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Technical Note

GIS-Based Multi Criteria Evaluation for Thermal Power Plant Site Selection in Kahnuj County, SE Iran

Siefi, S.[1], Karimi, H.[1*], Soffianian, A.R.[2] and Pourmanafi, S.[3]

[1] M.Sc., Department of Natural Resources, Isfahan University of Technology, Isfahan, Iran.
[2] Associate Professor, Department of Natural Resources, Isfahan University of Technology, Isfahan, Iran.
[3] Assistant Professor, Department of Natural Resources, Isfahan University of Technology, Isfahan, Iran.

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ABSTRACT: Choosing a location for a power plant site is a complex task that involves evaluation of multiple factors, which should satisfy a number of economic and environmental requirements. The main aim of this study is to determine the best possible candidates for thermal power plant sites using Multi-criteria Evaluation and Geographic Information System (GIS) in Kahnuj County in the southeast of Iran. First, the affecting factors to find the best sites for power plant establishment were identified including socio-economic and environmental factors. Each criterion was mapped in the GIS environment. Then, the layers were standardized and the relative weights of these layers were determined. Finally, weighted information layers were consolidated by Weighed Linear Combination approaches in GIS environment and the suitable locations were selected and ranked accordingly. The final index maps were grouped in five categories ranging from “no suitability” to “high stability” with an equal interval classification method. As a result the most suitable sites were patches located in the north-west parts of the study area.

Keywords: GIS, Multi Criteria Evaluation, Thermal Power Plant, WLC.

INTRODUCTION

Nowadays, a vast demand has been requested in the amount of different energy sources for different tasks. It is projected that the world will have seen an increase in global spending energy over 36% by 2030, with 70% of this growth in demand expected to come from developing countries (BP Energy Outlook, 2012). The most important reason for the significant raise in the energy demands stems from the wish of nations to progress their living standards and their population growth through industrialization. This rapid growth of population and industrialization contributed to the sitting of new energy sources e.g. thermal, geothermal, nuclear, hydro power plant (Beheshtifar et al., 2010, Comber et al., 2015; Noorollahi et al., 2016; Sanchez et al., 2013).

The selection of suitable sites is a vital point in industrial sitting process. In the past,

* Corresponding author E-mail: hazhir.karimi25@gmail.com

site selection was almost based economic and technical criteria (IEEO, 2002; Sadeghi et al., 2012; Jiuping, 2015). Today, selecting new sites should satisfy social and environmental requirements, which are imposed by governmental regulations and guidelines. The selected available locations are the results of process in which consider requirements before construction which minimize all involved health and environmental costs, and maximize economic benefits of developers and stakeholders (Mevlut, 2013; Sanchez et al., 2013; IEEO, 2002; Saeidi, 2006; Yeo and Yee, 2014). To accomplish this task number of information and layers with a different theme needed to be prepared. Additionally, the processing of numerous data by traditional means needs extensive time and cost and may not obtain the favorite results (Motlagh and Sayadi, 2015; Atici et al., 2015; Thomas et al., 2013).

Geographical Information Systems are an ideal tool for spatial analysis due to its ability to manage large volumes of spatial data onto a variety of sources (Malczewski, 1999; Makdoum et al., 2011). It designed for spatial analysis which are be able to capture, collection, inquiry, analyze, display and output information layers (Karimi et al., 2016; Beheshtifar et al., 2010). Recent development in the field of decision making leads to drastic use of GIS in site selection studies (Mevlut, 2013; Jiuping et al., 2015; Höhn et al., 2014; Jangid et al., 2016).

In recent years, GIS has considerably been progressed to evaluate/select the optimum sites for power plant and energy sources (Ahmadabadi and Samadi, 2010; Beheshtifar, 2010; Jafari et al., 2015; Sadeghi et al., 2012; Beheshtifar, 2010). For instance, Sadeghi et al. (2012) evaluated the optimal placement of thermal power plants using GIS based multi-criteria decision making (MCDM) Chabahar area, Iran. Jiuping et al. (2015) proposed a GIS modeling methodology for Coal-fired Power Plant (CPP) and identified potential sites based on factors such as roads, available electric networks, fuel supplies and land use. Beheshtifar et al. (2010) identified new locations for sitting power plant using GIS and fuzzy logic in Fars Province, Iran. Yeo and Yee (2014) proffered an approach for urban energy supply plants in GIS environment.

