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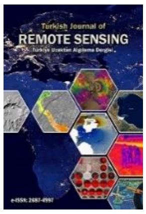

Determination of Potential Geothermal Areas in Konya Seydişehir District Using GIS-based Multi-Criteria Decision Analysis

Münevver Gizem Gümüş*[1], Süleyman Savaş Durduran[2]

[1]Niğde University, Engineering Faculty, Geomatics Engineering, Niğde, Turkey
[2]Necmettin Erbakan University, Engineering Faculty, Geomatics Engineering, Konya, Turkey

Keywords
Analytical Hierarchy Method
Geographic Information System
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ABSTRACT

Today, one of the main challenges that countries face in their economic and social development efforts is to ensure access to cheap, clean and reliable energy resources. Especially the damages caused by fossil fuels and major environmental problems such as global warming increase the need for renewable energy sources. Turkey is among the richest countries in the world in terms of geothermal energy potential. Our country has great geothermal potential, ranking first in Europe and seventh in the world. Seydişehir district of Konya province is a residential area that has attracted attention in recent years with its geothermal energy potential and developments in the field of thermal tourism and the process of exploring geothermal areas is ongoing. In this study, the Analytic Hierarchy Process (AHP) method, which is a GIS-based Multi-Criteria Decision Analysis method (MCDA), was used to identify potential geothermal areas. All criteria used for the AHP method were determined by taking expert opinion and literature research. The potential geothermal map of the region was produced by combining the weighted layers of the standardized data according to AHP. With such a study, it is foreseen that the geothermal potential areas identified in the region will constitute an important infrastructure inventory for local governments and decision-makers in terms of evaluating and developing geothermal resources and providing suggestions for investments to be made in order to bring the maximum capacity to the national economy.

Konya Seydişehir İlçesinde CBS Tabanlı Potansiyel Jeotermal Alanların Belirlenmesi için Çok Ölçütlü Karar Analizi Kullanımı

Anahtar Kelimeler:
Analitik Hiyerarşi Yöntemi
Coğrafi Bilgi Sistemi
Çok Ölçütlü Karar Verme
Jeotermal Enerji
Mekânsal Analiz

ÖZ

Günümüzde, ülkelerin ekonomik ve sosyal kalkınma çabalarında karşılaştıkları temel sorunlardan biri, ucuz, temiz ve güvenilir enerji kaynaklarına erişimi sağlamaktır. Özellikle fosil yakıtların yaydığı zararlar ve küresel ısınma gibi büyük çevresel sorunlar, yenilenebilir enerji kaynaklarına olan ihtiyacı artırmaktadır. Türkiye, jeotermal enerji potansiyeli bakımından dünya genelinde zengin ülkeler arasında yer almaktadır. Ülkemiz, Avrupa'da birinci, dünyada ise yedinci sırada yer alarak büyük bir jeotermal potansiyele sahiptir. Konya ili Seydişehir ilçesi, son yıllarda jeotermal enerji potansiyeli ve termal turizm alanındaki gelişimleriyle dikkat çeken ve jeotermal alanları araştırma süreci devam eden bir yerleşim bölgesidir. Bu çalışmada, potansiyel jeotermal alanların tespiti için CBS tabanlı Çok Kriterli Karar Analiz yöntemi olan Analitik Hiyerarşi Süreci (AHP) yöntemi kullanılmıştır. AHP yöntemi için kullanılan tüm ölçütler uzman görüşü alınarak ve literatür araştırmaları sonucu oluşturulmuştur. Belirlenen kriterler AHP'ye göre standartlaştırılmış verilerin ağırlıklı katmanları birleştirilerek bölgenin potansiyel jeotermal haritası üretilmiştir. Böyle bir çalışma ile bölgedeki belirlenen jeotermal potansiyel alanların ülke ekonomisine maksimum kapasite ile kazandırılması amacıyla jeotermal kaynakların değerlendirilmesi, geliştirilmesi ve yapılacak yatırımlar için öneriler sunulması noktasında yerel yönetimler ve karar vericiler için önemli bir altlık envanter oluşturacağı öngörülmektedir.

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***Corresponding Author:** Münevver Gizem Gümüş, gizemkisaaga@ohu.edu.tr, +90 388 225 4643

