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ORIGINAL ARTICLE

Geoheritage Assessment with Entropy-Based WASPAS Approach: an Analysis on Karçal Mountains (Turkey)

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Abstract
Besides being a past witness of the planet's history, the components of geoheritage also have many benefits. Therefore, in recent years, a significant effort has been made by researchers to record, evaluate and highlight areas of important geological and geomorphological value. Many qualitative and quantitative methods developed with this effort have also been frequently used in geoheritage assessment. This study aims to make a geoheritage assessment by using entropy and WASPAS approaches, which are among the multi-criteria decision making (MCDM) techniques. Eight evaluation criteria obtained from the literature were used to evaluate the glacial and periglacial landforms detected in the Karçal Mountains in northeast Anatolia. In the methodological approach, firstly, geosites were scored according to criteria and indicators. This assessment reflects a classical approach. Then, the criteria were weighted with the entropy method, and the priority values of the alternatives (geosites) were determined according to the weighted criteria with WASPAS. This evaluation is the methodological approach proposed in the research. The results suggest significant differences between the classical assessment approach and the proposed methodological approach. It is anticipated that the proposed methodology and results will provide various theoretical implications for the subject area.

Keywords Geoheritage · Glacial · Periglacial · Entropy · WASPAS · Karçal Mountains · Turkey

Introduction

Since the 1990s, the promotion and protection of geological heritage have developed rapidly due to the increasing interest in geoparks and geotourism (Suzuki and Takagi 2018). This development has revealed that geoheritage is an important resource for science, education, and tourism and provides socio-economic benefits to its location (Brilha 2016; Brilha et al. 2018; Ruban et al. 2021). In particular, geotourism, which has developed on the axis of geoheritage, has gained popularity as an alternative tourism form that focuses on social, cultural, environmental, and economic sustainability criteria (Zafeiropoulos and Drinia 2022). For this reason, it is stated that the correct classification and evaluation of geoheritage elements is beneficial for the promotion and use of geosites (Brilha 2016; Jia et al. 2022; Suzuki and Takagi 2018; Zouros 2007; Reynard et al. 2016; Zafeiropoulos and Drinia 2022). Many qualitative and quantitative methodological approaches have been developed over the last decade to assess the value of geosites (Różycka and Migoń 2018; Mucivuna et al. 2022). Most of these evaluation methods are based on various criteria (Fassoulas et al. 2012) and were developed to understand the scientific, educational, touristic, and additional values of geosites (Zafeiropoulos and Drinia 2022). Quantitative methods are usually based on various criteria and related indicators to which different scores or parameters can be assigned (Maghsoudi et al. 2019). These methods have been used frequently by different researchers as they are more objective and unbiased (e.g., Bruschi et al. 2011; Cengiz et al. 2021; Pereira et al. 2007; Spyrou et al. 2022; Ruban et al. 2021; Sena et al. 2022; Golfinopoulos et al. 2022; Fassoulas et al. 2012; Khalaf and El-Kheir 2022). However, despite the many developed methods for the quantitative evaluation of geosites, there is no generally accepted method so far (Brilha 2016). In addition, there is still a great debate about the values and criteria to be used in the geosite evaluation process (Coratza et al. 2019). In

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most qualitative evaluation methods used, different criteria sets were scored by other researchers and calculated with various indexes or basic mathematical operations. However, studies with MCDM techniques, which are more specific calculation methods, have been limited (e.g., Jia et al. 2022; Elkaichi et al. 2021; Hoang et al. 2018; Maghsoudi et al. 2019; Mandal and Chakrabarty 2021). Therefore, the present study focused on using MCDM techniques in geoheritage assessment. MCDM techniques are known as approaches that help solve symmetrical and asymmetrical problems with many parameters (Shaaban and Mesalam 2022). MCDM approaches are carried out under several basic procedures, such as evaluating alternatives according to given criteria, combining evaluations, ranking alternatives, and making decisions accordingly (Tao et al. 2021). In MCDM techniques, criteria weights can be determined objectively or subjectively. For example, entropy is an objective criterion weighting technique, while SWARA is a subjective approach. Since criterion weights directly affect the overall results, objective weighting methods must be applied to obtain meaningful rankings in the MCDM process (Ecer 2021). Today, MCDM methods are widely used in many research areas. However, its use in geoheritage assessment studies has been limited. In the geoheritage evaluation, the difficulty of choosing the best among several options is an MCDM problem. Therefore, an MCDM framework is proposed in which qualitative and quantitative criteria are considered in the current study. In this proposed methodology, the evaluation criteria obtained from the literature were used to evaluate glacial and periglacial landforms in the Karçal Mountains, located in the northeast of Anatolia, as geoheritage. This is similar to standard approaches in the general literature. After the evaluation, the existing criteria were weighted with the entropy technique. The priority values of the geosites were obtained using the WASPAS technique according to the weighted criteria. It is thought that the proposed methodology will further expand the geoheritage assessment literature.

