to 5811 km^2. In total, Mashhad County has considerable potential for solar energy production.

Keywords: Climate change; Desert; Photovoltaic; Renewable; Khorasan Razavi; Iran

Introduction

The global population is surging at an alarming rate and is believed to reach 7.8 billion as of 2020, to level out around 2100 at 10.9 billion (Hoornweg and Pope, 2017). This significant population growth will have a considerable environmental footprint. As of now, global warming is torching the earth and maximum temperatures are making a new record each year (Change, 2018). However, non-renewable energy sources such as fossil fuels are estimated to fall short of global energy demand in $30-40$ years (Pimentel et al., 2008). Fossil fuels and the surge in their demand and consumption have adverse effects on the environment such as air and soil resources contamination and serious health issues related to pollution (Ebhota and Jen, 2020). This concern over energy demand in the future as well as environmental concerns and global raising awareness has led countries to push towards renewable sources and especially solar energy. The mid-latitude countries like Iran enjoy a great number of sunny days and sunshine every year. This has made them an ideal candidate for solar energy production (El Ouderni et al., 2013; Musembi et al., 2016). Introducing new energy sources and using rangelands for energy production offers the possibility of lowering pressure on these degraded lands in Iran while minimizing their economic output (Heitschmidt and Walker, 1996).

Iran is a major oil and gas-producing country as well as a major emitter of greenhouse gases (Shahsavari et al., 2019). Its fossil-fueled power plants annually emit nearly 180 million tons of carbon dioxide. Iran's total area is around 1600,000 km^2 or 1.6×10^{12} m^2 with about 300 clear sunny days in a year and an average of 2200 kW-h solar radiation per square meter. Considering only 1% of the total area with 10% system efficiency for solar energy harness, about 9 million MW hours of energy can be obtained in a day. The government's goal in 2012 was to install 53,000 MW capacity plants for electricity generation. It is expected that by 2030 solar energy production capacity will reach 2.8 GW in Iran (Najafi et al., 2015).

Despite this huge solar energy production potential, little research has been done surrounding it. Among the studies, one would mention Shahsavari et al. (2019) who evaluated Iran's country-wise production. Based on their results, the installed capacity of solar energy was around 17.3 megawatts (MW) by 2015, while each kilowatt-hour of solar electricity could save around 715 g of CO_2. Alamdari et al. (2013) studied the feasibility of using solar energy in different regions of Iran. They reported annual average horizontal radiation of above 500 W/m^2 in most areas of Iran, which shows its potential for photovoltaic applications. Kashani et al. (2014) determined the theoretical solar irradiation potential in Iran by using the Niroo Research Institute irradiation model based on geographical and meteorological data. They found solar energy as a viable and reliable source of power in Iran.

Most of the literature has focused on the large-scale statistical analysis of solar power and yet ignores the local variation of energy distribution. The introduction of geographical information systems (GIS) into scientific fields has made it possible to quickly and reliably evaluate site suitability for different purposes (Charabi and Gastli, 2011). GIS is a suitable tool for conducting site suitability analysis, but it still lacks a trust-worthy decision-making system to turn evaluation endeavors automatically. Performing manual decision-making using huge datasets is not cumbersome, but prone to error. Since graphical data layers are hard to imagine in full detail, a visual representation could be of great help. The application of multi criteria decision-making systems (MCDM) has made it possible to use both visual interpretations and informed decision-making in site suitability analysis (Jafari et al., 2018; Jafari Shalamzari et al., 2019). However, there is a paucity of research in terms of local evaluation of solar energy potential using GIS. Among the few studies concerning the application of GIS and MCDM systems in site suitability analysis for solar energy, production one would mention the work of Asakereh et al. (2017) who attempted to prioritize the land of Khuzestan province, Iran to install solar photovoltaic farms, based on techno-economic and environmental aspects. Based on the results, the potential of solar electricity generation in Khuzestan through the worst scenario is approximately 1.75 times more than the gross electricity produced in Iran in 2013. In another study, Sadeghi and Karimi (2017) determined suitable sites for solar farms and wind turbines using GIS and AHP in Tehran, to generate a distributed network to increase power network stability. Farajzadeh and Taghilo (2013) have found the combination of MCDM and GIS a promising methodology for site selection.

As mentioned, the application of GIS and decision-making methods in identifying suitable locations for solar panel installations is still an immature science and requires further studies in Iran. Therefore, we have applied a combination of these two techniques in identifying suitable areas for solar farms in Mashhad County rangelands of Iran which is a major energy consumer and a mega city in Iran with considerable projected urban expansion in the future. The rangelands of the area are under great grazing pressure and introducing solar panels and photovoltaic power might open new doors for improving vegetation conditions in these rangelands. This urban expansion would require a major enhancement of energy production. To comply with global warming emission reduction requirements in Iran, solar energy is an important energy alternative. Therefore, the main objective of this research was to perform a suitability analysis using the multicriteria evaluation technique (MCE) for energy production from solar panels in this part of the country.

