Geothermal Exploration with GIS Based Multi Criteria Decision Analysis Methods: Akarcay Basin (Afyonkarahisar)

[1]Mustafa Yalcin and *[2]Fatmagul Kilic
*[1]Faculty of Engineering, Department of Geomatic Engineering Afyon Kocatepe University, Turkey
[2]Faculty of Civil Engineering, Department of Geomatic Engineering Yildiz Technical University, Turkey

Abstract

Geothermal energy that is renewable and not to harm the environment and atmosphere is vitally important in today's world, as one of the alternative energy resources. Afyonkarahisar has significant geothermal potentials that is located in the Aegean Region of Turkey. In this study, geothermal potential areas are defined by Geographical Information Systems (GIS) Based Multi-Criteria Decision Analysis Method (MCDA). Analytic Hierarchy Process (AHP) was used in stage of decision analysis of MCDA, and the method of scoring method was applied in order to determine relative weights of the each criteria in the scope of the AHP. This study is one of few studies in literature that uses GIS based MCDA (G-MCDA) and remote sensing. Exploring the new resources in the Afyonkarahisar within the boundaries of Akarcay Basin will increase potential of thermal tourism, housing heating, greenhouse and balneogeological applications and contribute to the renewable energy production in Turkey.

Key words: GIS, MCDA, Geothermal Energy

1. Introduction

Geothermal energy could significantly contribute many needs such as heating and cooling, buildings, processing biofuels, generation of electrical energy. For every kilowatt of electrical energy displaced by geothermal energy use, the greenhouse gas emissions that would have been produced from a fossil-fueled power plant are reduced by a minimum of 90%, and in many cases, they are eliminated completely [1]. In addition to this, it is widely used in many fields such as tourism, greenhouse cultivation, industry, fishery and, balneological applications.

Active geothermal areas have varied natural manifestations at the ground surface. Geothermal exploration make use of such manifestations and other investigation techniques and measurements to identify prospective geothermal resources. The decision-making process involved in locating prospective areas involves combining the results of a number of different surveys and studies; human errors are unavoidable during this complex procedure. To minimize human errors, using GIS to identify prospective areas by combining various digital data layers [2].

Spatial decision problems typically involve a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria. The alternatives are often evaluated by a number of individuals (decision-makers, managers, stakeholders, interest groups). The individuals are typically characterized by unique preferences with respect to the relative importance of criteria on the basis of which the alternatives are evaluated. Accordingly, many spatial decision problems give rise to the G-MCDA [3]. With the integrated use of GIS with

*Corresponding author: Address: Faculty of Engineering, Department of Geomatic Engineering, Afyon Kocatepe University, 03400, Afyonkarahisar TURKEY. E-mail address: mustafayalcin@aku.edu.tr, Phone: +902722281423 Fax: +902722281422

MCDA method is made available directly to decision-makers for geothermal exploration [2, 4]. In this study, G-MCDA method has been applied in a suitability analysis for geothermal resource exploration in the Afyonkarahisar within the boundaries of Akarcay Basin.

2. Study Area

Turkey is divided into 25 hydrological basin according to integrated watershed management. Akarcay Basin is a closed basin in these hydrological basin that located between the Central Anatolia, Aegean and Mediterranean regions and located into Afyonkarahisar and Konya provinces boundaries. Study area is the Afyonkarahisar province within the boundaries of Akarcay Basin and located between 30°- 32° east longitude and 38°- 40° north latitude (Figure 1).

Figure 1. Study Area (Afyonkarahisar within the boundaries of Akarcay Basin)

2.1. Thermal Potential in Study Area

Turkey is the sixth country in the world and the first country in Europe in terms of geothermal potential with more than 227 geothermal fields which can be useful at the economic scale and about 2000 hot and mineral water resources (spring discharge and reservoir temperature) which have the temperatures ranged from 20- 287^{o}C, have been determined. Geothermal manifestations are located mainly along the major grabens at the Western Anatolia, along the Northern Anatolian Fault Zone, Central and Eastern Anatolia volcanic regions [5 - 8].

Afyonkarahisar is one of provinces with significant geothermal potential in Turkey. Warm waters in Afyonkarahisar that located along the fault lines is medium temperature according to geothermal temperature groups. A lot of springs and wells of the geothermal fields within the city boundaries are used for thermal tourism, house heating, greenhouse cultivation and balneological applications.

The city has one-third of the thermal accommodation capacity in Turkey with timesharing application and a large number of touristic facilities that serving with balneological applications. The city has the second high capacity after İzmir in the house heating with geothermal energy in Turkey. Approximately 9000 houses is heated with geothermal energy. Moreover, the greenhouse cultivation is benefited from geothermal energy about 80000 square meters in the city that holds an important place in agriculture of Turkey [9-10].