Study Area

Karçal Mountains (3431 m a.s.l.) extend in the northeast-southwest direction between Şavşat and Borçka districts within the borders of Artvin province in the northeast of Anatolia (Fig. 1). This mountainous mass forms the western extension of the Lesser Caucasus Mountains (4090 m a.s.l.). The unit separating the Lesser Caucasus Mountains and the Eastern Black Sea Mountains (3932 m a.s.l.) from each other was the Çoruh River.

Karçal Mountains is a mass formed by the morphological units Karçal (3431 m a.s.l.), Ziyaret (3200 m a.s.l.), and Büyükmera (3035 m a.s.l.) (Fig. 2). In the Karçal Mountains, there is a decrease in elevation values from southwest to northeast. The general geological structure of the Karçal Mountains is composed of volcanic rocks. Diorite, hornblende, and dacite are commonly observed in the Karçal unit (Keskin 2013a). Andesitic and dacitic volcanics are widespread in the visiting unit. The Büyükmera unit contains basalt, andesite, and volcaniclastic rocks (Keskin 2013b).

Karçal Mountains rise like a wall in a short distance. Therefore, it has favourable conditions in terms of glaciation and cold ambient conditions (Fig. 3). Glacial and periglacial landforms have developed in the areas of the Karçal Mountains with suitable elevation, aspect, and slope values (Dede 2016).

Glacial landforms in Karçal Mountains are seen throughout the area. The glacial landforms in question are glacial valleys, cirques, moraines, pyramidal peaks, aretes, roche moutonnee, glacial notches, and glacial lakes. There are 26 glacial valleys in the Karçal Mountains. Cirques, moraines, glacial notches, glacial lakes, and roche moutonnees are distributed within these glacial valleys. Pyramidal peaks and aretes are the boundaries of glacial valleys. The actual glaciers in the Karçal Mountains, on the other hand, are the character of adhering to the walls of the cirques within the glacial valleys (Figs. 4 and 5).

Periglacial landforms in Karçal Mountains are concentrated in the south of the area. Periglacial landforms; rock glaciers, non sorted steps, navigation cirques and non sorted stripes. Rock glaciers formed in glacial valleys. Nivation cirques and nonsorted steps developed on the slopes of glacial valleys. Non sorted stripes are located at the neck points (Fig. 6).

Method and Analysis

Two different methodological approaches were used in the present study. In the first stage, criteria and indicators used in geoheritage evaluation were selected from the literature and scored within a certain scale. This evaluation method reflects the approach that can be described as classical. Then, entropy was used to calculate the importance weights of the criteria used in the evaluation made in the first stage, and WASPAS methods were used to rank the alternatives according to the weighted criteria. This is the methodological approach proposed in the research. In the geoheritage evaluation literature, no study was found using the Entropy-based WASPAS method.

Proposed Approach

The number of geosite evaluation criteria in the general literature is relatively high. For this reason, the most appropriate criteria to meet the elements in the research field

