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Modelling site selection for solar power establishment by fuzzy logic and ordered weighted averaging methods in arid and semi-arid regions (Case study Yazd province-IRAN)

Saeedeh Nasehi[1], Sakineh Shadkam Birak Olia[1], Saeed Karimi*[1], Sousan Heydari[2]

[1]*Department of Environment, University of Tehran, Tehran, Iran*

[2]*Department of Geography University of Tehran, Tehran, Iran*

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Abstract

Solar energy as one of the cleanest, cheapest and available energies in the arid and semi- arid regions is receiving lots of scientific attention. Two thirds of Iran's country having more than 300 sunny days in the year with average solar radiation of 4.5-5.5 Kw/hr/m2/day. The aim of this study is to provide a conceptual model for solar power site selection by considering spatial and climatologically information using Fuzzy Logic (FL), Analytic Network Process (ANP) and Ordered Weighted Averaging (OWA) methods. The database including climatic, geomorphologic, environmental, spatial and constrain parameters is prepared for analysis in the Geographic Information System (GIS). In the next step each layer was standardized and weighted through the fuzzy logic approach and overlaid by ANP and OWA methods Finaly, the best power solar site map with four classes of suitable, moderately suitable, relatively unsuitable and unsuitable is produced. The results showed that a conceptual model based on the combining FL, MCDM, OWA and ANP methods could provide the best solar power site with high accuracy in the arid and semi-arid regions. The cities of this province were inspected in terms of land suitability for solar power plant establishment. Many areas in the study area are placed in the appropriate category. Clearer Results showed Counties of Khatam and Sadugh have the best Suitability for the establishing of solar power plant, while cities of Marvast, Harat, Abarkooh, Ashkezar and Bafg in are among the suitable regions for development of the solar power plant.

***Corresponding Author:** Saeed Karimi ✉ karimis@ut.ac.ir

Introduction

Energy is considered as a key element for resistible development and success of a society (Amer and Daim, 2011). Energy is the driving engine for economic development through the world. The sustainable energy is defined as combining the equal allocation of energy to all people and succeeding generations' environmental protection (Tester *et al*., 2005). Global energy resources are categorized in three groups that are Fossil energies (oil, gas, coal, etc.), Nuclear energy, and Renewable energies (wind, solar, geothermal, hydro-power, biomass, hydrogen, ocean, etc.) (Alamdari *et al*., 2013). Since fossil fuels produce most of the world's energy fossil fuel use influences the world economy, ecology, and global climate significantly (Uyan, 2013). Since the fossil fuels resources are increasing and also the environment is being polluted, use of renewable energy resources is raised in the 21st century (Lee and Kim, 2000). Compared to the other kinds of energy, solar power generation has some advantages such as environmental advantages, government motivations, flexible locations and modularity (Uyan, 2013). Renewable energy is really vital because it provides some advantages and would not cause pollution and environmental damages. Among all the Renewable Energy resources, solar energy seems to lead the Iran's economic sector towards sustainability in future. RES usually differ temporarily and spatially. They would eliminate the troubles caused by fossil and nuclear energies since the state enjoy a plenty of solar radiation (Abedi, 2012). Renewable energy is one of the best choices. It would increase the energy efficiency by decreasing the negative impacts of climate change (Elliott., 2007). At least one local source of renewable energy can generally be found at almost any location on the Earth's surface (Ramedani *et al*., 2013). While Sun provides 99.8% of the energy of the Earth's surface, solar energy is one of the most low-cost, pollution-free, infinite renewable energy resources (Ramedani *et al*., 2013; Shahzada *et al*., 2012). It is difficult to select a site for solar power system. It has puzzled the electricity generation projects, grid projects and government. Since determining the sites for power plant determines the plant's security, it should meet the meteorological, economic, environmental and social requirements (Yun-Noah *et al*., 2013). Being located between 25 and 40 north latitude, Iran is in a favorable situation in terms of the received amount of solar energy. Solar radiation in Iran is evaluated to be about 1800–2200kWh/m2 per year, which is more prominent than normal. Over more than 90% of Iran's territorial land has an average of more than 280 sunny days, which is a highly meaningful potential source of energy (Alamdari *et al*., 2013). Two classes of decision rules that can be considered as specific cases of a family of OWA are offered by multi criteria decision analysis's recent developments (Malczewski, 2006). OWA has been expanded as a generalization of multi criteria combination (Yager, 1988). Integrating the OWA concept has been a core of GIS multi criteria decision analysis over the last decade or so. Eastman has expanded the GIS applications by OWA - as a part of a decision support module in GIS-IDRISI. Some years later, Jiang and Eastman found that the GIS-OWA would be effective for land use/suitability problems (Jiang and Eastman, 2000). Various applications of OWA to environmental and urban planning problems indicate that the OWA concept could be executed in IDRISI15.01 (Jankowski, 1995). The important view of integrating the GIS and OWA capabilities is the manner of the order weights. For example, the IDRISI-OWA procedure does not supply a user (decision maker) with a method for getting the order weights (Jiang and Eastman, 2000). These complex problems need simultaneous evaluation of many measures. For this goal, MCDM can help decision makers with choosing the best alternative (Jankowski, 1995).

This method is a process consisting of ascertaining the best alternative among a set of applicable options. The purpose or ultimate goal of an MCDM method is to explore a number of options in the light of criteria and conflicting objectives (Voogd, 1983). In order to overcome this drawback, Saaty proposed the ANP, which is a generalization of the AHP. While the AHP represents a framework with unidirectional hierarchical relationships, the ANP allows for complex interrelationships among decision levels and features (Lee and Kim, 2000). In other words, ANP represents a decision problem as a network of components which are grouped into clusters (De Felice and Petrillo, 2013). The components of a cluster may influence some or all the elements of any other cluster, which signifies that a network may include the interdependence of cluster and/or feedback within them (García Melón *et al*., 2008). In sum, ANP allows for working with interdependent criteria and offers a more accurate technique for modeling complex environments (Liang *et al*., 2013). Fuzzy set theory is an expansion of the classical set theory, which is based on two valuable logic; this logic is in or out. In other words, membership is dichotomous: an element is either a member or not. Fuzzy sets, on the other hand, were formulated by Zadeh. Theses sets are based on the simple idea of bringing out a degree of membership of an element (Zadeh, 1965). The main idea of fuzzy sets, which has relevance and instinctive meaning to the sustainability assessment process, is the membership function.

There are only a few researches covering an evaluation of location suitability, or the optimization of sites for solar power plant development which additionally apply appropriate MCDM methods. We review some of them in this article. Carrión *et al.* (2008) used Environmental decision-support systems and optimal site selection for grid-connected photovoltaic power plants. They used the AHP to provide layer Land Proportionality grid-connected photovoltaic power plants.

