Journal of Green Energy Research and Innovation

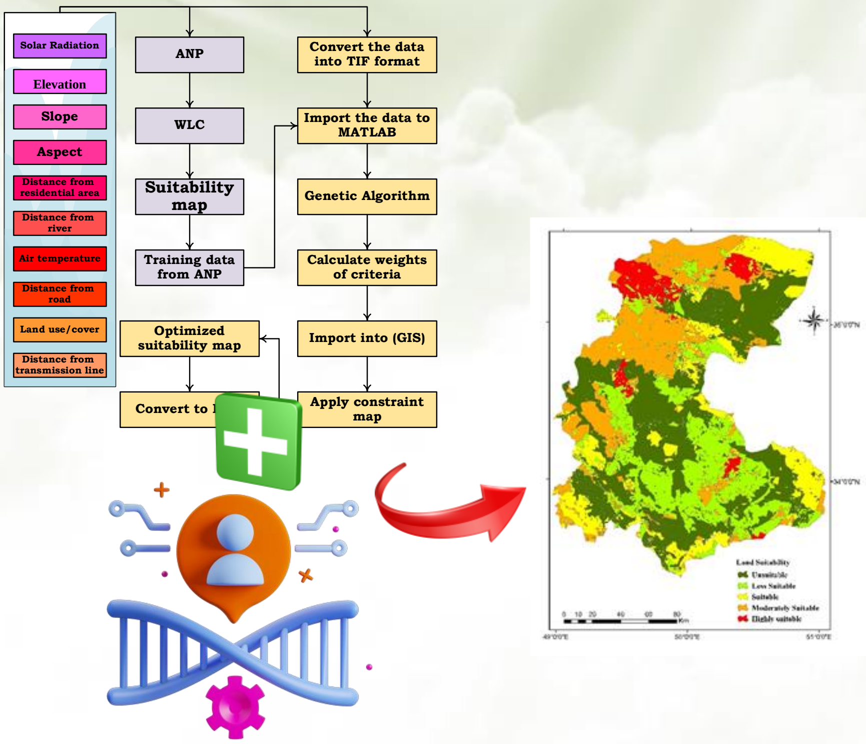
Optimal Site Selection of Solar Power Plant Stations Using GIS-ANP and Genetic Optimization Algorithm in Markazi Province, Iran

Fatemeh Masteri Farahani, Azadeh Kazemi, Amir Hedayati Aghmashadi

Highlight

- The use of renewable resources for electricity production is unavoidable.
- Creating solar power plants can help reduce the environmental effects of fossil fuel consumption.
- Site selection of solar power plants using modern methods is important.
- Among the methods, the ANP method has not been used so far.
- It is better to use the genetic algorithm method to verify the location.

Graphical Abstract



Use your device to scan and read the article online

Citation
F. Masteri Farahani, A. Kazemi, and A. Hedayati Aghmashadi, "Optimal Site Selection of Solar Power Plant Stations Using GIS-ANP and Genetic Optimization Algorithm in Markazi Province, Iran," *Journal of Green Energy Research and Innovation*, vol. 1, no. 4, pp. 47-63, 2024.

https://doi.org/10.61186/jgeri.1.4.47

JGERI
Journal of Green Energy Research and Innovation

Journal of Green Energy Research and Innovation 1(4) (2024) 47–63

Online ISSN: 3041-9018

Journal of Green Energy Research and Innovation

Journal Homepage: www.jgeri.araku.ac.ir

Optimal Site Selection of Solar Power Plant Stations Using GIS-ANP and Genetic Optimization Algorithm in Markazi Province, Iran

Fatemeh Masteri Farahani [1], Azadeh Kazemi[1]*, Amir Hedayati Aghmashadi [2]

[1] *Department of Environmental Science and Engineering, Faculty of Agriculture and Environment, Arak University, 38156879 Arak, Iran.*

[2] *Department of Sustainable Landscape Development, Institute of Geosciences and Geography, Martin Luther University Halle-Wittenberg, 06120 Halle, Germany.*

*** Corresponding Author: a-kazemi@araku.ac.ir***

ARTICLE INFO

Keywords:
Solar power plant stations;
Genetic algorithm;
Optimal site selection;
Analytic network process (anp).

Article history:
Received: 14 April 2024;
Revised: 27 April 2024;
Accepted: 30 April 2024;

Article type:
Research Article

ABSTRACT

The demand for non-renewable energy sources in power generation is crucial for residential and commercial uses, significantly impacting national development. However, with the depletion of fossil fuels, there is a shift towards renewable energy sources such as solar, water, and wind, which have seen a surge in use over recent decades. In Iran, despite abundant fossil fuel resources, solar energy is vital due to the country's favorable geographic conditions for solar exploitation. This study applies the analytic network process (ANP) and Genetic algorithm (GA) to identify optimal locations for Solar Power Plant Stations in Markazi province, Iran. Key morphological factors considered include slope, elevation, and solar radiation. The research identified the northwest and northern parts of Markazi province as the most suitable for solar photovoltaic systems, primarily due to their simpler topography. Using a genetic algorithm, which outperformed the ANP, it was found that about 24,000 km^2 in these areas are apt for solar power facilities, categorized into highly suitable (2,429.312 km^2), moderately suitable (16,818.49 km^2), and suitable (5,029.007 km^2). Saveh showed the highest potential, while Ashtian, Khondab, and Shazand had the least. These findings provide crucial insights for stakeholders looking to develop solar energy projects in Markazi province.

1. Introduction

Throughout history, renewable energy has been utilized and is currently acknowledged as essential in light of the finite nature of fossil fuels and growing environmental apprehensions [1,2]. Burning fossil fuels leads to pollution and an increase in CO_2 emissions, but this can be mitigated by shifting towards renewable energy sources [3]. The demand for energy holds significant importance on both national and international levels. Presently, the primary sources of energy in Iran, as well as in many other countries, are fossil fuels like oil, natural gas, and coal. Given their lengthy natural formation process and limited availability, these nonrenewable resources are expected to become increasingly expensive as their reserves diminish. In light of these factors, there is a growing need for an energy transition towards renewable sources [4]. The increasing utilization of solar energy in urban environments has become a common practice, emphasizing the significance of accurate tools and methods for assessing land potential for solar power generation at the local level [5].

Numerous studies have focused on analyzing solar power plants and selecting optimal sites using different methods. However, not much attention has been given to the Markazi province in Iran. Selecting optimal locations for building a solar power plant is a critical decision as it can result in higher energy output, improved efficiency, as well as better economic advantages.

Al Garni et al. [6] studied several applications of the geographical information systems (GIS) and an analytical hierarchy process (AHP) technique to assess the factors and calculate a land suitability index (LSI) for analyzing potential locations in Saudi Arabia. Merrouni et al. [7] evaluated the appropriateness of the Eastern area of Morocco for accommodating extensive Concentrating Solar Power facilities through a merger of GIS and AHP. Habib et al. [8] identified the optimal sites for setting up photovoltaic plants in Egypt through a combination of GIS, Remote Sensing (RS), and Multi-Criteria Decision Making (MCDM). Hassaan et al. [9] developed a GIS model for conducting a multi-criteria suitability analysis to identify the best locations for photovoltaic plants in Kuwait. Mirzaei et al. [10] attempted to identify the most suitable site for establishing a solar power plant using six distinct criteria among five cities in southern Turkey. This was done through three widely recognized MCDM approaches, namely ANP, AHP, and PROMETHEE.