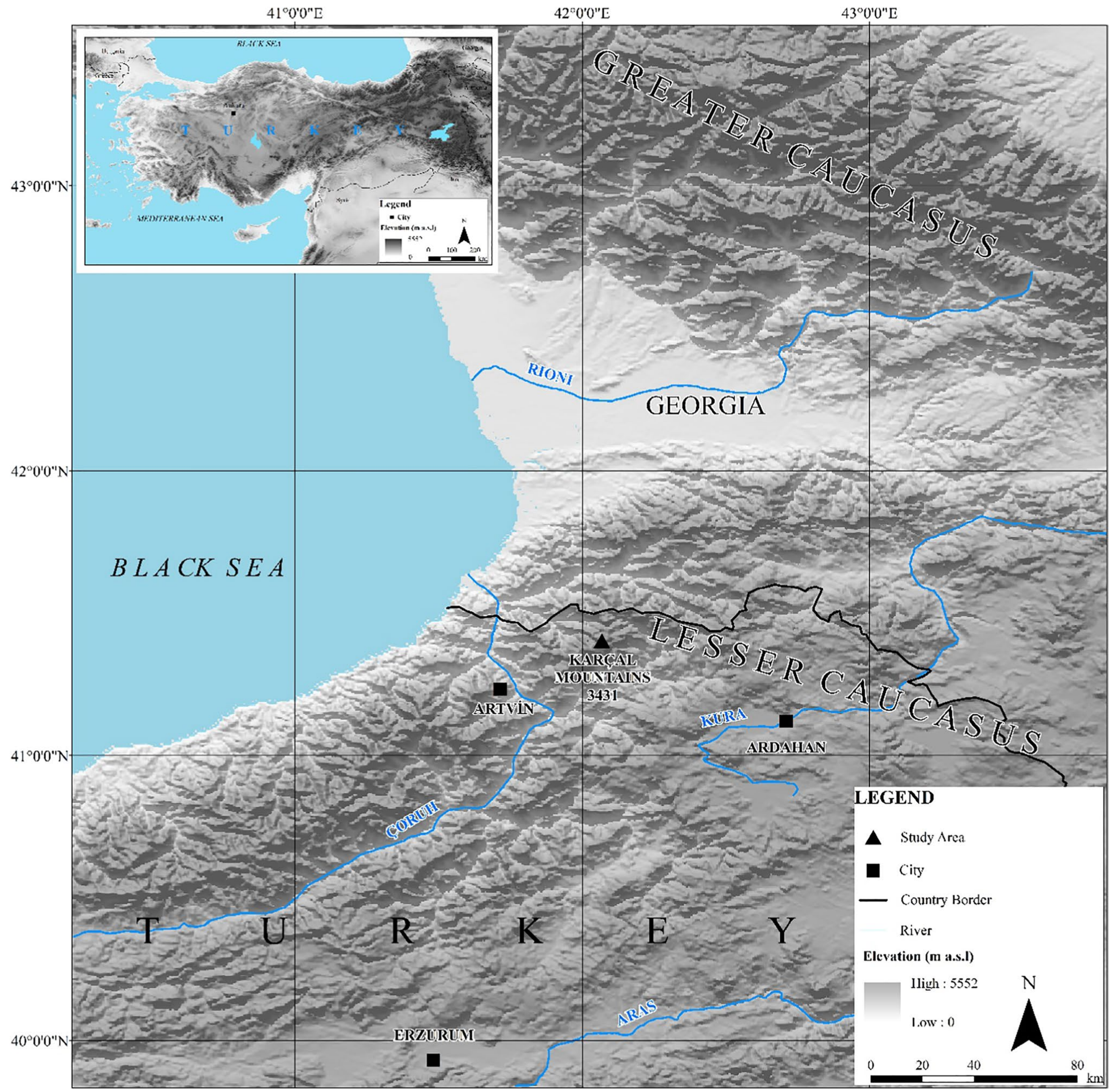

Fig. 1 Location map of Karçal Mountains

were selected for the study. Five criteria (scientific value, educational value, additional value, aesthetic value, and state of preservation) were used by Różycka and Migoń (2018) in their research in Poland, and three criteria (touristic value, safety, and accessibility) from the study of Suzuki and Takagi (2018) were selected for geoheritage assessment. Four indicators were suggested by Różycka and Migoń (2018) for each criterion. However, rather than the scoring scale they used in their study (0–3), it was used as a numerical scale of 25–100 points in the current study. The said scale and the indicators corresponding to these scales are presented in Table 1.

The eight criteria in Table 1 are used to evaluate the glacial and periglacial landforms in the Karçal Mountains as geoheritage using the Entropy-based WASPAS method. No study in the literature integrates Entropy and WASPAS methods for geoheritage assessment. In the proposed approach, firstly, each criterion was evaluated with scale scores corresponding to the indicators. Then, a decision matrix consisting of eight criteria and seven identified

Fig. 2 General view of Karçal Mountains

Fig. 3 General view of the actual glacier in Karçal Mountains (Karçal Glacier)

alternatives (geosites) was created. The criteria in this matrix were weighted using the entropy method. Finally, by applying the calculation steps of the WASPAS method to the matrix in which the weighted criteria and alternatives are included, the priority values of the seven determined geosites were obtained.

Entropy Weighting Method (EWM)

The concept of entropy is used to measure the uncertainty associated with a random variable (Karaca and Ulutaş 2018). The EWM proposed by Shannon and Weaver in 1947 is used to determine the objective weights of attributes/responses (Kumar et al. 2021). It is a method often used to calculate criterion weights when decision-makers have conflicting opinions about weighting values (Kumar Vaid et al. 2022). The most significant advantage of EWM over subjective weighting models is that it increases the objectivity of the results by preventing the intervention of human factors during the weighting process (Kumar Vaid et al. 2022; Zhu et al. 2020). EWM operates on the principle that superior weight indicator information is more constructive than lower indicator information (Kumar et al. 2021).

For this reason, EWM has been widely used, adapting it to many subject areas. However, the use of this method in geoheritage assessment has not been found in the literature. Due to these advantages and the gap in the literature, this method has been deemed appropriate for the