Beccali *et al.* (2003) used the ELECTRE III method to evaluate a plan of action for the distribution of renewable energy technologies at regional level. Sen. (2007) proposed a nonlinear model to estimate the total solar radiation using the sunshine hour's data available. Hofierka & Kaňuk. (2009) present a methodology for the assessment of photovoltaic potential in urban areas using open-source solar radiation tools and a 3D city model implemented in a geographic information system. They provide this solar radiation tools by R. Sun solar radiation model and using the PVGIS Software estimation utility. Dagdougui *et al.* (2011) proposed a GIS-based decision making methodology for the choosing the most promising locations to set up renewable hydrogen production systems. In order to obtain the evaluation of the optimal placement of photovoltaic solar power plants in southeast Spain, they combined a Geographic Information System (GIS) and tools or multi-criteria decision making (MCDM) methods. Aragonés-Beltrán *et al.* (2010). published the results of their studies in a research titled "An ANP-based approach for the selection of photovoltaic solar power plant investment projects. They chose the best variable based on risk minimization for photovoltaic solar power plant projects by using Analytic Network Process of the four variables.

Djurdjevic. (2011) carried out a study aimed to review some key issues and views related to solar photovoltaic power engineering in the Republic of Serbia. Solar radiation maps are presented in this study using PVGIS Software. The results indicate that the Republic of Serbia has great potential for utilizing standalone and grid-connected solar PV energy systems.

Gastli and Charabi. (2010) predicted the solar energy potential for power generation in Oman using GIS maps. They first reviewed the methods developed for producing solar radiation maps using GIS tools and then developed Oman's solar radiation GIS maps for the months of January and July. They also applied several methods to calculate the annual electrical energy generation potential. The results showed that the country had the potential to use solar energy all the year.

Zoghi *et al.* (2015) used Fuzzy logic model and Weighted Linear Combination method for optimizing the solar site selection in Iran - arid and semi-arid region. The results showed a high accuracy for the combination of fuzzy logic, WLC and MCDM, and also positioning in locating optimal solar sites.

In this paper, the ANP, as one of the MCDM, FUZZY and OWA methods, will be used to investigate the weight of the criteria or factors and obtain the evaluation of potential and feasibility of solar power plants site selection in different regions of Yazd province, Iran.

This province, which is one of the biggest provinces of Iran, is in the very high radiation zone rate. Therefore, it has a very good potential for using solar energy.

Materials and methods

Case study

Iran is a developing country located in the Middle East with around 1, 648,195km2 and about 73 million populations. The climate features in Iran are as follows: average annual rainfall in Iran is about 288 mm; average temperatures in summer and in winter are 19–38°C and 10–25°C respectively. The average solar radiation in Iran is about 19.23MJ/m². Solar energy in the north and south has been recorded around 2.8kwh/m2 and 5.4kwh/m² respectively (Zarezadeand Mostafaeipour, 2016).

Yazd province is located in the central part of Iran. Since this province locates in the sunny-belt, solar radiation in this region is relatively good. Yazd is located at 31°90N and 54°37E, and is 1237, 2 m above the sea level and covers an area about 131,575km² (Mostafaeipour *et al.*, 2014). Solar radiation on the horizontal surface of Yazd city, as the capital of Yazd province, has been recorded as 7787 MJ/m². Fig.1 shows the location of the study area in solar energy map.

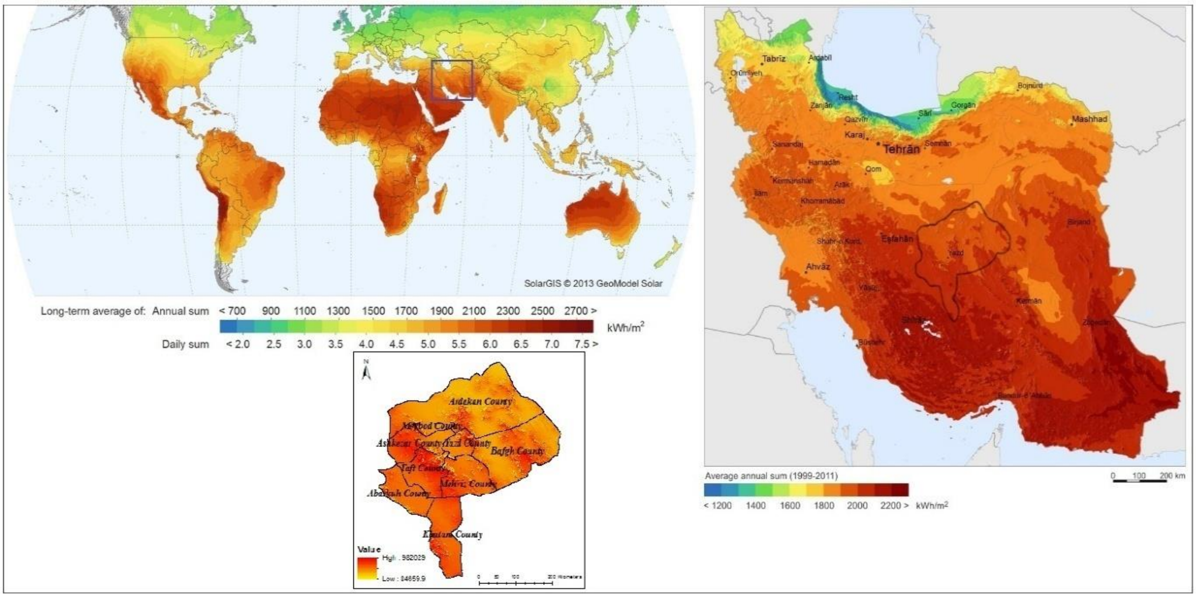

Fig. 1. Introduction of the study area in a term of solar energy zoning

Method

At first, the literature and methods of locating a solar power plant provided by other researchers were surveyed. Then, in order to determine the best location for a solar power plant in Yazd, a province in Iran, multi-criteria evaluation method of analytical network was selected based on the research objectives. This model was selected among other models due to the fact that it is feasible to quantify qualitative indicators in this model. The process of weighting the criteria was taken place by network analysis.

Analytical Network Process (ANP) takes into account the complex relationship between and among decision elements and this feature of ANP provides a precise attitude towards the issues.

In this study, weighting and prioritizing criteria were carried out by the views of planning and management of the environment and renewable energies experts. In this study, ten relevant criteria were used. These criteria were categorized into four groups including environmental (distance from fault, and land cover), climatic (Humidity, Solar radiation), geomorphologic

(Aspect, elevation, geology, slope), and spatial (distance from the city, distance from the transportation network). Also, four layers (cites, roads, protected areas and water sources) were considered limitation and were deducted from the final map. Each criterion was fuzzified by IDRISI software and was put in the numerical range 0-255. Afterwards, all standardized layers were multiplied by each weight of network analysis model by combining ANP and Fuzzy models. Eventually, overlapping layers was conducted by OWA model. OWA model has great flexibility to fulfill decision-makers' needs and prioritization by providing various results with different levels of risk and compensation. The process of solar power plant site selection is shown in Fig. 2.