Materials and methods

Study area

The study area of this research is the Mashhad County of Khorasan Razavi Province of Iran located between 35° 43′ 9″ to 36° 58′ 4″ N and 59° 3′ 48″ and 60° 36′ 21″ E, with a total area of 10326 km^2 (figure 1). Elevation ranges between 950 m and 1150 m above sea level. The region is characterized by a semi-arid climate going under annual precipitation of 250 mm with an annual average temperature of 15.7 °C. The temperature reaches its maximum of 43 °C in July and its minimum of −23 °C in January. Most of the precipitation is concentrated in the winter and early spring, indicating a Mediterranean Climate. Mashhad County has a complex geological setting with several active faults within its boundaries. Mashhad is bounded to the north by the Kalat and Dargaz, to the east by the Sarakhs plains, to the south by the Torbat Heidarieh, and to the west by Neishabour. Based on the results of the census conducted in 2010, Mashhad is home to 3070000 people mostly concentrated in cities. Mashhad Plain is a surrounded valley 100 km in length and 25 km in width as part of the Kashafroud watershed. Geologically, the region is mostly covered with the Karstic and evaporative Mozdouran Sedimentary Carbonates with suitable underground reservoirs (Majidifard, 2003). The water Table has been dropping over the past decade and most of the rivers and streams have dried out. The location of the study area is illustrated in figure 1.

Iran is geographically located in a suitable area for photovoltaic power generation (Gholami et al., 2020). The data from the global solar energy atlas https://globalsolaratlas.info/ for the monthly and hourly distribution of solar energy in the study area in figures 2 and 3 show that most months of the year enjoy 12 – 15 hours of sunshine which makes them ideal for energy production.

The monthly distribution of solar energy output for the study area also shows that spring and summer are the ideal months for energy production. The highest solar energy output is in August 181.9 MW.h solar energy output (figure 3).

Site suitability analysis

To locate suitable areas for solar panel installation, the following set of indicators (Table 1) and thresholds were

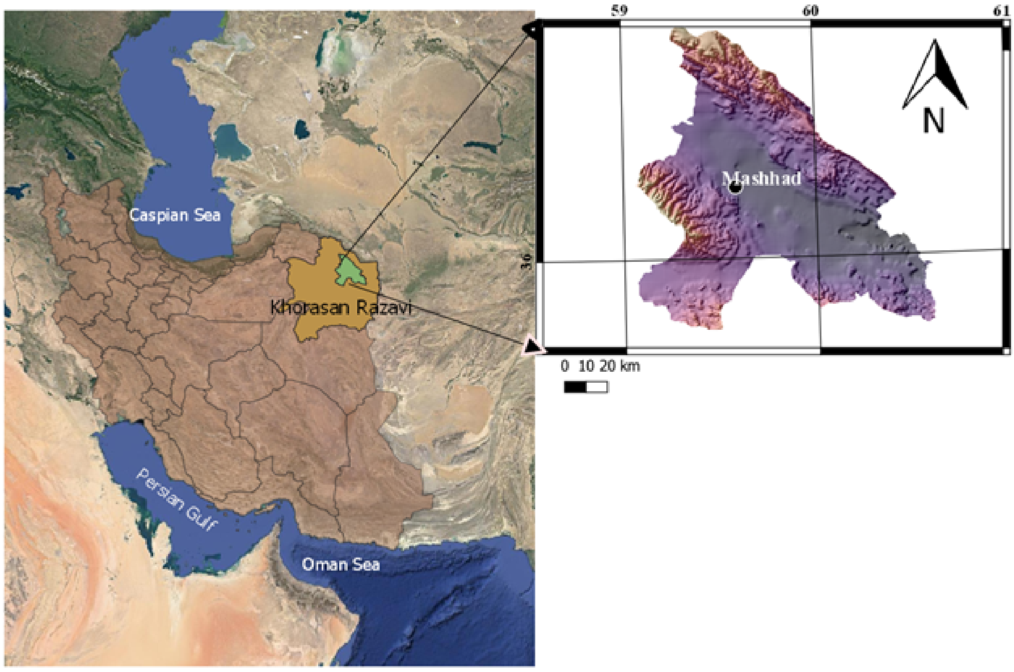

Figure 1. Location of Mashhad Area in Iran and Khorasan Razavi Province, as well as the elevation.

