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A QUANTITATIVE-BASED ASSESSMENT OF THE VALUE OF GEOHERITAGE AND ITS USE FOR GEOTOURISM PURPOSES (FUZZY PIPRECIA-ROUGH WASPAS): THE CASE OF BAYBURT PROVINCE (TÜRKİYE)

Jeomiras Değerinin Nicel Analizi ve Jeoturizm Amaçlı Kullanımı (Bulanık PIPRECIA-Kaba WASPAS): Bayburt İli Örneği (Türkiye)

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ÖZET

Doğal mirasın ayrılmaz bir parçası olan jeomiras ögeleri, sürdürülebilir kalkınma ve bölgesel kalkınma süreçlerinde değişken değerlere sahip çeşitli kullanım potansiyelleri barındırmaktadır. Bu potansiyellerin rasyonel bir şekilde açığa çıkarılması ve jeoturizm faaliyetlerine kazandırılması, söz konusu ögelerin nicel değerlerinin somut parametrelerle belirlenmesiyle mümkündür. Bu bağlamda gerçekleştirilen çalışmada, Bayburt ili sınırları içerisinde belirlenen 14 jeositin bilimsel, eğitsel, ekonomik, jeokoruma ve ek değer faktörleri açısından önem derecelerinin bütüncül bir yaklaşımla değerlendirilmesi amaçlanmıştır. Değerlendirme sürecinde, çağdaş çok kriterli karar verme yöntemlerinden F-PIPRECIA (Bulanık Pivot İkili Karşılaştırmalı Kriter Önem Derecesi Değerlendirmesi) ve R-WASPAS (Kaba Kümelerle Ağırlıklandırılmış Toplam Çarpım Değerlendirmesi) metotları entegre bir şekilde analize dahil edilmiştir. Araştırma sonucunda, jeositlerin temel jeolojik, jeomorfolojik ve kültürel özellikleri tanımlanmış, kriterlerin ağırlık katsayıları hesaplanmış ve nihai olarak jeositlerin önem düzeyleri matematiksel olarak sıralanmıştır. Elde edilen bulgulara göre; G12 (Sırakayalar Şelalesi), G13 (Helva Köyü Buz Mağarası) ve G14 (Çımağıl Mağarası) incelenen tüm faktörler matrisinde "çok yüksek öneme sahip jeosit" olarak en üst sırada öne çıkarken; kültürel bir jeosit niteliği taşıyan G1 (Soğanlı Dağı Tarihi Yolu) ise ek değerler parametresinde bu grupta yer almıştır. Geriye kalan jeositlerin büyük bir bölümünün ise farklı çevresel ve lojistik faktörlere bağlı olarak yüksek, orta veya düşük önem derecesine sahip olduğu tespit edilmiştir. Bu çalışmanın, mevcut jeomiras değerlendirme ölçütlerini F-PIPRECIA ve R-WASPAS yöntemleriyle bütünleştirerek jeomiras değerlendirme literatürüne yöntemsel ve uygulamaya dönük katkı sağlaması beklenmektedir. Ayrıca elde edilen ampirik sonuçların, bölgede gelecekte yürütülecek potansiyel jeopark projelerinde, planlama süreçlerinde ve jeokoruma faaliyetlerinde karar verici pozisyondaki paydaşlar için uygulamaya yönelik pratik, sürdürülebilir ve stratejik perspektifler sağlayacağı öngörülmektedir.

ABSTRACT

Geoheritage elements, as an integral part of natural heritage, possess various utilization potentials with varying values in sustainable and regional development processes. The rational revelation of these potentials and their integration into geotourism activities are dynamic processes that depend on determining the quantitative values of the subject elements through tangible parameters. In this context, this study aims to evaluate 14 geosites identified in Bayburt Province and to comprehensively determine their significance levels in terms of scientific, educational, economic, geoconservation, and additional value factors. In the evaluation process, modern multi-criteria decision-making methods, namely F-PIPRECIA (Fuzzy-Pivot Pairwise Relative Criteria Relevance Assessment) and R-WASPAS (Rough-Weighted Aggregated Sum Product Assessment), were integrated into the analysis. As a result of the research, the main geological, geomorphological, and cultural characteristics of the geosites were described, criterion weighting coefficients were calculated, and the importance levels of the geosites were mathematically ranked. According to the empirical findings, G12 (Sırakayalar Waterfall), G13 (Helva Village Ice Cave), and G14 (Çımağıl Cave) stood out at the top of the matrix as "geosites of very high importance" across all analyzed factors, while G1 (Mount Soğanlı Historical Road), characteristically a cultural geosite, was included in this group under the additional values parameter. The vast majority of the remaining geosites were determined to possess high, medium, or low levels of importance, depending on various environmental and logistical factors. By integrating established geoheritage evaluation criteria with the F-PIPRECIA and R-WASPAS methods, this study is expected to provide a methodological and practice-oriented contribution to the geoheritage assessment literature. Furthermore, the obtained empirical results are anticipated to provide stakeholders and decision-makers with practical, sustainable, and strategic perspectives for future potential geopark projects, planning processes, and geoconservation activities in the region.

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1. INTRODUCTION

The valuation of geoheritage areas and sites has received increasing attention in recent years due to their potential for scientific, educational, and tourism use. Understanding this concept is crucial, as it plays a critical role in geoconservation efforts and initiatives. Geoheritage comprises selected elements of geodiversity whose significance justifies their identification, assessment, and conservation (Brilha 2016, 2018). Within this framework, geosites represent in situ occurrences of geodiversity with particular scientific significance, whereas geomorphosites refer specifically to geomorphological features and landforms recognised for their heritage value (Brilha 2016; Kubalíková and Kirchner 2016). Accordingly, the identification and assessment of geosites and geomorphosites constitute important components of geoconservation and provide a basis for their educational and geotourism use (Brilha 2016; Kubalíková and Kirchner 2016). The recognition of geoheritage as a resource providing socio-economic benefits (Habibi et al. 2018; Mikhailenko and Ruban 2019; Ruban et al. 2022; Sallam et al. 2022; Zorlu et al. 2024a, b; Zorlu et al. 2025) has also highlighted its diverse potential uses. Despite considerable attention to its potential use, the actual patterns of this resource utilisation are not yet fully understood (Ruban et al. 2022). Undoubtedly, geotourism activities that provide economic benefits to local communities (Farsani et al. 2011) are the most prominent aspect of this resource utilisation. The term “geotourism” was initially defined as “the provision of interpretive and service facilities to enable tourists to gain knowledge and understanding of the geology and geomorphology of an area beyond mere aesthetic evaluation” (Hose 1995). From a broader perspective, geotourism has evolved as a form of nature tourism, known as the ABC (abiotic-biotic-culture) approach, which focuses on landscape and geology while also incorporating biotic and cultural characteristics linked to the abiotic nature (Kubalíková 2019). This paradigm shift in geotourism has occurred in parallel with the development of nature conservation policies worldwide. In Türkiye, a growing number of studies have focused on the identification, characterization, and assessment of geoheritage resources (Çiftçi and Güngör 2021; Güney 2020; Erginal et al. 2021; Doğan et al. 2019; Eraslan et al. 2023; Zorlu et al. 2022; Dede and Zorlu 2023; Karadeniz et al. 2022; Kazancı 2012; Kazancı et al. 2015; Kazancı et al. 2019; Köroğlu and Kandemir 2019; Köroğlu and Mülayim 2023; Özer and Mülayim 2022; Özkul et al. 2024; Zorlu and Dede 2023a, b; Zorlu et al. 2023, 2024a, b; Canpolat et al. 2026; Efe et al. 2026). Although these studies demonstrate increasing scholarly interest in geoheritage, research remains spatially uneven and is largely concentrated on selected regions and individual case studies. Consequently, systematic geoheritage inventories and comprehensive assessments are still limited in many parts of Türkiye. Therefore, greater attention should be directed toward areas that have not yet been examined in detail but possess rich geological diversity, as also emphasized by Yashalova and Ruban (2024). Although several studies have examined individual geological, geomorphological, archaeological, and tourism-related features in Bayburt Province, these studies have generally focused on specific sites or particular aspects of their natural and cultural characteristics. For instance, previous research has addressed Sırakayalar Waterfall (Doğanay 2000), the ecotourism potential of Çımağıl Cave and its surroundings (Birinci and Zaman 2016), the architectural and functional characteristics of Aydıntepe Underground City (Metin and Yılmaz 2023), and the geological and gemological characteristics of amber occurrences in the Bayburt region (Başar 2021). However, these site-specific studies have not provided an integrated, province-scale comparative assessment of multiple geosites based on a common set of scientific, educational, economic, geoconservation, and additional-value criteria. Accordingly, an important gap remains in the systematic and quantitative evaluation of Bayburt's geoheritage resources within a unified decision-making framework. Therefore, this study aims to define the characteristics of fourteen geosites identified in Bayburt province and to determine their values according to various factors using F-PIPRECIA (Fuzzy-Pivot Pairwise Relative Criteria Relevance Assessment) and R-WASPAS (Rough-Weighted Aggregated Sum Product Assessment) methods. To achieve this aim, this study addresses the following research questions: (i) What are the main geological, geomorphological, and cultural characteristics of the geosites identified in Bayburt Province? (ii) What is the level of scientific, educational, economic, conservation, and additional value of the identified geosites? (iii) What can be done to address the conservation and utilisation problems of these geosites This study is expected to contribute methodologically and practically to the geoheritage literature by integrating F-PIPRECIA and R-WASPAS methods for the comparative evaluation of geosites. This methodological choice is not based solely on the novelty of combining the two methods. F-PIPRECIA was selected because it enables the weighting of a relatively large number of criteria without requiring their prior ranking and incorporates fuzzy linguistic evaluations to better represent uncertainty in expert judgments. R-WASPAS, on the other hand, combines the weighted sum and weighted product approaches and incorporates rough numbers to represent uncertainty, ambiguity, and imprecision in expert-based evaluations of the alternatives. Their integration therefore provides a two-stage decision-making framework in which uncertainty is addressed both in the determination of criterion weights and in the comparative ranking of geosites. In this respect, the proposed approach addresses methodological limitations that may arise in expert-based multi-criteria assessments, particularly the need for predetermined criterion ordering and the treatment of subjective judgments as exact values, rather than introducing the method combination solely for the sake of novelty. Furthermore, the findings are expected to provide practical insights for stakeholders involved in future geopark planning, geoconservation initiatives, and geotourism development in Bayburt Province.

2. STUDY AREA AND GEOLOGICAL SETTINGS

The research area is located in northeastern Türkiye, within the borders of Bayburt province and in the Çoruh River basin (Figure 1). To the north of the study area are the provinces of Gümüşhane, Trabzon, and Rize, while to the south are the provinces of Erzurum and Erzincan. The study area is situated behind the Eastern Black Seamountain range, between the Soğanlı Mountains to the north and the Otlukbeli Mountains to the south, in a predominantly plateau-like terrain, exhibiting a morphological structure extending approximately in a southwest-northeast direction (Uzun, 1993).

The study area encompasses the Bayburt province in northeastern Türkiye, situated within the Eastern Pontides belt (Okay and Tüysüz 1999), one of the primary tectonic units that form the Anatolian plate (Arslan et al. 2005; Danacı 2009). This region is situated within the southern zone of the Eastern Pontides as defined by Özsayar et al. (1981) (Arslan et al. 2005; Kaygusuz and Vural 2024). Within the regional geological framework, the foundation of the study area comprises Palaeozoic rocks, including the Pulur Metamorphics (Palaeozoic), also known as the Hercynian basement, and the Gümüşhane Granite (Yılmaz 2002; Demirbağ 2023). The study area also exposes rocks such as the Dogger-Malm-Lower Cretaceous

Hozbirikyayla Formation and the Lower-Middle Eocene volcanosedimentary units, the Yazyurdu Formation (Keskin et al. 1989; Kaygusuz and Vural 2024). These Eocene volcanosedimentary units are unconformably overlain by Miocene lacustrine sedimentary rocks and Quaternary units in the south of the region (Demirbağ 2023).

Figure 1: Location of the research area.

As shown in Figure 2, the spatial distribution and morphological characteristics of the investigated geosites are closely related to the lithological diversity of Bayburt Province. In the northern part of the study area, G1 (Mount Soğanlı Historical Road) is associated with Carboniferous granitoid basement rocks, whereas G2 (Somarova Tor Topography) developed on the Middle Eocene Somarova Pluton, which is mainly composed of diorite, tonalite, and granodiorite; weathering of these intrusive rocks played an important role in the development of the tor morphology (Yılmaz 2002; Demirbağ 2023; Kaygusuz and Vural 2024). In the western and central parts, G3 (Nişantaşı Gorge Valley) and G4 (Dragon Rocks) are associated with a valley system cutting Mesozoic, Eocene, and Miocene units, particularly the volcanosedimentary lithologies of the Yazyurdu Formation, while G5 (Aydıntepe Underground City) was excavated within Eocene tuff layers and G6 (Çiğdemtepe Mound) and G9 (Baksı Meanders) are also spatially associated with Eocene volcanosedimentary units (Uzun 1990; Keskin et al. 1989; Arslan et al. 2005; Metin and Yılmaz 2023). In the northeastern part, G7 (Aydıncık Amber Mining Area) is related to amber-bearing levels within the Eocene Sırataşlar Formation, whereas G11 (Dikmetaş Dike) represents an intrusive body cutting the Paleozoic metamorphic basement (Başar 2021; Demirbağ 2023). Lithological control is particularly evident in the southern part of the province, where G12 (Sırakayalar Waterfall) developed over Quaternary travertine layers, while G13 (Helva Village Ice Cave) and G14 (Çımağıl Cave) formed within Jurassic–Lower Cretaceous limestones that provided favourable conditions for karstification and cave development (Doğanay 2000; Birinci and Zaman 2016). Therefore, lithological differences, together with tectonic and geomorphological processes, have played an important role in controlling the formation, morphology, and spatial distribution of the geosites examined in Bayburt Province.