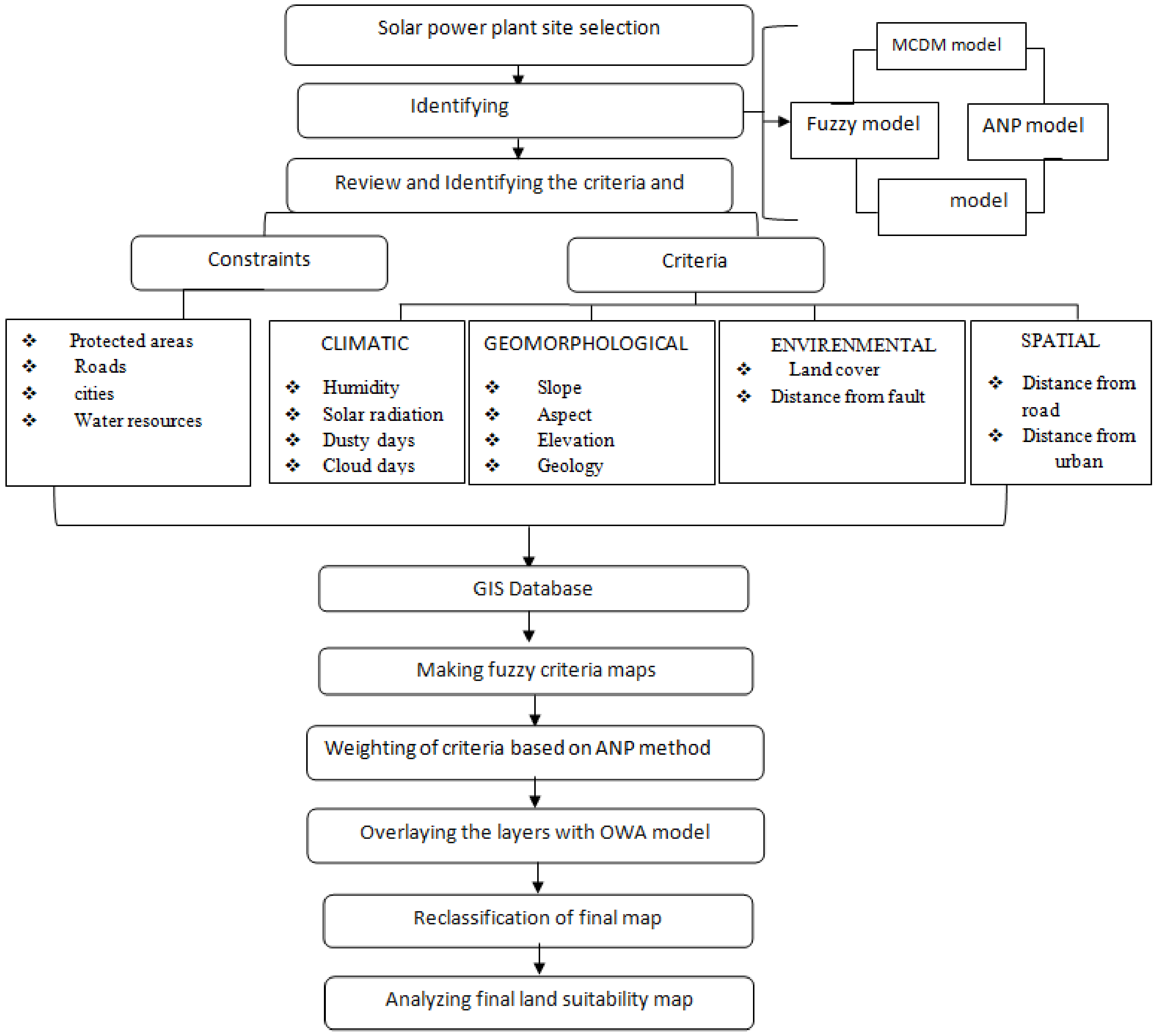

Fig. 2. Conceptual model for solar power plant site selection.

Analytic Network Process (ANP model)

Analytic Network Process is one of the multiple criteria decision making techniques and fall into the category of compensation models. It is a useful tool because it allows modelling the problem as a network of criteria and alternatives (which are called elements) and it is arranged in clusters (Saaty, 2005). Since analytical network process is a general and advanced mode of AHP, it contains AHP's positive features such as simplicity, flexibility, simultaneous usage of qualitative and quantitative criteria, and the ability to check the compatibility of judgments. In addition, it can consider the complex relationships (interdependencies and feedbacks) between and among the decision elements via applying the network structure rather than a hierarchical structure.

All elements in a network can be associated with each other in any way. In other words, feedbacks and interactions between and among the clusters are possible in a network. The mentioned feature of ANP makes it possible to consider the interdependencies between the elements thus provides precise attitude to the issues (Molinos-Senante *et al.*, 2015).

The ANP consists of the following major steps

Step 1. Structuring the problem like a network. The problem should be stated clearly. It should be classified like clusters including the alternative cluster which is made up of various elements or nodes. Then, the relationships between nodes and clusters should be identified (Fig. 3). Thus, it models a network with cycles connecting its nodes and loops that connect components to themselves. Decision makers can obtain the network structure through brainstorming or other appropriate methods. The whole complex of interrelationships should be represented through a matrix of inter factorial domination (Reig *et al.*, 2010).

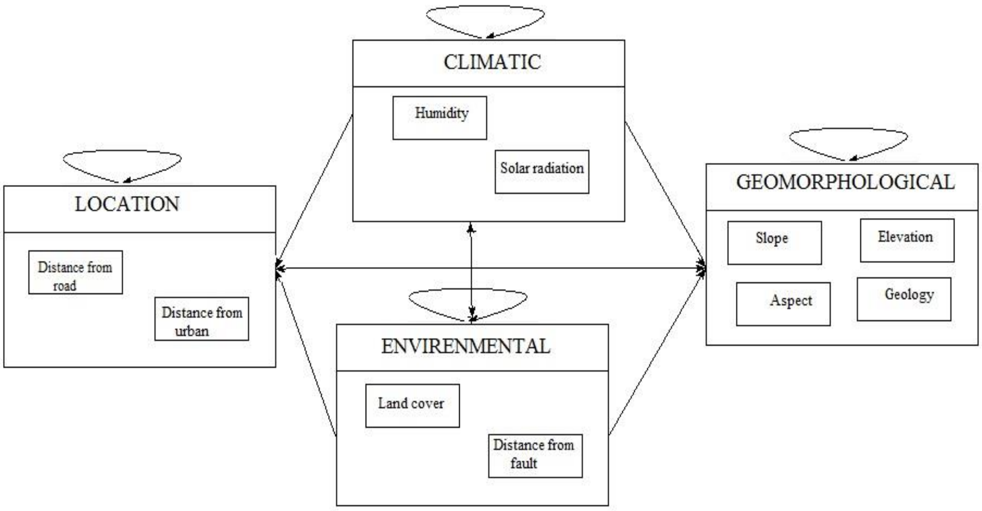

Fig. 3. Designing conceptual model by ANP.