2.2. Geothermal Areas in Study Area

There are four geothermal fields within the Afyonkarahisar province. These are; Omer - Gecek - Kizik - Uyuz geothermal field, Gazligol geothermal field, Sandikli geothermal field, and Heybeli geothermal field. Omer - Gecek -Kizik - Uyuz geothermal field, Gazligol geothermal field, and Heybeli geothermal field are located within the Akarcay Basin. Although Sandikli geothermal field is in the Afyonkarahisar, it isn’t located in the Akarcay Basin. Therefore, it is not within the study area.

3. Materials and Method

In this study, geothermal potential areas are proposed by G-MCDA. Project’s flow diagram was depicted in Figure 2.

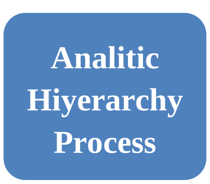
Figure 2. Flow Diagram of Study

Initially, literature researches were conducted and expert opinions were taken according to the specified purposes to define the criteria. Acquired data from various corporation and edited for defined criteria. After the data layers were created, normalizing, weighting, and synthesis stages were carried out respectively in the scope of Analytic Hierarchy Process (AHP) Method. Criteria layers were normalized with the Linear Scale Transformation method. Each criteria were compared with scoring method by expert opinions. The geothermal potentials were mapped via synthesizing with normalized data layers and their weights in the AHP. Comparisons were made over the synthesis of data, and as a result of these, final proposals were composed.

3.1 Decision Criteria

Initially, literature researches were conducted and take a poll with geologists according to the specified purposes. As a result of poll and literature researches, criteria were defined as drainage density, land surface temperature, proximity to current geothermal fields, proximity to geological formation that manifestations of geothermal potential area and proximity to active faults. This is a subjective matter so that criteria could be changed, reduced, and increased according to expert opinions and literature researches.

3.2 Data Collection and Editing



Digital elevation model (DEM) were derived from 1/25000 scale digital topographic maps, lake boundaries (natural, pond, and reservoir), drain lines (stream, river, wadi), active faults, 1/25000 scale digital geological map, ASTER satellite images at nighttime data acquired to create criteria layers.

Drainage density criteria was derived from drain lines that contain streams, rivers and wadis in the study area. Drainage density (D_d) is defined as total length of drain lines ($\sum L_u$) in the unit area (A) [11] that generally use per square kilometer. Drainage density criteria layer was calculating by using Formula 1.

$$D_d = \frac{\sum Lu}{A} \tag{1}$$

Proximity to active faults criteria layer was derived from active faults that was defined by Turkey General Directorate of Mineral Research and Exploration. Euclidean Distance Method was used to create proximity to active faults criteria layer.

Proximity to current geothermal fields criteria layer was derived from location of Omer, Gecek, Kizik, Uyuz, Gazligol, and Heybeli geothermal field. Euclidean Distance Method was used to create proximity to these geothermal fields.

Proximity to geological formations criteria was created by using 1/25000 scale digital geological map. Geological formations that identifier of geothermal potential area were researched with geologists and using inventory of geothermal sources [8] in the study area. Marble, limestone, andesite, basalt, tuff, and agglomerate nearby the travertine were defined manifestations of geothermal potential area. Euclidean Distance Method was used to create proximity to geological formations criteria layer by using these formations.

Finally land surface temperature layer is derived from the thermal infrared bands of ASTER satellite images at nighttime. The study area is covered with 3 different frames that each of them belong to different times that 11.09.2015 20:08, 20.09.2015 20:01, 29.09.2014 19:55 at the GMT time zone respectively.

3.3 Normalization

Normalization methods that is an AHP stages, is used to synthesis of all layers in the same denominator that each criteria layer values changing from 0 to 1. There are too many normalization methods and Linear Scale Transformation method is a most widely use of these methods. Similarly there are a lot of types of Linear Scale Transformation method and the maximum value method and maximum and minimum value range methods are widely is used in the method. Maximum and minimum value range method was used in the study (Figure 3).