A nation's prosperity is linked to its ability to achieve energy self-sufficiency, thus reducing reliance on foreign energy supplies. The socioeconomic soundness and stability of a country are closely connected to its energy independence and efforts to diversify domestic energy sources. Even if a country possesses abundant primary energy resources, efficient conversion of these resources into secondary energy requires advanced technology and expertise. Cost-effective utilization of readily available domestic natural resources such as hydropower is achievable through less sophisticated technologies at minimal costs. It is essential to prioritize sustainability and minimize greenhouse gas emissions in this process [11]. Markazi province, situated in Iran, is recognized as a significant industrial hub. The third largest fossil fuel power plant in Iran with significant greenhouse gas emissions is located in this province. Given its considerable potential for solar power plant construction, a comprehensive assessment of suitable locations for such facilities is crucial. This study introduces a new method for evaluating the viability of renewable energy sources in Markazi province. By integrating ANP with a genetic optimization algorithm, the research identified the most suitable sites with high potential for establishing PV systems in the study area. The study explored the suitability of ANP and genetic algorithms (GA) in site selection for solar power through a qualitative method rather than using predefined metrics. The effectiveness and accuracy of GA were compared and evaluated against ANP for each region individually.

2. Data and methodology

2.1. Study area

Markazi province is located in the center of Iran, with an area of 29530 km^2, covering latitudes 33°23’–35°33’ N and longitudes 48°56’–51°3’ E. It is made up of 12 counties, 35 cities, and 13,941 villages. Markazi covers 1.82% of Iran's expanse, with a population of 1,429,475, which is 1.6% of Iran's total population. It has a complex geomorphology, with elevations of 950 m in the north and 3,388 m in the southwest. Markazi's climate is semi-arid continental, and its summers are sunny and warm and its winters are generally rainy and cool.

Notable distinctions in the region are influenced by its characteristics and elevation, with the northern section exhibiting a semi-desert climate, the eastern section exhibiting altitude-driven coldness, and the southern section being home to freezing highlands [12]. As an industrial hub, this province is perfect for constructing solar farms for several reasons, including strategic location, ample solar radiation year-round, numerous expansive plains, diverse geographical features enabling the use of various modern panel mounting structures, and a growing population that requires more electricity. Solar farms can benefit the region by reducing power imports, creating a self-sufficient province, improving its energy-based sustainability, combating air pollution, and boosting public health. Presently, energy imports cannot meet the province's demand, which shows the urgency of establishing such plants. Figure 1 demonstrates the location of the study area.

2.2. The GIS Database

The research data was gathered from a variety of sources, each of which is comprehensively described.

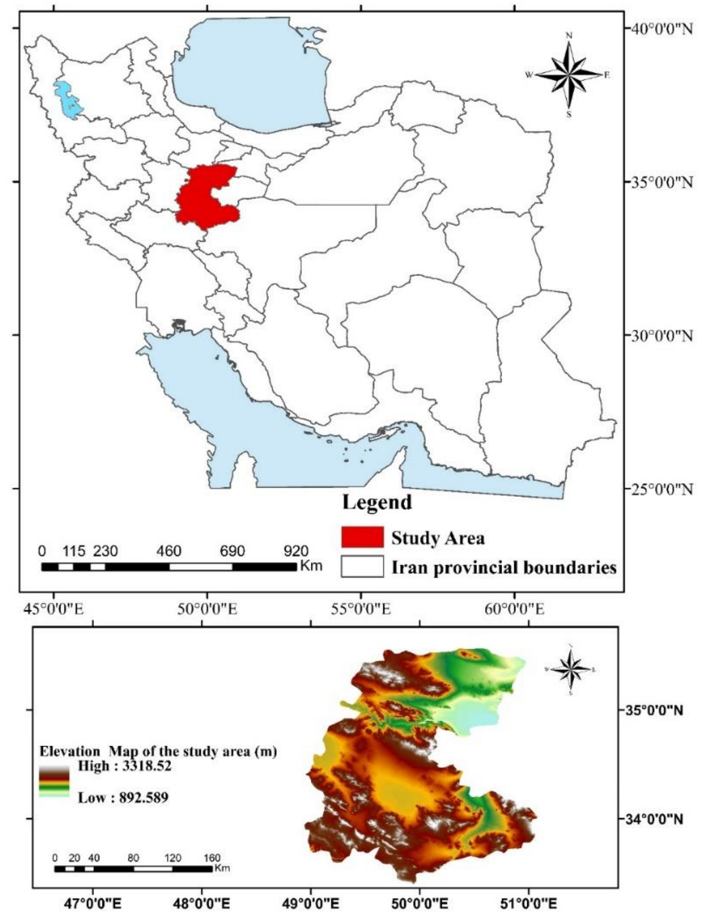


Figure 1. (a) Map and geographical coordinates of Iran, (b) elevation map of the study area.

2.2.1. Solar radiation

Optimal locations for photovoltaic power generation were primarily identified based on solar irradiance levels [13]. Solar radiation data for Markazi was derived from Shuttle Radar Topography Mission data at a 30 × 30 m resolution. The analysis revealed an average annual solar radiation of 1,574 kWh/m², indicating the province's potential for establishing solar farms. Surface solar radiation values were computed for 1000 random points across the study area using ArcGIS 10.8 and later interpolated with Kriging Interpolation. The resulting data showed that in Markazi province, the annual minimum solar radiation was 1,374 kWh/m², and the maximum value was 1,776 kWh/m², making it suitable for installing solar panels. Figure 2 illustrates a raster classification dividing suitability into five classes, while Table 1 shows the classified solar radiation values across the research area.

2.2.2. Digital Elevation Model (DEM)

The elevation of a region can have a significant effect on its industrial sites. The height above sea level has an inverse correlation with atmospheric density [14]. Greater elevations lead to increased expenses and challenges in transporting infrastructure and labor. DEM enables analysis of the fundamental topographic features (such as elevation, aspect, slope, and sky view). In complex terrains, solar radiation distribution undergoes significant changes. A digital elevation model and a geometric approach that depends on DEM resolution accuracy can be used to assess topographic effects. DEM provides an artificial horizon and the sun's relative position for each point. The Shuttle Radar Topography Mission's DEM provides data on elevation, solar radiation, slope, and aspect for the study area. Figure 2 illustrates the digital area elevations while Table 1 displays classified research-area elevations.

2.2.3. Slope

When choosing the best place for establishing solar power plants, it is important to analyze its slope [15]. How much sunlight an area gets can change based on how steep it is, which also influences where to put solar panels to collect energy from the sun. In this study, we made a map of the area's slope using ArcGIS 10.8 and data from SRTM with a detail level of 30 m DEM. We then split these slopes into five different categories shown in Figure 2 and Table 1.