Step 2. Criteria are compared, using Super Decisions software (Fig. 4), in the whole network in order to form aun weighted super matrix by pairwise comparisons conducting a pairwise comparison on the elements to establish the relative importance of the different elements. With respect to a certain component of the network, experts and stakeholders are individually asked to respond to a series of pairwise comparisons. The comparisons are made using Saaty's Fundamental Scale which is a 9-point scale where a score of one represents equal importance between the two elements and a score of 9 indicates the great importance of one element compared to the other one (Saaty, 2001).

Since the comparisons are carried out through personal judgment, it is vital to verify their consistency in order to guarantee that we can depend on the judgments.

Saaty introduced the consistency index (CI) and the consistency ratio (CR) as follows:

$CI = \theta max - n/n - 1$ (1)

$CR = CI/RI$ (2)

Where CI is the consistency index; θ max is the maximum eigenvalue; n is the number of elements in the judgment matrix; CR is the consistency ratio and; RI is the consistency index of a randomly generated reciprocal matrix from the 9-point scale, with forced reciprocals. The CR is a measure of how a given.

matrix compares to a purely random matrix in terms of the CI (Saaty, 1980). For matrixes larger than 3×3, a value of the CR ≤ 0.1 is considered acceptable while the decision-maker should revise their judgments for larger values of the CR. Pairwise comparisons between the applicable elements are used as the input to calculate the weighted priority vector which is related to the main eigenvector of the comparison matrix.

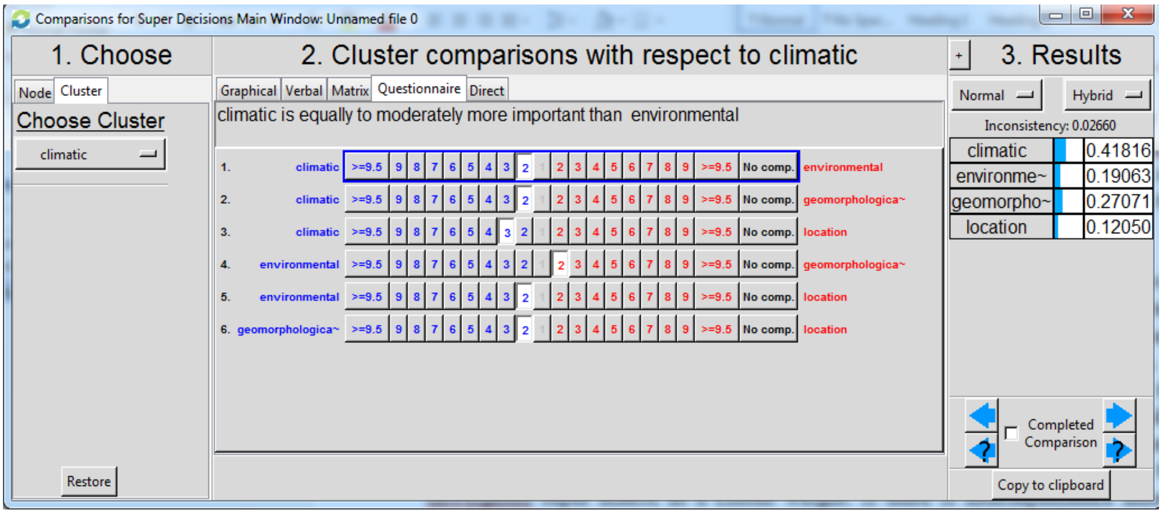

Fig. 4. Pairwise comparisons in supper decisions software.

Step 3. Forming a super matrix to obtain global priorities in a system with interdependent influences. The local priority vectors are entered in the suitable columns of a matrix - known as a super matrix. It is a partitioned matrix where each sub-matrix consists of a set of relationships between and within the levels. In the first step, unweight super matrix is obtained which contains all the eigenvectors derived from the pairwise comparison matrices of the model.

Subsequently, to obtain the weighted super matrix, the eigenvector obtained from a cluster level comparison with respect to the control criterion is applied to unweight super matrix as a cluster weight.

If there is interdependence among clusters in a network, as generally happens, the columns of the super matrix sum to More than one. Therefore, the super matrix must be changed to make it stochastic (Saaty, 2005).

Step 4. Final priorities. Eventually, the weighted super matrix is converged to obtain a long-term stable set of weights. In this process, the weighted super matrix is increased to the power of 2k, where k is an arbitrarily large number. The outcome of such operation is called the limit super matrix (Saaty, 2005). The final priorities of all the elements in the matrix can be obtained by normalizing each block of the limited super matrix.

Since the weighted super matrix usually covers the whole network, the priority weights of alternatives can be found in the column of alternatives in the normalized super matrix. The alternative with the largest overall priority would finally be selected because it is the best alternative as determined by the related calculations which are made by using matrix operations (Reig *et al.*, 2010).

Fuzzy modeling approach

For the first time, Professor Askar Lotfi Zadeh developed Fuzzy logic under uncertain conditions. This theory can formulate many incorrect and unambiguous variables, systems and concepts and it provides control and decision making under uncertainty. The ability of GIS systems in Raster map analysis makes it possible to execute different approaches such as Fuzzy, because the positive and negative threshold data (0 to 1, not binary) the degree of membership of the variables would be determined.

The fuzzy logic approach creates more flexible compositions of weighted maps and it can be easily executed with GIS modeling language (Lee *et al.*, 2012). The fuzzy logic approach creates more flexible compositions of weighted maps and it can be easily implemented with GIS modeling language (Alavipoor *et al.*, 2014). In order to show the membership degree of the set (Fig. 5) values are selected based on subjective judgment. Parameters of positioning problems largely have Fuzzy nature.

For example, factors related to proper distance from some complications are Fuzzy collections. Each pixel has a different membership degree in this collection according to its distance from complication.

Pixels membership criterion in the collection is appropriate or inappropriate and is determined between 0 and 1. These values are established using the knowledge of experts. One of the most important steps in fuzzy logic defines Fuzzy membership value for each criterion. In this model, the membership of an element in the collection would be defined in a range of 1 (full membership) to zero (non-membership) (Bonham -Carter, 1991).