In Kerman Province in Iran, economic growth and development activities have been increased the annual demand for energy supplying. Thus, construction of new power generation has changed to a certain necessity. The Iranian Ministry of Energy (MOE) plans to develop the electricity generation capacity and distribution network for this region. In this plan the construction of a thermal power plant is an expansion program for more electricity generation. The main aim of the current research is to identify the suitability of the area to locate thermal power plant sites by the assistance of GIS and Multi Criteria Evaluation (MCE) techniques in Kerman Province in the southeast of Iran. For these purpose, the data for environmental and socio- economic criteria have been gathered, and supporting by Weighted Linear Combination (WLC) the criteria maps were calculated and the optimal available locations were identified.

MATERIALS AND METHODS

Study Area

The study area is Kahnuj County (Kerman Province) which located at the east of Iran, between 30º 42′-34º 30′ N and 49º 36′- 55º 32′ E Figure 1. At the 2012 national census, the population of the studied area covers 84950 inhabitants. This region is relatively flat and covers an area of approximately 656 km^2 with 1.3 % of total province. It is located at an elevation of about 1400 meters above sea level and it has a dry and semi-humid climate with significant difference between day and night temperatures. Daily temperature varies from 19.2 °C to 33.6 °C and the average annual temperature has been recorded as 26.4 °C. The annual rainfall is 184.6 mm and much of the precipitation falls in late autumn and early spring (Nov. - Feb.) where the month of January having the highest precipitation.

Currently the main source of electricity energy in this region is supplied from Kohnuj combined cycle-power plant which is located at 15 km east of Kahnuj. It was built in two stages and has power generation capacity of 484 MW consisting two 162 MW natural gas and a 162 MW thermal units. The required water is supplied from a well nearby the plant and the needed fuel (gas and gas oil) is provided by pipelines.