1. INTRODUCTION

Today, the continuous increase in energy consumption and the deepening of environmental problems have led people to more sustainable energy sources. Renewable energy sources are resources that can be continuously regenerated by natural processes and can be used indefinitely. These resources contribute to environmentally friendly, sustainable, and clean energy production compared to fossil fuels. Geothermal energy, which is one of these energy sources, is obtained by extracting the energy in the form of vapor or hot water from the thermal energy of the earth. Geothermal energy sources offer low carbon emissions and a continuous energy source (Bulut & Filiz, 2005). The exploration and development of geothermal resources is a very interesting research topic today. The identification of geopotential areas is a complex process integrating Geographic Information System (GIS) and remote sensing technologies. Geoprocessing analyzes the natural resources, climate, topography, topography, and other factors in a region to identify potential risks and opportunities. These areas play a fundamental role in strategic decision-making in many areas such as planning, natural resource management, environmental sustainability, and disaster risk reduction. Different studies have been conducted in the literature to identify potential geothermal areas. Yousefi et al. (2007) created a model using GIS as a decision-making tool for targeting potential geothermal resources in Iran. Noorollahi et al. (2015) developed the GIS Model for Geothermal Resource Exploration (GM-GRE) tool, a toolbox that uses GIS as a decision-making tool to locate potential geothermal areas. Nwaiwu et al. (2023) utilized Multi-Criteria Decision-Making (MCDA) techniques for a GIS-based geothermal site selection study in Nigeria. Noorollahi et al. (2007) conducted a study to determine the geothermal potential in Akita and Iwate regions. In this research, they developed a GIS model using a weighted overlay selection query to identify priority areas for geothermal exploration by considering geological, thermal, and geochemical factors. Yalcin & Gul (2017), in the study conducted in Akarçay Basin, geothermal potential areas were identified using GIS-based MCDA. Analytic Hierarchy Process (AHP) method was used in the decision analysis phase and the geothermal potential map of the region was created by synthesizing the weights of standardized data layers.

Abuzied et al. (2020) performed a GIS-based analysis utilizing a Multi-Criteria Decision-Making approach. The study focused on geothermal resource exploration in the coastal region of the Gulf of Suez, Egypt, employing data derived from remote sensing and geophysical techniques. Yalcin et al. (2023) used the machine learning method Maximum Entropy (Maxent) Method and MCDA to identify potential geothermal areas in their study. The results of the two methods were compared and the potential status of the region was revealed.

Turkey is among the richest countries in the world in terms of geothermal energy potential (Figure 1). Our country has great geothermal potential, ranking first among European countries and seventh in the world (Kilic, 2016; Serpen et al., 2009; Kömürcü & Akpınar, 2009).

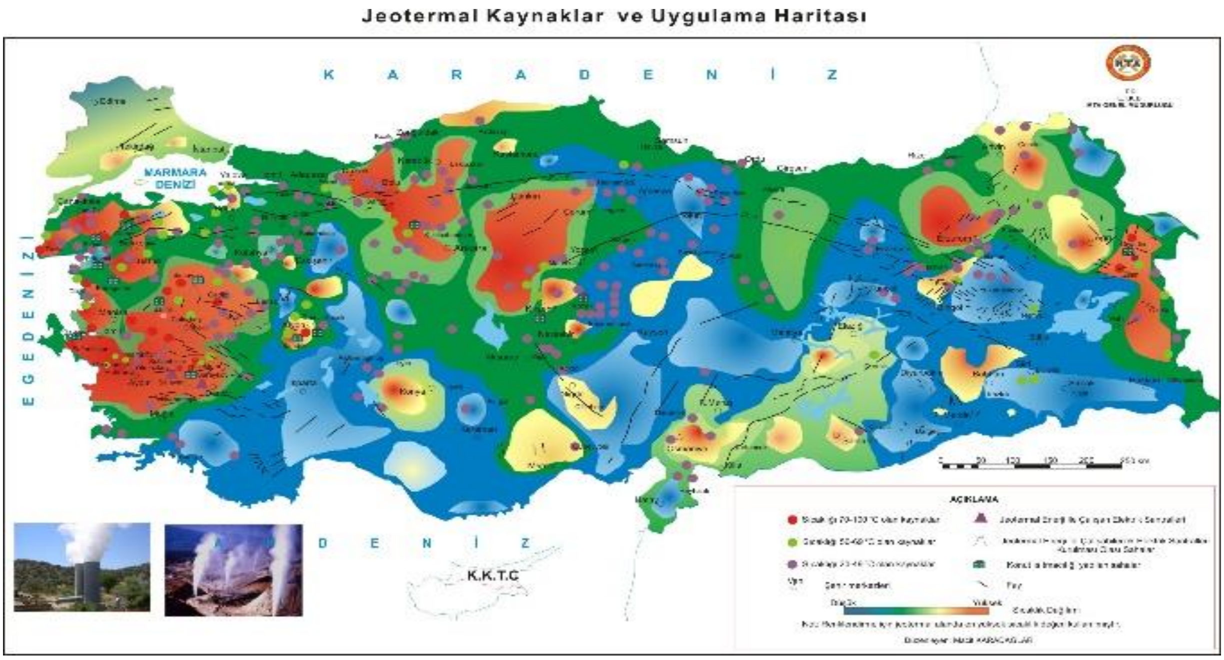
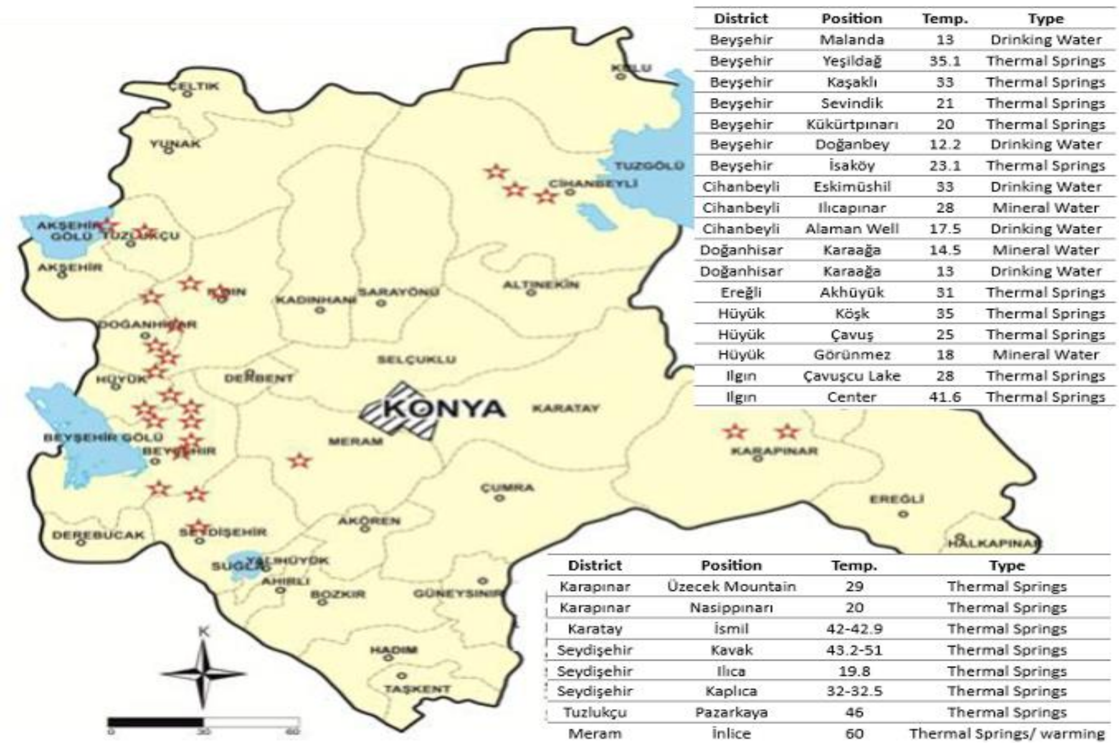