For this reason, the Membership Fuzzy operating instruction is used. Actually, the definition of the Fuzzy membership (or standardizing the criteria) is one of the main steps of Multiple Criteria Decision Making (MCDM). Fuzzy membership functions are categorized from two aspects: Type and Shape.

Types include an S-shaped (Sigmoidal), J-shaped (Jshaped), and linear. Shapes include monotonically increasing, monotonically decreasing, and symmetric(Eastman *et al.*, 1993).Weights and control point of criteria are presented in Table 1, based on expert opinions and reviewing scientific articles and technical reports. Fig. 6 shows digital layers of Fuzzy membership.

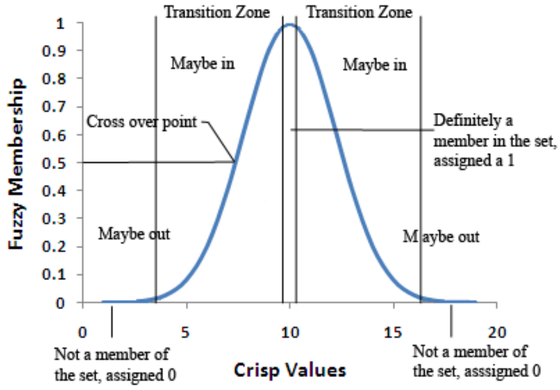

Fig. 5. Fuzzy membership function diagram (Alavipoor *et al.*, 2014), (Dombi, 1990).

Table 1. The final control points and weights for suitability assessment of the criteria land for Yazd province.

Criteria	Fuzzy function a	b	c	d	Weight	reasons of selection	Chart type	
Potential solar radiation	$8*10^5$ (wh/ m² /y)	$1.5*10^6$ (wh/ m² /y)	-	-	0.248	Increase the intake of energy from sun.(Sánchez-Lozano *et al.*,2013)	Sigmoidal /Monotonically increasing	CLIMATIC
Humidity	25%	-	-	40%	0.083	Absorbing solar energy through carbon dioxide and water vapor and reducing the energy intake. (Bunruamkaew and Murayama 2011)	Sigmoidal / Monotonically decreasing	
Total days of cloud cover(day)	25	-	-	50	0.105	Solar energy reflected by clouds and reduced amount of received energySolar energy.	Sigmoidal / Monotonically decreasing	
Dusty days(day)	20	-	-	50	0.081	Absorbed by dust and reduced amount of received energy.(Sánchez-Lozano *et al.*,2013)	Sigmoidal / Monotonically decreasing	
Elevation (m)	500	1000	2000	3500	0.042	Related with temperature, rainfall and sun potential(Bunruamkaew and Murayama 2011).	Linear/Symmetric	GEOMORPHOLOGICAL
Slope	3%	10%	-	-	0.139	Reducing costs and making it possible to construct bigger plants (Kamali *et al.*, 2010).	Sigmoidal / Monotonically decreasing	
Aspect	N,NE (0–45)	S,F (0,180)	SW, SE,W (225,135)	E, NE (90,45)	0.037	Increasing the intake of energy from the sun and reducing the costs.	Sigmoidal/Symmetric	
Geology	hard	usual	-	-	0.064	Reducing costs and making it possible to construct bigger plants (Kamali *et al.*, 2010).	Sigmoidal /Monotonically increasing	
Distance from urban (m)	2000	5000	20000	80000	0.053	Negative environmental impacts of placing a solar farm near urban areas on the urban growth and population.	Sigmoidal/Symmetric	SPATIAL

Criteria	Fuzzy function				Weight	reasons of selection	Chart type
	a	b	c	d			
Distance from roads (m)	1000	5000	15000	80000	0.051	Increasing the accessibility of the site and reducing equipment costs(Sánchez-Lozano *et al*.,2013).	Sigmoidal/Symmetric
Distance from faults (m)	2000	4000	-	-	0.041	Increasing security and reducing the cost of reconstruction and repair.	Linear/Monotonically increasing
land cover (range)	>50% (1)	25-50% (2)	<25% (3)	no range (4)	0.056	Protection of natural environment.	Linear/Monotonically increasing
Constraint Parameter		Main road 250 m	Protected area 1000m	Water resource 250m	Urban area 500 m		