adopted. In this research, we have developed a tool for solar panel installation in Mashhad County, Iran. The first stage of the work includes removing unsuitable areas for the installation. These areas included built-up and environmentally protected areas. Since there are no water bodies in the study area, we excluded this indicator from the data analysis. We also excluded slopes greater than 15% and elevations above 2000 m since they induce limitations for site preparation and installation. The remaining area was evaluated using a multi-criteria decision-making method.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5-6				2	19	28	18	6	0			
6-7		0	14	60	99	110	96	81	60	25	0	
7-8	20	63	129	198	250	276	258	263	266	218	106	25
8-9	211	255	279	353	414	448	435	456	470	413	309	242
9-10	360	407	415	487	549	588	581	608	628	568	443	393
10-11	468	528	525	590	643	682	681	722	738	675	549	493
11-12	532	603	614	647	680	724	729	775	792	731	592	543
12-13	538	631	637	638	659	714	725	769	776	698	574	534
13-14	492	561	541	557	585	665	676	712	707	613	497	474
14-15	404	469	441	454	482	562	579	612	592	484	376	373
15-16	237	337	324	337	347	427	449	468	426	314	152	100
16-17	16	89	183	196	211	270	287	285	224	31	8	4
17-18		3	18	65	85	114	125	103	32	1		
18-19				2	13	26	23	8				
19-20						0	0					
20-21												
Sum	3278	3946	4120	4586	5036	5634	5662	5868	5711	4771	3606	3181

Figure 2. Total photovoltaic power output [kWh] in the study area (the left column indicate the hours of the day).

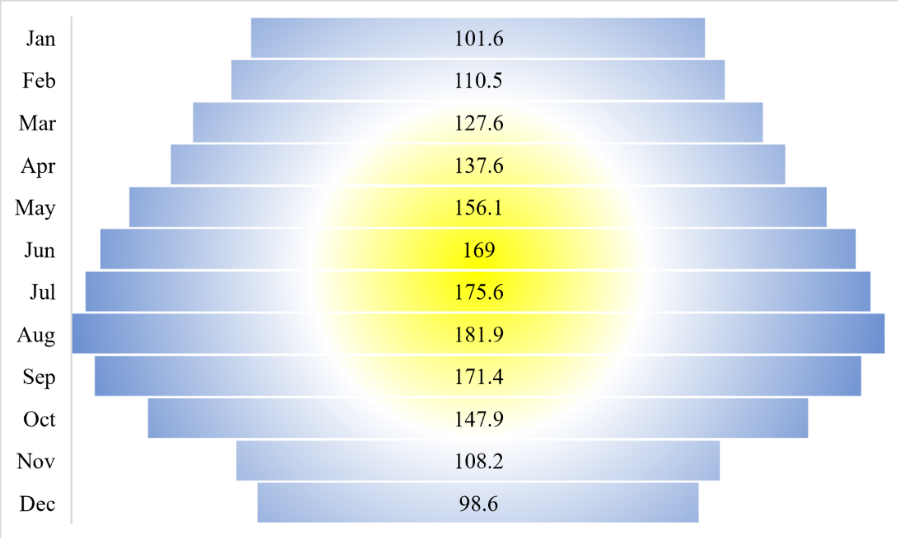

Figure 3. Total photovoltaic power output in different months in the study area (MW.h).

Data collection

To combine different criteria and indicator layers, data were processed as indicated in the diagram below. Data for topography was downloaded from Alos DEM 12.5 m from Alaska State Data Hub at asf.alaska.edu. Data for environmentally protected areas was obtained as shapefiles from the local environment protection office (Iranian Department of Environment). Data for railways roads and residential areas were downloaded from https://mapcruzin.com/free-iran-arcgis-maps-shapefiles.htm. Data for fault-lines were obtained from the Department of Geology Surveys and Mineral Exploration of Iran (https://ncc.gov.ir/). Climate data was obtained from the Worldclim at https://www.worldclim.org. To generate buffer layers for thematic layers, the Euclidean Distance Tool in ArcGIS 10.3 was used.

Methodology

We used a combination of the MCDM-AHP (Multicriteria Decision Making – Analytical Hierarchy process) model for locating suitable spots for solar panel installation. The AHP method is used for weighting thematic layers while multi-criteria decision-making is used to combine the weighted and standardized thematic layers into a final suitability map. The following diagram (figure 4) was used for suitability analysis. The thematic layers were separated into limiting and factor layers. The decision-making criteria were defined based on expert knowledge and group discussions. The layers were standardized, weighted, and combined to find the final suitable areas. The detail of each step is given in the following sections.