Figure 1. Türkiye geothermal resources and application map (URL-2)

The biggest advantage of geothermal energy is that it can be used in many different areas such as home heating, greenhouse cultivation, tourism, industry, and medicine as well as electricity generation. In our country, greenhouse activities are carried out on 1200 acres with geothermal energy, and 100,000 acres of residential area is heated in 15 different settlements. Konya province is a very important potential area in terms of geothermal energy resources, and almost all of the fields in the region can be used as hot springs and drinking water. The temperatures of the existing resources in the area vary between 250-45°C (URL-1). The distribution of geothermal fields in Konya is concentrated around Beyşehir, Seydişehir, Ilgın, Tuzlukçu, Hüyük, Cihanbeyli, Ereğli, Karapınar, and Doğanhisar, especially in the western region where fracture zones are known to be intense (Figure 2).



District	Position	Temp.	Type
Beyşehir	Malanda	13	Drinking Water
Beyşehir	Yeşildağ	35.1	Thermal Springs
Beyşehir	Kaşaklı	33	Thermal Springs
Beyşehir	Sevindik	21	Thermal Springs
Beyşehir	Kükürtpınarı	20	Thermal Springs
Beyşehir	Doğanbey	12.2	Drinking Water
Beyşehir	İsaköy	23.1	Thermal Springs
Cihanbeyli	Eskimüshil	33	Drinking Water
Cihanbeyli	Ilıcapınar	28	Mineral Water
Cihanbeyli	Alaman Well	17.5	Drinking Water
Doğanhisar	Karaağa	14.5	Mineral Water
Doğanhisar	Karaağa	13	Drinking Water
Ereğli	Akhüyük	31	Thermal Springs
Hüyük	Köşk	35	Thermal Springs
Hüyük	Çavuş	25	Thermal Springs
Hüyük	Görünmez	18	Mineral Water
Ilgın	Çavuşcu Lake	28	Thermal Springs
Ilgın	Center	41.6	Thermal Springs

District	Position	Temp.	Type
Karapınar	Üzecek Mountain	29	Thermal Springs
Karapınar	Nasippınarı	20	Thermal Springs
Karatay	İsmil	42-42.9	Thermal Springs
Seydişehir	Kavak	43.2-51	Thermal Springs
Seydişehir	Ilıca	19.8	Thermal Springs
Seydişehir	Kaplıca	32-32.5	Thermal Springs
Tuzlukçu	Pazarkaya	46	Thermal Springs
Meram	İnlice	60	Thermal Springs/ warming

Figure 2. Distribution of Geothermal Areas in Konya (Arık, 2011)

In this study, it is aimed to identify the potential geothermal areas of Seydişehir district of Konya province, which has attracted attention in recent years with its geothermal energy potential and developments in the field of thermal tourism, and which is a settlement region whose geothermal areas research process is ongoing. In this context, AHP method, which is a GIS-based MCDA method, was used to identify potential geothermal areas. All criteria used for the AHP method were created by taking expert opinions and as a result of literature research. The data sets used in the analysis consist of geological, hydrogeological, topographic, and geophysical information. The potential geothermal map of the region was produced by combining the weighted layers of the standardized data according to AHP. The workflow diagram of the study is as shown in the figure 3.