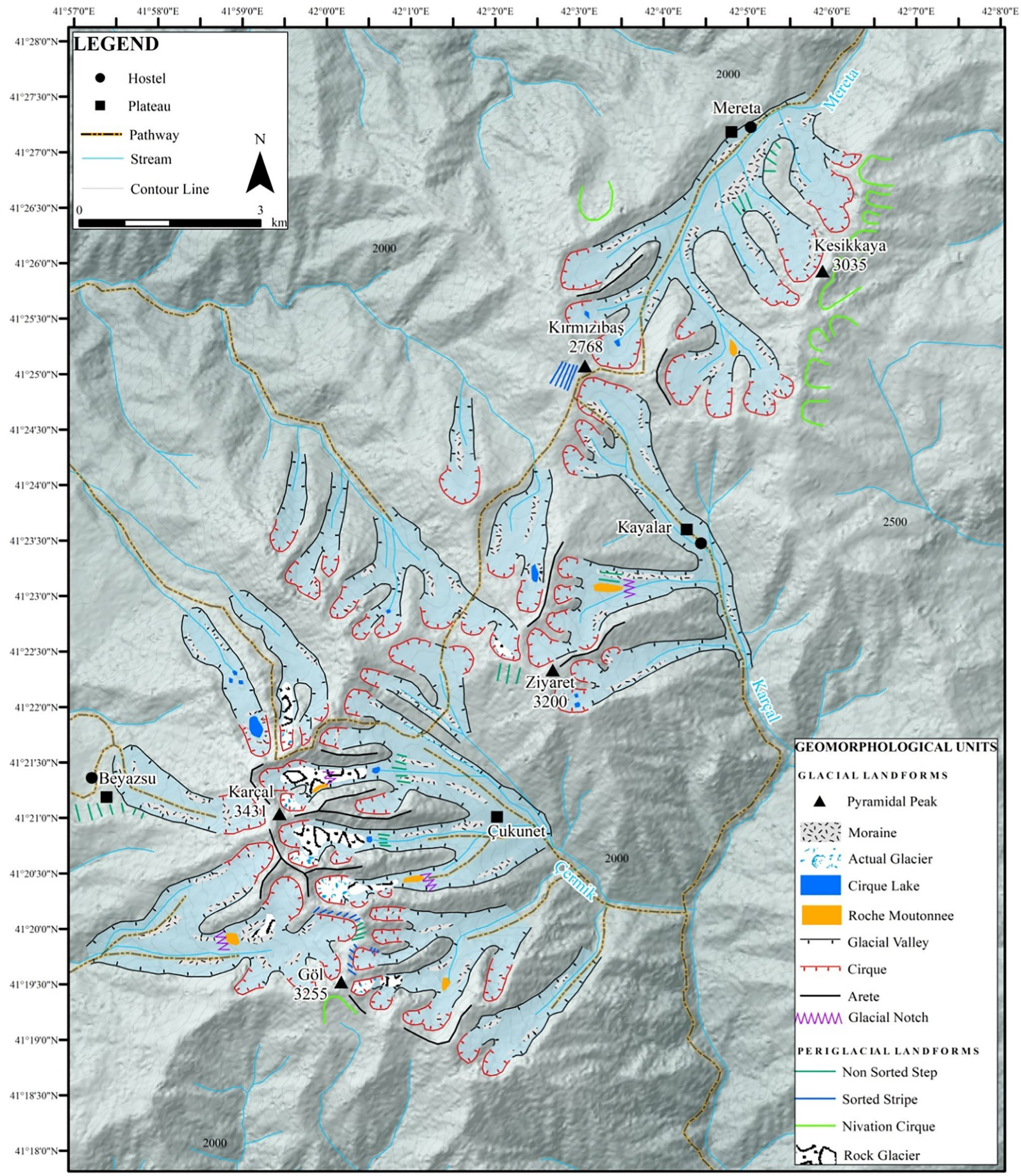

Fig. 4 Glacial and periglacial geomorphology map of Karçal Mountains (Dede 2016)

geoheritage evaluation in the current study. The implementation of the method consists of 4 stages (Karaca and Ulutaş 2018; Kumar et al. 2021; Kumar Vaid et al. 2022; Wang and Lee 2009; Zhu et al. 2020).

Step 1: A decision matrix (*X*) consisting of criteria and alternatives is created. Equation (1) is used to construct this matrix:


a
b
c
d
e
f
g
h

◂**Fig. 5** Glacial landforms in Karçal Mountains (**a** glacial valley, **b** cirque, **c** Moraine, **d** pyramidal peak, **e** arete, **f** roche moutonnee, **g** glacial notch, **h** glacial lake)

$$X = [X_{ij}]n \times m = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (1)$$

where X_{ij} is the preference of the i^{th} alternative with regard to the j^{th} criterion.

Step 2: The normalisation operations of the values in the decision matrix are calculated. The standardised value of the *i*th index in the *j*th example is denoted as p_{ij}, and the calculation method is carried out with the help of Eq. (2):

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}};\forall_j \quad (2)$$

Step 3: After the normalisation process, the entropy value of each criterion is calculated using the following Eq. (3).

$$e_j = -k.\sum_{i=1}^{m} p_{ij}.ln(p_j) i = 1,2,...,mandj = 1,2,...,n \quad (3)$$

where k is calculated by the formula: $k = \frac{1}{ln(m)}$, where m is a set of alternatives.

Step 4: Finally, the objective weight of each criterion is calculated using Eq. (4):

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \quad (4)$$

where the w_j value shown here indicates the weight of the *j*th criterion. As a result of all the mentioned stages, the weight values of the criteria are obtained.

WASPAS Method

WASPAS, Zavadskas et al. (2012), is one of the MCDM methods developed. This method is an MCDM approach that combines the results of two different models, WSM (weighted sum model) and WPM (weighted product model). The prioritisation of alternatives is done based on the combined optimality criteria value calculated from the results of these two models (Deveci et al. 2018; Prajapati et al. 2019). Also, this technique can check for consistency in alternative rankings by performing sensitivity analysis within its function (Chakraborty and Zavadskas 2014). The WASPAS technique was used in the present study due to the advantages it provides and its ability to be integrated with the entropy method. The stages of the WASPAS method are as follows (Ghorabaee et al. 2016; Zavadskas et al. 2012; Deveci et al. 2018; Tuş and Adalı 2019).