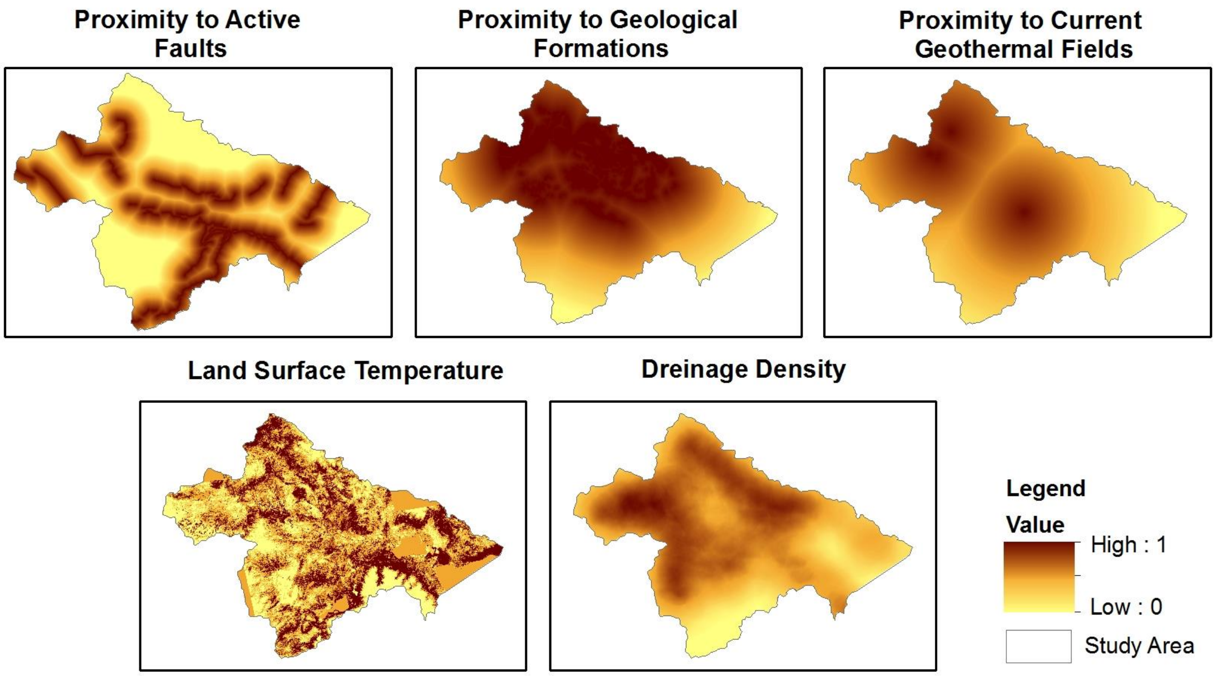


Figure 3. Normalized Criteria Layers

3.4 Weighting

Defining weights is a subjective matter that weights are changeable according to different experts. There are a lot of weighting methods as trade-off analysis method, ranking method, rating method, and pairwise comparison method. Rating method was used to define weights of criteria, because the method is a most widely use of these methods. Take a poll with geologist to scoring of each criteria ranging from 0 to 100. As a result of these the criteria weights are shown Table 1.

Table 1. Criteria weights according to scoring method

Criteria	Land surface temperature	Proximity to active fault	Proximity - geological formation	Proximity- geothermal fields	Drainage Density
Weights	0.10	0.40	0.25	0.18	0.07

3.5 Synthesizing

The value of each criteria layers were multiplied by their weights and then the synthesis layer was produced by adding these pixel based values on top of each other. The results data was multiply by 100 in order to scoring the pixel values that range 0 to 100. Probability of geothermal potential map was created via synthesizing normalized data layers with their weights. The map was classified because classes are shown with ranging in color from beige to dark brown colors, created a more open and understandable data integrity about the potential area on the layer result and more comfortable ability to comment gained. Synthesize map was classified with six classes (very low, low, medium, high, very high and, extremely high) by using Natural Breaks Jenks Method. Geothermal potential areas were highly proposed that extremely high class and secondarily very high class. Dark brown and brown areas demonstrate proposed highly potential areas, orange areas demonstrate medium potential areas and beige areas demonstrate low potential areas in the Figure 4.

3.6 Comparisons

Results of the study were compared with the current geothermal fields that Gazligol, Omer, Gecek, Kizik, Uyuz, Heybeli geothermal fields. The score (pixel values) of the probability of geothermal potential map were calculated at the current geothermal fields location. The score of the current geothermal fields are shown in the Table 2.

Table 2. Value of geothermal potential map at the current geothermal fields

Geothermal Fields	Omer	Gecek	Kizik	Uyuz	Gazligol	Heybeli	Mean
Score	92.1	95.4	96.0	91.1	92.1	93.5	**93.4**

In addition, all of the geothermal fields are in the extremely high class of probability map of geothermal potential area that are seen in Figure 4.