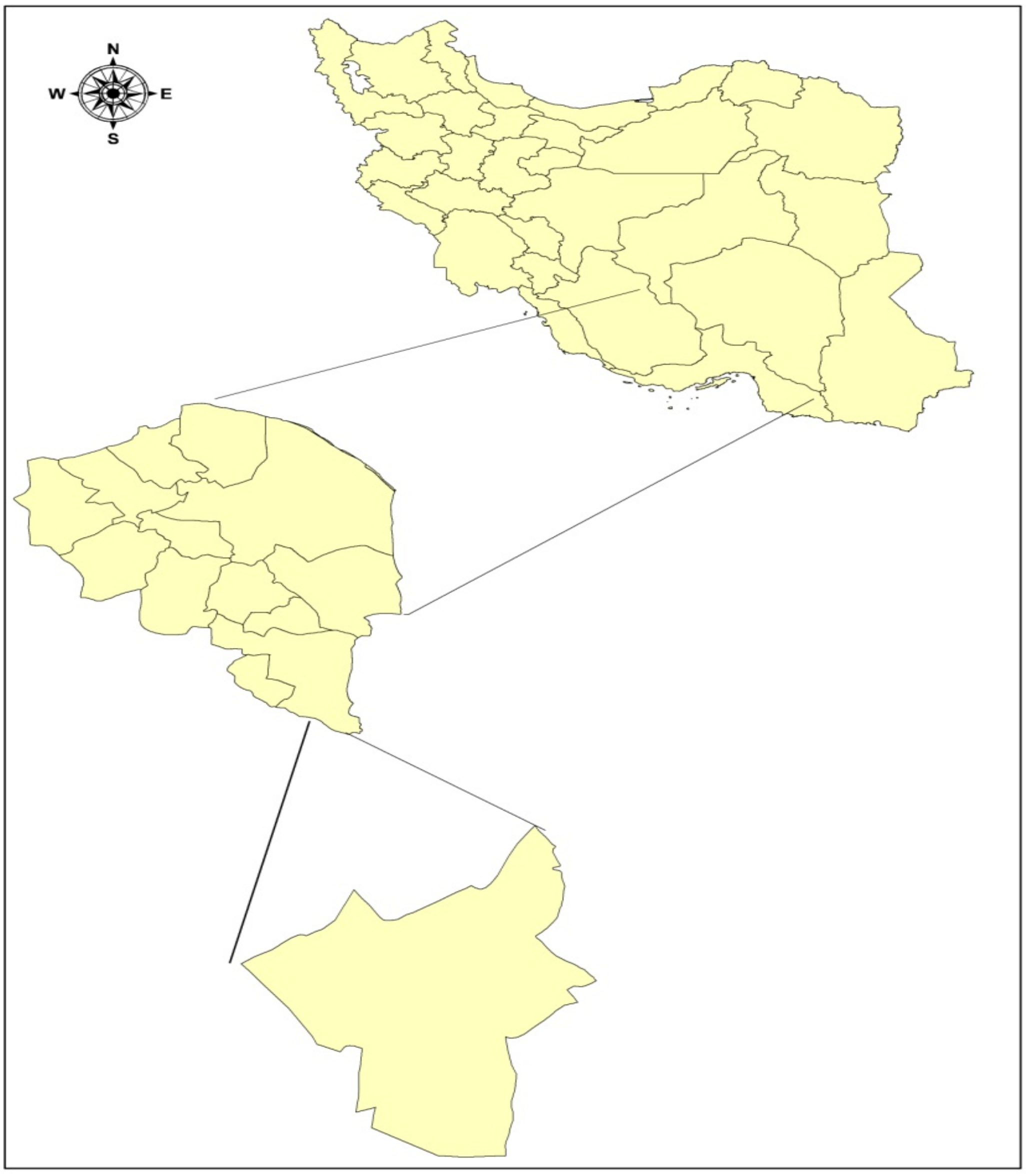

Fig. 1. Location of the study area, Kahnuj County, Iran

Methodology

Data Preparation and Standardization

The first step of each site selection study is defining important criteria for specific selection. In this research, eight criteria within two main groups were considered for determining the best location for thermal power plant sitting Figure 2. The criteria were selected based on review of the available literature, Iranian legislation and regulations and advice from experts. The principle sub criteria that used for spatial analysis were slope, elevation, distance from surface water, distance from faults, distance from ground water, distance from residential area and land use.

The main sources for preparing criteria layers were remote sensing images (Aster, 2010; Landsat, 2012), 1:250000 scale topographic map, 1:250000 scale geological map, GPS survey and available data from departments. These data were used to extract criteria layers and information using ArcGIS 10.1 software. Since criteria are measured by different scale, transform the layers to comparable units (standardized to a common scale) is necessary. Sigmoidal membership, J-shape membership with linear fuzzy membership functions using the minimum and maximum values as scaling points were applied for standardization in IDRISI environment. It is provided to normalize criterion map to 0-255 scale, in which 0 illustrates the least suitable areas and 255 illustrate the most suitable area. Table 1 shows the control points (a, b) which govern the shape of the fuzzy membership function and the type of membership functions that used to standardize the factors in IDRISI software. Figure 3 (a-d) and Figure 4 (a-d) illustrate the standardized maps of criteria in the assessment of thermal power plant suitability of the study area.

Weighting Criteria

As different criteria have different importance on the site selection process, the relative importance of criteria must be determined before aggregation. Relative weights for criteria and were obtained using the Analytic Hierarchy Processes (AHP) (Saaty, 2008). The first step in the analytic hierarchy processes is to model the problem as a hierarchy. In this study, hierarchy was separated into three stages of 1, 2 and 3, indicating objective, criteria and sub-criteria (factor), respectively (Figure 2).

Table 1. Fuzzy set memberships and functions with control points used for thermal locating thermal power plan

Criteria	Control Point a	Control Point b	Fuzzy Function/Membership
Elevation (m)	1000	1800	Linear-increasing
Slope (%)		10	Sigmoid-decreasing
Distance from the surface water (m)	1000	1600	Linear-increasing
Distance from the ground water (m)	53	121	Linear-increases
Distance from residential areas (m)	5000	20415	Linear-increasing
Distance from the roads (m)	1500	5000	Linear-symmetric
Distance from the fault (m)	2000	5000	Linear-increasing
Land use (no Units)			0
Urban			0
Agricultural			0
Forest			50
Source of water surface			150
Mod range			200
Poor range Bare land			250