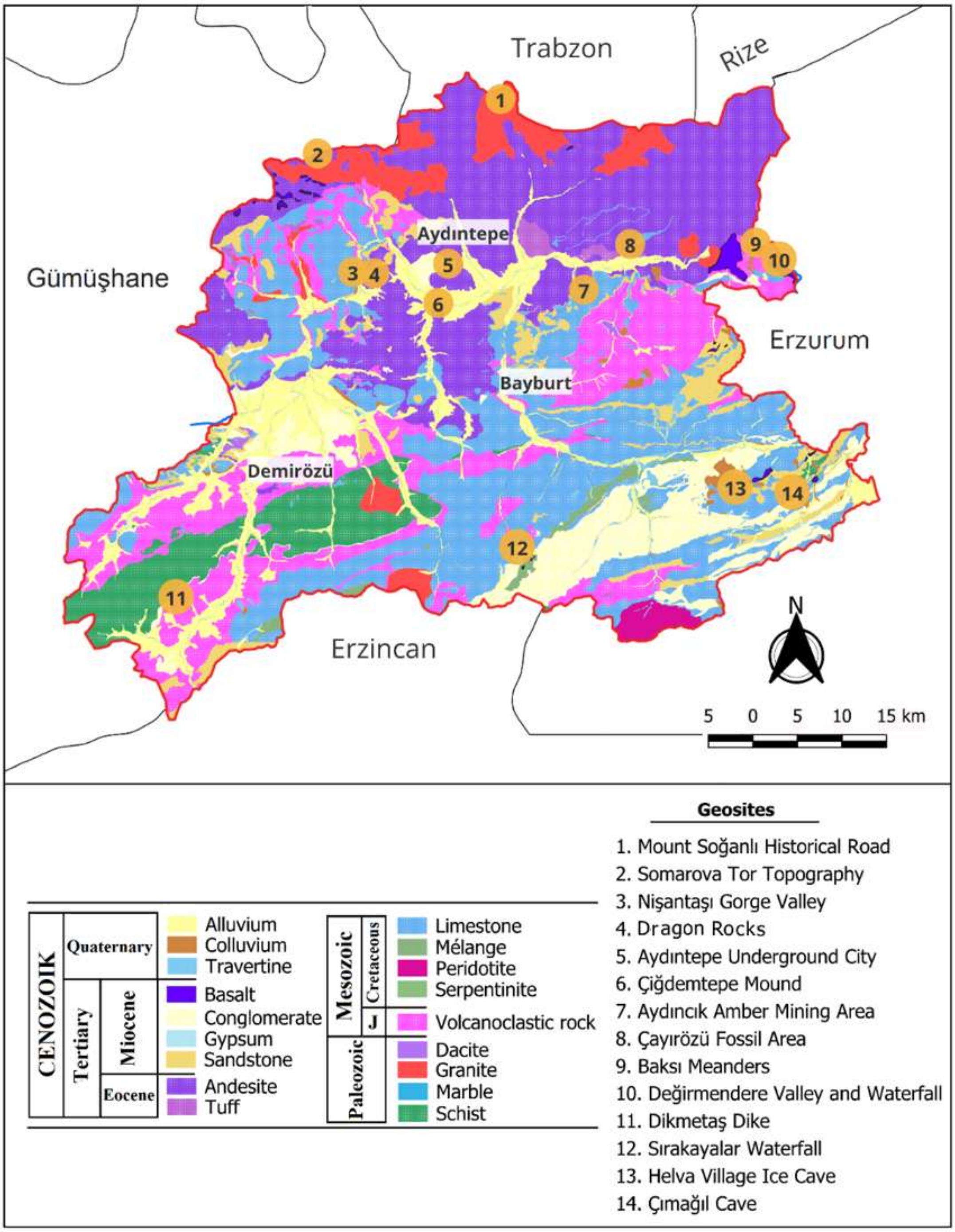

Figure 2: Geology of the research area and distribution of the geosites studied.

The Bayburt region is situated within the southern zone of the Eastern Pontides (Özsayar et al. 1981; Arslan et al. 2005; Danacı 2009; Demirbağ 2023). Elevations in the region reach approximately 3,500 m, although the principal peaks within the study area are the Soğanlı Mountains (3,082 m) and the Otlukbeli Mountains (2,976 m) (Uzun 1993; Demirbağ 2023). The geomorphological development of the study area exhibits a polygenic character resulting from the combined influence of tectonic, lithological, fluvial, and climatic processes (Uzun 1990). The present-day landscape is characterised by a predominantly plateau-like relief dissected by valleys and locally bordered by mountainous areas. Tectonic uplift and deformation have promoted river incision and the development of deeply incised valleys, while different stages of uplift have contributed to the formation of stepped topographic surfaces and terrace-like levels, particularly in the western part of the province (Uzun 1990; Demirbağ 2023). In carbonate terrains, lithological conditions have also favoured karstification and the development of cave systems, as exemplified by the Helva Village Ice Cave and Çımağıl Cave. Thus, the current geomorphology of Bayburt reflects the combined effects of tectonic evolution, lithological contrasts, fluvial erosion, karst processes, and climatic controls. The geological structures observed in the region also reflect a complex tectonic evolution. While compressional structures such as reverse faults, thrusts, and folds occur near the suture zone in the south, the effects of the extensional tectonic regime that developed after the Middle Eocene are dominant in Bayburt and its surroundings (Demirbağ 2023). This extensional regime resulted in NW–SE-trending deformation and the development of normal, strike-slip, and listric faults, together with horst and graben structures such as the Vızvız Dağı horst (Demirbağ 2023). Eocene volcanism also exhibits regional variations. In the Bayburt region (Southern Zone), the "Bayburt Tuffs" related to Eocene rhyodacitic–dacitic felsic volcanism are dominant (Arslan et al. 2005; Demirbağ 2023), whereas more widespread calc-alkaline volcanic sequences, including andesite and basalt, occur in the northern parts.

3. MATERIALS AND METHODS

3.1. Operations on Fuzzy Numbers

If the membership function $\mu_{\tilde{A}}(x): R \rightarrow [0,1]$ is equal to Equation (1), then a fuzzy number $\tilde{A}$ on R will be a triangular fuzzy number (TFN):

$$\mu_{\tilde{A}}(x) \begin{cases} \frac{x-l}{m-l} & l \leqslant x \leqslant m \\ \frac{u-x}{u-m} & m \leqslant x \leqslant u \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where, l represents the lower bound and u the upper bound of the fuzzy number $\tilde{A}$, and m is the modal value. It can be written as TFN $\tilde{A}=(l,m,u)$.

The operations for TFN $\tilde{A}_1=(l_1,m_1,u_1)$ and $\tilde{A}_2=(l_2,m_2,u_2)$are as follows:

(1) Addition:

$$\tilde{A}_1 \oplus \tilde{A}_2=(l_1,m_1,u_1)+(l_2,m_2,u_2)= (l_1+l_2,m_1+m_2,u_1+u_2) \quad (2)$$

(2) Multiplication:

$$\tilde{A}_1 \otimes \tilde{A}_2=(l_1,m_1,u_1)\otimes(l_2,m_2,u_2)= (l_1 \times l_2,m_1 \times m_2,u_1 \times u_2) \quad (3)$$

(3) Subtraction:

$$\tilde{A}_1 \ominus \tilde{A}_2=(l_1,m_1,u_1)-(l_2,m_2,u_2)= (l_1-u_2,m_1-m_2,u_1-l_2) \quad (4)$$

(4) Division:

$$\frac{\tilde{A}_1}{\tilde{A}_2}=\frac{(l_1,m_1,u_1)}{(l_2,m_2,u_2)}=\left(\frac{l_1}{u_2},\frac{m_1}{m_2},\frac{u_1}{l_2}\right) \quad (5)$$

(5) Reciprocal:

$$\tilde{A}_1^{-1}=(l_1,m_1,u_1)^{-1}=\left(\frac{1}{u_1},\frac{1}{m_1},\frac{1}{l_1}\right) \quad (6)$$

3.2. Basic notions of rough sets

In RS theory, an ambiguous viewpoint can be represented based on lower and upper approximations (Figure 3) (Zavadskas et al. 2018). In this study, MCDM methods integrated with rough set theory were used to address uncertain and ambiguous information that may arise in the evaluation of geoheritage resources. The fundamental principles of rough sets (Pamučar et al. 2018; Zavadskas et al. 2018; Zorlu et al. 2024a) are discussed in the following section.

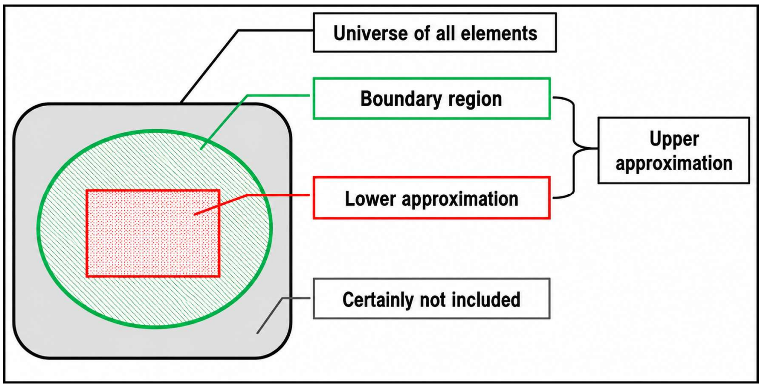

Figure 3: Elementary concept of rough set theory (Zavadskas et al. 2018).

Let's assume *U* is a universe containing all objects and X is a random object from *U*. Then, it is assumed that there exists a set $R=(J_1,J_2,...,J_k)$ with k classes expressing the preferences of DMs and the conditional $J_1<J_2<,...,J_k$. Then, the lower approximation $\forall X \in U, J_q \in R, 1 \leqslant q \leqslant k$ the upper approximation $\underline{Apr}(J_q)$ and the boundary interval $Bnd(J_Q)$ are obtained as follows:

$\underline{Apr}(J_q)=\{X \in U/R(X) \leqslant J_q\}$	(7)
$\overline{Apr}(J_q)=\{X \in U/R(X) \geqslant J_q\}$	(8)
$Bnd(J_q)=\{X \in U/R(X) \neq J_q\}=\{X \in U/R(X)>J_q\} \cup \{X \in U/R(X)<J_q\}$	(9)

The object can be viewed via a rough number (*RN*) defined by the lower limit $\underline{Lim}(J_q)$ and the upper limit $\overline{Lim}(J_q)$ respectively:

$\underline{Lim}(J_q)=\frac{1}{M_L}\sum R(X) \mid X \in \underline{Apr}(J_q)$	(10)
$\overline{Lim}(J_q)=\frac{1}{M_U}\sum R(X) \mid X \in \overline{Apr}(J_q)$	(11)

where, M_L, M_U are the number of objects in $\underline{Apr}(J_q)$ and $\overline{Apr}(J_q)$ respectively. The difference between them is roughly expressed as the boundary interval $\left(IRBnd(J_q)\right)$.

$IRBnd(J_q)=\overline{Lim}(J_q)-\underline{Lim}(J_q)$	(12)

Operations for two rough numbers $RN(a)=[\underline{Lim}(a),\overline{Lim}(a)]$ and $RN(\beta)=[\underline{Lim}(\beta),\overline{Lim}(\beta)]$

(1) Addition of two RNs (a) and (β):

$RN(a)+RN(\beta)=[\underline{Lim}(a)+\underline{Lim}(\beta),\overline{Lim}(a)+\overline{Lim}(\beta)]$	(13)

(2) Subtraction of two RNs (a) and (β):

$RN(a)-RN(\beta)=[\underline{Lim}(a)-\overline{Lim}(\beta),\overline{Lim}(a)-\underline{Lim}(\beta)]$	(14)

(3) Multiplication of two RNs (a) and (β):

$RN(a)\times RN(\beta)=[\underline{Lim}(a)\times\underline{Lim}(\beta),\overline{Lim}(a)\times\overline{Lim}(\beta)]$	(15)

(4) Division of two RNs (a) and (β):

$RN(a)\div RN(\beta)=[\underline{Lim}(a)\div\overline{Lim}(\beta),\overline{Lim}(a)\div\underline{Lim}(\beta)]$	(16)

(5) The scalar product of the rough number *RN(α)* where *μ* is a non-zero constant:

$\mu\times RN(a)=[\mu\times\underline{Lim}(a),\mu\times\overline{Lim}(a)]$	(17)

3.3. The F-PIPRECIA Method

The F-PIPRECIA is known as a new multi-criteria decision-making technique developed by Stević et al. (2018). Compared to the SWARA method, a commonly used criterion weighting technique, F-PIPRECIA offers significant advantages in decision problems with a large number of criteria because it does not require prior ranking of the criteria (Đalić et al. 2020; Stević et al. 2018). Furthermore, since this method utilises fuzzy scales in the evaluation of criteria, it contributes to a more objective determination of criterion weights (Yenilmezel and Ertuğrul 2024). The F-PIPRECIA method has been successfully applied and validated in various subject areas by numerous researchers (Blagojević et al., 2020; Đalić et al. 2020; Yenilmezel and Ertuğrul 2024; Stanković et al. 2020; Stević et al. 2018; Tanrıverdi et al. 2025; Zorlu and Dede 2024). However, its application to the evaluation of geoheritage has not been encountered. Due to the advantages offered by the method, the use of F-PIPRECIA in determining the weights of the criteria used in evaluating geoheritage was deemed appropriate in this study. The F-PIPRECIA method consists of the 10 steps shown below (Stević et al. 2018; Tanrıverdi et al. 2025; Zorlu and Dede 2024; Vesković et al. 2020):

Step 1: A set of criteria is created for evaluation by experts. In this step, all criteria are listed from the first to the last without being classified.