Table 1. Criteria and indicators for selecting suitable sites for solar energy production. According to (Sánchez-Lozano et al., 2013; Yousefi et al., 2018; Jafari Shalamzari et al., 2019)

Dimension	Criteria	Range
Environmental	Residential areas	>2000 m
	Highways and roads	>500
	Railways	>300
	Rivers	>500
	Environmental protected areas	>2000
	Faults	>500m
	Land cover	Bare lands/Rangelands
Physiographic	Elevation	<2000
	Slope	<15%
	Direction	Flat areas, southern and eastern aspects
Climatic	Solar irradiation	No limitation
	Temperature	Lower average maximum temperatures

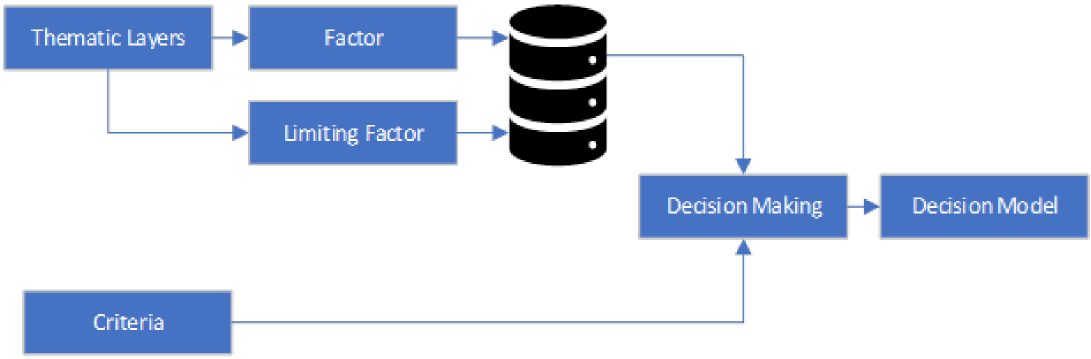

Figure 4. Flow-diagram of the study.

Normalization

To combine the RS thematic layers, they must have a common scale of measurement. The process of converting data into a comparable range of values is called standardization. There are several standardization procedures such as Min-Max, Z-score, Median Normalization, Fuzzy Transform, etc. (Jain et al., 2005). We used the Fuzzy transform method for data normalization into a range of 0 and 1. The Fuzzy Transform was first introduced by Zadeh (1996) to convert verbal expressions into mathematical equations. The Fuzzy set X has its Fuzzy subset A which is defined by a membership function $f_A(x)$ which maps each element in A onto a real number between $0-1$. Since we were only interested in the lower and upper part of the data, indicating severe conditions conducted for desertification, the Large and Small fuzzy membership functions in ArcGIS were applied. The Large fuzzy membership function is defined as:

$$f(x) = \frac{1}{1+(\frac{x}{f^2})^{-f^1}} \tag{1}$$

where:

f^1 is the spread parameter defining the shape and character of the transition zone and

f^2 is the midpoint, after which numbers have a higher possibility of becoming a member of the set (Jafari Shalamzari et al., 2019).

The Small fuzzy membership function is defined as (Farajzadeh and Taghilo, 2013; Sánchez-Lozano et al., 2013):

$$f(x) = \frac{1}{1+(\frac{x}{f^2})^{-f^1}} \tag{2}$$

In the small function, numbers after the midpoint have a lower possibility of becoming a member of the set.

Combination

The final desertification intensity was calculated using the weighted overlay combination as (Eq. 3) (Sánchez-Lozano et al., 2013):

$$DI = \sum_{i=1}^{n} W_i \times y_i \tag{3}$$

where:

W_i is the weight assigned to each layer, and

y_i is the fuzzy layer.

Results

Topographic features of the study area

The weights of the factors affecting site suitability for solar panel installation were in the following order:
Topography (0.32), radiation (0.38), fault lines and protected areas (0.20), land cover, solar climatic parameters (0.10), with the inconsistency ratio of 0.04. The distribution of elevation, slope gradient, and slope direction in the study area is shown in figure 5. The elevation of the area ranges from 671 to 3100 m, with an average of 1520 m. The slope gradient map (figure 5b) also indicates that flat lands are the dominant slope gradient class. Most of the altitudes are distributed along the northern and south-western sections imposing little limitation for the installation of solar panels. As for the slope direction and based on the results of the slope gradient, the majority of spots are flat with a minor southern and western inclination and impose no significant limitation on land suitability for solar farm construction.

Fault lines and protected areas

The faults are a major concern for the installation of solar panels. Among the faults, active faults are the greatest source of concern. Therefore, we used the data on the location of active fault lines to find suitable areas for solar farms. Another major concern was the legal procedure of land-use change in Iran which prohibits altering land uses in environmentally sensitive areas and wildlife reserves. Therefore, we excluded those areas from the final suitability map. In total, 7.3% of the total area was covered with protected areas accounting for ~ 720 km^2. The location of wildlife reserves and the fault lines in Mashhad County is shown in figure 6.