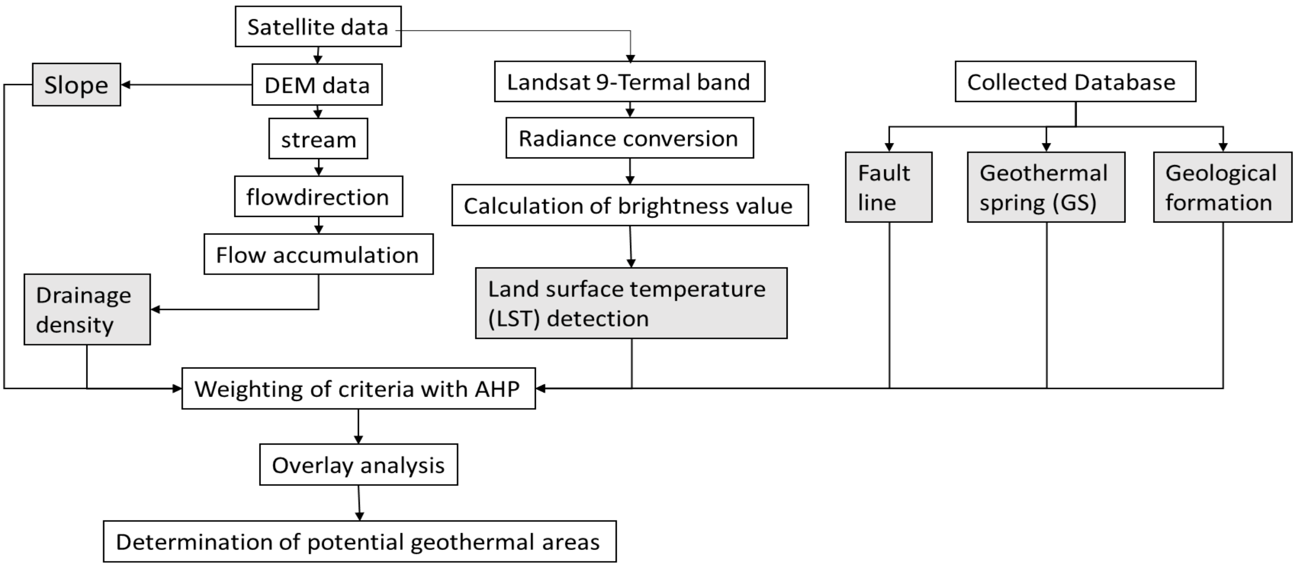


Figure 3. Workflow diagram

2. METHOD

2.1. Study Area

Seydişehir district is a region located 107 km from Konya city center. The average height above sea level is 1,123 meters. The district borders Beyşehir in the north, Yalıhüyük, Ahırlı, and Akseki districts of Antalya province in the south, Derebucak in the west and Akören district in the east. Located on the northern foothills of the Taurus Mountains, the district lies in a fertile valley called Suğla Plain. Mount Küpe Mountain extends from the west to the south, while Mount Gidengelmez is home to rich bauxite deposits in the south. There are many springs and springs on the slopes of Mount Küpe. There are also natural beauties such as Pınarbaşı, Kuğulu, and Beldibi Ponds, which are located in Seydişehir and fed by the springs on Mount Küpe (URL-3). Beyşehir Lake lies to the northwest of the district and Suğla Lake to the southeast. Seydişehir district is a region that attracts attention with its impressive geographical features and natural richness (Figure 4).