Step 2: To determine the relative importance of the criteria, each decision-maker evaluates the pre-listed criteria individually, starting with the second criterion, as shown in Equation 18.

$$\bar{s}_j^r = \begin{cases} >\bar{1} \text{ if } C_j > C_j\text{-}1 \\ =\bar{1} \text{ if } C_j = C_j\text{-}1 \\ <\bar{1} \text{ if } C_j < C_j\text{-}1 \end{cases} \quad (18)$$

where, $\bar{s}_j^r$ represents the evaluation of the criteria by r decision-makers. Then, to obtain a linguistic matrix $\bar{s}_j$, it is necessary to take the average of the $\bar{s}_j^r$ matrix using the geometric mean. Decision-makers evaluate the criteria by applying the scales defined in Tables 1 and 2.

Step 3: The coefficient $\bar{k}_j$ is determined as in Equation (19).

$$\bar{k}_j = \begin{cases} = 1 \; if \; j = 1 \\ 2 - \bar{s}_j \; if \; j > 1 \end{cases} \quad (19)$$

Step 4: Fuzzy weight values ($\bar{q}_j$) are determined.

$$\bar{q}_j = \begin{cases} =\bar{1} \text{ if } j=1 \\ \dfrac{\overline{q_j\text{-}1}}{\bar{k}_j} \text{ if } j>1 \end{cases} \quad (20)$$

Table 1: Scale 1–2 for evaluation of criteria.

Linguistic term			TFNs			
			l	*m*	*u*	DFV
Almost equal value		1	1.000	1.000	1.050	1.008
Slightly more significant		2	1.100	1.150	1.200	1.150
Moderately more significant		3	1.200	1.300	1.350	1.292
More significant	Scale 1-2	4	1.300	1.450	1.500	1.433
Much more significant		5	1.400	1.600	1.650	1.575
Dominantly more significant		6	1.500	1.750	1.800	1.717
Absolutely more significant		7	1.600	1.900	1.950	1.858

Table 2: Scale 0-1 for evaluation of criteria.

TFNs						Linguistic term
l	*m*	*u*	DFV			
0.667	1.000	1.000	0.944	1*		Weakly less significant
0.500	0.667	1.000	0.694	2*		Moderately less significant
0.400	0.500	0.667	0.511	3*		Less significant
0.333	0.400	0.500	0.406	4*	Scale 0-1	Really less significant
0.286	0.333	0.400	0.337	5*		Much less significant
0.250	0.286	0.333	0.288	6*		Dominantly less significant
0.222	0.250	0.286	0.251	7*		Absolutely less significant

Step 5: Determining the relative weight of the criterion $\overline{w_j}$.

$$\overline{w_j}=\frac{\overline{q_j}}{\sum_{j=1}^{n}\overline{q_j}} \quad (21)$$

The next steps involve implementing the inverse fuzzy PIPRECIA method.

Step 6: Starting from the penultimate criterion, the evaluation between the criteria is carried out as shown in Tables 1 and 2.

$$\overline{s_j^{r'}}=\begin{cases} >\bar{1} \text{ if } C_j>C_j+1 \\ =\bar{1} \text{ if } C_j=C_j+1 \\ <\bar{1} \text{ if } C_j<C_j+1 \end{cases} \quad (22)$$

Step 7: The coefficient $\overline{k_j^{'}}$ is determined as in Equation (23).

$$\overline{k_j^{'}}=\begin{cases} =1 \text{ if } j=n \\ 2-\overline{s_j^{'}} \text{ if } j>n \end{cases} \quad (23)$$

Step 8: Fuzzy weight values ($\overline{q_j^{'}}$) are determined.

$$\overline{q_j^{'}}=\begin{cases} \bar{1} \quad j=n \\ \dfrac{\overline{q_{j-1'}}}{\overline{k_{j'}}} \text{ if } j<n \end{cases} \quad (24)$$

Step 9: Determine the relative weight of the criterion $\overline{w_j^{'}}$.

$$\overline{w_j^{'}}=\frac{\overline{q_j^{'}}}{\sum_{j=1}^{n}\overline{q_j^{'}}} \quad (25)$$

Step 10: To determine the final weights of the criteria, the average value of $\overline{w_j^{''}}$ needs to be calculated.

$$\overline{w_j^{''}}=\frac{\overline{w_j}+\overline{w_j^{'}}}{2} \quad (26)$$

3.4. R-WASPAS Method

The WASPAS method was proposed by Zavadskas et al. (2012). As a new method, it is frequently used as the most suitable MCDM method for accuracy-based or confirmation purposes, combining two methods (Weighted Sum Model and Weighted Product Model). Later studies (Stojić et al. 2018) extended the WASPAS method to incorporate rough numbers to represent uncertainty, ambiguity, and imprecision. The use of the R-WASPAS method for ranking geoheritage elements according to their importance levels has not been found in the literature. The steps of R-WASPAS are as follows (Sremac et al. 2018; Stojić et al. 2018):

Step 1: Formulation of a model consisting of *m* alternatives and *n* criteria.

Step 2: Formation of a team of *k* experts to evaluate the alternatives according to all criteria.

Step 3: Creation of initial individual matrices based on the evaluations made by the experts. It is necessary to create as many individual matrices as there are experts.

Step 4: Conversion of the individual matrix into a group rough matrix. Each matrix consisting of $k_1,k_2,\ldots k_n$ experts need to be converted into a rough group matrix (RGM):

$$RGM=\begin{bmatrix} [x_{11}^L,x_{11}^U] & [x_{12}^L,x_{12}^U] & \cdots & [x_{1n}^L,x_{1n}^U] \\ [x_{21}^L,x_{21}^U] & [x_{22}^L,x_{22}^U] & \cdots & [x_{2n}^L,x_{2n}^U] \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ [x_{m1}^L,x_{m1}^U] & [x_{m2}^L,x_{m2}^U] & \cdots & [x_{mn}^L,x_{mn}^U] \end{bmatrix} \quad (27)$$

Step 5: In this step, the previous matrix needs to be normalized using Equations (28) and (29):

$$n_{ij}=\frac{[x_{ij}^L;x_{ij}^U]}{\max[x_{ij}^{+L};x_{ij}^{+U}]} \text{ for } c_1,c_2,c_3\ldots c_n \in B \quad (28)$$

$$n_{ij}=\frac{\min[x_{ij}^{-L};x_{ij}^{-U}]}{[x_{ij}^L;x_{ij}^U]} \text{ for } c_1,c_2,c_3\ldots c_n \in B \quad (29)$$

where, $[x_{ij}{}^L;x_{ij}{}^U]$ denotes the values taken from the initial rough group matrix; $\max[x_{ij}{}^{+L};x_{ij}{}^{+U}]$ represents the maximum value of the criterion if it belongs to the same set of benefit criteria, and $\min[x_{ij}{}^{-L};x_{ij}{}^{-U}]$ represents the minimum value of the criterion if it belongs to the same set of cost criteria.

Values are marked with “+” and “-” to make it easier to recognise the same criteria belonging to different types of criteria. In the empirical application of this study, all 18 sub-criteria were operationalized in the benefit direction, such that higher expert scores indicate more favourable conditions for geoheritage value. In particular, GV1 (Actual threats and risks) and GV2 (Potential threats and risks) were evaluated inversely in terms of threat intensity: higher scores indicate lower actual or potential threats, whereas lower scores indicate higher levels of threat or risk. Similarly, higher scores for GV3 (Current status of site) indicate a better-preserved site condition, while higher scores for GV4 (Legislative protection) indicate stronger protection. Accordingly, the benefit-criterion normalization was applied to the empirical decision matrices. The cost-criterion formulation is retained above only as part of the general R-WASPAS procedure. Equations (30) and (31) can be written in a simpler way as follows:

$$n_{ij}=\left[\frac{x_{ij}^{L}}{x_{ij}^{+U}};\frac{x_{ij}^{U}}{x_{ij}^{+L}}\right] \text{for } c_1,c_2,c_3...c_n \in C \tag{30}$$

$$n_{ij}=\left[\frac{x_{ij}^{-L}}{x_{ij}^{U}};\frac{x_{ij}^{-U}}{x_{ij}^{L}}\right] \text{for } c_1,c_2,c_3...c_n \in C \tag{31}$$

and a normalised matrix similar to Equation (32) is obtained:

$$NM=\begin{bmatrix} [n_{11}^{L},n_{11}^{U}] & [n_{12}^{L},n_{12}^{U}] & \cdots & [n_{1n}^{L},n_{1n}^{U}] \\ [n_{21}^{L},n_{21}^{U}] & [n_{22}^{L},n_{22}^{U}] & \cdots & [n_{2n}^{L},n_{2n}^{U}] \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ [n_{m1}^{L},n_{m1}^{U}] & [n_{m2}^{L},n_{m2}^{U}] & \cdots & [n_{mn}^{L},n_{mn}^{U}] \end{bmatrix} \tag{32}$$

Step 6: The normalised matrix is weighted by multiplying the previously obtained matrix by the weighted values of the criteria using Equation (33).

$$V_n=[v_{ij}^{L};v_{ij}^{U}]_{m\times n}$$
$$v_{ij}^{L}=w_j^{L}\times n_{ij}^{L},\ i=1,2,...,m \tag{33}$$
$$v_{ij}^{U}=w_j^{U}\times n_{ij}^{U},\ i=1,2,...,m$$

where, w_j^L is the lower limit of the weight value of the criterion obtained by applying one of the multi-criteria decision-making methods to determine the significance of the criteria, and w_j^U is the upper limit.

Step 7: All the values of the alternatives obtained with equation (34) are summed up:

$$Q_i=[q_{ij}^{L},q_{ij}^{U}]_{1\times m}$$
$$q_{ij}^{L}=\sum_{j=1}^{n} v_{ij}^{L},\ q_{ij}^{U}=\sum_{j=1}^{n} v_{ij}^{U} \tag{34}$$

Step 8: The weighted product model is determined using equation (35):

$$P_i=[p_i^{L},p_i^{U}]_{1\times m}$$
$$p_i^{L}=\prod_{j=1}^{n}(n_{ij}^{L})^{w_j^{L}} \tag{35}$$
$$p_i^{U}=\prod_{j=1}^{n}(n_{ij}^{U})^{w_j^{U}}$$

In this study, the WPM component of the R-WASPAS method was calculated following the formulation of Stojić et al. (2018). Accordingly, the lower and upper bounds of the weighted normalized rough values, vijL and vijU, obtained in Equation (33), were raised to the corresponding criterion weights and multiplied across the criteria, as shown in Equation (35).

Step 9: Relative values of alternative A_i are determined using equation (36):

$$A_i=[a_{ij}^{L},a_{ij}^{U}]_{1\times m}$$
$$A_i=\lambda\times Q_i+(1-\lambda)\times P_i \tag{36}$$

The coefficient λ can have net values in the range of *0, 0.1, 0.2,..., 1.0,* but it is recommended to apply Equation (37) in its calculation:

$$\lambda=0.5+\frac{\sum P_i}{\sum Q_i+\sum P_i}=0.5+\frac{\sum[p_{ij}^{L},p_{ij}^{U}]}{\sum[q_{ij}^{L},q_{ij}^{U}]+\sum[p_{ij}^{L},p_{ij}^{U}]} \tag{37}$$

Step 10: Ranking the alternatives. The highest value for an alternative reflects the best ranking, while the lowest value reflects the worst.

3.5. Proposed Approach

In this study, 14 geosites identified in Bayburt province were evaluated according to various criteria using the methods presented above. The study consisted of three main stages: defining the geosites and evaluation criteria, as well as adapting the proposed methods (Figure 4). The first stage involved identifying and characterizing geosites in Bayburt Province through fieldwork and a review of the relevant geological, geomorphological, archaeological, and tourism-related literature. The 14 geosites evaluated in this study were not selected from an exhaustive provincial inventory; rather, they represent the sites identified, documented, and examined within the scope of the present research. Accordingly, the study does not claim that these 14 sites comprise all potential geoheritage resources in Bayburt Province. The evaluation framework retained the five main criteria and 18 sub-criteria reported by Ghosh et al. (2021), namely scientific, educational, economic, geoconservation, and additional values. No criteria were added to or removed from the original criterion structure. The adaptation in the present study concerned the quantitative evaluation procedure: criterion weights were determined using F-PIPRECIA, while the identified geosites were evaluated by experts on a 1–9 scale and subsequently ranked using R-WASPAS. The operational definitions and scoring directions of the sub-criteria are presented in Table 3.