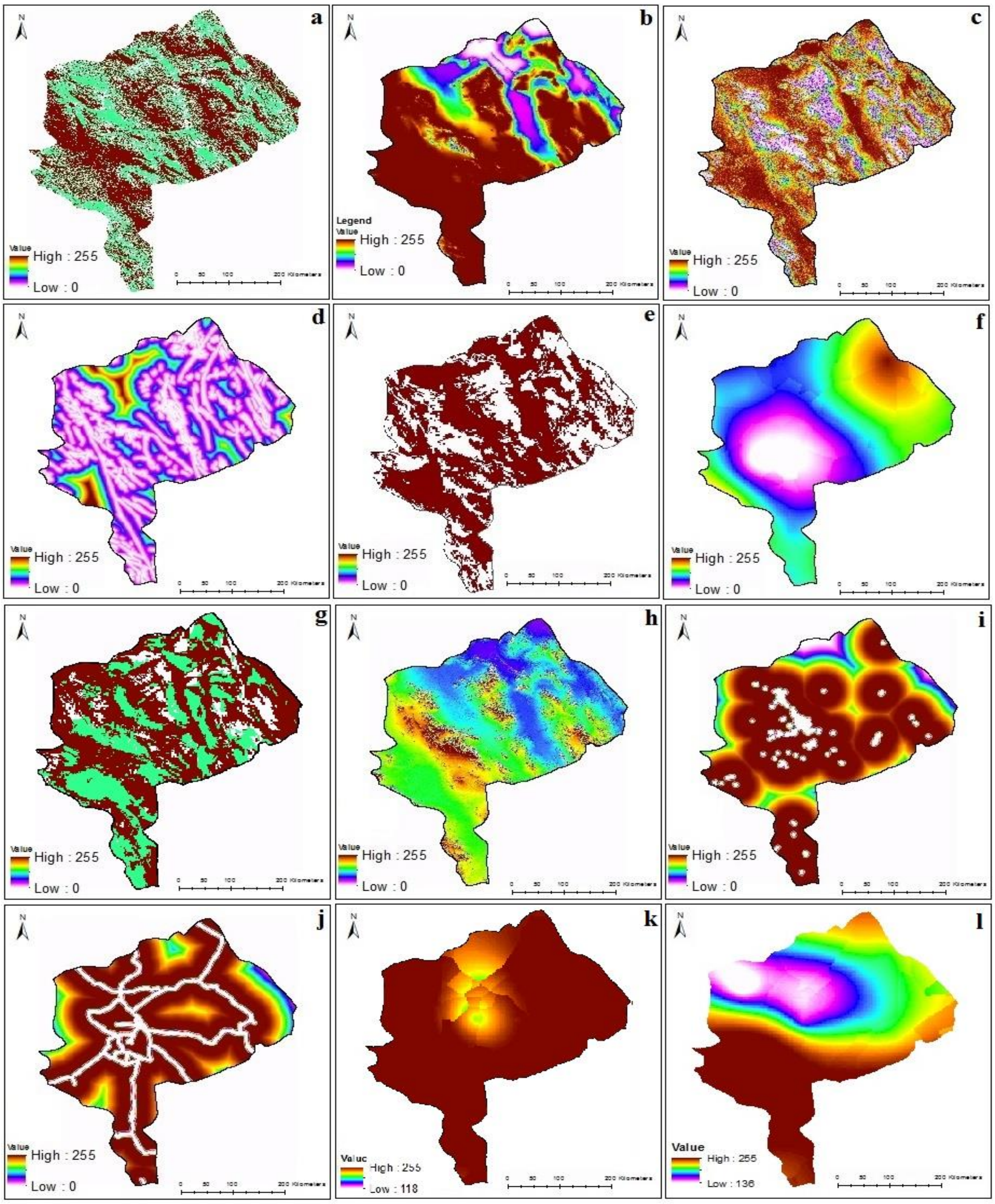

Fig. 6.a) Aspect b) Elevation c) Slope s d)distance from fault e) Geology f) Humidity g) Land cover h) Potential solar radiation i)Distance from Cities j) Distance from transport network k) Dusty days l)Total days of cloud cover.

Extracting the restrictive

A particular inappropriate occasion for a given user would be determined based on a series of criteria. Limitations prevent rules imposed by man or nature; they make the options inapplicable. We examined the region, resources, and standards.

Then we regarded the following layers as restricted areas and removed them from the final map: cities, transport network, water resources and protected areas. Fig. 7 shows the restriction maps.

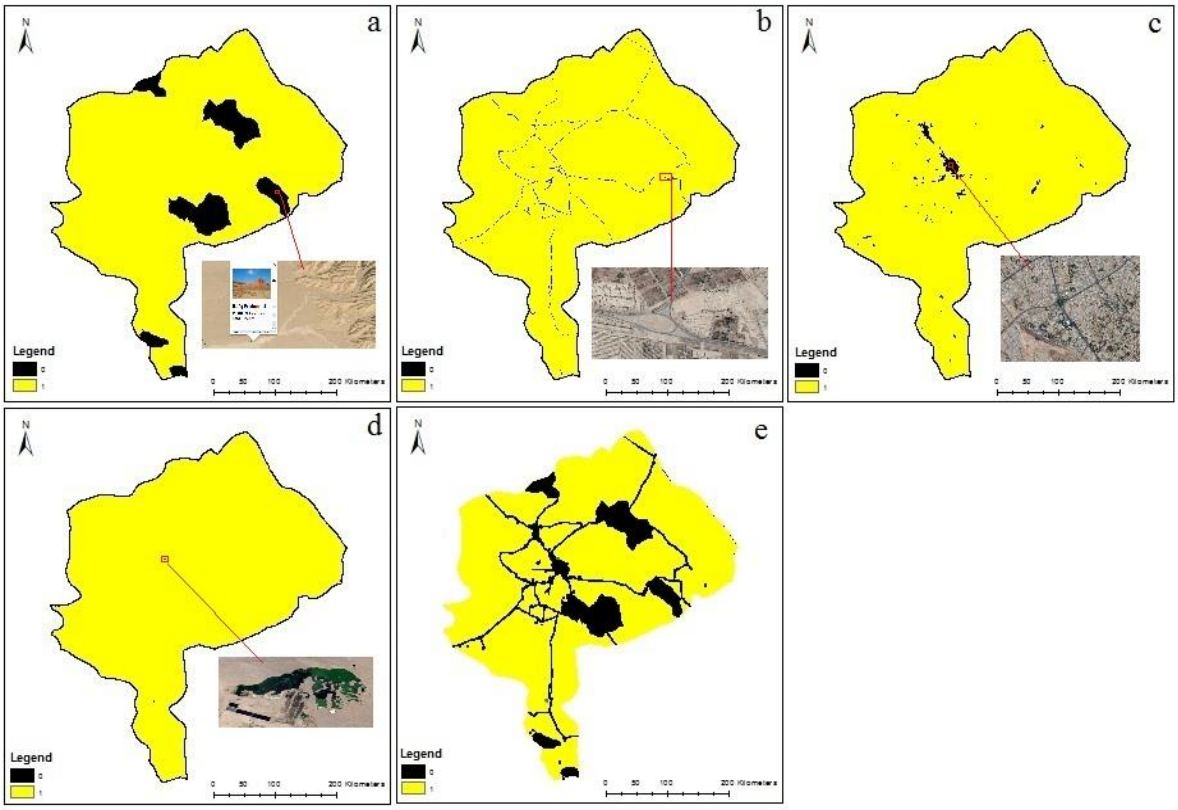

Fig.7. a) Protected area b) Transport network c) Urban area d) water resource e) Final exclusionary map for solar plants site selection in Yazd Provinc.

Ordered weighted averaging (OWA model)

Ordered weighted averaging (OWA) technique is one of the combination methods in MCDM methods and it has been developed based on the theory of Fuzzy sets (Yager, 1988). Using this method is not limited to fuzzy sets (Malczewski *et al.*, 2003). A new concept for the development of Boolean (classic) decision rules and weighted linear combination has been provided as well. This new concept includes ordinal weights that differ from standard weights. Standard weights have been assigned to the used criteria while the ordinal weights are assigned to the values of criteria pixel by pixel. A wide range of outcomes (maps) can be obtained in spatial decision-making, determining and applying an appropriate set of ordinal weights.

In other words, since this method is highly flexible in meeting the needs and priorities of decision makers, it can provide different results with different levels of risk and compensation (balance) (Fig. 8). The OWA technique is comprised of three kinds of composite functions including the Union (OR), the Intersection (AND), and the Fuzzy average. The operator plays a balancing role in the category of Fuzzy operators and creates a good condition regarding to the related degree of AND and OR. This method allows the decision-maker to control decision-making on both the Risk and Balance axes. The OWA operator includes the Fuzzy Minimum and Maximum. The Maximum operator matches the logical OR and the Minimum operator matches the logical AND.