Step 1: A decision matrix (*X*) showing the performance of different alternatives according to various criteria is created using Eq. (1).

Step 2: The generated decision matrix is normalised. Equations (5) and (6) are used to normalise the benefit and cost criteria.

$$x_{ij}^{*} = \frac{x_{ij}}{max_i(x_{ij})} i = 1,2,...,mandj = 1,2,...,n \quad (5)$$

$$x_{ij}^{*} = \frac{min_i x_{ij}}{x_{ij}} i = 1,2,...,mandj = 1,2,...,n \quad (6)$$

where x_{ij}^{*} *j*th *i*th is the normalised performance value of the alternative according to the criterion.

Step 3: Based on weighted sum method (WSM), *i*, the overall relative importance of the alternative is calculated using Eq. (7).

$$Q_i^{(1)} = \sum_{j=1}^{n} x_{ij}^{*} w_j \quad (7)$$

Step 4: Based on weighted product method (WPM), *i*, the overall relative importance of the alternative is calculated using Eq. (8).

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(x_{ij}^{*}\right)^{w_j} \quad (8)$$

Step 5: The total relative importance of WSM and WPM for each alternative is combined with the help of Eq. (9). Thus, weighted combined final scores (Q_i) for each alternative are obtained.

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda)Q_i^{(2)} \quad (9)$$

where λ lies between 0 and 1.

Finally, the alternatives are ranked according to their Q values. The best alternative has the highest Q value. If the λ value is 0, WASPAS method is converted to WPM; if λ is 1, it is converted to WSM.

Entropy-WASPAS Application

Glacial and periglacial landforms are the subject of geoheritage assessment in the Karçal Mountains. It consists of G1-pyramidal peaks, G2-aretes, G3-glacial lakes and cirques, G4-moraines, G5-glacial valleys, G6-roche moutonnees and glacial notches, and G7-periglacial landforms

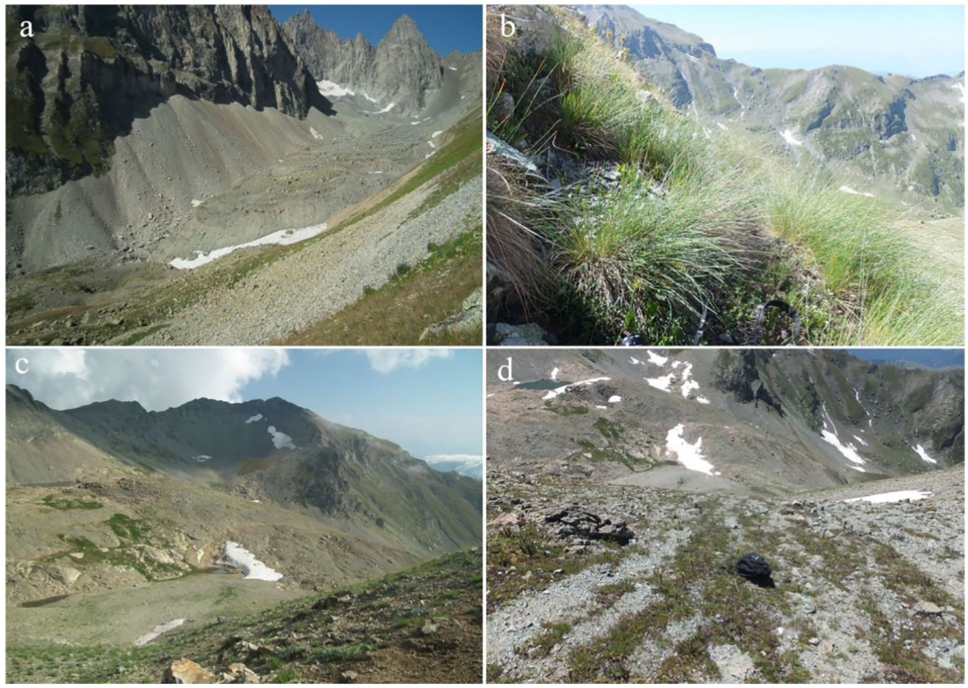

Fig. 6 Periglacial landforms in Karçal Mountains (**a** rock glacier, **b** non sorted step, **c** nivation cirque, **d** nons orted stripe)

(non sorted steps, rock glaciers, navigation cirques, and non sorted stripes). The mentioned elements were scored on a scale of 25–100 according to eight criteria obtained from the literature, and the criteria were weighted by following the application steps of the entropy method. At this stage, a decision matrix with criteria and alternatives was created using Eq. (1) (Table 2).

The values in the decision matrix are normalised with the help of Eq. (2). Table 3 shows the normalised decision matrix.

In the second step, the natural logarithm of each criterion value (p_{ij}) in Table 3 is taken (*lnfij*) to calculate the e_j and k values, and its value is multiplied by the obtained logarithm value. $p_{ij} \times In(f_{ij})$ values are presented in Table 4.