Table 3: Evaluation criteria, operational definitions, and scoring directions adapted from Ghosh et al. (2021).

Criteria	Sub-criteria	Operational definition / assessment basis	Direction
Scientific valuation (SV)	Integrity	Degree to which the site's geological/geomorphological features are preserved and remain clearly observable	Benefit (+)
	Rarity	Relative scarcity of comparable geological or geomorphological features within the study area	Benefit (+)
	Scientific knowledge	Extent to which the site has been documented in scientific publications, reports, or other scientific studies	Benefit (+)
	Diversity	Variety of geological/geomorphological features and processes observable within the site	Benefit (+)
Educational valuation (EV)	Representativeness and visibility	Clarity and visibility with which the site represents the relevant geological or geomorphological feature or process	Benefit (+)
	Exemplarity	Potential of the site to clearly demonstrate geological/geomorphological features and processes for teaching and interpretation	Benefit (+)
	Existing educational products	Availability of educational or interpretive materials such as maps, webpages, brochures, information panels, or similar resources	Benefit (+)
	Actual use for educational purposes	Extent to which the site is currently used for field education, teaching, scientific excursions, or related educational activities	Benefit (+)
Economic valuation (EcV)	Accessibility	Ease and safety of reaching the site, considering road access, parking and walking requirements	Benefit (+)
	Present tourist infrastructure	Availability and proximity of visitor-related facilities such as accommodation, restaurants, and other tourism services	Benefit (+)
	Local products	Presence or potential association of the site with local products or geoproducts that may contribute to the local economy	Benefit (+)
Geoconservation valuation (GV)	Actual threats and risks	Current level of natural or anthropogenic pressures capable of degrading the site; higher scores indicate lower current threat	Benefit (+)
	Potential threats and risks	Likelihood of future degradation due to natural or human-induced pressures; higher scores indicate lower potential threat	Benefit (+)
	Current status of site	Present preservation and management condition of the site	Benefit (+)

	Legislative protection	Existence and effectiveness of legal or administrative protection applicable to the site	Benefit (+)
Assessment of added values (AAV)	Cultural values	Historical, archaeological, religious, traditional, or mythological associations related to the site	Benefit (+)
	Ecological values	Relationship of the geological/geomorphological features with habitats, vegetation, fauna, or other ecological elements	Benefit (+)
	Aesthetic values	Visual and scenic quality of the site, including landscape character, visual diversity, and availability of viewpoints	Benefit (+)

Note: The sub-criteria were evaluated by the experts using a 1–9 ordinal scale, in which higher scores represent more favourable conditions in terms of geoheritage value. For GV1 (Actual threats and risks) and GV2 (Potential threats and risks), the scoring direction was reversed conceptually; therefore, higher scores indicate lower levels of threat and risk.

The second stage involved determining the weighting coefficients of the criteria using the F-PIPRECIA method. At this stage, a three-member expert panel was purposively selected based on their academic expertise in fields directly related to geoheritage assessment, their research experience in geology, geomorphology, geoheritage and/or geotourism, and their familiarity with the geological and geomorphological characteristics of the study area. These selection criteria were considered important to ensure that the experts had sufficient disciplinary knowledge and experience to evaluate both the scientific characteristics of the geosites and their conservation and utilization potential. The three experts independently evaluated the criteria using the linguistic scales presented in Tables 1 and 2. In the subsequent step, these linguistic evaluations were converted into triangular fuzzy numbers (TFNs). In the final step, calculations were performed using Equations (18–26) to determine the weights of the sub-criteria separately within each of the five main criterion groups. The five main criteria—scientific, educational, economic, geoconservation, and additional values—were not weighted against one another, because the study was designed to evaluate each dimension independently rather than to produce a single aggregated overall score. Accordingly, F-PIPRECIA-derived sub-criterion weights were calculated separately for each main criterion group, and R-WASPAS was subsequently applied to obtain five independent rankings of the geosites, one for each main evaluation dimension. A detailed example of the calculation process is presented in the Results section. In the third stage of the analysis, the experts evaluated the geosites according to the criteria. For this purpose, the experts independently evaluated each geosite according to each sub-criterion using a five-level ordinal scale coded as 1, 3, 5, 7, and 9. The scores were interpreted as follows: 1 = very low/very unfavourable, 3 = low/unfavourable, 5 = moderate, 7 = high/favourable, and 9 = very high/very favourable performance with respect to the evaluated criterion. Since all sub-criteria were operationalized in the benefit direction, higher scores generally indicated more favourable conditions in terms of geoheritage value. For GV1 (Actual threats and risks) and GV2 (Potential threats and risks), this interpretation was reversed in terms of threat intensity: 1 indicated a very high level of threat, whereas 9 indicated a very low level of threat. In the next step, the priority values of the geosites were calculated separately for each main criterion using Equations (27–37) following the R-WASPAS procedure. An example of the calculation process is provided in the Results section.

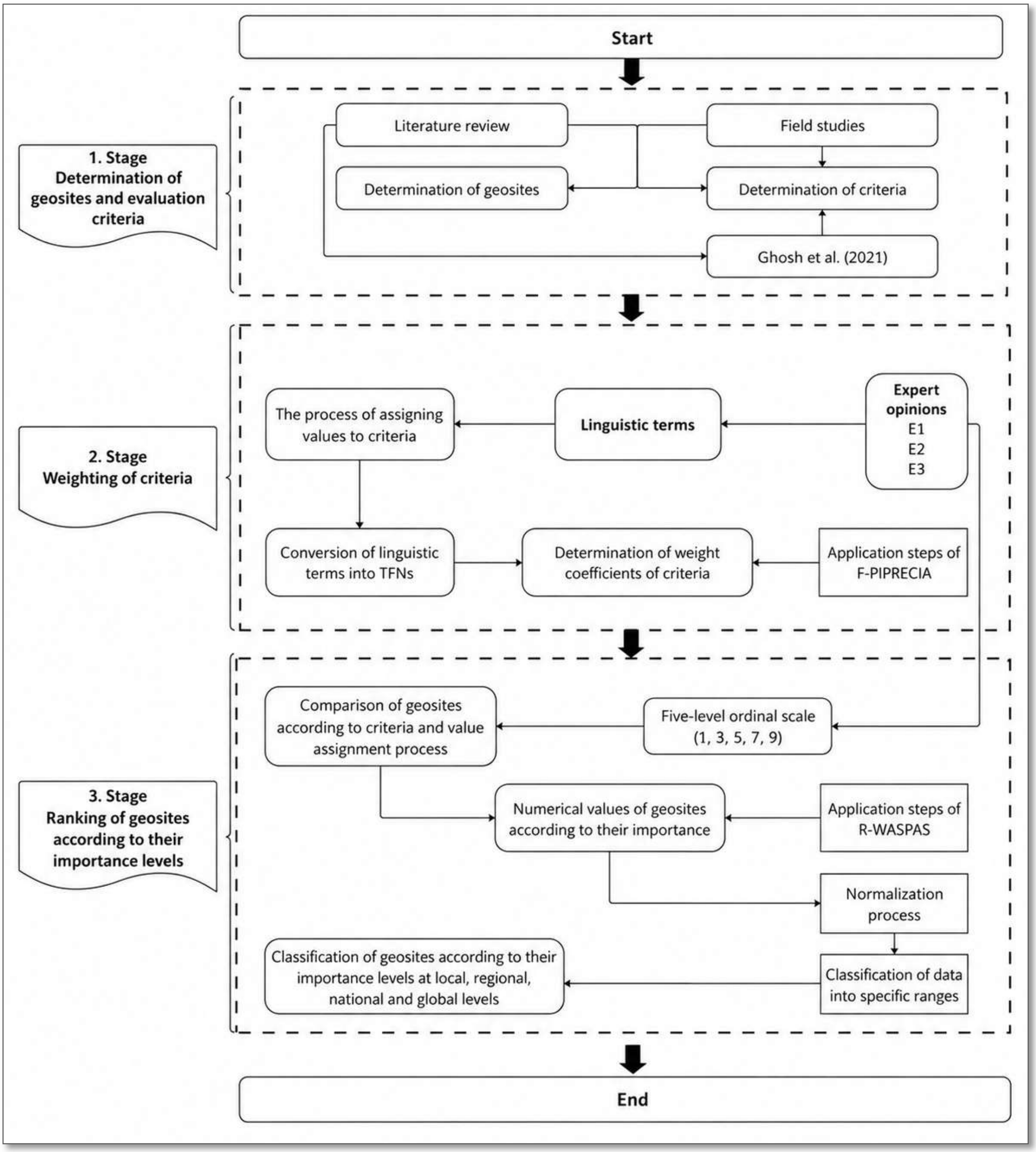

Figure 4: Methodological flowchart.

4. RESULTS

The study's findings were presented in three main parts: identification of the proposed geosites, determination of the weighting coefficients for the criteria, and assessment of the importance levels of the geosites based on the weighted criteria.

4.1. Proposed Geosites

Geosite 1—Soğanlı Mountain Historical Road: The Soğanlı Mountain Historical Road (Figure 5; G1 and G1a) is located in the Eastern Black Sea Region, at an altitude of approximately 1850 m above sea level. It is situated north of the Aydıntepe district, on the Bayburt-Trabzon provincial border, and on the northeastern slope of the Soğanlı Mountains. Geologically, the road route developed on granite masses that form the Hercinian (Variscan) basement of the Eastern Pontides (Demirbağ 2023; Yılmaz 2002) and are generally determined to be of Carboniferous age (Topuz et al. 2004). These Paleozoic deep-seated rocks cut through the metamorphic rocks in the region (Keskin et al. 1989; Yılmaz 2002). The peak height of the Soğanlı Mountains reaches 3082 m (Uzun 1990). The historical road begins at the valley floor of the Şeker Su Stream (1,720 m), follows a zigzag line on the northeastern slopes of Soğanlı Mountain, and ascends to an altitude of approximately 2010 m.

Geosite 2 - Somarova Tor Topography: This geosite (Figure 5; G2 and G2a) is situated near the Salmankaş Pass on the border between Bayburt and Trabzon provinces, with an average elevation of 2,075 m. This region, known as the Somarova Pluton in geological studies (Kaygusuz and Vural 2024), is situated in the southern zone of the Eastern Pontides (Kaygusuz and Vural 2024; Demirbağ 2023). Petrographic studies have revealed that the rocks comprising the Somarova Pluton are primarily composed of diorite, tonalite, and granodiorite (Kaygusuz and Vural 2024). This pluton is Middle Eocene in age (Kaygusuz and Vural 2024; Kaygusuz et al. 2019) and is emplaced by cutting through units such as the Dogger-Malm-Lower Cretaceous Hozbirikyayla Formation and the Late Cretaceous Arduç Formation in the study area (Kaygusuz and Vural 2024; Keskin et al. 1989). The tor topography (high rock formations created by the weathering of granitic masses) in the region extends along an east-west trending line on the south-facing slopes of the Zilfo Mountain massif. The development of the tor topography is primarily related to differential weathering along joints and fractures within the granitic rocks, followed by the removal of the weathered mantle and the exposure of more resistant residual blocks. The post-Middle Eocene extensional tectonic regime should therefore not be considered a direct formative mechanism of the tors. Rather, the regional uplift and associated relief development may have enhanced denudation and facilitated the removal of the weathered regolith, thereby contributing to the progressive exposure of the pre-existing granitic weathering forms at the surface (Demirbağ 2023). In the general Eastern Pontid region, Palaeozoic granitoids and metamorphic rocks, which form the Hercynian basement, are also present (Yılmaz 2002; Topuz et al. 2010).

Geosite 3 - Nişantaşı Gorge Valley: The Nişantaşı Gorge Valley (Figure 5; G3 and G3a) is located in the western part of Bayburt province. It is defined as an epigenic (overlapping) gorge valley (superimposed valley) carved by the Büyükçay, one of the two main tributaries of the upper reaches of the Çoruh River (Uzun 1990). The valley is situated between the Mormus Plain in the south and the Aydıntepe Plain in the north (Uzun 1990). Geologically, the valley carves its main body through Malm-Lower Cretaceous formations while also cutting through Liassic, Eocene, and Miocene terrains (Uzun 1990). The Eocene sequence of the region (Yazyurdu Formation) is represented by alternating levels of sandstone, siltstone, and marl with volcano-sediments (Keskin et al. 1989; Arslan et al. 2005). Biostratigraphic investigations of the Nişantaşı measured section identified calcareous nannoplankton assemblages corresponding to the Lutetian–Bartonian interval of the Middle Eocene (Danacı 2009).

Geosite 4 – Dragon Rocks: Located in the western part of Bayburt province, near the Nişantaşı Gorge, this geosite (Figure 5; G4 and G4a-b) reflects the geological and morphological characteristics of the valley system carved by the Büyükçay River (Uzun 1990). The base of the geosite consists of Malm-Lower Cretaceous formations cut along the valley, as well as Liassic, Eocene, and Miocene units (Uzun 1990). Particularly prevalent are the Middle Eocene Yazyurdu Formation lithologies (Keskin et al. 1989); these units comprise alternating bluish-green marl and sandstone layers, as well as limestone levels bearing Nummulites (Danacı 2009). The morphological development of the region is associated with the extensional tectonic regime that became effective after the Middle Eocene, and this regime controlled the region's rapid vertical uplift (Uzun 1990; Demirbağ 2023). This uplift caused the formation of shoulders and plains (terraces) at different levels in the terrain around the valley (Uzun 1990).