2.2.4. Aspect

Aspect is very important for PV farms because the direction they face greatly affects how much sunlight they get [16]. The east, west, and south sides get more sunlight than the north. Areas that are flat or face south get the most sun throughout the year [16].

2.2.5. Distance from residential areas

Constructing solar power plants near residential areas can affect their environment and future developments. Locations within 30 km or more than 3 km are deemed most suitable. Areas with a distance of over 50 km but fewer than 3 km are considered least suitable [17].

2.2.6. Distance from rivers

The proximity to running water is another important feature. There is a river network in this region, which was derived from SRTM DEM to be used in generating a distance map via the Euclidean distance toolbox in ArcGIS.
As per existing literature, the raster data was categorized into five classes, with details available in Table 1. Figure 2 demonstrates the map of distance from rivers.

2.2.7. Distance from roads

The next important feature for site selection is roadways. These networks play a significant role in transporting equipment, providing site access, facilitating regular maintenance, and monitoring farm operations. An optimal site must be situated at specific distances from the roads. Figure 2 shows a map of the study area's road network. The distances were determined using the Euclidean distance toolbox. Table 3 presents information related to proximity to roads.

2.2.8. Air temperature

In this study, a Land Data Assimilation System product for 2020 is used to analyze air temperature with a resolution of 0.1 degrees. The resulting raster is resampled to match the resolution of other data at 30 m and divided into five categories. The air temperature map of the research region can be seen in Figure 2, and statistical information for this thematic layer is provided in Table 1.

2.2.9. Distance from transmission lines

The main transmission line passing through the main cities is provided in a grid file. The polylines were created and cropped to the study area using ArcGIS. Proximity calculations for these polylines were categorized into five classes, as shown in Figure 2, with statistical details provided in Table 1.

2.2.10. Land use

An optimal solar power plant site should have flat terrain, no shading, and be located in non-agricultural areas. In our study area, we created a land use and land cover (LU/LC) map through Sentinel-2 imagery with a high resolution in the Google Earth Engine (GEE). Support Vector Machine algorithm was used to classify different LU/LC classes in the study area. The LU/LC map shows four classes which are detailed in Table 1, and visually presented in Figure 2.

2.2.11. Methodology

The study used GA and the ANP to identify suitable locations for establishing PV systems. The genetic algorithms were fed with the ANP outputs. Hence, these outputs were used to train ANP for weighing the related criteria, effectively integrating ANP information to enhance its performance in site selection. Selecting locations for large-scale solar farms and turbine systems can be a complex problem whose solution calls for examining various variables [15]. Solar potential is not the only factor to consider, rather land suitability and disposal are also important [16]. The research data was obtained in different formats from various sources. Spatial data modeling, coding, and image processing were performed using a range of applications. LU/LC were obtained from GEE, and satellite imagery was analyzed using JavaScript.

Table 1. Statistical data on the research criteria.

Criteria	Ranking Values	Classes	Area percentage (km²)	Suitability
Solar Radiation (kWh/m2)	1	1374–1470	30.6	Unsuitable
	2	1470–1662	18.5	Very less suitable
	3	1662–1686	26.5	Less suitable
	4	1686–1746	9.4	Moderately suitable
	5	1746–1776	15	Highly suitable
Elevation (m)	5	2500–3300	2.9	Unsuitable
	4	2000–2500	29.4	Very less suitable
	3	1500–2000	50.4	Less suitable
	2	1000–1500	15	Moderately suitable
	1	800–1000	2.3	Highly suitable
Slope (%)	5	25–49	2.8	Unsuitable
	4	20–25	2.4	Very less suitable
	3	15–20	4.7	Less suitable
	2	10–15	8.5	Moderately suitable
	1	0–10	81.6	Highly suitable
Aspect	1	North	12.7	Unsuitable
	5	Northwest, west	23.3	Very less suitable
	2	Northeast	13.7	Less suitable
	3	East	11.7	Moderately suitable
	4	South, Southeast, Southwest,	38.6	Highly suitable
Distance to the residential area (km)	1	0–5	7.8	Unsuitable
	5	30–50	1.9	Very less suitable
	4	20–30	10.1	Less suitable
	3	10–20	30.5	Moderately suitable
	2	5–10	49.7	Highly suitable
Distance to river (m)	1	0–500	23	Unsuitable
	5	3500–7000	14	Very less suitable
	4	2500–3500	11	Less suitable
	3	1500–2500	19	Moderately suitable
	2	500–1500	33	Highly suitable
Air temperature (c°)	1	1–5	50.4	Unsuitable
	2	6–10	9.2	Very less suitable
	3	11–16	11	Less suitable
	4	17–21	21.8	Moderately suitable
	5	22–27	7.6	Highly suitable
Distance to road (km)	1	0-5	51	Unsuitable
	5	30–40	1	Very less suitable
	3	30–20	2	Less suitable
	4	10–20	19	Moderately suitable
	2	5–10	27	Highly suitable
Land use/land cover	1	Vegetation	71	Unsuitable
	2	Barren lands	23	Highly suitable Unsuitable
	3	Urban	0.5	Unsuitable
	4	Snow	0.6	Unsuitable
	5	Water	4.9	
Distance to the transmission line (km)	1	>70	13.2	Unsuitable
	2	50–70	15.6	Very less suitable
	3	30–50	19.5	Less suitable
	4	15–30	21	Moderately suitable
	5	<15	30.7	Highly suitable