Land cover

Not all land covers are suitable for installing solar farms. The best candidates for this purpose are the bare lands and rangelands. The land cover of the study area which is derived from the sentinel 2 dataset and available at https://livingatlas.arcgis.com/landcover/ is shown in figure 7. There are four categories of land cover in the study

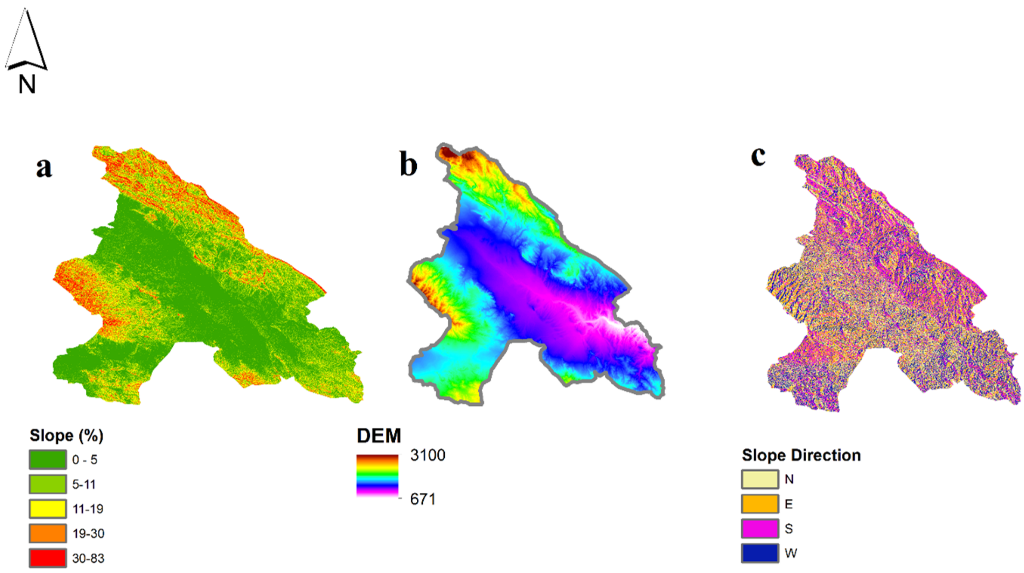

Figure 5. Topographic features of the study area, (a) slope gradient, (b) elevation, and (c) slope direction.

area including croplands, built-up areas and artificial surfaces (roads and railways), bare lands, and rangelands. Rangelands with sparse vegetation are the dominant land cover in the area accounting for 59% (6000 km^2) of the area. The second largest land cover is bare lands with approximately 21% of the total area (2167 km^2). Croplands cover 13% of the area totaling built-up areas and roads 1341 km^2. Built-up areas are merely 7% of the total area (1032 km^2).

Solar radiation

One of the factors necessary for site suitability evaluation for solar panels is the Total photovoltaic power output. The data which was obtained from the global solar atlas in kWh units is shown in figure 8. As shown, total photovoltaic output ranges between 1348 and 2082 kW/h per year. Most suitable areas are therefore located in the southern, northern, and a small spot in the eastern sections of the study area. These values indicated a very promising condition for solar energy production in the area.

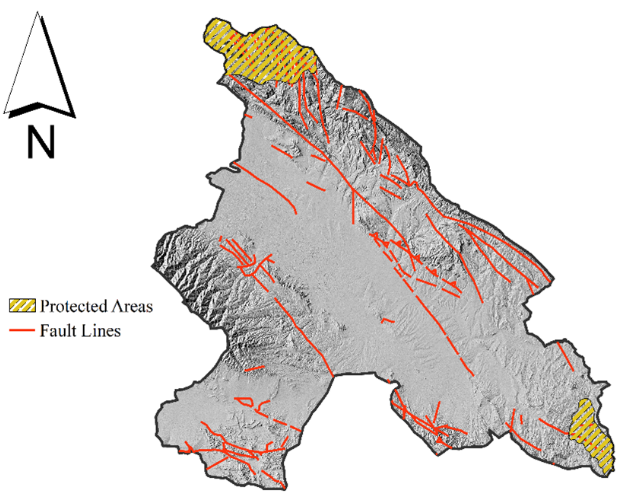

Figure 6. Location of environmentally conserved areas along with the location of active fault lines in Mashhad County.