Geosite 5 - Aydıntepe Underground City: The Aydıntepe Underground City (Figure 5; G5) is located in the interior of the Eastern Black Sea Region, just below the Aydıntepe (formerly Hart) district centre of Bayburt Province (Metin and Yılmaz 2023). This area is situated on a slope north of the Aydıntepe Plain, in a geography that intersects with the Soğanlı Mountains, which are part of the North Anatolian Mountains (Metin and Yılmaz 2023; Uzun 1990). The underground city was excavated within relatively soft and fine-grained tuffite layers locally known as Bayburt stone (Metin and Yılmaz 2023). These tuffite layers occur within the Eocene volcano-sedimentary succession of the Yazyurdu Formation and, owing to their relatively low hardness and workability, provided suitable bedrock for excavation and the development of the underground architectural complex (Metin and Yılmaz 2023). These tuffite, according to petrochemical analyses, are products of Eocene calc-alkaline felsic volcanism (Arslan et al. 2005). As a result of the studies, it is thought that the underground city may have been built in the 3rd century AD and used for a long period from the Late Roman to the Middle Byzantine Period (as a protective measure for those fleeing persecution by the Roman Empire) (Metin and Yılmaz 2023). In the present study, Aydıntepe Underground City is therefore considered a geoarchaeological and geocultural geosite whose heritage significance derives from the close interaction between geological properties and human use. In particular, the workability of the Eocene tuffite bedrock enabled the excavation and long-term utilization of the underground complex, providing a clear example of how lithological characteristics influenced the development of a cultural heritage site.

Geosite 6 - Çiğdemtepe Mound: Çiğdemtepe Mound (Figure 5; G6) is located in Çiğdemtepe village in the central district of Bayburt, on the western margin of a natural plateau overlooking the Aydıntepe Plain (Yücel and Akyüz 2023; Parlıtı and Akyüz 2023). Archaeological investigations indicate that the site was occupied from the Late Chalcolithic to the Early Bronze Age and played an important role within the prehistoric settlement system of northeastern Anatolia (Yücel and Akyüz 2023; Parlıtı and Akyüz 2023). Its geomorphological position on an elevated plateau margin created a close spatial relationship between the settlement and the surrounding plain, providing visual command over the adjacent landscape and access to agricultural areas. In the present study, Çiğdemtepe Mound is therefore considered a geoarchaeological and geocultural geosite whose heritage significance derives primarily from the interaction between human settlement and its geomorphological setting rather than from a single geological feature. The surrounding geological framework is characterised by Eocene volcano-sedimentary units of the Yazyurdu Formation, including felsic volcanic products (Keskin et al. 1989; Arslan et al. 2005; Kaygusuz et al. 2019). However, no direct causal relationship is assumed between a specific lithology and the construction of the settlement. Instead, the geosite value of Çiğdemtepe is interpreted through the combined archaeological, cultural, and landscape significance of the mound and its topographic setting. (Arslan et al. 2005; Kaygusuz et al. 2022).

Geosite 7 - Aydıncık Amber Mining Area: Located approximately 18 km northeast of Bayburt city centre, near Aydıncık Village (1.5 km from the village centre), this geosite (Figure 5; G7 and G7a) contains Eocene amber formations (Başar 2021). Amber is the fossilised form of resin, a natural defence mechanism of trees (Başar 2021). The amber formations are observed regionally within the Sırataşlar Formation, an Eocene-aged flysch marine unit consisting of limestone, sandstone, conglomerate, and marl levels (Başar 2021). The observation of channel structures filled with sand and gravel in the upper levels of these layers indicates that the sequence generally accumulated in a coastal and delta environment (Başar 2021).

Geosite 8 - Çayırözü Fossil Area: The site is located in the northeastern part of Bayburt Province, north of Çayırözü village (Figure 5; G8 and G8a). The locality exposes Eocene volcano-sedimentary strata associated with the Yazyurdu Formation, which is regionally characterized by alternations of sandstone, claystone, marl, tuff, and tuffite. Biostratigraphic investigations of the Yazyurdu Formation in the Bayburt region have documented a rich calcareous nannoplankton assemblage comprising 29 genera and 85 species (Danacı 2009). Among the principal index taxa, *Nannotetrina fulgens*, *Discoaster tanii nodifer*, and *Discoaster saipanensis* define biozones corresponding respectively to the Lutetian, Lutetian–Bartonian, and Bartonian intervals of the Middle Eocene (Danacı 2009). These fossil assemblages are scientifically important because they provide a basis for biostratigraphic dating and for reconstructing the depositional and palaeoenvironmental conditions of the Eocene succession. Accordingly, the Çayırözü locality is evaluated in this study as a palaeontological and biostratigraphic geosite, where the fossil-bearing Eocene succession contributes to understanding the age and geological evolution of the Yazyurdu Formation. (Danacı 2009).

Geosite 9 - Baksı Meanders: Located approximately 45 km northeast of Bayburt city centre, near Bayraktar Village, this geosite (Figure 5; G9) is situated within the Yazyurdu Formation, composed of Lower-Middle Eocene volcano-sedimentary rocks in the Bayburt region (Keskin et al. 1989; Kaygusuz and Vural 2024). This formation represents the Middle Eocene period, specifically the Lutetian-Bartonian age range (Middle to Upper Eocene) (Danacı 2009). The lithological composition of the formation consists of alternating volcanics and sedimentary rocks (Keskin et al. 1989). The rocks include sandstone, siltstone, and marl levels, along with volcanic units such as andesitic lava, agglomerate, tuff, and dacitic tuff (Keskin et al. 1989). These volcanic rocks have been defined as products of calc-alkaline felsic volcanism with rhyodacitic-dacitic composition (Arslan et al. 2005). The meander morphology at Baksı is interpreted primarily as the result of fluvial processes rather than as a direct consequence of the post-Middle Eocene extensional tectonic regime. Meander development is controlled more directly by factors such as channel gradient, discharge and sediment regime, valley-floor geometry, and the erodibility of bank materials. Although the regional tectonic evolution of Bayburt has influenced the broader relief and drainage framework (Demirbağ 2023), the present study does not provide site-specific morphometric, stratigraphic, or structural evidence sufficient to establish a direct causal relationship between post-Middle Eocene tectonics and the formation of the Baksı meanders. Therefore, tectonics is considered here as part of the regional geomorphological context rather than as the immediate mechanism responsible for the meander pattern.

Geosite 10 - Değirmendere Valley and Waterfall: Located approximately 45 km northeast of Bayburt city centre, near Bayraktar Village, this geosite (Figure 5; G10) is associated with the Yazyurdu Formation, which is widely outcropped in the Bayburt region and contains Lower-Middle Eocene units (Keskin et al. 1989; Kaygusuz and Vural 2024; Danacı 2009). The Yazyurdu Formation generally represents the Middle-Upper Eocene (Lutetian-Bartonian) age range and lithologically consists of alternating volcanic and sedimentary rocks. In the region, these units comprise sedimentary levels such as sandstone, siltstone, marl, and claystone, as well as volcano-sedimentary rocks like tuff and tuffite (Keskin et al., 1989; Arslan et al. 2005; Danacı 2009). The morphological development that influenced the formation of valley and waterfall systems, such as Değirmendere, is associated with regional uplift processes controlled by the extensional tectonic regime that became active in the post-Middle Eocene period (Uzun 1990; Demirbağ 2023).

Geosite 11 - Dikmetaş Dike: Located approximately 56 km southwest of Bayburt city centre, near Dikmetaş Village, this geosite (Figure 6; G11) occurs within the Pulur Metamorphics, which constitute part of the Paleozoic metamorphic basement of the Eastern Pontides in the Bayburt region (Ketin 1951; Yılmaz 2002; Topuz et al. 2004). The Pulur Metamorphics comprise a heterogeneous assemblage including schist, gneiss, marble, amphibolite, and metagranitic rocks, and regional geological studies also report acidic dykes and sills within this metamorphic basement (Keskin et al. 1989; Topuz et al. 2004). At G11, the principal geoheritage feature is a dyke-like intrusive body that cross-cuts the older metamorphic basement, making the intrusive relationship with the host rock directly observable in the field (Demirbağ 2023). However, because no site-specific petrographic, geochronological, or structural measurements were undertaken for this body in the present study, a precise lithological composition, absolute age, thickness, and strike or dip orientation are not assigned here. Accordingly, its geoheritage significance is interpreted primarily from the clearly expressed cross-cutting intrusive relationship between the dyke and the older metamorphic host rocks. The Dikmetaş Member mentioned in regional stratigraphic studies is a separate Lower Jurassic basal sedimentary member of the Hamurkesen Formation and consists mainly of conglomerate, sandstone, siltstone, and locally coal-bearing levels (Keskin et al. 1989). No genetic or stratigraphic relationship is implied between this sedimentary member and the intrusive body evaluated here as the Dikmetaş Dike; the shared name reflects geographical nomenclature rather than equivalence between the two geological units. (Keskin et al. 1989).

Geosite 12 - Sırakayalar Waterfall: The waterfall (Figure 5; G12) is located approximately 13 km south of the Erzurum-Bayburt highway, north of Sırakayalar village (Doğanay 2000). Its distance from Bayburt city centre is approximately 22 km (Doğanay 2000). Sırakayalar Waterfall flows along the Kopuz Stream bed. The surface where the waterfall cascades consists of travertine layers, formations from the Quaternary period (Doğanay 2000).

Geosite 13 - Helva Village Ice Cave: The cave is situated in the south of Bayburt Province, within the boundaries of Helva Village, on the northern slope of Kızoğlan Mountain, at an altitude of approximately 2,585 m (Birinci and Zaman 2016). The Ice Cave (Figure 5; G13 and G13a) is

Figure 5: G1- G1a = Mount Soğanlı Historical Road; G2-G2a = Somarova Tor Topography; G3-G3a = Nişantaşı Gorge Valley; G4-G4a-b = Dragon Rocks; G5 = Aydıntepe Underground City; G6 = Çiğdemtepe Mound; G7-G7a = Aydıncık Amber Mining Area; G8-G8a = Çayırözü Fossil Area; G9 = Baksı Meanders

a significant karst formation developed within the Jurassic-Lower Cretaceous limestones that are widely distributed in the region (Uzun 1990; Birinci and Zaman 2016; Uzun and Zeybek 1996). Geomorphologically, the cave is a fossil cave situated in a ventilation (vados) zone, having formed as a result of the lowering of the base level due to tectonic movements (Uzun 1990; Birinci and Zaman 2016).

Geosite 14 - Çımağıl Cave: Çımağıl Cave (Figure 6; G14 and G14a-b) is located in the southeast of Bayburt province, on the slope of Akdağ and at an altitude of 2550 m above sea level (Birinci and Zaman 2016). The Akdağ massif, where the cave was formed, consists of Jurassic-Lower Cretaceous limestones (Uzun 1990; Birinci and Zaman 2016). This part of the region is situated within the southern zone of the Eastern Pontid Belt, which is characterised by the predominance of sedimentary rocks (Yılmaz 2002; Birinci and Zaman 2016). The cave is a fossil cave that developed in a vadose zone (Birinci and Zaman 2016). Its formation began with surface waters causing dissolution in the ground, depending on the local base level (Birinci and Zaman 2016). In the second stage, due to regional uplifts resulting from tectonic movements, the base level lowered, and the cave remained in its current ventilation zone (Uzun and Zeybek 1996; Birinci and Zaman 2016). The tectonic uplifts that influenced the cave's development caused it to show a gradual (stepped) development downwards from the entrance (Birinci and Zaman 2016). The cave entrance is located 670 m above the Çımağıl depression, through which the Çoraklar Stream passes (Birinci and Zaman 2016).

4.2. Weighting of Criteria with F-PIPRECIA

The first stage of the analysis involves applying the steps of F-PIPRECIA and inverse F-PIPRECIA. Tables 4 and 5 show the weighting of the criteria set used in the study, the evaluation of three different DMs, and a geometric mean (GM) of these opinions.