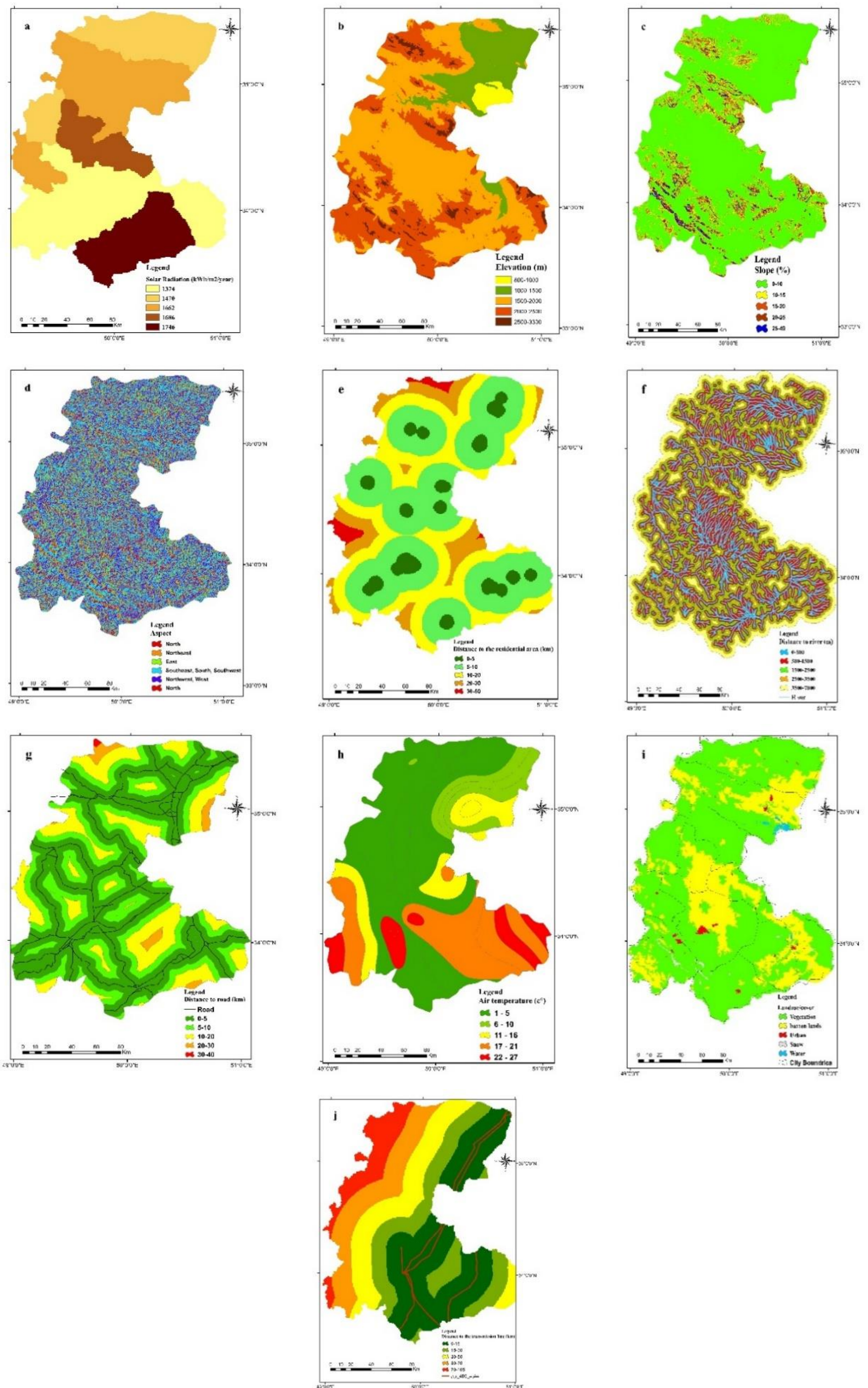


Figure 2. Criteria map used in this research; (a) solar radiation, (b) elevation, (c) slope, (d) aspect, (e), distance from residential area, (f) distance from river, (g) distance from road, (h) air temperature, (i) land use/land cover, (j) distance from transmission line**.**

ArcGIS (V10.8) was used for preparing the necessary input for site selection, modeling, and ultimate map outputs. Super Decision was employed to calculate criteria weights, while MATLAB's genetic algorithm optimized site selection. The research flowchart can be seen in Figure 3.

2.3.1. GIS-based multi-criteria analysis

For selecting sites in large-scale PV projects, various social, technological, economic, and environmental factors must be taken into account [18]. Researchers and policymakers use MCDM to effectively address this challenge. By using these techniques, decision-makers can identify and select appropriate locations. Figure 3 illustrates the connection between criteria, objectives, and options. GIS-based studies typically use MCDM methods for suitable site identification and selection based on their objectives. These methods include ANP, Analytic Hierarchy Process, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW), Ordered Weighted Averaging (OWA), and Weighted Linear Combination (WLC). ANP is particularly popular since it is more flexible, simple, and transparent when it comes to site selection in GIS. On the whole, ANP proves an effective tool for GIS-based decision-making problems thanks to its ability to pinpoint optimal sites and, in the case of this study, boost solar energy production.

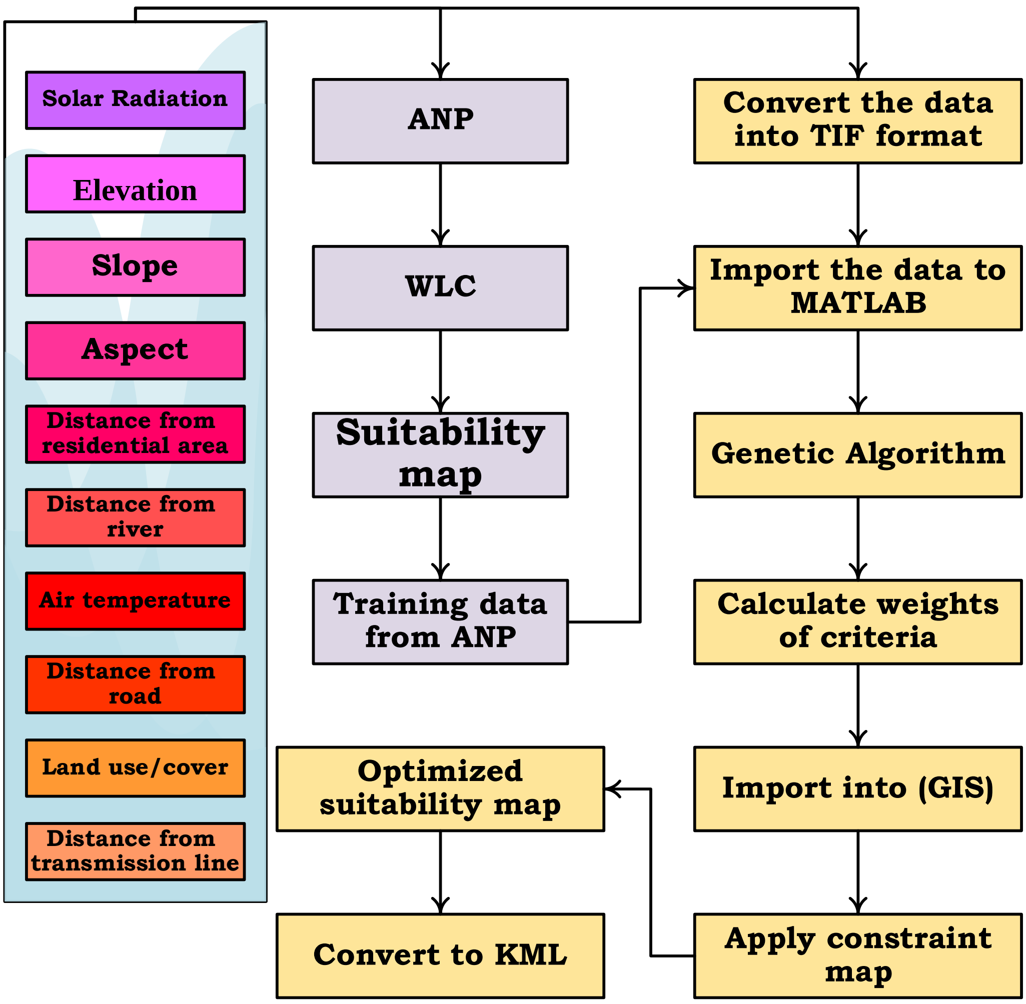


Figure 3. The methodology workflow.