Choosing the most fitted location in decision making implies a low level of risk. In this case, we should use the Boolean method or the similar method AND. If the purpose of decision-making is the minimum requirements, we should use the OR operator, which indicates a high risk in decision-making. In OWA method, we can simultaneously change the risk and balance levels of the measures so that the Risk level can vary from the minimum to maximum and the Balance level vary from no balance mode to the Maximum balance mode and then to the no balance mode (Malczewki *et al.*, 1999).

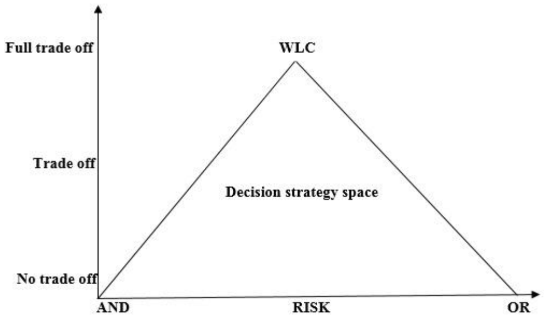

Fig. 8. Decision Strategy Space in the Ordered Weighted Average [42].

The final classified map obtained from fuzzy models, ANP and OWA in combination with the county maps of the province is shown in Fig. 9 and Table 2 shown suitability amount of classes.

OWA operator is defined by equation (1):

$$OWA_i=\sum_{j=1}^{n}(u_j v_j/\sum_{j=1}^{n} w_j\, v_j)z_{ij} \qquad (1)$$

Where z_i1≤ … ≤ zin derivate from putting the values of one criterion in order. Vi is the ordinal weight and Wj is the standard ordered weight. OWA operator contains two main characteristics that represent the behavior and position of the operator. 1-orness degree 2- permutation balances the relationship. Orness degree represents the OWA operator position in relations between and (minimum) and Or (maximum) and represents the risk-taking and risk aversion of the decision maker. The Orness degree is defined by equation (2):

$$\text{Orness}= \frac{n}{n-1}\sum_{i=1}^{n}(n-i).v_i (2)$$

The second feature of OWA operator shows the degree which one index can be exchanged or affected by the other indices, this is expressed by equation (3):

$$\text{Trade off}= 1- \sqrt{\frac{n}{n-1}\sum_{i=1}^{n}(v_i-\frac{1}{n})^2}(3)$$

Where V_i is the criteria ordinal weight and n is the number of the criteria (Carlsson *et al.*, 1997). The final categorized map obtained from fuzzy models, ANP and OWA in combination with the county maps of the province is shown in Fig. 9 shows the final solar power plant site selection map and Table II shows suitability amount of classes.

Result and discussion

In this study, important criteria were detected in order to select a suitable location to establish a solar power plant in the study area and were weighted by the process of weighting analytical network. The limitations for locating a power plant were recognized and were omitted from the final map. Special inappropriate occasion for a given user would be determined based on a series of criteria. Restrictions are barriers imposed by man or nature and make the options inapplicable. We studied and analyzed the region, resources, and standards. This map include: cities, transport network, water resources and protected areas. The proposed limitations were the ones which ought to be protected in location. Having fuzzified and having combined layers and their weights, the layers were put over one another by OWA.

Yazd province is located in hot and arid climatic situation and provides suitable conditions for investing in solar energy sector. According to being located in optimal field in suitable distance from population centers, development of solar powerhouse in Yazd can be used as a tool to improve quality level of residents' life and use of solar energy including exploitation of solar electrification system.

Obtained results in this study indicates high solar potential and necessity of investment for this industry in this province. According to this study, most of prone fields in this province are located in arid regions without vegetation, in fields with high solar potential, suitable climate and elevations and slope.

Comparison of criteria in analysis process of network shows that solar potential, humidity, cloud days, dusty days, slope and geology have the highest weight coefficient that indicates high significance and value of climatic and geomorphological factors for localizing pone fields to construct a powerhouse.

Slopes more than % 10 and elevations higher than 2500 have the lowest potential to develop the solar power plant. Southern and Eastern parts of this province and Northern parts have the highest and lowest solar potential, respectively. Generally, the whole of this province has the high average for receiving solar energy.

In general, the results of this study conform to overall studies and Iran Energy Atlas and confirm the high regional potential to receive solar energy. Using fuzzy hybrid model of ANP and OWA can produce results with high accuracy. So by applying an accurate and principal plan and according to potential of the region, projects for developing the solar. Powerhouses can be suggested in this province and effective step can be taken to achieve this goal. In the study area, a lot of regions can be determined to be high suitability. Yazd province is the best geographical location to exploit solar energy and among the 10 counties of Yazd province, Khatamcounty and Sadugh county gained the highest percentage in the class of suitable and are selected as the best county for the construction of solar power plant (Fig.10).

Clearer Results showed cities of Marvast and Harat in Khatamcounty, Abarkooh in Abarkooh county, Ashkezar in Sadugh county and Bafg in Bafg county are among the suitable regions for development of the Solar power plant.

Generally Due to the climatic situation and geographical location of Yazd province such as low humidity, high quantity solar radiation and excellent condition for other criteria Yazd province will be attractive for establishment in solar energy projects.

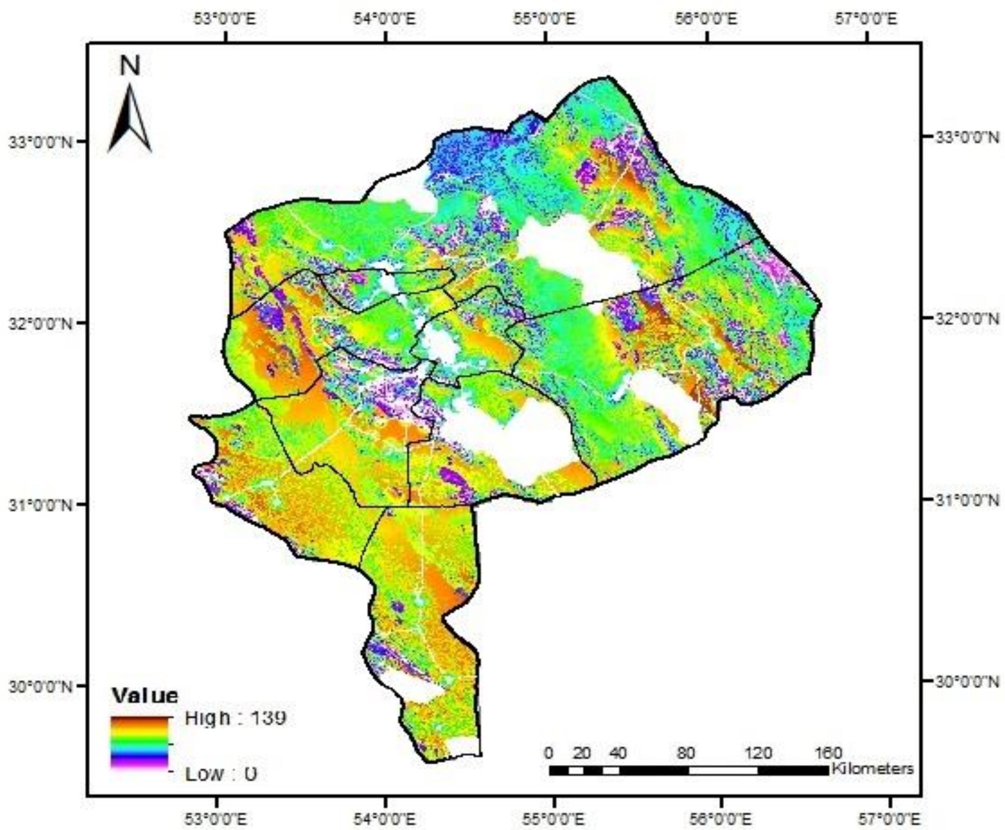

Fig. 9. The final solar power plant site selection map.