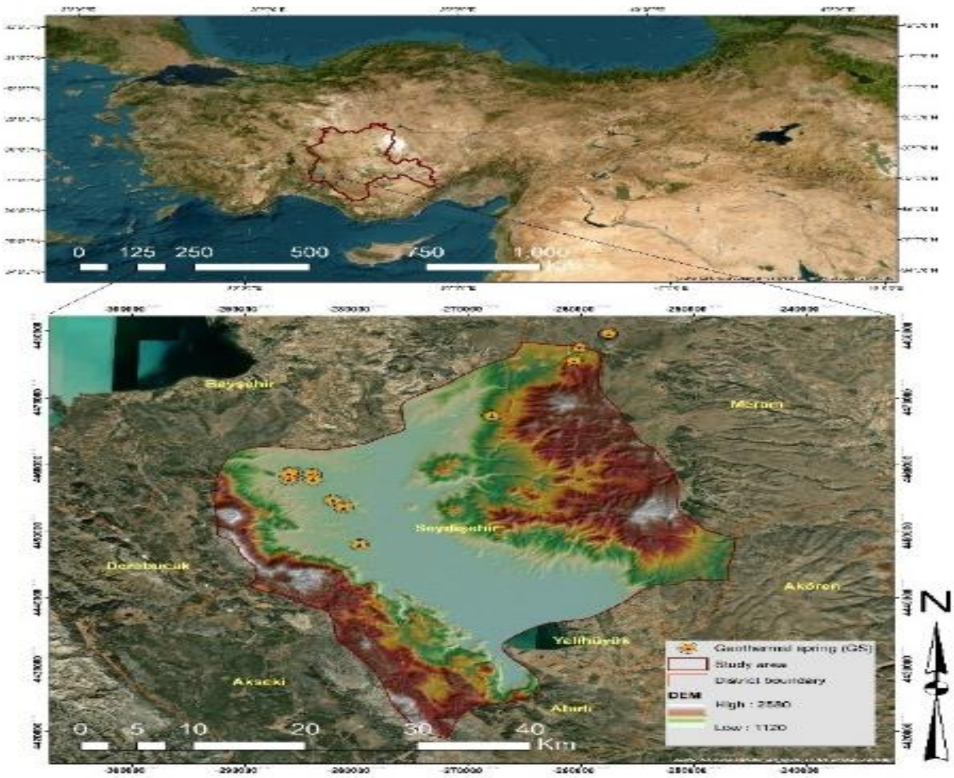


Figure 4. Seydisehir district boundary (study area) representation

Survey studies have been carried out by the General Directorate of Mineral Research and Exploration (MTA) since 1998 to determine the geothermal energy potential of Konya-Seydişehir district and its surroundings. There are wells and springs in Seydişehir-Center, İnlice, Bükçe, Kavak and Yenice villages (URL-1). In 2006, 2 geothermal exploration drillings were carried out at these points (Figure 5).

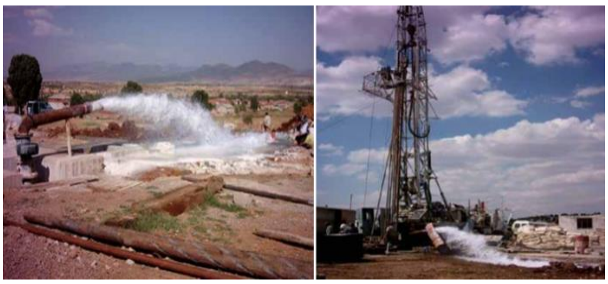


Figure 5. Konya Seydişehir KSK-1 well production image (URL-2)

In the first well of the drilling works, a temperature of 38.3°C and in the other well, a temperature of 43.2°C and a total flow rate of 130 l/s were reached (URL-2) (Table 1).

Table 1. Well Data in Seydişehir Geothermal Area (URL-1)

Location	Well name	Temperature (°C)	Flow (l/sec)	Depth (m)	Company	Opening year
Center	Ilıcatepe, IT-1	32	1.42		Seydişehir Municipality	
	Ilıca hot spring ITky-2	32.1	0.2		Seydişehir Municipality	
	Ketirlik hill, JT-1	43	8	118	Seydişehir Municipality	
	OSBky					
Kavak Village	KSK-1	38.6	100	182	Wells have been vandalized	2006
	KSK-2	43.3	40	317	Wells have been vandalized	2006
	KSK-3					2006
İnlice	İK-1	54.5	30	751	AGN. PET. CONST. MAD.	2010
	BK-1 well					
Yenice	SK-1	37	2.5	348	Seydişehir Thermal Facilities	2008
	SK-2	38.6	110	411		2016

2.2. Criteria Selection and Data Used

In the criterion selection stage, the criteria that affect the decision problem should be identified. The criteria should reflect the objectives in the decision-making process and include factors that are important for the decision to be taken correctly. Criteria selection is a stage of high importance in the finalization of the study. In the study, the criteria were determined by literature research and expert opinions in the field. The criteria determined are "Drainage density, Distance to the fault line, Slope, Land Surface Temperature, Distance to existing resources, Geological formation".

ALOS PALSAR DEM images were used for drainage data and slope data among the data belonging to the criteria. ALOS PALSAR contains data provided by a synthetic aperture radar (SAR) satellite developed by Japan's Remote Sensing and Space Exploration Agency (JAXA). ALOS PALSAR's data resolution generally comes in two main modes: Fine (F) mode with a resolution of 1 to 3 meters and ScanSAR (Scan Synthetic Aperture Radar) mode with a resolution of 10 to 100 meters (URL-4). It was used in this study due to its high resolution and open access (URL-5).

Fault line and geological formation data were provided by the General Directorate of Mineral Research and Exploration (URL-2). The existing geothermal resource data was created based on the locations identified in the Konya province report of the Geothermal Resources Assessment Project (URL-1).