2.3.2. Analytic Network Process (ANP)

Developed by Saaty in 1996, ANP is a method for multi-criteria decision-making [19]. It calculates priority scores based on relative assessments rather than absolute numbers. ANP is valuable for evaluating decision problems as it reveals the level of interdependence between criteria and alternatives [20].
The process of using ANP to make decisions is comparable to AHP, except for a few distinctions. AHP uses a source node (main goal) alongside a sink node (alternative goals), as well as a linear top-down structure without feedback from higher to lower levels. In contrast, in ANP no specific order is in place for arranging clusters, and the network can expand in every direction allowing influence to be extended within a cluster as well. ANP's alternative cluster can have feedback to other clusters or not [20].

2.3.3. Weighted Linear Combination (WLC)

WLC is a geographic information systems-based multicriteria assessment model commonly utilized to analyze whether or not different locations are suitable for the purpose under consideration. It can prioritize site selection and land use through value standardization, weighting, and overlaying [21].
GIS-based WLC can help clarify and consider criteria for selecting ideal locations for specific development activities [22]. WLC combines factors, sub-factors, and constraints to determine the overall land suitability. It uses weights to combine parameters affecting landslides. The main challenge of this method lies in assigning individual weights to each parameter separately [23]. The mathematical definition of weighted linear combination is represented as Equation (1).

$$WLC = \sum_{i=1}^{N} W_i \times K_i \tag{1}$$

Where
WLC is the Weighted Linear Combination
W_i is the Normalized weight of factor i
K_i is the criterion score of factor i
N is the number of factors.

2.4. Genetic algorithm

GA can model genetic selection and natural elimination in biological evolution [24]. Wu and Shan (2000) conducted significant research in this area, narrowing the search space to find optimal solutions [25]. Unlike conventional AI optimization algorithms, GA automatically collects information about the search space and controls the entire search process in a self-adaptive manner using random optimization techniques [26]. As a result, finding the best global solution becomes more likely without facing the overwhelming increase in possibilities caused by ignoring important information within the search space [27].
Genetic algorithms are known for their simplicity, robustness, and adaptability to parallel processing and numerous applications. They have been successfully employed to solve combinatorial optimization problems (COPs) as well as non-linear problems that have complicated constraints or an objective function that is not differentiable [28].

In GA, candidate solutions are ranked based on their quality, and any unqualified member is eliminated based on a specific fitness value. Acceptable solutions undergo genetic operations such as crossover, mutation, inversion, and translocation to generate new candidate solutions for the next generation. This process is iterated until reaching a specific convergent condition. The traditional knapsack problem serves as an illustration of this principle and its algorithm [25].

Sites are selected considering the specific purposes pursued, which should be aligned with the different considerations (economic, environmental, etc.) of the study area. The integration of MCDM and MODM with GA is employed to achieve practical and coherent outcomes. A fitness function is utilized to determine proper sites for establishing solar farms by taking into account multiple factors.

GA pursues two main objectives, namely to minimize or maximize factors. Factors to be minimized consist of distance from transmission lines, roads, and population centers, elevation, and slope. Meanwhile, factors to be maximized are LST, solar radiation, and air temperature. By incorporating these goals into the evaluation process through fitness scores given to potential solutions given their performance in fulfilling both criteria; feasibility is assessed by minimizing the determined factors while maximizing others. When using genetic algorithms to solve a problem, a fitness function is needed for each chromosome. This function returns a non-negative value indicating the merits or abilities of the chromosomes [29].

3. Results and discussion

3.1. ANP-based PV maps using WLC

The research data underwent processing and categorization to generate PV potential maps. ANP helped to determine the importance of different layers in the weighting process. These computed weights were then used to create PV potential suitability maps based on nine criteria, three of which were prioritized in the ANP process. The metrics for pairwise comparison and the obtained criteria weights can be seen in Tables 2 and 3.

3.2. Potential sites for solar power plants

ANP helped to identify the main areas with solar energy potential in the southern and eastern parts of Markazi province. The calculated weights of the layers significantly affected the results obtained by ANP.

According to ANP, higher weights were assigned to solar radiation, slope, and aspect, respectively, considering their suitability in receiving higher amounts of solar radiation in southern parts.

The northwestern and northern parts of the research area were not suitable due to higher topographic heterogeneity. The spatial distribution of the identified potential locations can be seen in Figures 4 and 5.

Table 2. Comparison matrix for solar power plant site selection.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
Solar Radiation (C1)	1	3	1.3	3	5	3	5	3	5
Elevation (C2)		1	3	1.3	1.3	1.3	1.2	3	1.2
Slope (C3)			1	1	5	3	5	3	3
Aspect (C4)				1	3	3	3	3	3
Distance from residential area (C5)					1	1.3	1	1.3	1
Air temperature (C6)						1	3	1	3
Distance from road (C7)							1	1.3	1
Land use/cover (C8)								1	1.3
Distance from transmission line (C9)									1

Table 3. Obtained weights for solar power plant criteria.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	Total
Weights	0.221	0.049	0.156	0.142	0.131	0.074	0.112	0.036	0.079	1

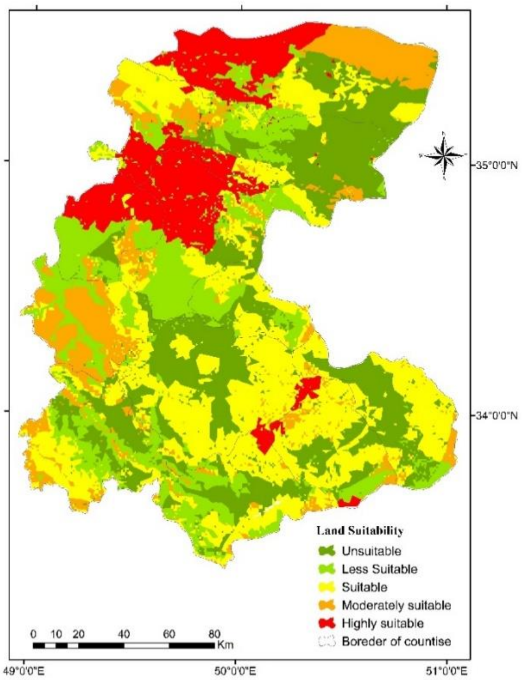


Figure 4. Land suitability map for solar energy potential based on ANP.