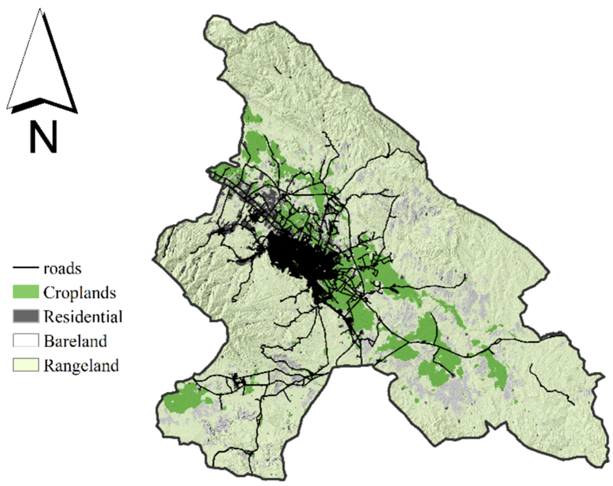

Figure 7. Land cover of Mashhad County derived from sentinel 2 dataset.

Temperature

Temperature is important for the proper performance of solar panels. The data for surface temperature obtained from the global solar energy atlas is shown in figure 8 and 9. Based on the map, the average annual temperature in the area ranges from 2.4 to 16.5 °C that is a suitable condition for the performance of solar panels. As expected, highlands are characterized by the lowest temperatures while plains in the middle section of the area show the highest temperature. However, there is another major limitation for areas with lower temperatures which is the elevation, slope gradient, and slope direction of the site which make these spots less appealing for the construction of solar farms.

Suitability analysis

The results of the final suitability for solar farm installation in Mashhad County are shown in figures 10 and 11. Figure 10 is the suitability without imposing the limiting factors and figure 11 is the final map after including all the binary factors into consideration. Based on the results of

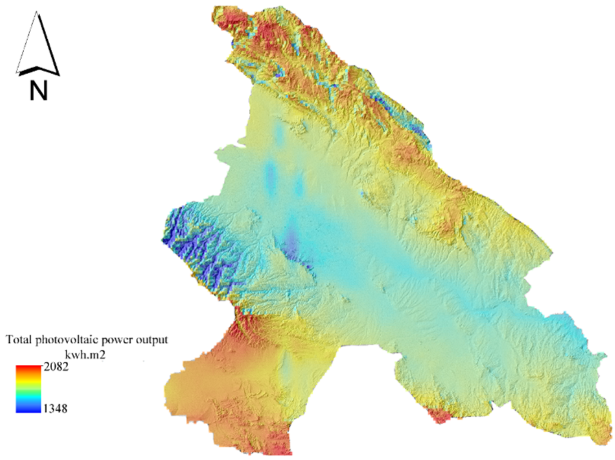

Figure 8. Distribution of total photovoltaic power output in the study area.

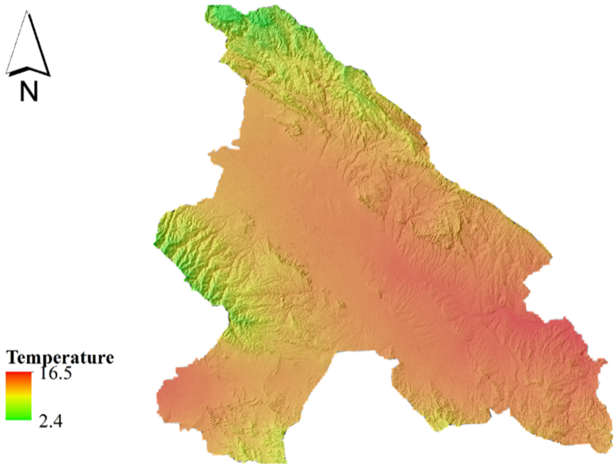

Figure 9. Distribution of average annual temperatures in the study area.

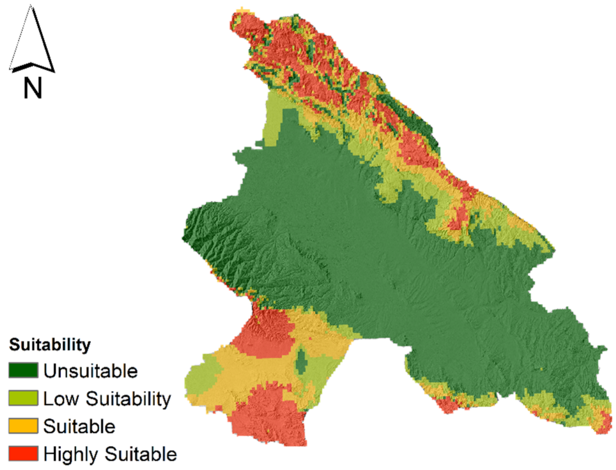

Figure 10. final suitability analysis map of the study area before imposing the limiting factors.