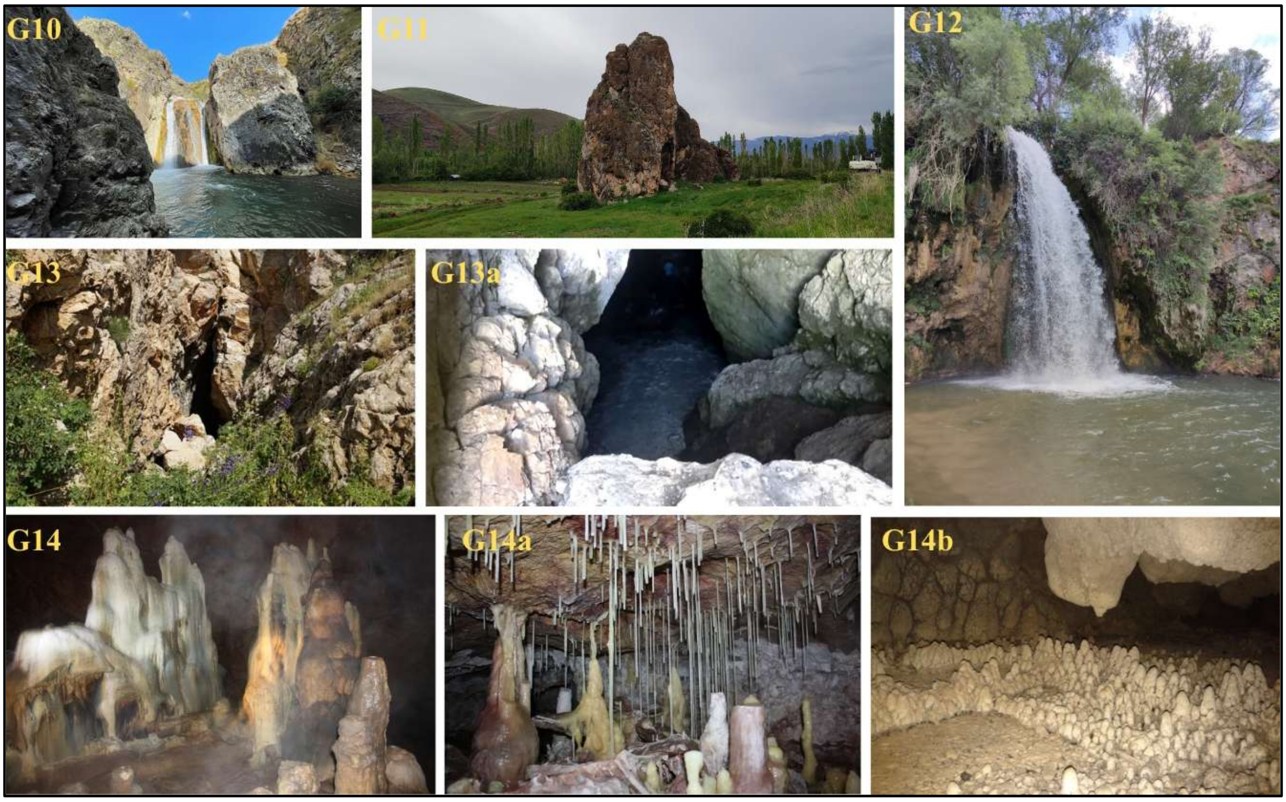

Figure 6: G10 = Değirmendere Valley and Waterfall; G11 = Dikmetaş Dike; G12 = Sırakayalar Waterfall; G13- G13a = Helva Village Ice Cave; G14-G14a-b = Çımağıl Cave.

Table 4: Evaluation of criteria for the F-PIPRECIA method with three DMs.

PIPRECIA	SV1	SV2			SV3			SV4	
DM1	1,400	1,600	1,650	1,200	1,300	1,350	1,300	1,450	1,500
DM2	0,500	0,667	1,000	0,667	1,000	1,000	1,200	1,300	1,350
DM3	1,400	1,600	1,650	0,286	0,333	0,400	1,300	1,450	1,500
GM	0,993	1,195	1,396	0,612	0,756	0,814	1,266	1,398	1,448
	EV1	EV2			EV3			EV4	
DM1	0,500	0,667	1,000	1,200	1,300	1,350	0,667	1,000	1,000
DM2	0,400	0,500	0,667	1,300	1,450	1,500	1,200	1,300	1,350
DM3	0,667	1,000	1,000	1,100	1,150	1,200	1,000	1,000	1,050
GM	0,511	0,693	0,874	1,197	1,294	1,344	0,928	1,091	1,123
	GV1	GV2			GV3			GV4	
DM1	1,000	1,000	1,050	1,100	1,150	1,200	1,400	1,600	1,650
DM2	0,400	0,500	0,667	1,300	1,450	1,500	1,600	1,900	1,950
DM3	1,100	1,150	1,200	1,200	1,300	1,350	1,400	1,600	1,650
GM	0,761	0,832	0,944	1,197	1,294	1,344	1,464	1,694	1,744
	EcV1	EcV2			EcV3				
DM1	1,600	1,900	1,950	0,667	1,000	1,000			
DM2	1,400	1,600	1,650	0,400	0,500	0,667			
DM3	1,100	1,150	1,200	0,250	0,286	0,333			
GM	1,351	1,518	1,569	0,406	0,523	0,606			
	AAV1	AAV2			AAV3				
DM1	0,667	1,000	1,000	1,200	1,300	1,350			
DM2	0,400	0,500	0,667	1,400	1,600	1,650			
DM3	0,286	0,333	0,400	1,500	1,750	1,800			
GM	0,424	0,550	0,644	1,361	1,538	1,589			

Table 5: Evaluation of criteria for the Inverse F-PIPRECIA method with three DMs.

PIPRECIA	SV4	SV3			SV2			SV1	
DM1	0,500	0,667	1,000	1,200	1,300	1,350	1,300	1,450	1,500
DM2	0,667	1,000	1,000	1,400	1,600	1,650	0,400	0,500	0,667
DM3	0,333	0,400	0,500	1,600	1,900	1,950	0,500	0,667	1,000
GM	0,481	0,644	0,794	1,390	1,581	1,632	0,638	0,785	1,000
	EV4	EV3			EV2			EV1	
DM1	1,000	1,000	1,050	1,300	1,450	1,500	1,100	1,150	1,200
DM2	0,500	0,667	1,000	1,500	1,750	1,800	1,200	1,300	1,350
DM3	0,667	1,000	1,000	1,400	1,600	1,650	1,100	1,150	1,200
GM	0,693	0,874	1,016	1,398	1,595	1,645	1,132	1,198	1,248
	GV4	GV3			GV2			GV1	
DM1	0,667	1,000	1,000	1,200	1,300	1,350	1,300	1,450	1,500
DM2	0,250	0,286	0,333	1,400	1,600	1,650	0,500	0,667	1,000
DM3	0,400	0,500	0,667	1,500	1,750	1,800	1,000	1,000	1,050
GM	0,406	0,523	0,606	1,361	1,538	1,589	0,866	0,989	1,163
	EcV3	EcV2			EcV1				
DM1	1,600	1,900	1,950	0,667	1,000	1,000			
DM2	1,400	1,600	1,650	1,100	1,150	1,200			
DM3	1,600	1,900	1,950	0,500	0,667	1,000			
GM	1,530	1,794	1,844	0,716	0,915	1,063			
	AAV3	AAV2			AAV1				
DM1	0,667	1,000	1,000	1,200	1,300	1,350			
DM2	0,250	0,286	0,333	1,200	1,300	1,350			
DM3	0,333	0,400	0,500	1,400	1,600	1,650			
GM	0,382	0,485	0,550	1,263	1,393	1,443			

In the second step, the linguistic evaluation matrix was constructed in accordance with Equation (18). The matrix for the SV factor is as follows:

$$\overline{s_2} = (0.993, 1.195, 1.396)$$
$$\overline{s_3} = (0.612, 0.756, 0.814)$$
$$\overline{s_4} = (1.266, 1.398, 1.448)$$

Then, by applying Equation (8), the values in the matrix $\overline{s_j}$ were subtracted from the number two to obtain the matrix $\overline{k_j}$.

According to Equation (8), the value $\overline{k_1}$= (1.000, 1.000, 1.000)

$\overline{k_2}$=
(2-1.396, 2-1.195, 2-0.993)=(0.604, 0.805, 1.007)

$\overline{k_3}$=
(2-0.814, 2-0.756, 2-0.612)=(1.186, 1.244, 1.388)

$\overline{k_4}$=
(2-1.448, 2-1.398, 2-1,266)=(0.552, 0.602, 0.734)

According to equation (9), the values of $\overline{q_j}$ were obtained as follows:

$$\overline{q_1} = (1.000, 1.000, 1.000)$$
$$\overline{q_2} = \left(\frac{1.000}{1.007}, \frac{1.000}{0.805}, \frac{1.000}{0.604}\right) = (0.993, 1.243, 1.657)$$
$$\overline{q_3} = \left(\frac{0.993}{1.388}, \frac{1.243}{1.244}, \frac{1.657}{1.186}\right) = (0.716, 0.999, 1.397)$$
$$\overline{q_4} = \left(\frac{0.716}{0.734}, \frac{0.999}{0.602}, \frac{1.397}{0.552}\right) = (0.975, 1.660, 2.532)$$

By applying equation (10), the relative weights were calculated as follows:

$$\overline{w_1} = \left(\frac{1.000}{3.683}, \frac{1.000}{4.902}, \frac{1.000}{6.586}\right) = (0.272, 0.204, 0.152)$$
$$\overline{w_2} = \left(\frac{0.993}{3.682}, \frac{1.243}{4.902}, \frac{1.657}{6.586}\right) = (0.270, 0.254, 0.252)$$
$$\overline{w_3} = \left(\frac{0.716}{3.682}, \frac{0.999}{4.902}, \frac{1.397}{6.586}\right) = (0.194, 0.204, 0.212)$$
$$\overline{w_4} = \left(\frac{0.974}{3.682}, \frac{1.660}{4.902}, \frac{2.532}{6.586}\right) = (0.265, 0.339, 0.384)$$

Table 6: Calculation of F-PIPRECIA for the criteria and results.

SV	sj			kj			qj			wj			DF
SV1				1,000	1,000	1,000	1,000	1,000	1,000	0,271	0,204	0,152	0,207
SV2	0,993	1,195	1,396	0,604	0,805	1,007	0,993	1,243	1,657	0,270	0,253	0,252	0,256
SV3	0,612	0,756	0,814	1,186	1,244	1,388	0,716	0,999	1,397	0,194	0,204	0,212	0,204
SV4	1,266	1,398	1,448	0,552	0,602	0,734	0,975	1,660	2,532	0,265	0,339	0,384	0,334
							3,683	4,902	6,586				
EV	sj			kj			qj			wj			DF
EV1				1,000	1,000	1,000	1,000	1,000	1,000	0,304	0,247	0,209	0,250
EV2	0,511	0,693	0,874	1,126	1,307	1,489	0,672	0,765	0,888	0,204	0,189	0,185	0,191
EV3	1,197	1,294	1,344	0,656	0,706	0,803	0,837	1,084	1,354	0,254	0,268	0,283	0,268
EV4	0,928	1,091	1,123	0,877	0,909	1,072	0,781	1,194	1,545	0,237	0,295	0,323	0,290
							3,289	4,043	4,787				
GV	sj			kj			qj			wj			DF
GV1				1,000	1,000	1,000	1,000	1,000	1,000	0,213	0,142	0,111	0,149
GV2	0,761	0,832	0,944	1,056	1,168	1,239	0,807	0,856	0,947	0,172	0,122	0,105	0,127
GV3	1,197	1,294	1,344	0,656	0,706	0,803	1,005	1,213	1,444	0,214	0,172	0,160	0,177
GV4	1,464	1,694	1,744	0,256	0,306	0,536	1,874	3,967	5,652	0,400	0,564	0,625	0,547
							4,686	7,035	9,042				
EcV	sj			kj			qj			wj			DF
EcV1				1,000	1,000	1,000	1,000	1,000	1,000	0,285	0,223	0,201	0,230
EcV2	1,351	1,518	1,569	0,431	0,482	0,649	1,540	2,073	2,319	0,439	0,463	0,465	0,460
EcV3	0,406	0,523	0,606	1,394	1,477	1,594	0,966	1,404	1,663	0,275	0,314	0,334	0,311
							3,506	4,477	4,982				
AAV	sj			kj			qj			wj			DF
AAV1				1,000	1,000	1,000	1,000	1,000	1,000	0,381	0,314	0,283	0,320
AAV2	0,424	0,550	0,644	1,356	1,450	1,576	0,635	0,690	0,737	0,242	0,217	0,209	0,220
AAV3	1,361	1,538	1,589	0,411	0,462	0,639	0,993	1,494	1,793	0,378	0,469	0,508	0,460
							2,627	3,184	3,530				

To determine the final weights of the criteria, Equation (11)– (15), i.e., the inverse F-PIPRECIA methodology, must be applied. The only difference from the steps above is that the calculations start from the last criterion.

Table 7: Calculation of F-PIPRECIA for the criteria and results.