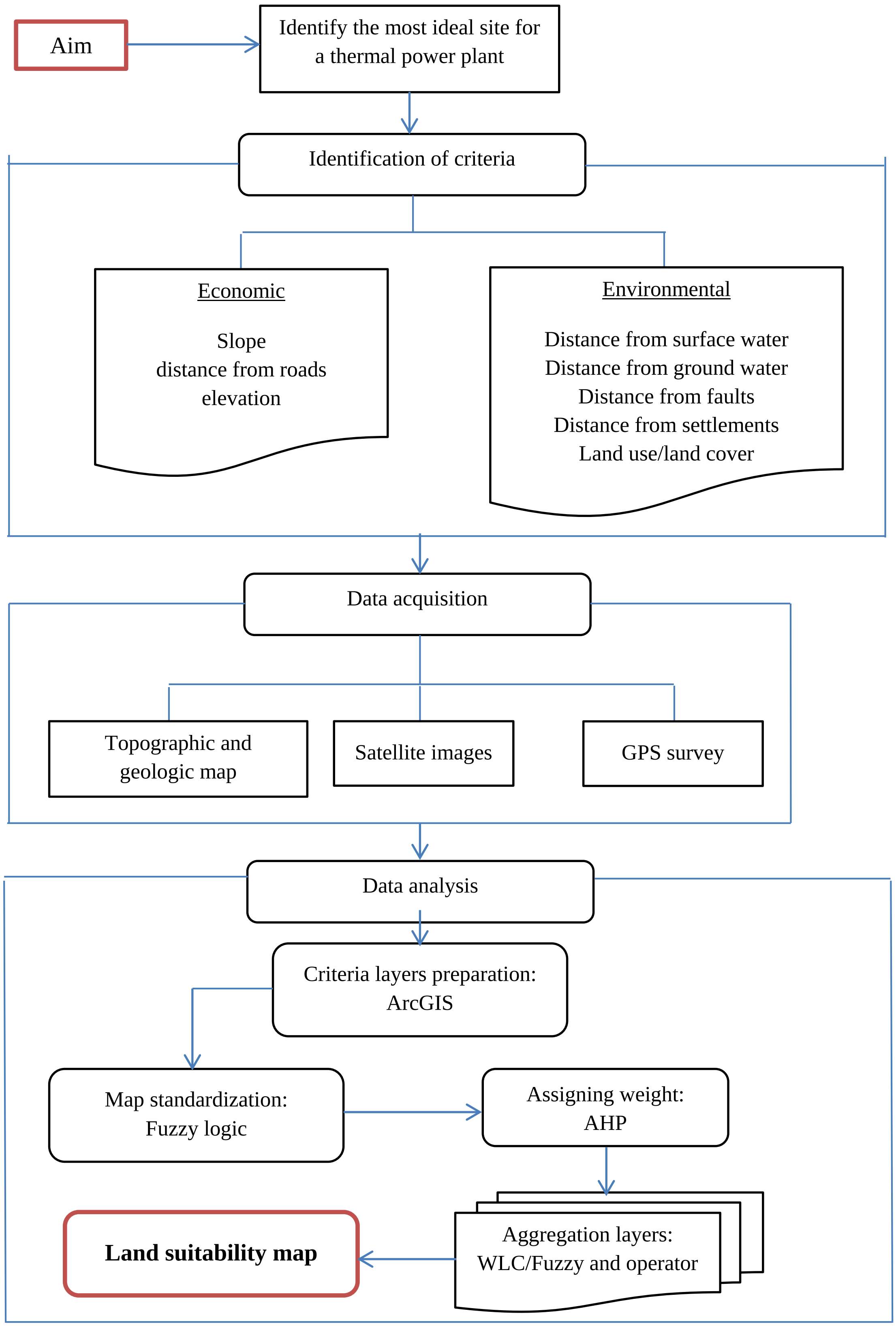

Fig. 2. Flowchart of the methodology

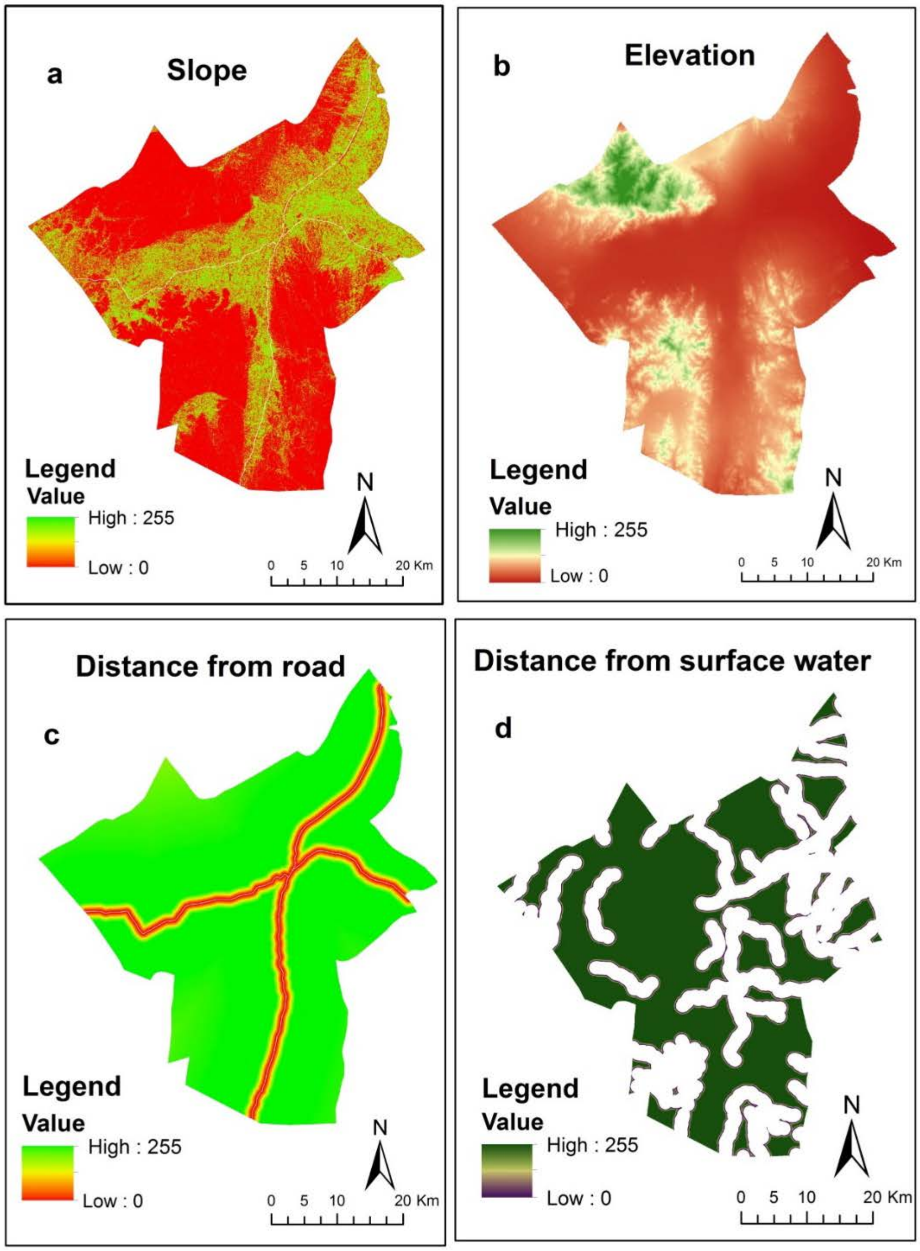

Fig. 3. a) Fuzzy standardized slope map; b) Fuzzy standardized elevation map; c) Fuzzy standardized distance from roads map; d) Fuzzy standardized distance from surface water map

When the hierarchy was created, decision makers systematically evaluated its various elements by comparing them to each other two at a time, with respect to their importance on the goal. In this stage each factor was rated for its importance relative to every other factor using a 9-point reciprocal scale (i.e. if 7 represent substantially more important, 1/7 would indicate substantially less important). Table 2 illustrates this rating scale along with a completed comparison matrix and the best fit weights produced.

A revision of the preference matrix should be made if and only if $CR<0.1$. The CR is calculated as the following equation:

$$CR = \frac{CI}{RI} \quad (1)$$

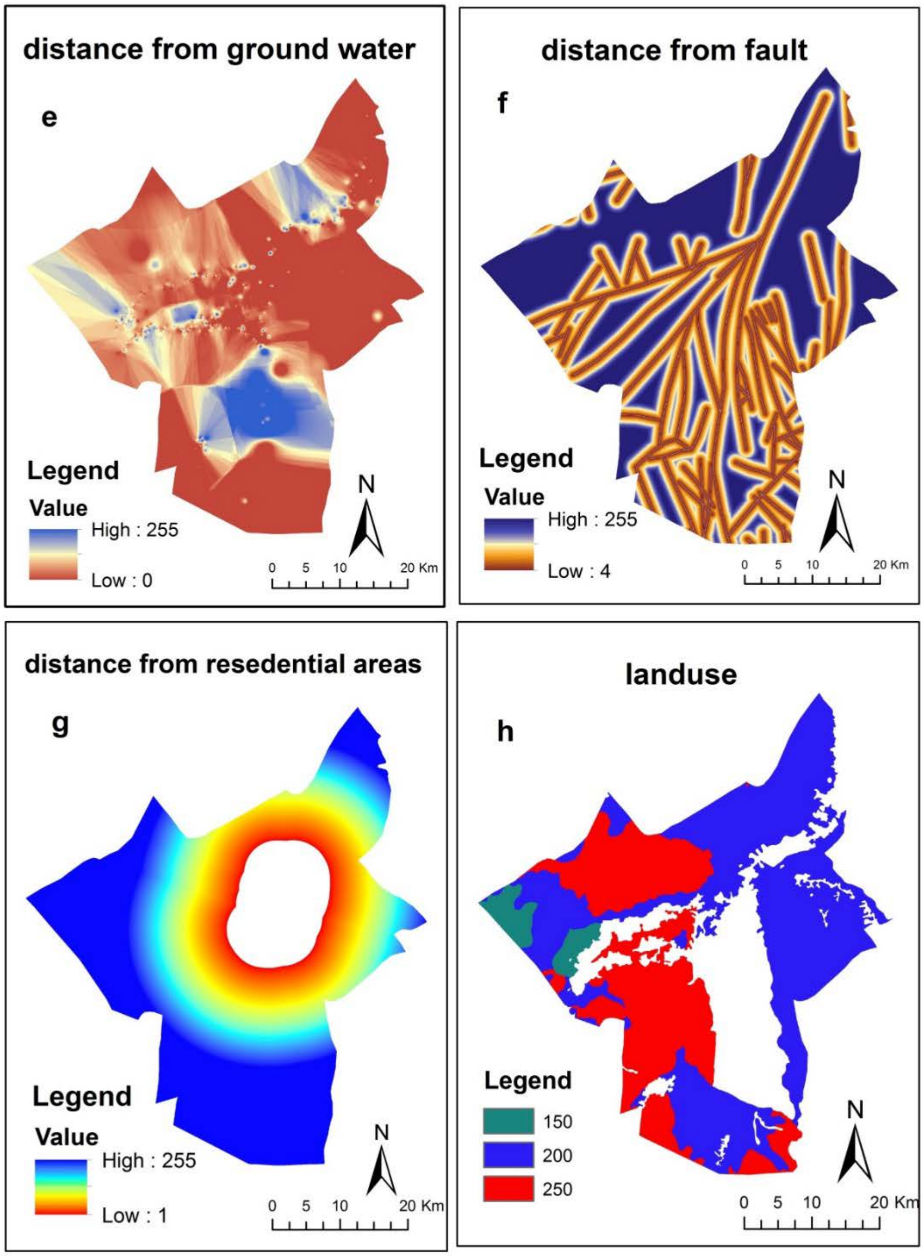

Fig. 4. e) Fuzzy standardized distance from ground water, f) Fuzzy standardized distance from faults, g) Fuzzy standardized distance from residential areas, h) Fuzzy standardized land use

where *CR* is consistency ratio, *CI* is consistency index; *RI* is mean/average consistency index (Eq. (2)).

$$CI = \frac{\lambda max - n}{n - 1} \quad (2)$$

where max is the greatest Eigen value of preference matrix and n is the order of matrix.

The consistency ratio (CR) in this research was 0.04, which indicates a good consistency of the judgments used for the comparison.

Weight of criteria and sub criteria were shown in Table 3. According to the table, the highest weight assigned to the distance from residential areas, distance from faults and distance from ground waters depth, while distance from road and distance from water sources were considered as the least important criterion for thermal power plant establishment.

Aggregation Criteria

The computed weights and the various factors maps, economic and environmental layers, were aggregated using WLC approach, to yield the final suitability map for thermal power plant sites. The WLC technique is the sum of the product of each standardized factor map and the factor weights (Eq. (3)) (Eastman, 2006). As formula, suitability map are obtained factors by applying a weight to each followed by a summation of the results.

$$S = \sum_{1}^{n} Wi.Ci \qquad (3)$$

where *S* is suitability, C_i is criterion score of i, W_i is weight of criterion i.

RESULTS AND DISCUSSION

To determine the most suitable area for thermal power plant sites, GIS based WLC was used to assess and evaluate scores based on selected criteria. Each criteria map was prepared using ArcGIS and the final suitability map was driven using WLC approaches in IDRISI. The final index maps were grouped into five categories i.e. no suitability, very low, low, moderate and high suitability for locating thermal power plant. Field observation was conducted to investigate regulate sites. Land suitability that was obtained by WLC approach is shown in Figure 5. The results indicate that 6.63% (140 km^2) of the study area has high suitability for thermal power plant establishment where are patches of land found in the northwest of the study. The results of the WLC method are compatible with our field observations and show that there is highly suitability degree for landfill sites in the selected areas.

Table 2. The comparison scale in AHP (Saaty, 1980)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

Table 3. Final weight of selected criteria

Weight	Criteria
0.099	Slope
0.043	Elevation
0.044	Distance from road
0.043	Distance from surface water
0.246	Distance from ground water
0.248	Distance from faults
0.256	Distance from residential areas
0.198	Land cover/Land use