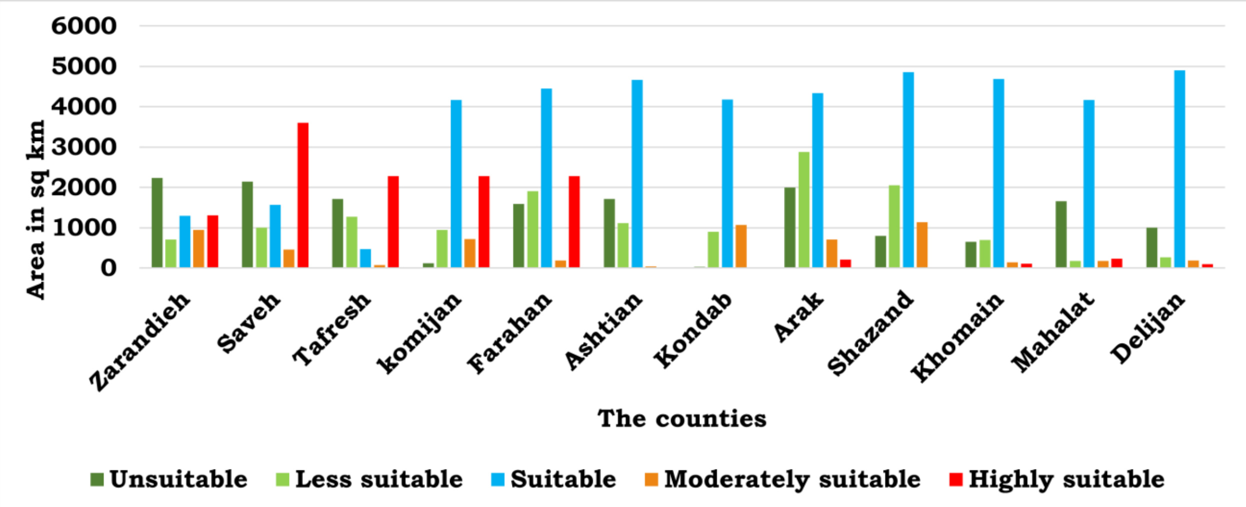


Figure 5. The area of lands with solar power potential in different counties based on ANP.

3.3. GA results

GA can be used for determining proper weights and ultimately selecting potential sites. In this study, the results of the GA method outperformed those of ANP. ANP outputs were used to train a genetic algorithm. Then, the values of nine effective factors (namely, land use, slope, elevation, aspect, air temperature, solar radiation, distance from transmission lines, distance from residential areas, and distance from roads) were extracted for 1000 random points across the study area. The suitability value of the ANP results was also determined. Two specific records were introduced to improve GA's performance in selecting optimal locations.

These included optimal values for each variable (highest suitability), and unfavorable values for lowest suitability. This data helped to identify the less favorable site selection criteria. By incorporating these outlier cases into the training dataset, our goal was to teach the GA optimization algorithm how to identify and give priority to the best locations. Therefore, the training data, which included these records, was imported into MATLAB to train the GA. As a result, the algorithm learned how to adjust itself and make better decisions in site selection. Table 4 displays the weights assigned to each layer.

3.4. GA-based potential sites for solar power plants

The genetic algorithm's findings indicated that morphological factors significantly influence the suitability of the area. Specifically, slope, elevation, and solar radiation had a strong impact on the GA results. A comprehensive investigation of the genetic algorithm output revealed that potential locations with lower topographic complexity are predominantly located in the northwestern and northern parts of the study area. Furthermore, the potential increased from east to west across the province. Figures 6 and 7 show the GA-based potential locations.

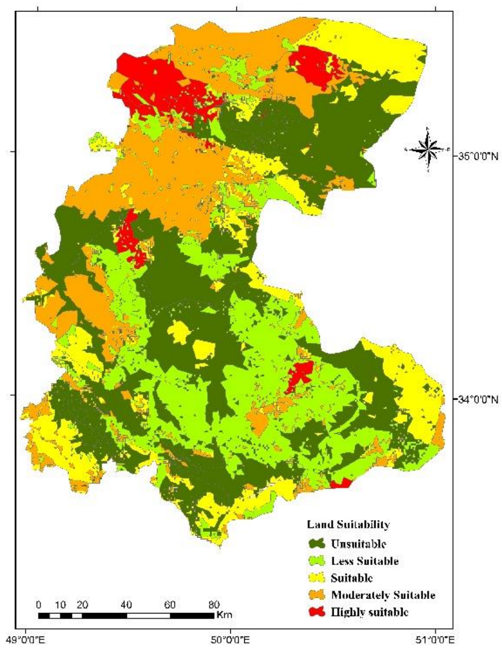


Figure 6. GA-based map of solar energy potential.

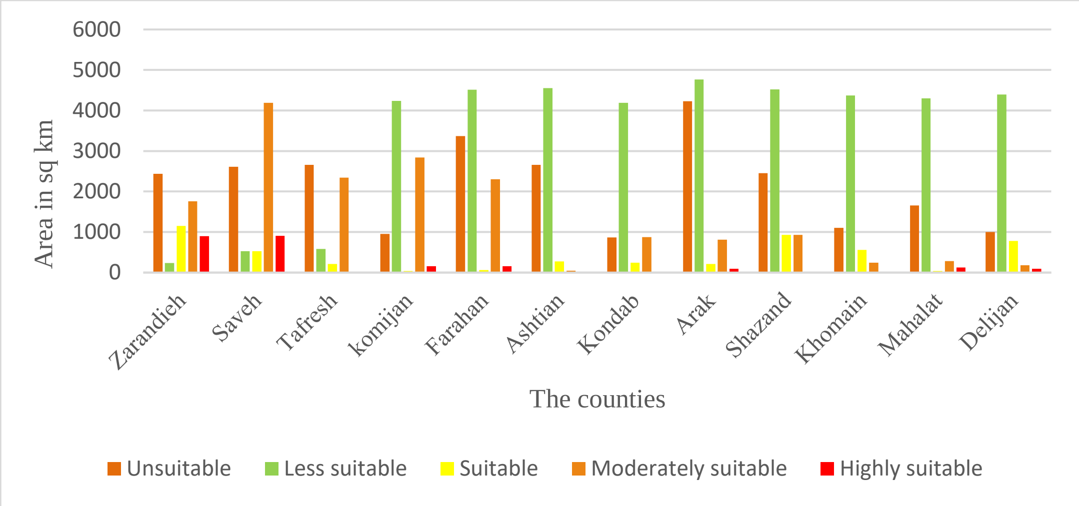


Figure 7. The area of lands with solar power potential in different counties based on GA.

Table 4. GA-based weights for the criteria.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	Total
Weights	0.201	0.069	0.149	0.128	0.131	0.084	0.119	0.046	0.073	1

4. Discussion

The study's findings indicate that GA yielded more precise results compared to ANP. The GA-derived weights were utilized to pinpoint suitable locations for PV systems in the research area. GAs excel over ANP by encompassing a broader set of selection criteria. A comparison of the research results showed their alignment with those of other studies, including Mirzaei and Nowzari (2021) [10], Awasthi (2017) [6], and Merrouni et al. (2018) [7]; these studies assessed various approaches for a comparable issue through the use of GIS methods, MCDA, and optimization algorithms. The research revealed that morphological factors such as elevation, slope, and solar radiation had a substantial effect on site suitability. In the present study, areas with the highest potential for establishing solar power plants were located in the northwestern and northern regions of the Markazi province, which have less topographic complexity.