Landsat 9 TIRS image was used for land surface temperature data. The thermal satellite data was obtained from the open access source of the US Geological Survey (USGS) (URL-6, 2023). Landsat 9's Thermal Infrared Sensor 2 (TIRS-2) is a sensor designed to measure thermal radiation emitted from the land surface. TIRS-2 operates in two thermal infrared bands. These bands generally cover wavelengths between 10.60-11.19 micrometers and 11.50-12.51 micrometers. The resolution of the thermal bands for Landsat 9's Thermal Infrared Sensor 2 (TIRS-2) is 100 meters. This refers to the unit of distance used by the sensor when measuring the area of a pixel on the surface. Thus, each pixel represents an area of 100 square meters on the land surface (URL-6). These thermal bands help determine the temperature characteristics of objects by measuring the thermal energy emitted from the earth's surface. Landsat 9's thermal bands are used in applications such as agriculture, water management, natural resources monitoring and tracking environmental changes. All the criteria used in the study are presented in Figure 6.

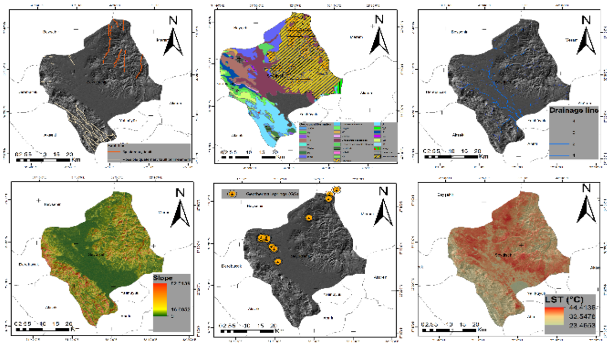


Figure 6. Criteria used to identify potential geothermal fields

2.3. Calculation of Land Surface Temperature

Land Surface Temperature (LST) is an important remote sensing parameter that represents the temperature of an earth point (Brunsell & Gillies, 2003; Solanky et al., 2018). The definition of LST refers to the actual temperature of the object, net of atmospheric effects (Deo & Şahin, 2017). In geothermal research, the measurement of LST plays an important role in identifying heating or cooling events in the subsurface. This provides critical information for the exploration and evaluation of geothermal energy resources.

Landsat TIR receives thermal temperature data and stores this information as a DN between 0 and 255. The first step in the calculation of LST values is radiometric correction. The aim here is to convert the DN values obtained from the satellite data into spectral radiance values. Equation (1) used for this process is as follows:

$$L\lambda = [(LMAX\lambda - LMIN\lambda)/(QCALMAX - QCALMIN)] * [QCAL - QCALMIN] + LMIN\lambda \quad (1)$$

Lλ: Spectral radiance at the sensor (W/m2sr µm), LMAXλ: Spectral radiance scaled relative to QCALMAX, LMINλ: Spectral radiance scaled by QCALMIN, QCAL: Luminance values, QCALMAX: Maximum brightness value, QCALMIN: Refers to the minimum brightness value.

To convert the spectral radiance values obtained by applying this mathematical model into real LST values, the following equation is used (2):

$$Tb = K2 /(\ln(((K1 /l\lambda) + 1)) \quad (2)$$

K1= Calibration constant, K2 = Calibration constant, Tb = Surface Temperature Finally, the LST values are obtained by converting the obtained surface temperature into degrees (Equation 3).

$$LST = Tb - 273 \text{ (Kelvin to Degree conversion)} \quad (3)$$

2.4. Analytic Hierarchy Method (AHP)

The AHP method is a mathematical model used in the multi-criteria decision-making process developed by Saaty (1994). This method is used to determine the importance of different criteria and alternatives in the decision-making process (Saaty,1980; Saaty, 2004). The process steps of the AHP method in identifying potential geothermal areas can be listed as follows: First, the criteria to be used in the decision-making process are determined. Then, the importance levels of the criteria are determined. Then, the alternatives, if any, in the decision-making process are evaluated according to the determined criteria. Weighted scores are calculated by multiplying the importance scores obtained by weighting the criteria by the scores obtained by evaluating the alternatives. Finally, the results obtained are evaluated and the potential geothermal map of the region is produced by combining the weighted layers of the standardized data according to AHP.

3. RESULTS

In the study, criteria were first established to identify potential geothermal areas. Six basic indicators were determined in line with literature studies (Şener & Şener, 2021; Li et al., 2023; Tinti et al. ,2018; Kiavarz & Jelokhani-Niaraki, 2017; Xu et al., 2021; Meng et al., 2021) and expert opinions. These criteria are; "Proximity to fault line, Drainage density, Proximity to existing resources, Land surface temperature, Slope and Geological formation". Priority values were determined by 12 different experts by making pairwise comparisons between the hierarchically ranked subjective criteria. All data were analyzed in the Expert Choice v.11 program and normalization was performed by dividing each column value separately by the total of the relevant column. These values obtained through the normalization process constitute the weight of each criterion (Figure 7).