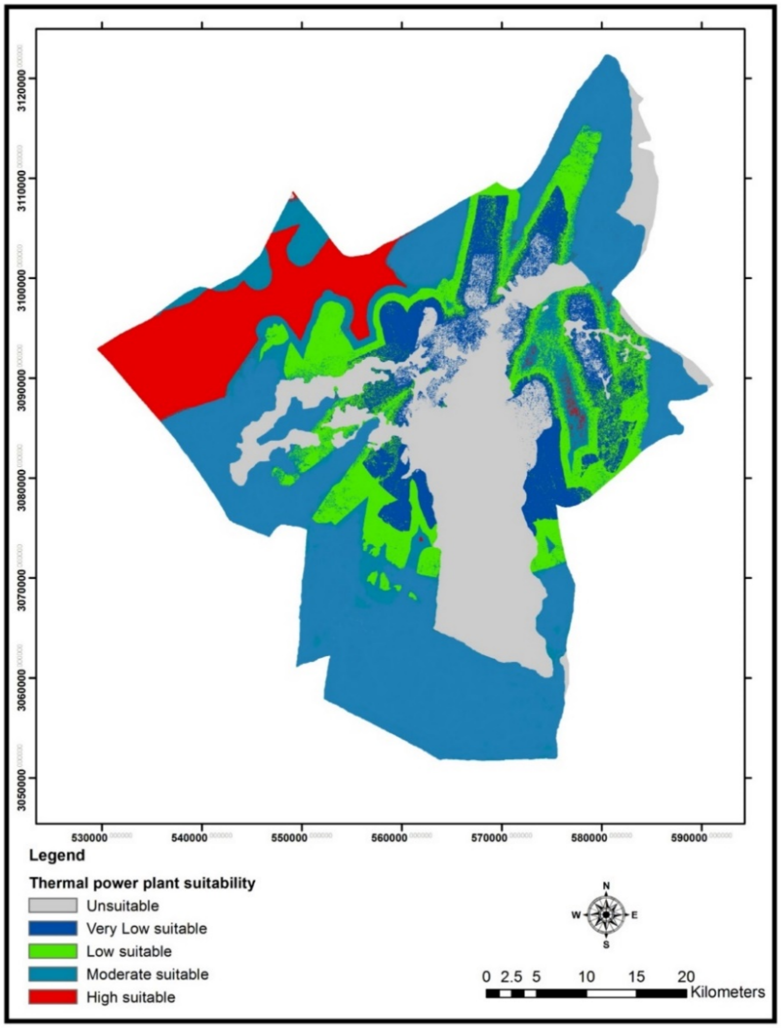

Fig. 5. Power plant site suitability map

WLC is characterized by average risk and lies in the middle of this continuum. The amount any single factor can compensate for another is, however, determined by its factor weight. The results obtained by WLC will be implicated in order to establish a thermal power plant suggests more areas with acceptable appropriateness. Among these identified regions obtained by WLC method, policy makers can choose the best site in the terms of price, availability and accessibilities parameters.

The results of this paper on the ability of WLC in site selection process are consistent with other researcher findings (Khorasani et al., 2004; Ghayoumian et al., 2007; Raiesi and Soffianian, 2013; Motlagh and Sayadi, 2015; Yao Chen et al., 2013). For example, Khorasani et al. (2004) compared Boolean and WLC methods and found that, fuzzy logic produce more appropriate results through making up between criteria and more flexibility. According to Raiesi and Soffianian (2013) by comparing Boolean and WLC found that, using WLC approach in site selection is more suitable for valuation of the location of industrial estates establishment in the study area since, this method suggests more areas with acceptable appropriateness class to decision makers and planners in order to establish industries.

CONCLUSIONS

This research presents an application of GIS-based multi criteria evaluation approach for identification the best sites for thermal power generation in Kohnuj county in Iran. The combination of multi criteria evaluation and GIS in decision support systems is of clear and unarguable benefit. Unlike mathematical models, GIS have the capability of storing, analyzing and displaying spatially reference data with integrated spatial data. Moreover, GIS reduce both the errors and the time needed for the analysis of criteria, thus decreasing the overall cost of the selection process. The integration of GIS and multi criteria analysis show that this combination can successfully select feasible sites, assess their economic value and give a preliminary impact assessment on environment consideration.

In this research, the selection of factors for thermal power plant sites was determined accordance to Iranian legislations and laws as well as available literature. Also, the availability of data was considered when defining factors. Thus, with regards to emphasize on environmental criteria, we suppose that some key socio-economic factors have been omitted which could potentially yield different decision alternatives. If more socio-economic criteria (e.g. land prices and accesses to electricity) had been considered, the suitability map could be more accurate. However, the most important emphasis of these results and methodology is the implementation of this flexible methodology rather than fully accounting in order to evaluate all possible criteria and parameters.

Potential areas for the location of a thermal power plant site were delineated WLC techniques. This approach offer more flexibility than other MCE approach such as Boolean and Overlay. These methods let criteria to be differentially weighted and be standardized in a rather continuous fashion, and exchange with each other. Nevertheless, we recommend applying other MCE methods, such as Ordered Weighted Averaging (OWA), which is a relatively new MCE method. In GIS-based OWA approach, both order and criteria weights are taken into account that makes the decision strategy and uncertainty even more complex.