Noorollahi et al. [30], Van Hoesen and Letendre [31], and LEE [32] assessed the influence of topographic factors on solar power site suitability, yielding similar results to this research. These findings are important as they provide insights to policymakers and investors. They can serve as a guide for advancing large-scale solar projects in the province to expand renewable energy use while decreasing reliance on fossil fuels; however, it is worth noting that certain limitations such as overlooking socio-economic factors could hinder project development in these areas. Additionally, close attention must be paid to the expenses associated with building transmission lines to connect these sites to the national grid (Figure 8).

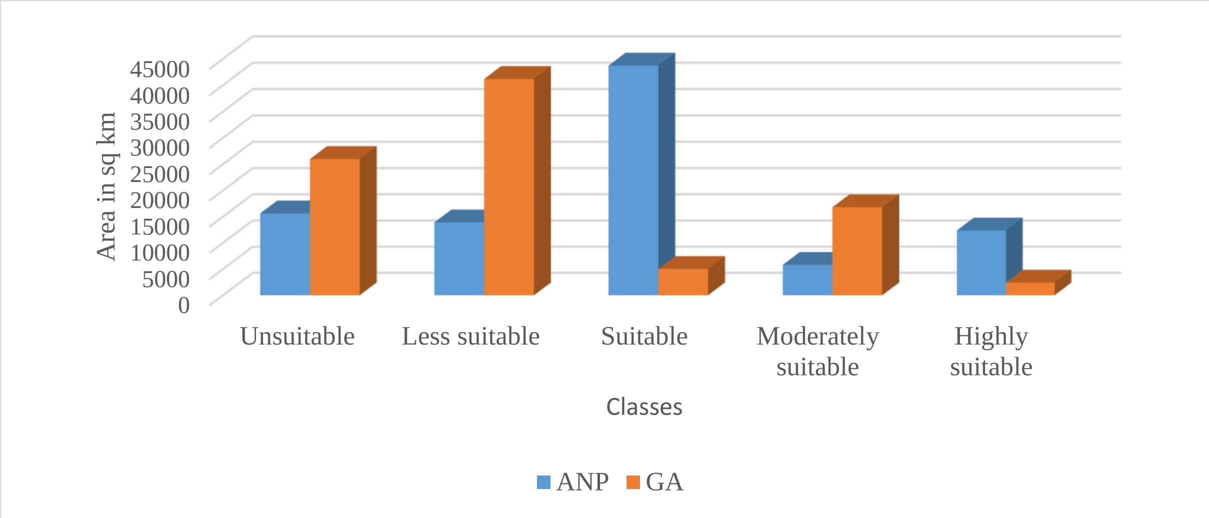


Figure 8. Comparison of GA and ANP outputs regarding potential areas for establishing solar power plants.

5. Conclusion

This study integrated GA with ANP in an attempt to identify and select optimal sites for establishing solar power plants. ANP played a vital for in training the genetic algorithm, enabling effective optimization using valuable information derived from the ANP. GA and ANP were compared to assess the accuracy of each region's selection without using particular factors.

The research findings indicate that the ANP approach identified specific areas in the Markazi province with high potential for solar power plant development. For instance, Saveh in the northwest and Zarandieh in the north of the province had the highest potential, respectively. According to ANP, Saveh had the most potential areas for PV systems, followed by Tafresh, Farahan, Komijan, and Zarandieh, whereas Khondab and Shazand had the least potential. According to the outputs of the genetic optimization algorithm, Saveh and Zarandieh had the highest potential. Both GA and ANP identified Saveh as a suitable area for establishing solar energy plants. Overall, GA favored northern sections as high-potential sites.

This research illustrated that the integration of ANP and evolutionary algorithms can enhance the precision and effectiveness of sites identified for renewable energy initiatives. The combination of these techniques enables the stakeholders and decision-makers to more effectively pinpoint and prioritize sites that are suitable for solar power installations. The results underscored the significance of a methodical approach in determining the best areas for developing green energy resources.

This research examined the potential for implementing renewable energy plants in the Markazi province and emphasized the advantages of utilizing solar power to address the country's energy demand. Due to substantial differences in the capacity of different areas for solar energy, policymakers should concentrate on promising regions and create the necessary infrastructure to support the development of solar farms in these areas.

References

[1] O. A. AL-Shahri, F. B. Ismail, et al., "Solar Photovoltaic Energy Optimization Methods, Challenges and Issues: A Comprehensive Review," *Journal of Cleaner Production*, vol. 284, 125465, 2021

[2] S. Zereshkian, and D. Mansoury, "A Study on The Feasibility of Using Solar Radiation Energy and Ocean Thermal Energy Conversion to Supply Electricity for Offshore Oil and Gas Fields in The Caspian Sea," *Renewable Energy,* vol. 163, pp. 66-77, 2021.

[3] S. Moonchai, and N. Chutsagulprom, "Short-term Forecasting of Renewable Energy Consumption: Augmentation of a Modified Grey Model with a Kalman Filter," *Applied Soft Computing*, vol. 87, 105994, 2020.

[4] A. Mollahosseini, S. A. Hosseini, M. Jabbari, A. Figoli, and A. Rahimpour, "Renewable Energy Management and Market in Iran: A Holistic Review on Current State and Future Demands," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 774-788, 2017.

[5] S. Zhang, and X. Li, "Future Projections of Offshore Wind Energy Resources in China using CMIP6 Simulations and a Deep Learning-based Downscaling Method," *Energy,* vol. 217, 119321, 2021.

[6] H. Z. Al Garni, A. Awasthi, "Solar PV Power Plant Site Selection using A GIS-AHP Based Approach with Application in Saudi Arabia," *Applied Energy*, vol. 206, pp. 1225-1240, 2017.

[7] A. A. Merrouni, F. E. Elalaouni, A. Ghenniouni, A. Mezrhab, and A. Mezrhab, "A GIS-AHP Combination for the Sites Assessment of Large-Scale CSP Plants with Dry and Wet Cooling Systems Case Study: Eastern Morocco," *Solar Energy*, vol. 166, pp. 2-12, 2018.

[8] S. M. Habib, A. E. R. E. Suliman, A. H. Al Nahry, and E. N. Abd El Rahman, "Spatial Modeling for the Optimum Site Selection of Solar Photovoltaics Power Plant in the Northwest Coast of Egypt," *Remote Sensing Applications: Society and Environment*, vol. 18, 100313, 2020.

[9] M. A. Hassaan, A. Hassan, and H. Al-Dashti, "GIS-Based Suitability Analysis for Siting Solar Power Plants in Kuwait," *The Egyptian Journal of Remote Sensing and Space Science*, vol. 24, no. 3, pp. 453-461. 2021.

[10] N. Mirzaei, and R. Nowzari, "Applying A Combination of AHP, ANP, and PROMETHEE Methods to Find the Optimal Location for Solar Power Plant," *Avrupa Bilim Ve Teknoloji Dergisi*, vol. 32, pp. 1076-1085, 2022.

[11] S. M. W. Sadat, and N. R. Sabory, "Afghanistan Renewable Energy Sector's Human Resources Estimation until 2032," *Repa Proceeding Series*, vol. 1, no. 1. pp. 96-101, 2020.