The e_j value is calculated in the next step by taking the sum of the values in Table 4 using Eq. (3). The entropy coefficient was found to be $k = 1/ln(m) = 0.5581$. Then, d_j uncertainty is obtained by subtracting 1 from each e_j value. At the last stage, w_j weight values are calculated with Eq. (4) to determine the importance of the j criterion. The values obtained in the last three stages are presented in Table 5.

After weighting the criteria with the entropy method, the priority values of the alternatives were calculated according to the weighted criteria using the WASPAS method. A decision matrix with criteria and alternatives is created at this stage, as in Table 2, using Eq. (1). The matrix in question is not given at this stage because it is the same as the matrix in the entropy method. The created decision matrix is normalised with the help of Eqs. (5) and (6). The criteria weights obtained by this matrix and entropy method are presented in Table 6.

Based on WSM i, the overall relative importance of the alternative ($Q_i^{(1)}$) is calculated using Eq. (7) (Table 7).

Based on WPM i, the overall relative importance of the alternative is calculated using Eq. (8) (Table 8).

WSM ($Q_i^{(1)}$) and WPM ($Q_i^{(2)}$) total relative importance values obtained for each alternative were combined with the help of Eq. (9) to get weighted combined final scores (*Qi*) for each alternative (Table 9). It has been determined that the G3 alternative with the highest value is in the first rank, while the G7 alternative, which is the lowest, is in the last rank.

In addition, the calculation of alternatives for different λ values is shown in Table 10. There was no change in the ranking of the alternatives in these values.

Results and Discussion

According to the findings obtained with the methodological approach proposed in the present study, the weights of the criteria are, respectively, state of preservation (0.1805), scientific value (0.1666), educational value (0.1598), accessibility and safety (0.1424), additional value (0.1075), aesthetic value (0.0525), and the touristic value is (0,0484). It has been determined that the most important element that can be considered geoheritage is glacial lakes and circuses. The geoheritage element with the lowest value was periglacial landforms. In addition, two different findings

Table 1 Criteria of assessment of geosites (Suzuki and Takagi 2018; Różycka and Migoń 2018)

Criteria	Characteristics (indicators)	Score
C1-scientific value	Distinctive in the region and scientifically well recognised	100
	Distinctive in the region and mentioned in literature	75
	Typical in the region and described in literature	50
	Typical in the region, no specific features	25
C2-educational value	At least one geoscience topic can be presented as an outstanding example	100
	More than one geoscience topic can be presented, including at least one being a good example	75
	One geoscience topic can be presented as a good example	50
	Very limited geoeducational use	25
C3-additional value	Significant object of cultural heritage or outstanding biological values (nature reserve)	100
	Moderately important object of cultural heritage or presence of valuable biotic elements	75
	Historical element of local importance and/or viewpoint	50
	No significant biological, cultural, or historical elements	25
C4-aesthetic value	Outstanding element of regional landscape and easy to appreciate in full size	100
	Distinctive element of regional landscape and easy to appreciate or outstanding element but with	75
	restricted visibility	50
	Typical element of regional landscape	25
	No specific aesthetic features	
C5-touristic value	High touristic value	100
	Moderate touristic value	75
	Low tourist value	50
	No touristic value	25
C6-accessibility	< 30 min	100
	30 min to 1 h	75
	1–2 h	50
	More than 2 h	25
C7-safety	Safe area	100
	Low risk of danger	75
	Moderate risk of danger	50
	Relatively dangerous (e.g., helmet and trekking shoes are required)	25
C8-state of preservation	No signs of degradation, well exposed	100
	Slightly damaged, partially overgrown	75
	Damaged, markedly overgrown, but main geological and geomorphological features are still visible	50
	Devastated, entirely overgrown, main geological and geomorphological features poorly exposed	25

Table 2 Decision matrix consisting of criteria and alternatives

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	Sum	Rank
G1	50,00	75,00	75,00	75,00	75,00	25,00	25,00	100,00	500	5
G2	50,00	75,00	75,00	100,00	75,00	25,00	25,00	100,00	525	4
G3	75,00	100,00	100,00	100,00	100,00	50,00	50,00	100,00	675	1
G4	75,00	100,00	50,00	25,00	25,00	50,00	50,00	75,00	450	6
G5	75,00	100,00	75,00	100,00	100,00	50,00	50,00	100,00	650	2
G6	75,00	100,00	50,00	75,00	50,00	50,00	50,00	100,00	550	3
G7	50,00	50,00	25,00	25,00	25,00	50,00	50,00	75,00	350	7

Table 3 Normalised decision matrix

Criterion	C1	C2	C3	C4	C5	C6	C7	C8
G1	0,111	0,125	0,167	0,150	0,167	0,083	0,083	0,154
G2	0,111	0,125	0,167	0,200	0,167	0,083	0,083	0,154
G3	0,167	0,167	0,222	0,200	0,222	0,167	0,167	0,154
G4	0,167	0,167	0,111	0,050	0,056	0,167	0,167	0,115
G5	0,167	0,167	0,167	0,200	0,222	0,167	0,167	0,154
G6	0,167	0,167	0,111	0,150	0,111	0,167	0,167	0,154
G7	0,111	0,083	0,056	0,050	0,056	0,167	0,167	0,115