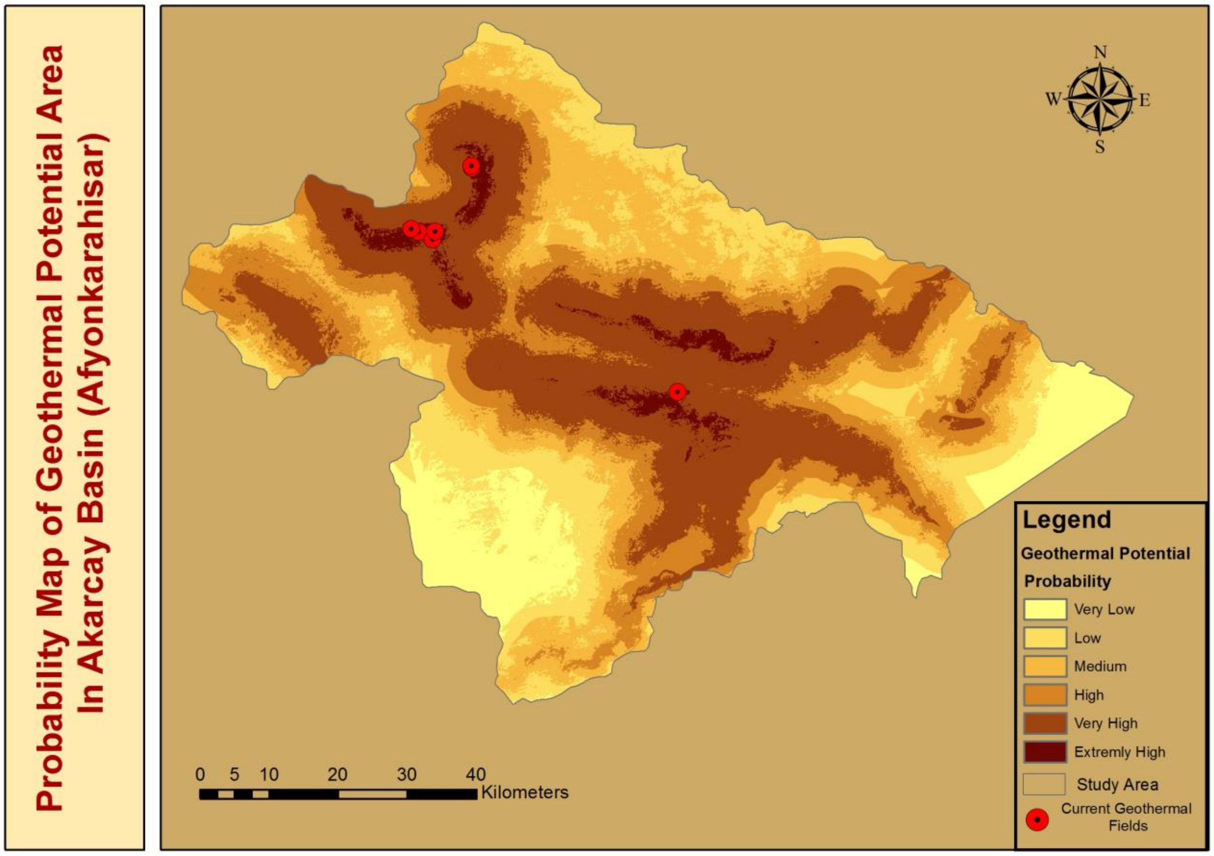


Figure 4. Probability map of geothermal potential area in Akarcay Basin (Afyonkarahisar)

4. Conclusion

In the study, the definition of problem, criteria selection, identifying for criteria weight with method of scoring, normalization, creation of results data with AHP method, classification, and comparisons were described in detail. Synthesis of data obtained by AHP method were organized with classification, and then compared to the current geothermal fields.

It is important to state that the criteria selection and weight determination are subjective matters that influence the results in the study. Therefore, the criteria and weights may vary according to the expert opinions, literature research, and the characteristics of the study area.

In conclusion, all the current geothermal fields are in the extremely high class that was defined by G-MCDA method. Therefore, the comparison results present that this study is able to efficiently propose geothermal potential areas.

The land surface temperature criteria is defined by remote sensing techniques in this study. In the futures studies, mineral alteration zones determined by remote sensing will contribute to the study in order to improve the effectiveness of the study since the use of remote sensing techniques continue to increase.

This study is one of few studies in literature that explores the geothermal areas with G- MCDA. Exploring the new resources in the city within the boundaries of Akarcay Basin will increase potential of thermal tourism, housing heating, greenhouse, and balneogeological applications, which contribute to the renewable energy production in Turkey.

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