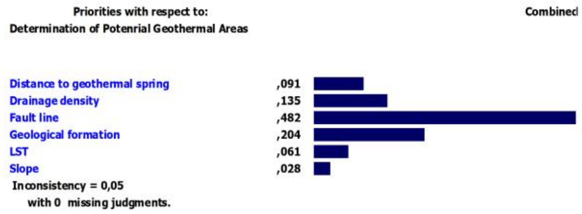


Figure 7. Potential site selection criteria and weights –Expert Choice program output

When the graphs created as a result of the study are examined, it is seen that the criterion with the highest degree of importance in the comparison of the six main criteria is the proximity to the fault line (0.482). The next ranking was determined as Geological formation (0.204), Drainage density (0.135), Distance to geothermal springs (0.091), Land surface temperature (0.061) and Slope criterion (0.028).

The findings found in the AHP method were mapped in order to be integrated into GIS and to visualize the data obtained by concretizing them. The data collected according to the priority values created by AHP were processed in ArcGIS 10.8 software and potential geothermal field analysis for Seydişehir district of Konya province was carried out. In the spatial analysis dimension, the district center boundary layer was created first. Then, the relevant criteria data were digitized and a separate vector data layer was created for each criterion. For the drainage density criterion, it was produced over DEM data using the hydrology analysis module in ArcGIS toolbox. The density map was created using the Euclidean Distance Method. The distance of each pixel in the raster generated by Euclidean Distance to the nearest drainage line was calculated. Similarly, slope analysis was performed on DEM data using the surface analysis module in ArcGIS toolbox. Euclidean distance method was also used for distance analysis of geological formation and proximity to existing resources. For the last criterion, land surface temperature, thermal bands were utilized and mapped by applying the process steps specified in the methodology (Figure 8).

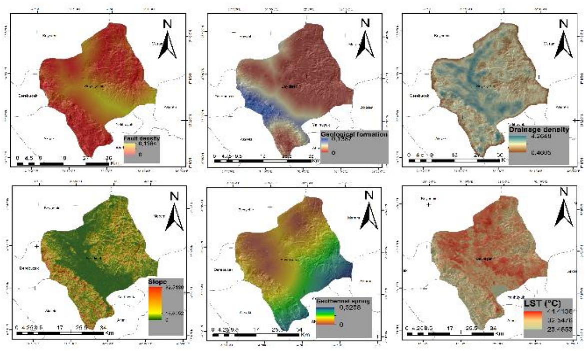


Figure 8. Mapping of criteria densities

The class ranges for the relevant criteria were then normalized and mapped (Figure 9).

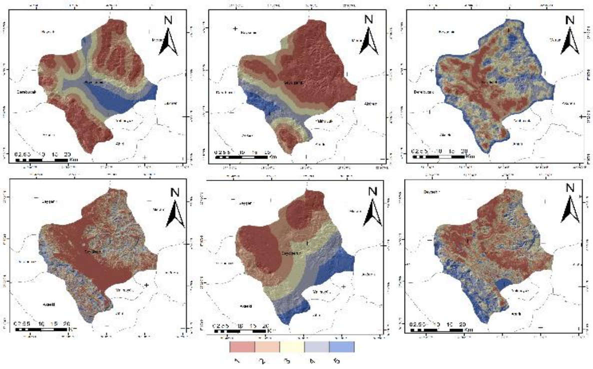


Figure 9. Normalized criteria layers; a. fault line proximity criterion, b. Geological formation criterion, c. Drainage density criterion, d. Slope criterion, e. Geothermal spring proximity criterion, f. LST criterion

Normalization is the process of bringing data into a specific range or distribution. In this process, data is usually standardized using a specific formula or method. The standardization method, which is an AHP stage, is used to standardize the values of the criteria layers between 0 and 1. This standardization process makes data at different scales comparable. Especially in the study where the geothermal potential area was examined, the maximum and minimum value range method was used. This method shows the positive and negative impacts of the geothermal potential area by standardizing according to the lowest and highest values of each criteria layer. In this context, using the normalization method, the new values close to 0 indicate a low geothermal area potential and close to 1 indicates a high potential.

In the synthesis section, which is the last stage of the study, a model was created by weighted registration with all normalised data layers. Modelling was performed using the Modelbuilder module in ArcGIS software. Modelling the synthesis stage of AHP using ArcGIS software provides an effective way to perform complex site selection analyses and integrate geographic elements. The synthesis process using the model was preferred because it allows the users to bring together a set of tools and processes to create and manage complex workflows without writing software code. The model design visualisation is presented in Figure 10.