[12] H. Ataee, and R. Fanaee, "Studying the Climate Change of Markazi Province by Mann-Kendall Method," *Nivar*, vol. 36, no. 77-76, pp. 37-48, 2012.

[13] A. M. Patel, and S. K. Singal, "Optimal Component Selection of Integrated Renewable Energy System for Power Generation in Stand-Alone Applications," *Energy*, vol. 175, pp. 481-504, 2019.

[14] M. Zoghi, A.H. Ehsani, M. Sadat, M. J. Amiri, and S. Karimi, "Optimization Solar Site Selection by Fuzzy Logic Model and Weighted Linear Combination Method in Arid And Semi-Arid Region: A Case Study Isfahan-IRAN," *Renewable and Sustainable Energy Reviews*, vol. 68, pp.986-996, 2017.

[15] S. Türk, A. Koç, and G. Şahin, "Multicriteria of PV Solar Site Selection Problem using GIS-Intuitionistic Fuzzy Based Approach in Erzurum Province/Turkey," *Scientific Reports*, vol. 11, no. 1, p. 5034, 2021.

[16] U. Munkhbat, and Y. Choi, "GIS-based Site Suitability Analysis for Solar Power Systems in Mongolia, " *Applied Sciences*, vol. 11, no. 9, p. 3748, 2021.

[17] O. Soydan, "Solar Power Plants Site Selection for Sustainable Ecological Development in Nigde, Turkey," *SN Applied Sciences*, vol. 3, no. 1, p. 41, 2021.

[18] N. Kundakcı, "An Integrated Multicriteria Decision Making Approach for Tablet Computer Selection," *European Journal of Multidisciplinary Studies*, vol. 2, no. 5, pp. 31-43, 2017.

[19] T. L. Saaty, "Decision Making with Dependence and Feedback: The Analytic Network Process," *RWS Publications*, vol. 4922, no. 2, 1996.

[20] T. L. Saaty, "Fundamentals of The Analytic Network Process — Dependence and Feedback in Decision-Making with a Single Network," *Journal of Systems Science and Systems Engineering*, vol. 13, no. 2, pp. 129-157, 2004.

[21] E. L. Subandi, Widiatmaka, and M. Ardiansyah, "Use of WLC (Weighted Linear Combination) to Determine Land Priorities for Development of Paddy Fields in Gorontalo Regency, Indonesia," *International Journal of Engineering and Management Research*, vol. 9, no. 3, pp. 58-63, 2019.

[22] S. Yin, J. Li, et al., "Optimization of the Weighted Linear Combination Method for Agricultural Land Suitability Evaluation Considering Current Land use and Regional Differences," *Sustainability*, vol. 12, no. 23, pp. 1-26, 2020.

[23] J. J. Silva-Gallegos, C. A. Aguirre-Salado, et al., "Locating Potential Zones for Cultivating Stevia Rebaudiana in Mexico: Weighted Linear Combination Approach," *Sugar Tech*, vol. 19, pp. 206-218, 2017.

[24] F. Mehdipour, M. S. Mesgari, B. Golchin, and M. R. Akbari, "Facility Sitting Using GIS and Genetic Algorithms," *25th International Cartographic Conference*, vol. 1, pp. 1816-1823, 2011.

[25] S. Rahimi, M. Shadman Roodposhti, and R. Ali Abbaspour, "Using combined AHP-genetic algorithm in artificial groundwater recharge site selection of Gareh Bygone Plain, Iran," *Environmental Earth Sciences*, vol. 72, pp. 1979-1992, 2014.

[26] M. Kumar, D. M. Husain, N. Upreti, and D. Gupta, "Genetic Algorithm: Review and Application," *International Journal of Information Technology and Knowledge Management*, vol. 2, no. 2, pp. 451-454, 2010.

[27] F. Buontempo, "Genetic Algorithms and Machine Learning for Programmers," *The Pragmatic Bookshelf*, vol. 52, no. 1, pp. 123-230. 2019.

[28] S. Van Dijk, D. Thierens, and M. De Berg, "Using Genetic Algorithms for Solving Hard Problems in GIS," *GeoInformatica*, vol. 6, pp. 381-413, 2002.

[29] N. Nagkoulis, E. Loukogeorgaki, and M. Ghislanzoni, "Genetic Algorithms-Based Optimum PV Site Selection Minimizing Visual Disturbance," *Sustainability*, vol. 14, no.19, p.12602, 2022.

[30] E. Noorollahi, D. Fadai, M. A. Shirazi, and S. H. Ghodsipour, "Land Suitability Analysis for Solar Farms Exploitation Using GIS and Fuzzy Analytic Hierarchy Process (FAHP) - A Case Study of Iran," *Energies*, vol. 9, no. 8, p. 643, 2016.

[31] J. Van Hoesen, and S. Letendre, "Evaluating Potential Renewable Energy Resources in Poultney, Vermont: A GIS-Based Approach to Supporting Rural Community Energy Planning," *Renewable Energy*, vol. 35, no. 9, pp. 2114-2122, 2010.

[32] K. R. Lee, W. H. Lee, "Solar Power Plant Location Analysis Using GIS and Analytic Hierarchy Process," *Journal of the Korean Association of Geographic Information Studies*, vol. 18, no. 4, pp. 1-13, 2015.

Declaration of Competing Interest

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. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, have been completely observed by the authors.

Credit Authorship Contribution Statement

Fatemeh Masteri Farahani: Conceptualization, Data curation, Methodology, Resources, Software, Roles/Writing - original draft. **Azadeh Kazemi:** Formal analysis, Funding acquisition, Investigation, Project administration, Supervision, Validation, Visualization, Writing-review & editing. **Amir Hedayati Aghmashadi:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Roles/Writing-original draft,

Bibliography

Fatemeh Masteri Farahani was born in 1998, in Arak, Iran. She received her B.Sc. and M.Sc. degrees in Environmental Science and Engineering and Environment (Assessment and Land Use Planning), respectively, from Arak University, in 2020 and 2023. Her fields of interest include The Environment and Wild Life.

Azadeh Kazemi is an assistant Professor with a PhD in environmental management and planning. She is currently a researcher at Arak University, Arak, Iran. She has more than 10 years of experience working with clients from different parties including indigenous peoples, private sections and governments to continuously improve their environmental performance. Her most important tasks, besides teaching and in the form of projects and assignments, are familiarizing himself with new environmental topics, carrying out environmental assessments, monitoring, planning and management, risk assessment and researching based on the remote sensing, environmental modelling and GIS.

Amir Hedayati Aghmashadi is a sustainability manager with a PhD in environmental planning. He is currently a researcher at Martin Luther University Halle-Wittenberg, Halle (Saale), Germany. He has more than 5 years of experience working with clients from different parties including indigenous peoples, private sections and governments to continuously improve their environmental performance. His most important tasks, besides teaching and in the form of projects and assignments, are familiarizing himself with new environmental topics, carrying out environmental assessments, monitoring, planning and management, risk assessment and complying with regulations based on the standards and criteria.