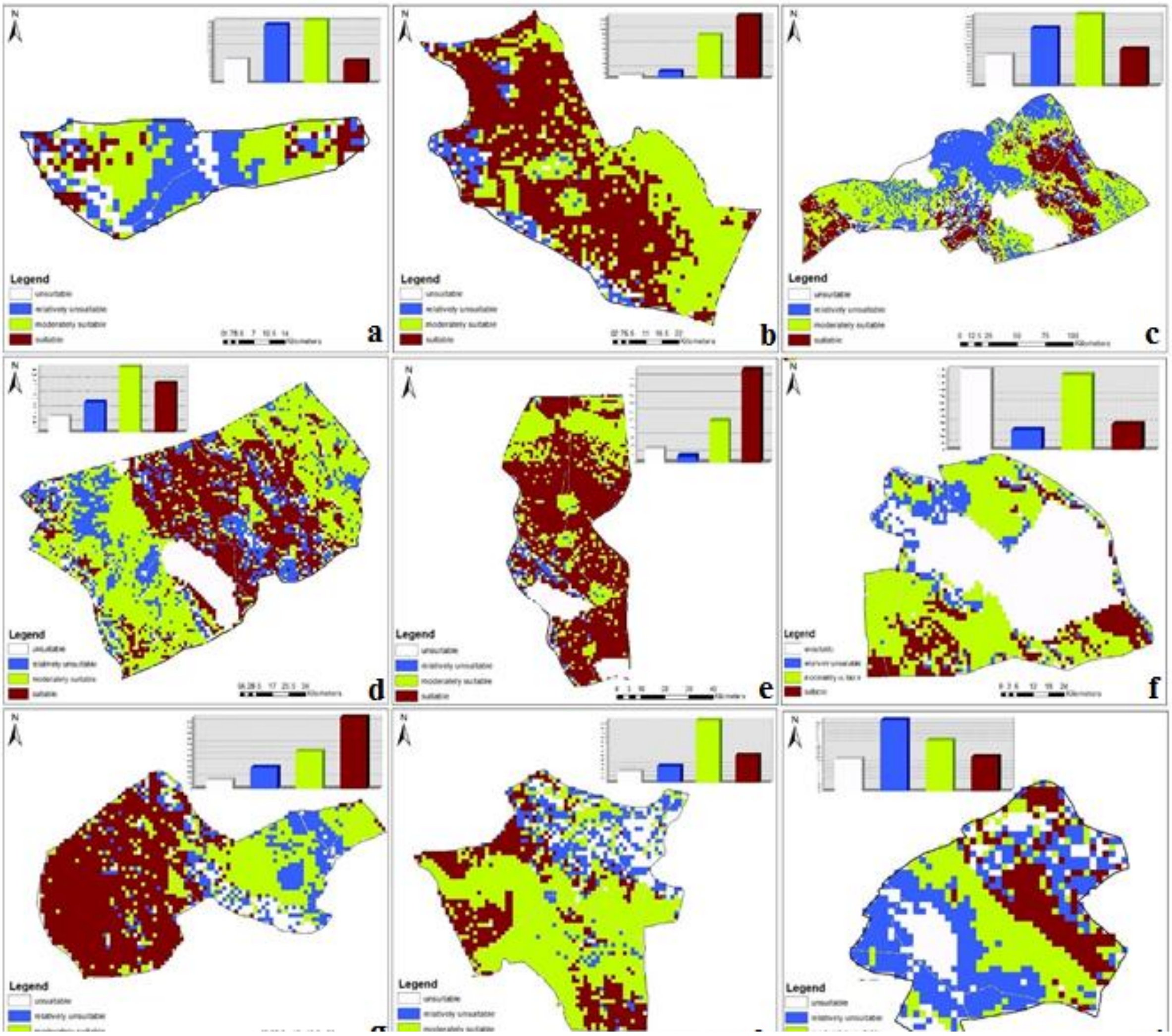

Fig. 10. a. Meybod County b. Abarkuh County c. Ardakan Countyd. Bafgh County e. Khatam County f. Mehriz County g. Sadugh County h. Taft County i. Yazd County.

Conclusions

With regard to the economic development and population growth, the domestic fossil fuels demand is steeply rising. It is necessary to consider the use of renewable energies such as solar energy in order to meet part of the electrical and thermal energy requires, meeting the goals of sustainable development, diversification of the domestic energy mix, and reducing the consumption of fossil fuels. After determining effective factors and their role in locating solar power plant in this study, we provided the relevant layers of information and required analyses.

Finally, integrating different information layers and applying the restrictions, we found the suitable area to construct the solar power plant.

Decision-making about the appropriate location for power plant construction requires considering several factors simultaneously. The Geographic Information System provides a consistent possibility to integrate information layers relating to the mentioned layers. Selected locations are entirely affected by the parameters included in the analysis and the related weights. The ANP model is a suitable model for weighting and valuating layers in the GIS environment. It provides suitable sites for power plant construction. In this research, we made the maps Fuzzy in IDRISI environment. Using Analytical Network Process (ANP) we conducted weighting by Super decision software. Finally, we overlaid the maps using ordered weighted averaging (OWA) method.

We resulted the related zones by using the GIS environment. We found the final map, which indicates the areas with a good potential for exploitation of solar energy. Comparing to the recent research in the field of locating power plants, the Fuzzy and Analytical Network Analysis (ANP) process and OWA in GIS environment are the top priority and able to take the qualitative and quantitative objectives into account (with the proper utilization of the experts' comments) and result the optimal mix of production. The results showed among the 10 counties of Yazd province, Khatam county gained the highest percentage in the class of suitable and relatively suitable (77%) and is selected as the best county for the construction of solar power plant. According to the final map six sites were introduced for candidate sites in order to establishing solar power plant site selection.

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