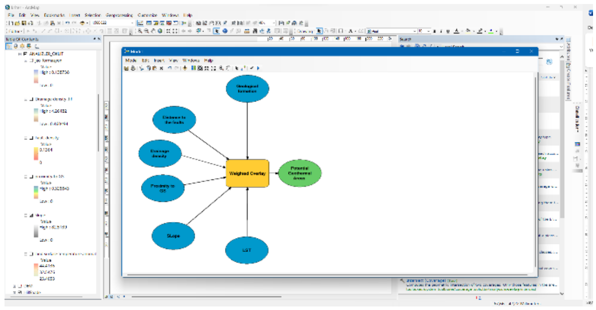


Figure 10. Analysis model created in ArcGIS Model Builder

This model was run to create a potential geothermal map of the region in 5 classes. The resulting map was classified from blue to red, from unsuitable to suitable areas (Figure 11)

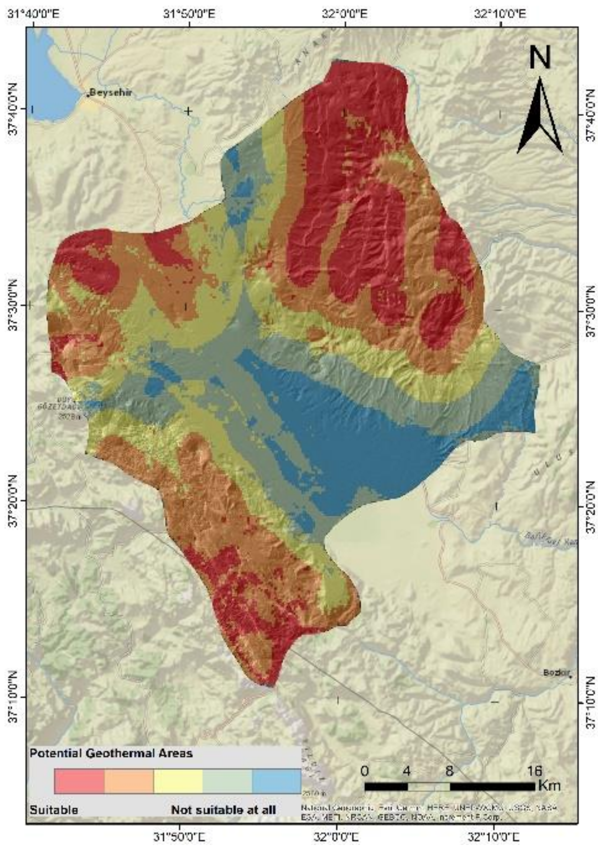


Figure 11. Map of the potential geothermal area in Seydişehir district

4. CONCLUSION

In this study, it is aimed to identify the potential geothermal areas of Seydişehir district of Konya province, which has attracted attention with its geothermal energy potential and developments in the field of thermal tourism in recent years and which is a residential area with ongoing geothermal areas research process. In this context, AHP method, which is a GIS-based MCDA method, was used to identify potential geothermal areas. All criteria used for the AHP method were created by taking expert opinions and as a result of literature research. The data sets used in the analysis consist of geological, hydrogeological, topographic, and geophysical information. The potential geothermal map of the region was produced by combining the weighted layers of the standardized data according to AHP. As a result of the analysis, the potential suitability of the region was classified in five basic classes from unsuitable to suitable areas. According to the potential suitability map produced in the study, 297.38 km^2 (22%) of the total area of 1362.5 km^2 of Seydişehir district is highly suitable for geothermal potential, 395.88 km^2 (29%) is moderately suitable, 265.02 km^2 (19 %) of the area is low suitable, 236.22 km^2 (17 %) of the area is not suitable for geothermal potential and 167.99 km^2 (12 %) of the area is completely unsuitable.

Determination of geothermal energy potential is an important issue in many aspects. Determining this potential is of great importance for energy planning and resource management. It also provides great benefits in issues such as minimizing environmental impacts, sustainable energy production and the use of alternative energy sources. Geothermal energy has many advantages over fossil fuels. The first of these is that geothermal energy is an environmentally friendly energy source. Unlike fossil fuels, greenhouse gas emissions in geothermal energy production are very low and its environmental impacts are minimal. In addition, geothermal energy is a continuous and unlimited resource, which provides a great advantage in terms of continuity of energy supply.

Identification of geothermal potential areas in an integrated manner with GIS and remote sensing makes many contributions to the literature. By using these methods, geothermal energy potential areas can be identified more quickly, economically and in detail. In addition, this integration provides important data for more efficient utilization of geothermal resources and energy planning. Determination of geothermal energy potential supports the use of an environmentally friendly, sustainable, continuous, and economical energy source compared to fossil fuels. Determination studies integrated with GIS and remote sensing contribute to the creation of more effective and efficient energy policies by providing important data to the energy sector and academic literature. Therefore, the determination of geothermal energy potential is of great importance for the energy sector and the environment.

As a result, the use of additional energy sources offers significant advantages not only in the energy sector, but also in the areas of environmental protection and sustainability. These resources can play a critical role for energy efficiency, economic growth and environmental health at the global level. Investments in renewable energy are an important step towards leaving a clean environment for future generations and meeting energy needs in a sustainable way.

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Author contributions

M. G. Gümüş: Data analysis, Research, Modeling, Visualization, Manuscript writing.
S.S. Durduran: Idea/Concept development, Data acquisition, Manuscript writing, Manuscript editing, Critical review.

Conflicts of Interest

The authors declare no conflict of interest.

Research and publication ethics statement

In the study, the authors declare that there is no violation of research and publication ethics and that the study does not require ethics committee approval.

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