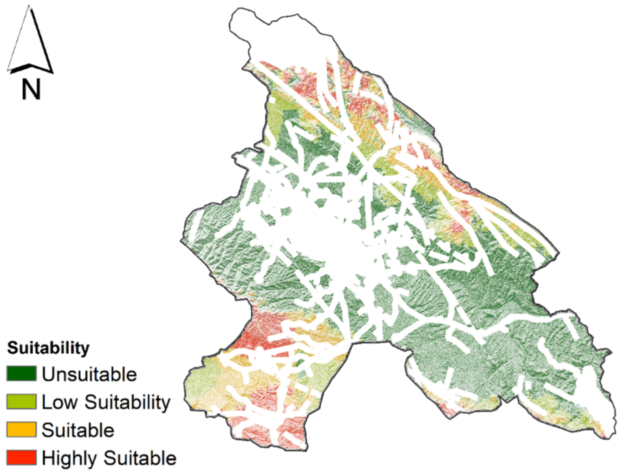

Figure 11. final suitability analysis map of the study area after imposing the limiting factors.

the classification, suitability ranged between 0.15 to 0.86 indicating both the lower and upper ranges of suitability. The range between 0 and 1 was divided into 4 classes with an interval of 0.25 to show areas unsuitable (lowest scores) to highly suitable for solar farm construction. Our results showed that the narrow strips to the south and north are the most suitable areas for solar energy production, while the middle areas had the lowest suitability scores. After imposing the limiting factors, the remaining area only covered 58.5% of the county, totaling 6047 km^2.

The areal distribution of the county into the four suitability categories is brought into Table 2. The total suitability was divided into 4 classes of $0-0.25$, $0.25-0.5$, $0.5-0.75$ and $0.75-1$ and the area for each class is calculated. Based on the results, the suitable class had the largest share of the final map. Highly suitable areas comprise 14.1% of the total area. The excluded lands from the analysis due to the limiting factors made up approximately 56% equal to 5811 km^2.

Discussion

Iran is spending a relatively great amount of budget on renewable energies, especially wind and solar energies. Iran has great potential for solar and wind energy production given its geographic location and climatic conditions. Most areas of the country enjoy more than 300 days of good sunshine for photovoltaic energy production and given the constant winds in the eastern wing of the country which lasts for at least 120 days a year, the potential for wind energy production is also immense (Bahrami and Abbaszadeh, 2013). However, since land suitability analysis requires accurate and iterative results with the ability to update the data layers, GIS application has received great interest in recent years' suitability analysis. Therefore, in this paper, we evaluated the suitability of Mashhad County in Iran for the installation of photovoltaic panels. We evaluated the area based on several factors including topographic features (slope gradient, slope direction, and height), roads and infrastructure, built-up areas, environmentally protected areas, solar photovoltaic output potential, air temperature, land cover, and active fault lines. Based on the topographic features, there is no significant limitation to the installation of solar farms. The only problem with the topography is the slope direction which in the best condition should be southeast and south for maximum energy production. Since most of the area is flat with minor elevations, there is no

Table 2. Classification of the final suitability map in Mashhad County after imposing the limiting factors.

Suitability	Area (km^2)	Area %
Unsuitable	1455.2	14.0
Low suitability	846.5	8.3
Suitable	2074.9	20.1
Highly suitable	1672	16.2
Total	6047	100

limitation on energy production. The largest share of the area has a slope gradient of less than 15% (3303 km^2), this factor also imposes no limitation. In terms of elevation also 42% (4335 km^2) of the area below 2000 m is suitable for solar farm construction. Topography affecting temperature, the difficulty of access to the site, and slope direction have considerable influence on the total amount of power producible from the area. Olson and Rupper (2019) also argue that topographic shading is an important factor contributing to surface energy balance. Lai et al. (2010) reported that topography could influence received solar radiation in both local meso and macro scales. Apart from solar radiation, the risk of landslides and rock slides is a major threat to the sites located in valleys and close to high elevations and northern slopes. This is in agreement with the results of Marques-Perez et al. (2020).