REFERENCES

Beheshtifar, S.M., Saadi Mesgari, M.J., Valadan Zoej, M. and Karimi, M. (2010). “Using fuzzy logic in GIS environment for site selection of gas power plan”, *Journal of Civil and Surveying Engineering*, 44(4), 583-595.

BP Energy Outlook 2030 London. (2012). “Energy outlook 2030”, BP, London, January.

Comber, A., Dickie, J., Jarvis, C., Phillips, M. and Tansey, K. (2015). “Locating bioenergy facilities using a modified GIS-based location–allocation-algorithm: Considering the spatial distribution of resource supply”, *Applied Energy*, 154, 309-316.

Höhn, J., Lehtonen, E., Rasi, S. and Rintala, J. (2014). “A Geographical Information System (GIS) based methodology for determination of potential biomasses and sites for biogas plants in southern Finland”, *Applied Energy*, 113, 1-10.

Iran Energy Efficiency Organization (IEEO - SABA). (2002). “Report of the site selection strategy for new thermal power plants with considering environmental impacts”, Tehran, Iran.

Jabarian, B., (2005). “Environmentally sensitive lands designated for the construction of power plants”, Energy Efficiency Organization, Ministry of Energy, Tehran, Iran

Jafari, H., Karimi, S., Nahavandian, M. and Balist, J. (2015). “Nuclear power plant locating by WLC & GIS (Case study: Iran, Hormozgan province)”, *International Journal of Basic and Applied Sciences*, 4(1), 132-139.

Jangid, J., Bera, A.K., Joseph, M., Singh, V., Singh, T.P., Pradhan, B.K. and Das, S. (2016). “Potential zones identification for harvesting wind energy resources in desert region of India, a multi criteria evaluation approach using remote sensing and GIS”, *Renewable and Sustainable Energy Reviews*, 65, 1-10.

Jiuping, X., Xiaoling, S., Yimin, W. and Ziqiang, Z. (2015). “GIS-modeling based coal-fired power plant site identification and selection, *Applied Energy*, 159, 520-539.

Karimi, H., Soffianian, A., Mirghaffari, N. and Soltani, S. (2016). “Determining air pollution potential using Geographic Information Systems and multi-criteria evaluation: A case study in Isfahan province in Iran”, *Environmental Processes*, 3(1), 229-246.

Khorasani, N., Mehrdadi, N., Darvishsefat, A.A. and Shokraie, A. (2004). “An environmental study toward site selection of landfill for the city of Sari”, *Iranian Journal of Natural Resources*, 57(2), 275-284.

Malczewski, J. (1999). *GIS and multicriteria decision analysis,* John Wiley and Sons, New York.

Mevlut, U. (2013). “GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey”, *Renewable and Sustainable Energy Reviews*, 28, 11-17.

Motlagh, Z. and Sayadi, M. (2015). “Siting MSW landfills using MCE methodology in GIS environment (Case study: Birjand plain, Iran)”, *Waste Management*, 46, 322-337.

Raisi, M. and Soffianian, A. (2013). “Industrial site selection by combining geographic information system and multi criteria decision analysis”, *WULFENIA*, 20(1), 116-129.

Saaty, T.L. (2008). “Decision making with the analytic hierarchy process”, *International Journal of Services Sciences*, 1 (1), 83-98.

Sadeghi, A., Danekar, A., Khorasani, N. and Naeimi, B. (2012). “Analysis of land suitability to locate thermal power plant by the use of environmental multi criteria evaluation approach, Case study: Chabahar town ship”, *Geography and Development*, 9(23), 123-140.

Saeidi, M., Karbasi, A., Sohrab, T. and Samadi, R. (2006). “Environmental management of thermal power plant report”, Iran Energy Efficiency Organization (IEEO - SABA), <saba.org.ir/saba_content/media/image/2012/04/3583_orig.pdf>.

Sanchez, J., Teruel, J., Soto, P. and Socorro, M. (2013). “Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south eastern Spain”, *Renewable and Sustainable Energy Reviews*, 24, 544-556.

Thomas, A., Bond, L. and Hiscock, K., (2013). “A GIS based assessment of bioenergy potential in England within existing energy systems”, *Biomass and Bioenergy*, 55, 107-121.

Yeo, I. and Yee, J. (2014). “A proposal for a site location planning model of environmentally friendly urban energy supply plants using an environment and energy geographical information system (E-GIS) database (DB) and an artificial neural network (ANN)”, *Applied Energy*, 119, 99-117.

Noorollahi, Y., Yousefi, H. and Mohammadi, M. (2016), “Multi-criteria decision support system for wind farm site selection using GIS”, *Sustainable Energy Technologies and Assessments*, 13, 38-50.