Table 4 Weighting the normalised decision matrix with its natural logarithm

Criterion	C1	C2	C3	C4	C5	C6	C7	C8
G1	−0,2441	−0,2599	−0,2986	−0,2846	−0,2986	−0,2071	−0,2071	−0,2880
G2	−0,2441	−0,2599	−0,2986	−0,3219	−0,2986	−0,2071	−0,2071	−0,2880
G3	−0,2986	−0,2986	−0,3342	−0,3219	−0,3342	−0,2986	−0,2986	−0,2880
G4	−0,2986	−0,2986	−0,2441	−0,1498	−0,1606	−0,2986	−0,2986	−0,2492
G5	−0,2986	−0,2986	−0,2986	−0,3219	−0,3342	−0,2986	−0,2986	−0,2880
G6	−0,2986	−0,2986	−0,2441	−0,2846	−0,2441	−0,2986	−0,2986	−0,2880
G7	−0,2441	−0,2071	−0,1606	−0,1498	−0,1606	−0,2986	−0,2986	−0,2492

Table 5 e_j, d_j, and w_j values.

Criterion	C1	C2	C3	C4	C5	C6	C7	C8
e_j	1,0754	1,0724	1,0487	1,0238	1,0219	1,0645	1,0645	1,0817
d_j	−0,0754	−0,0724	−0,0487	−0,0238	−0,0219	−0,0645	−0,0645	−0,0817
w_j	0,1666	0,1598	0,1075	0,0525	0,0484	0,1424	0,1424	0,1805
$k=1/ln(m)$	0,5581							

Table 6 Normalised decision matrix

Criterion	C1	C2	C3	C4	C5	C6	C7	C8
G1	0,667	0,750	0,750	0,750	0,750	0,500	0,500	1,000
G2	0,667	0,750	0,750	1,000	0,750	0,500	0,500	1,000
G3	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
G4	1,000	1,000	0,500	0,250	0,250	1,000	1,000	0,750
G5	1,000	1,000	0,750	1,000	1,000	1,000	1,000	1,000
G6	1,000	1,000	0,500	0,750	0,500	1,000	1,000	1,000
G7	0,667	0,500	0,250	0,250	0,250	1,000	1,000	0,750
wj	0,1666	0,1598	0,1075	0,0525	0,0484	0,1424	0,1424	0,1805

Table 7 Total relative significance values based on WSM

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	$Q_i^{(1)}$
G1	0,1110	0,1199	0,0806	0,0394	0,0363	0,0712	0,0712	0,1805	0,71,005
G2	0,1110	0,1199	0,0806	0,0525	0,0363	0,0712	0,0712	0,1805	0,72,318
G3	0,1666	0,1598	0,1075	0,0525	0,0484	0,1424	0,1424	0,1805	1,00,000
G4	0,1666	0,1598	0,0537	0,0131	0,0121	0,1424	0,1424	0,1354	0,82,547
G5	0,1666	0,1598	0,0806	0,0525	0,0484	0,1424	0,1424	0,1805	0,97,313
G6	0,1666	0,1598	0,0537	0,0394	0,0242	0,1424	0,1424	0,1805	0,90,894
G7	0,1110	0,0799	0,0269	0,0131	0,0121	0,1424	0,1424	0,1354	0,66,316

Table 8 Total relative significance values based on WPM

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	$Q_i^{(2)}$
G1	0,9347	0,9551	0,9696	0,9850	0,9862	0,9060	0,9060	1,0000	0,69,015
G2	0,9347	0,9551	0,9696	1,0000	0,9862	0,9060	0,9060	1,0000	0,70,066
G3	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,00,000
G4	1,0000	1,0000	0,9282	0,9298	0,9351	1,0000	1,0000	0,9494	0,76,621
G5	1,0000	1,0000	0,9696	1,0000	1,0000	1,0000	1,0000	1,0000	0,96,955
G6	1,0000	1,0000	0,9282	0,9850	0,9670	1,0000	1,0000	1,0000	0,88,413
G7	0,9347	0,8951	0,8616	0,9298	0,9351	1,0000	1,0000	0,9494	0,59,504

Table 9 Ranking of alternatives

Alternatives	$Q_i^{(1)}$	$Q_i^{(2)}$	Q_i	Rank
G1	0,71,005	0,69,015	0,70,010	6
G2	0,72,318	0,70,066	0,71,192	5
G3	1,00,000	1,00,000	1,00,000	1
G4	0,82,547	0,76,621	0,79,584	4
G5	0,97,313	0,96,955	0,97,134	2
G6	0,90,894	0,88,413	0,89,654	3
G7	0,66,316	0,59,504	0,62,910	7

were obtained in ordering the alternatives, in other words, the geosites. The first of these is the findings obtained with the existing criteria and the indicator and scoring scale of these criteria (classical geosite assessment approach); the latter are the findings obtained with the Entropy-WASPAS approach (Table 11). According to the findings, with the classical evaluation, the priority of the geosites, which are in the first three and the last place in the Entropy-WASPAS approaches, has not changed. According to these approaches, the first three most essential geosites were G3, G5, and G6, respectively, while G7 was last. Apart from this, G1 and G2 have the fifth and fourth priority, respectively, in the classical approach, while in the Entropy-WASPAS approach, they have the sixth and fifth priority. Another remarkable finding is that the priority of G4 increased by two ranks with the Entropy-WASPAS approach (Table 11).