SV	sj			kj			qj			wj			DF
SV1	0,638	0,785	1,000	1,000	1,215	1,362	0,793	1,448	2,251	0,225	0,293	0,356	0,292
SV2	1,390	1,581	1,632	0,368	0,419	0,610	1,080	1,760	2,250	0,306	0,356	0,356	0,347
SV3	0,481	0,644	0,794	1,206	1,356	1,519	0,658	0,737	0,829	0,186	0,149	0,131	0,152
SV4				1,000	1,000	1,000	1,000	1,000	1,000	0,283	0,202	0,158	0,208
							3,531	4,946	6,330				
EV	sj			kj			qj			wj			DF
EV1	1,132	1,198	1,248	0,752	0,802	0,868	1,464	2,735	3,813	0,325	0,401	0,438	0,395
EV2	1,398	1,595	1,645	0,355	0,405	0,602	1,271	2,194	2,867	0,282	0,322	0,330	0,317
EV3	0,693	0,874	1,016	0,984	1,126	1,307	0,765	0,888	1,017	0,170	0,130	0,117	0,135
EV4				1,000	1,000	1,000	1,000	1,000	1,000	0,222	0,147	0,115	0,154
							4,500	6,817	8,697				
GV	sj			kj			qj			wj			DF
GV1	0,866	0,989	1,163	0,837	1,011	1,134	0,865	1,450	2,084	0,249	0,316	0,376	0,315
GV2	1,361	1,538	1,589	0,411	0,462	0,639	0,981	1,466	1,743	0,282	0,319	0,314	0,312
GV3	0,406	0,523	0,606	1,394	1,477	1,594	0,627	0,677	0,717	0,181	0,147	0,129	0,150
GV4				1,000	1,000	1,000	1,000	1,000	1,000	0,288	0,218	0,180	0,223
							3,474	4,594	5,545				
EcV	sj			kj			qj			wj			DF
EcV1	0,716	0,915	1,063	0,937	1,085	1,284	1,658	4,480	6,856	0,346	0,433	0,480	0,427
EcV2	1,530	1,794	1,844	0,156	0,206	0,470	2,129	4,860	6,426	0,445	0,470	0,450	0,462
EcV3				1,000	1,000	1,000	1,000	1,000	1,000	0,209	0,097	0,070	0,111
							4,787	10,340	14,282				
AAV	sj			kj			qj			wj			DF
AAV1	1,263	1,393	1,443	0,557	0,607	0,737	0,839	1,088	1,239	0,341	0,396	0,423	0,391
AAV2	0,382	0,485	0,550	1,450	1,515	1,618	0,618	0,660	0,690	0,252	0,240	0,235	0,241
AAV3				1,000	1,000	1,000	1,000	1,000	1,000	0,407	0,364	0,341	0,367
							2,457	2,748	2,929				

The final weights of the criteria are obtained by applying Equation (15). Before applying this equation, it is necessary to defuzzify the values of the criteria obtained using Equation (7)−(15).

$$\overline{w}_1'' = \frac{0.207 + 0.292}{2} = 0.249$$

$$\overline{w}_2'' = \frac{0.256 + 0.347}{2} = 0.302$$

$$\overline{w}_3'' = \frac{0.204 + 0.152}{2} = 0.178$$

$$\overline{w}_4'' = \frac{0.334 + 0.208}{2} = 0.271$$

The final criterion weights obtained from the analyses are presented in Table 8. According to the results, in the SV (Scientific Valuation) category, SV2 (Rarity) had the highest weight (0.302), and SV3 (Scientific Knowledge) had the lowest weight (0.178). In EV (Educational Valuation), EV1 (Representativeness and Visibility) had the highest weight with a coefficient of 0.323. The other criteria had similar weight coefficients, ranging from 0.202 to 0.252. In the EcV (Economic valuation) category, EcV2 (Present tourist infrastructure) had the highest weight, while EcV3 (Local products) had the lowest weight. In GV (Geoconservation valuation), GV4 (Legislative protection) had a coefficient of 0.385, and GV3 (Current status of site) had a coefficient of 0.164. Finally, in the AAV (Assessment of Added Values) category, AAV3 (Aesthetic Values) was found to have the highest value, while AAV2 (Ecological Values) had the lowest. These results reflect the relative importance assigned to the sub-criteria by the expert panel within the context of the present study and should therefore be interpreted as study-specific weights rather than as universally applicable values.

Table 8: Final weights of the criteria.

SV		EV		GV		EcV		AAV	
SV1	0,249	EV1	0,323	CV1	0,232	EcV1	0,328	AV1	0,356
SV2	0,302	EV2	0,254	CV2	0,220	EcV2	0,461	AV2	0,230
SV3	0,178	EV3	0,202	CV3	0,164	EcV3	0,211	AV3	0,414
SV4	0,271	EV4	0,222	CV4	0,385				

4.3. Ranking of Geosites with R-WASPAS

After determining the weighting coefficients of the criteria for each factor group, the DMs evaluated the alternatives (Table 9). The individual matrices obtained as a result of this process were converted into rough matrices. The calculations for SV1 were performed as follows, for example:

$$\tilde{x}_{11} = \{5, 5, 3\}$$

$$\underline{Lim}(5) = \frac{1}{3}(5 + 5 + 3) = 4.33, \overline{Lim}(5) = 5$$

$$\underline{Lim}(3) = 3, \overline{Lim}(3) = \frac{1}{3}(5 + 5 + 3) = 4.33$$

$$RN(x_{11}^{1}) = RN(x_{11}^{2}) = [4.33, 5];\ RN(x_{11}^{3}) = [3, 4.33];$$

$$x_{11}^{L} = \frac{4.33 + 4.33 + 3}{3} = 3.89$$

$$x_{11}^{U} = \frac{5 + 5 + 4.33}{3} = 4.78$$

Table 9: DM's opinions.

	SV1			SV2			SV3			SV4		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
G1	5	5	3	7	7	5	5	5	5	3	3	3
G2	5	7	7	5	5	5	5	5	3	5	3	5
G3	5	5	5	3	3	3	3	5	5	3	3	5
G4	5	5	5	3	5	5	3	5	3	3	3	5
G5	5	7	5	5	5	5	3	3	5	3	3	3
G6	3	3	5	3	3	3	3	3	3	3	3	5
G7	3	3	3	5	5	3	5	5	7	7	7	7
G8	3	3	5	5	5	5	5	5	5	7	7	7
G9	5	5	5	3	3	3	3	3	3	5	5	5
G10	5	5	7	5	5	5	5	5	5	5	3	7
G11	3	3	7	3	3	5	5	5	5	7	7	7
G12	7	7	7	7	7	7	5	5	7	7	7	7
G13	7	7	9	7	7	9	7	7	9	7	7	7
G14	7	7	9	7	7	7	7	7	7	7	7	9

Table 10: Group rough matrix.

	SV1		SV2		SV3		SV4	
G1	3,89	4,78	5,89	6,78	5,00	5,00	3,00	3,00
G2	5,88	6,78	5,00	5,00	3,89	4,78	3,89	4,78
G3	5,00	5,00	3,00	3,00	3,89	4,78	3,22	4,11
G4	5,00	5,00	3,89	4,78	3,22	4,11	3,22	4,11
G5	5,22	6,11	5,00	5,00	3,22	4,11	3,00	3,00
G6	3,22	4,11	3,00	3,00	3,00	3,00	3,22	4,11
G7	3,00	3,00	3,89	4,78	5,22	6,11	7,00	7,00
G8	3,22	4,11	5,00	5,00	5,00	5,00	7,00	7,00
G9	5,00	5,00	3,00	3,00	3,00	3,00	5,00	5,00
G10	5,22	6,11	5,00	5,00	5,00	5,00	4,00	5,44
G11	3,44	5,22	3,22	4,11	5,00	5,00	7,00	7,00
G12	7,00	7,00	7,00	7,00	5,22	6,11	7,00	7,00
G13	7,22	8,11	7,22	8,11	7,22	8,11	7,00	7,00
G14	7,22	8,11	7,00	7,00	7,00	7,00	7,22	8,11

n the fifth step, the rough group matrix was normalized using Equations (28) and (29), as presented in Table 11. Since all sub-criteria were operationalized in the benefit direction, the normalization procedure for benefit criteria was applied. It should be noted that, in rough-number normalization, the upper bound of a normalized rough interval may exceed 1 because the upper bound of the original rough number is divided by the lower bound of the reference maximum interval. Therefore, values greater than 1 do not necessarily indicate a computational error but may arise from the interval-based structure of rough numbers. For example, the interval [7.22, 8.11] is normalized as [7.22/8.11, 8.11/7.22] = [0.89, 1.12]. The calculations were checked against the R-WASPAS normalization procedure described by Stojić et al. (2018) and were found to be consistent with the method:

$$n_{11} = \left[\frac{3.89}{8.11}, \frac{4.78}{7.22}\right] \rightarrow n_{11} = [0.48; 0.66]$$

Table 11: Normalised matrix.

	SV1		SV2		SV3		SV4	
G1	0,48	0,66	0,73	0,94	0,62	0,69	0,37	0,42
G2	0,73	0,94	0,62	0,69	0,48	0,66	0,48	0,66
G3	0,62	0,69	0,37	0,42	0,48	0,66	0,40	0,57
G4	0,62	0,69	0,48	0,66	0,40	0,57	0,40	0,57
G5	0,64	0,85	0,62	0,69	0,40	0,57	0,37	0,42
G6	0,40	0,57	0,37	0,42	0,37	0,42	0,40	0,57
G7	0,37	0,42	0,48	0,66	0,64	0,85	0,86	0,97
G8	0,40	0,57	0,62	0,69	0,62	0,69	0,86	0,97
G9	0,62	0,69	0,37	0,42	0,37	0,42	0,62	0,69
G10	0,64	0,85	0,62	0,69	0,62	0,69	0,49	0,75
G11	0,42	0,72	0,40	0,57	0,62	0,69	0,86	0,97
G12	0,86	0,97	0,86	0,97	0,64	0,85	0,86	0,97
G13	0,89	1,12	0,89	1,12	0,89	1,12	0,86	0,97
G14	0,89	1,12	0,86	0,97	0,86	0,97	0,89	1,12

The weighted normalized matrix was obtained by multiplying the elements of the normalized rough matrix by the corresponding criterion weights using Equation (34) (Table 12):

$$v_{13}^{L} = [0.249 \times 0.48; 0.249 \times 0.66] = [0.12; 0.16]$$

Table 12: Weighted normalised matrix.

Geosites	**SV1**		**SV2**		**SV3**		**SV4**	
G1	0,12	0,16	0,22	0,28	0,11	0,12	0,10	0,11
G2	0,18	0,23	0,19	0,21	0,09	0,12	0,13	0,18
G3	0,15	0,17	0,11	0,13	0,09	0,12	0,11	0,15
G4	0,15	0,17	0,14	0,20	0,07	0,10	0,11	0,15
G5	0,16	0,21	0,19	0,21	0,07	0,10	0,10	0,11
G6	0,10	0,14	0,11	0,13	0,07	0,07	0,11	0,15
G7	0,09	0,10	0,14	0,20	0,11	0,15	0,23	0,26
G8	0,10	0,14	0,19	0,21	0,11	0,12	0,23	0,26
G9	0,15	0,17	0,11	0,13	0,07	0,07	0,17	0,19
G10	0,16	0,21	0,19	0,21	0,11	0,12	0,13	0,20
G11	0,11	0,18	0,12	0,17	0,11	0,12	0,23	0,26
G12	0,22	0,24	0,26	0,29	0,11	0,15	0,23	0,26
G13	0,22	0,28	0,27	0,34	0,16	0,20	0,23	0,26
G14	0,22	0,28	0,26	0,29	0,15	0,17	0,24	0,30

The weighted normalized matrix was obtained by multiplying the elements of the normalized rough matrix by the corresponding criterion weights using Equation (34) (Table 12). In the seventh step, the values in each row of this matrix were summed using Equation (35) to obtain the Qi matrix representing the WSM component. Subsequently, in the eighth step, the Pi matrix representing the WPM component was calculated using Equation (36). The resulting WSM and WPM values are presented in Table 13.

$$q_{11}^{L} = [0.12 + 0.22 + 0.11 + 0.10] = 0.55$$

$$q_{11}^{U} = [0.16 + 0.28 + 0.12 + 0.11] = 0.68$$

$$p_{11}^{L} = [(0.12^{0.249}) \times (0.22^{0.302}) \times (0.11^{0.178}) \times (0.10^{0.271})] = 0.13$$

$$p_{11}^{U} = [(0.16^{0.249}) \times (0.28^{0.302}) \times (0.12^{0.178}) \times (0.11^{0.271})] = 0.17$$

Table 13: WSM and WPM values

	WSM		WPM	
G1	0,55	0,68	0,13	0,17
G2	0,58	0,74	0,15	0,19
G3	0,46	0,57	0,11	0,14
G4	0,48	0,63	0,12	0,16
G5	0,52	0,63	0,13	0,16
G6	0,38	0,50	0,10	0,12
G7	0,59	0,72	0,14	0,17
G8	0,63	0,74	0,15	0,18
G9	0,50	0,56	0,12	0,14
G10	0,59	0,75	0,15	0,19
G11	0,57	0,74	0,14	0,18
G12	0,82	0,95	0,21	0,24
G13	0,88	1,08	0,22	0,27
G14	0,88	1,05	0,22	0,27
Sum	8,43	10,33	2,10	2,58

In the ninth step, the relative values of the alternatives (Table 14) are calculated using Equation (28), l is obtained using Equation (29) and is equal to:

$$\lambda = 0.5 + \frac{[2.10, 2.58]}{[8.43, 10.33] + [2.10, 2.58]} = [0.663, 0.745]$$

Table 14: Relative values and ranking of geosites according to the SV factor.