Another important feature that could impact photovoltaic energy production is the geological activity of the area. We decided that the location of active fault lines is the best measure of analyzing the impact of geology on site suitability. Our results indicated some 72 active faults in Mashhad County which could severely limit land suitability. Most of these lines are aligned with the elevations in the north and south, leaving the middle and southern plains intact for PV farm construction. Günen (2021) also found active fault lines to be a major threat to solar farms in Turkey. Sites closer to fault lines are prone to a higher risk of earthquakes and consequent damage. The transmission lines are also at risk of subsidence due to geological activities. Fault lines also impose the project activities and personnel at risk and therefore, the areas farther from the faults are preferred for PV panels. The same results are reported in the work of Ibrahim et al. (2021). Another limitation in locating suitable areas for solar farms is the presence of environmentally sensitive sites. We excluded those lots falling into the protected area according to the national regulations. Any industrial and mining activities are banned inside the protected areas by law in Iran. The total share of these areas is 572 km^2. We also included a 2000 m buffer around these areas to best observe the regulations. Nonetheless, solar panels have both beneficial and adverse impacts on these sites if they were allowed inside the protected areas. Fthenakis et al. (2011) believe that solar panels could provide new habitats for local wildlife. Turney and Fthenakis (2011) also believe that solar farms are beneficial to local wildlife and general environmental conditions. However, there are other researchers opposed to this idea and believe that solar farms adversely impact the site's condition for vegetation and animals due to the destruction of their natural habitats (Dhar et al., 2020; Hamed and Alshare, 2022).

Land cover is one of the largest limiting factors for PV farm construction. Most landuses should be excluded from the total area because of their property rights, human life security, remoteness, surface features, and costs. We only included rangelands and bare lands for the analysis. The rangelands themselves, however, should be evaluated from the traditional utilization rights perspective yet we did not include this into consideration due to the lack of access to the data on ranchers and local owners. Some of the bare lands are also saline with high water Tables but we were unable to obtain the water table data for the measurement wells of the county. However, if one considers these two land covers suitable, there is considerable potential for finding suitable areas for the construction of solar farms. We did not include built-up areas, roads and infrastructure, and croplands in our analysis. A buffer was also included surrounding the residential areas and roads (highways, railways, and roads) for human safety. Croplands were also excluded for not impacting the food security of the region. In total, 72% of the area is available for constructing solar farms. The importance of land-cover on-site suitability analysis for PV farms is emphasized in the works of Guaita-Pradas et al. (2019) and Lu et al. (2021) who believe that large-scale solar farms could benefit the vegetation cover of rangelands with poor cover conditions.

Two other important features affecting the suitability of the site for solar energy production are air temperature and potential PV power output. Air temperature is a major determiner of the panel's performance. Most panels experience a major reduction in performance at high temperatures. Kawajiri et al. (2011) similarly reported that air temperature negatively affects panel performance and hence lands at middle earth latitudes by having higher temperatures face a great challenge in reaching optimal panel performance. Peng et al. (2017) reported that a solar panel that is cooled down can have a significant increase in the electric output. They also argued that the Life cycle assessment of these panels suggests the cost payback time of cooled PV can be reduced. Therefore, areas with lower average temperatures are more suitable for PV farms. We also included the total PV power output into our analysis and found no limitation in this regard. Therefore, the Mashhad County has both optimal condition in terms of potential power output and average air temperature. By combining all the limiting layers and factor layers into the final integrating equation, we found suitable sites for solar energy production. Our results indicated that using equal weights for factor layers doesn't significantly influence site suitability for PV farms.

Conclusion

In this research, the suitability of Mashhad County of Iran for solar energy production has been evaluated. The rangelands of Mashhad County are under heavy grazing pressure and introducing energy production from rangelands could not only lessen the pressure, but it could also improve economic output and vegetation condition, helping in other directions like soil conservation and income source generation. We included several limiting and factor layers in our analysis. However, other major driving factors should be included in future analysis. Our results showed that from a total of 10326 km^2, a narrow strip to the south and north are the most suitable for solar energy production, while the middle areas had the lowest suitability scores. After imposing the limiting factors, the remaining area only covered 58.5% of the county, totaling 6047 km^2. We also found that using equal weights for the criteria didn't change the suitability analysis to a large extent, indicating that topography and radiation are the most important suitability analysis factors. Since we did not have access to the data on transmission lines for security reasons, the results might change in a similar study. One unique feature of this study was the excluding environmentally sensitive areas from our analysis. Since the final intention for using renewable energies is to protect the environment, it would be the wisest decision not to disturb sensitive areas for installing PV panels. Most areas in Iran are hard to recover from once the damage is done given their low precipitation, high temperature, unsuitable geology, and current pressure from human activities. The results of our work could be the beginning of a series of research for also evaluating the economic aspect of solar energy production and locating the sites with the most cost-effective chance of investment. Therefore, the topic that we will be pursuing in our future work, will be locating the economic spots for constructing solar farms relying on the results of the suitability analysis in the current work. It is also recommended to compare the results of different decision-making methods in future studies since different methods and sets of driving factors might change the overall suitability.

Authors Contributions
All authors have contributed equally to prepare the paper.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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