The detection of different findings according to the approaches is due to both the weighting of the criteria and the ability to make more objective and sensitive calculations with MCDM techniques. The geographical environments in which potential geosites are found and the conditions under which they develop require weighting of the criteria. In other words, the importance of the criteria used in geoheritage assessment may vary depending on the location and the element. However, even if a quantitative method is adopted in geoheritage assessment, the subjective judgements of evaluators need to be reduced (Różycka and Migoń 2018). However, Brilha (2016) stated that subjectivity could never be eliminated in geoheritage evaluation. Even in the quantification phase, it becomes impossible to avoid subjectivity, as the allocation of values for most criteria is again dependent on the evaluator's opinion (Pereira et al. 2007). The Entropy-based WASPAS technique used can make the evaluation results more objective. Indeed, Jia et al. (2022) used AHP and PCA methods together in their study to reduce subjectivity in geoheritage assessment and stated that they could prevent the illogicality of the evaluation results created by both methods. With the research findings, the adaptability of MCDM techniques to geoheritage assessment methods has been proven.

Table 10 Ranking of alternatives for different λ values

	λ=0	λ=0.1	λ=0.2	λ=0.3	λ=0.4	λ=0.5	λ=0.6	λ=0.7	λ=0.8	λ=0.9	λ=1
G1	0,69,015	0,69,214	0,69,413	0,69,612	0,69,811	0,70,010	0,70,209	0,70,408	0,70,607	0,70,806	0,71,005
G2	0,70,066	0,70,291	0,70,516	0,70,741	0,70,967	0,71,192	0,71,417	0,71,642	0,71,867	0,72,093	0,72,318
G3	1,00,000	1,00,000	1,00,000	1,00,000	1,00,000	1,00,000	1,00,000	1,00,000	1,00,000	1,00,000	1,00,000
G4	0,76,621	0,77,214	0,77,806	0,78,399	0,78,991	0,79,584	0,80,176	0,80,769	0,81,361	0,81,954	0,82,547
G5	0,96,955	0,96,991	0,97,027	0,97,063	0,97,098	0,97,134	0,97,170	0,97,206	0,97,241	0,97,277	0,97,313
G6	0,88,413	0,88,661	0,88,910	0,89,158	0,89,406	0,89,654	0,89,902	0,90,150	0,90,398	0,90,646	0,90,894
G7	0,59,504	0,60,186	0,60,867	0,61,548	0,62,229	0,62,910	0,63,591	0,64,273	0,64,954	0,65,635	0,66,316

Table 11 Findings according to two different approaches

Geosites	Classical geosite assessment approach	Rank	Geosite assessment approach with Entropy-WASPAS	Rank
G1-pyramidal peaks	500	5	0,70,010	6
G2-aretes	525	4	0,71,192	5
G3-glacial lakes and cirques	675	1	1,00,000	1
G4-moraines	450	6	0,79,584	4
G5-glacial valleys	650	2	0,97,134	2
G6-roche moutonnees and glacial notches	550	3	0,89,654	3
G7-periglacial landforms	350	7	0,62,910	7

Conclusion

This study aimed to evaluate the glacial and periglacial landforms detected in the Karçal Mountains as geoheritage with the Entropy-based WASPAS approach. Seven geosite groups sampled in the field were compared with eight geoheritage criteria obtained from the literature and scored on a numerical scale between 25 and 100. In the evaluation matrix, the criteria weights were obtained by following the steps of the entropy technique. It has been seen that the most important criteria are the conservation status and scientific value criteria. A decision matrix consisting of alternatives with the criterion weights obtained was analysed using the WASPAS technique. According to weighted criteria, it was determined that glacial lakes and circuses were the most important alternatives. The methodological approach proposed in the present research helps to establish a preliminary quantitative geoheritage assessment system for the landforms in the Karçal Mountains. In addition, applying this approach to geoheritage areas at different spatial scales will contribute to the literature on the subject.

Additionally, existing MCDM techniques can be integrated with fuzzy sets to avoid subjectivity. Thus, vague and ambiguous judgements of the experts who make the evaluation can be avoided. As a result, glacial and periglacial landforms have the potential to be used in scientific, educational, and touristic activities. Evaluated geosites can be used for local development by protecting them within the scope of possible geopark planning in the region.

Author Contribution VD designed the study and obtained the data from the field. KZ provided a methodological contribution by analysing the data.

Data Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

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