SV	$\lambda \times Q_i$		$(1-\lambda) \times P_i$		A_i		Crisp A_i	Rank
G1-Mount Soğanlı Historical Road	0,364	0,510	0,045	0,042	0,409	0,552	0,481	9
G2-Somarova Tor Topography	0,386	0,552	0,049	0,047	0,435	0,599	0,517	6
G3-Nişantaşı Gorge Valley	0,304	0,425	0,038	0,036	0,342	0,461	0,402	13
G4-Dragon Rocks	0,316	0,468	0,040	0,040	0,356	0,508	0,432	11
G5-Aydıntepe Underground City	0,343	0,472	0,043	0,040	0,386	0,512	0,449	10
G6-Çiğdemtepe Mound	0,255	0,369	0,033	0,032	0,288	0,401	0,344	14
G7-Aydıncık Amber Mining Area	0,388	0,534	0,048	0,044	0,436	0,578	0,507	8
G8-Çayırözü Fossil Area	0,417	0,549	0,052	0,047	0,469	0,596	0,532	4
G9-Baksı Meanders	0,330	0,417	0,041	0,035	0,372	0,452	0,412	12
G10-Değirmendere Valley and Waterfall	0,391	0,557	0,050	0,048	0,441	0,605	0,523	5
G11-Dikmetaş Dike	0,377	0,550	0,046	0,047	0,424	0,597	0,510	7
G12-Sırakayalar Waterfall	0,546	0,706	0,070	0,061	0,617	0,768	0,692	3
G13-Helva Village Ice Cave	0,585	0,806	0,076	0,070	0,661	0,876	0,769	1
G14-Çımağıl Cave	0,582	0,782	0,075	0,068	0,657	0,850	0,753	2

The table above shows the final results for the SV category, while the results for the other criterion groups are presented in the appendices. The crisp values obtained from the final R-WASPAS results were transformed to the range [0,1] separately for each main criterion group using min–max normalization. The normalization was performed according to the following equation:

$$N_{\mathrm{i}} = \frac{x_{\mathrm{i}} - x_{\min}}{x_{\max} - x_{\min}}$$

where Ni represents the normalized value of geosite i, xi is the corresponding crisp R-WASPAS value, and xmin and xmax are the minimum and maximum crisp values within the same main criterion group, respectively. The normalized values were then classified into four importance levels: low (0–0.25), medium (>0.25–0.50), high (>0.50–0.75), and very high (>0.75–1.00). The normalized values and corresponding classifications are presented in Table A5, whereas the rankings and importance levels across the five main criterion groups are summarized in Table 15. These results provide a comparative overview of the relative importance and ranking of the geosites across the five main criterion groups. According to the results, G12 (Sırakayalar Waterfall), G13 (Helva Village Ice Cave), and G14 (Çımağıl Cave) were the top three geosites in the scientific, educational, and geoconservation value categories. These geosites were also identified as having very high geoheritage value. When other results are examined, six of the geosite locations (G1-Mount Soğanlı Historical Road, G2-Somarova Tor Topography, G7-Aydıncık Amber Mining Area, G8-Çayırözü Fossil Area, G10-Değirmendere Valley and Waterfall, and G11-Dikmetaş Dike) are of medium value in terms of scientific value, while the remaining five geosite locations (G3-Nişantaşı Gorge Valley, G4-Dragon Rocks, G5-Aydıntepe Underground City, G6-Çiğdemtepe Mound, and G9-Baksı Meanders) have low value.

Apart from the top three geosites in terms of educational value, seven of the remaining geosites were found to be of medium importance and four of low importance (Table 15). In terms of economic value, geosites G12, G5 (Aydıntepe Underground City), and G14 were ranked as having a very high level of importance. G9 (Baksı Meanders) and G6 (Çiğdemtepe Mound) were ranked as having a high level of importance. The remaining eight geosites were of medium and low importanceIn terms of geoconservation value, G9 (Baksı Meanders), G2 (Somarova Tor Topography), and G3 (Nişantaşı Gorge Valley) occupied the lowest three positions in the ranking (Table 15). Their low geoconservation scores reflect comparatively unfavourable conditions across the evaluated geoconservation sub-criteria, particularly threat levels and limited legislative protection. For example, G9 received particularly low scores for actual threats, potential threats, and legislative protection, while G2 and G3 also received low scores for legislative protection and relatively low scores for threat-related criteria. These results should not be interpreted as a direct ranking of conservation priority; rather, they indicate comparatively weaker geoconservation conditions and therefore suggest that these sites may require greater management and conservation attention. Finally, in the category of additional values, geosites G13, G1 (Mount Soğanlı Historical Road), G14, and G12 were identified as geosites with very high levels of importance. Apart from these, G4 (Dragon Rocks), G5 (Aydıntepe Underground City), and G6 (Çiğdemtepe Mound) are classified as high-level; G7 (Aydıncık Amber Mining Area), G9 (Baksı Meanders), G10 (Değirmendere Valley and Waterfall), and G11 (Dikmetaş Dike) as medium-level; and finally, G2 (Somarova Tor Topography), G3 (Nişantaşı Gorge Valley), and G8 (Çayırözü Fossil Area) as low-level geosites. A detailed interpretation of these results is given in the discussion section.

Table 15: Ranking and importance level of geosites according to each major factor.

Geosites	SV		EV		EcV		GV		AAV	
	Rank	Level	Rank	Level	Rank	Level	Rank	Level	Rank	Level
G1-Mount Soğanlı Historical Road	9	M	8	M	14	L	6	M	2	VH
G2-Somarova Tor Topography	6	M	9	M	12	L	13	L	12	L
G3-Nişantaşı Gorge Valley	13	L	12	L	9	M	12	L	14	L
G4-Dragon Rocks	11	L	7	M	7	M	10	L	6	H
G5-Aydıntepe Underground City	10	L	13	L	2	VH	9	M	5	H
G6-Çiğdemtepe Mound	14	L	14	L	5	H	5	H	7	H
G7-Aydıncık Amber Mining Area	8	M	10	M	10	M	4	H	11	M
G8-Çayırözü Fossil Area	4	M	6	M	11	L	7	M	13	L
G9-Baksı Meanders	12	L	4	M	6	H	14	L	8	M
G10-Değirmendere Valley and Waterfall	5	M	5	M	13	L	11	L	9	M
G11-Dikmetaş Dike	7	M	11	L	8	M	8	M	10	M
G12-Sırakayalar Waterfall	3	VH	2	VH	1	VH	1	VH	3	VH
G13-Helva Village Ice Cave	1	VH	3	VH	3	VH	2	VH	1	VH
G14-Çımağıl Cave	2	VH	1	VH	4	VH	3	VH	4	VH
Low (L)	0-0.250									
Middle (M)	0.251-0.500									
High (H)	0.501-0.750									
Very High (VH)	0.751-1.000									

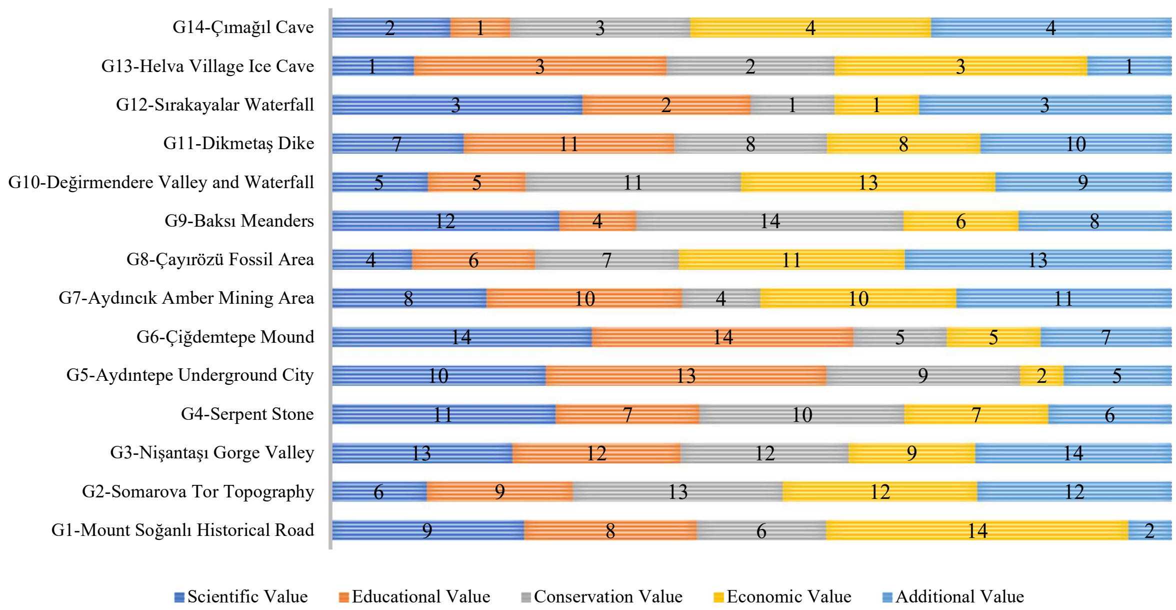

Figure 7: Ranking of geosites according to each major factor.

5. DISCUSSION

The aim of this study was to determine the scientific, educational, economic, conservation, and additional values of fourteen geosites identified and examined in Bayburt province using F-PIPRECIA and R-WASPAS methods. The findings obtained from the analyses provided several important insights. The results revealed that geosites with first-degree priority, i.e., very high importance (G12-Sırakayalar Waterfall, G13-Helva Village Ice Cave, G14-Çımağıl Cave), possess significant potential in all five different categories. Furthermore, G1 (Mount Soğanlı Historical Road) was identified as a first-degree priority geosite in terms of its additional value, and G5 (Aydıntepe Underground City) in terms of its economic value. The high importance levels of these geosites indicate that they represent strong candidates for geoheritage recognition and geoconservation. However, their formal inclusion in geoheritage inventories or conservation frameworks should be based on further assessment in accordance with the relevant national inventory and protection criteria, rather than on the MCDM ranking alone. Although the cited studies differ in terms of assessment methods, criterion sets, expert involvement, and geographical context, some comparable patterns can be identified at the level of specific evaluation dimensions. In particular, previous cave-related geoheritage studies have emphasized high scientific, educational, primary, and additional values associated with rarity, geological representativeness, interpretive potential, and geotourism use (Antić et al. 2022; Antić et al. 2025; Ballesteros et al. 2019; Pontes et al. 2019; Tičar et al. 2018; Massuqueto et al. 2022; Kudla et al. 2024). Similarly, studies focusing on waterfalls have highlighted their scientific, aesthetic, educational, and geotourism significance (Ortega-Becerril et al. 2017, 2019; Kayima and Karasiewicz 2025; Tamang et al. 2023; Zorlu and Dede 2023a; Zorlu et al. 2023). Therefore, the similarity with the present findings should be understood as a partial convergence in specific value dimensions rather than as direct methodological or numerical agreement among the studies. For example, Kudla et al. (2024), in their study evaluating geoheritage with GAM, found that three geosites consisting of caves have high primary and additional values. Similarly, Kayima and Karasiewicz (2025), in their studies in Uganda, identified Murchinson Falls as the geosite with the highest geotourism potential. The findings obtained in the present study can be interpreted in different ways. Firstly, caves are rare geosites and can provide a good interpretation of natural formation processes (Kudla et al. 2024). Therefore, the scientific, educational, and geotouristic values of Helva Village Ice Cave and Çımağıl Cave, identified in Bayburt province and possessing very high potential, should be highlighted more. This is because these caves currently have a moderate infrastructure and are frequently used for local tourism activities. Furthermore, these geosites serve as geological laboratories with didactic potential, which can be utilised for scientific and educational research at various learning levels. However, they are not known as geosites by visitors, and geotourists are rarely seen at these sites. For this reason, interpretation of the geological and geomorphological features of the caves should preferably be provided through information panels located at cave entrances or designated visitor areas, complemented by guided interpretation and digital tools where appropriate, rather than by installing multiple panels within the sensitive cave environment. In addition, Sırakayalar Waterfall, Aydıntepe Underground City, and Mount Soğanlı Historical Road are other geosites of very high economic and cultural significance. The functionalization of all geosites identified in this area requires their holistic presentation to visitors using the ABC interpretation approach (Dowling 2013). This concept can contribute to a holistic understanding of the geoheritage in the province. Such an initiative, through the appreciation of these sites by Bayburt residents and visitors and the creation of awareness and understanding of geoheritage, can also contribute to geoconservation.

On the other hand, according to other important findings, geosites with economic value (G9, Baksı Meanders), conservation value (G6, Çiğdemtepe Mound, and G7, Aydıncık Amber Mining Area), and finally, additional value (G5, Aydıntepe Underground City, G6, and G4, Dragon Rocks) were identified as secondary priority geosites, meaning they have a high level of importance. These geosites, along with primary importance geosites, can be evaluated in terms of conservation-utilisation balance and economic and geotourism contexts. These results are consistent with the findings of studies that consider and propose dragonstone (Taheri et al. 2025), meanders (Kubalíková and Kirchner, 2016, and mining areas (Čech et al. 2025; Gioncada et al. 2019; Carrión-Mero et al. 2022) as geoheritage For example, Taheri et al. (2025) reported that travertine formations interpreted as “stone dragons” contribute significant religious and mythological value to the evaluated geosite. Although the Dragon Rocks in Bayburt developed within a different geological context, the two sites are comparable in terms of their dragon-like morphological appearance and the cultural and mythological meanings attributed to these forms, rather than in terms of their geological origin. In another study focusing on meanders, Kubalíková and Kirchner (2016) reported that meanders may possess high scientific value. In the present study, Baksı Meanders ranked sixth in the economic value category and were classified at a high level after the relative normalization of the R-WASPAS results. However, this classification should not be interpreted as evidence of intensive current tourism use or a well-developed tourism economy. The expert evaluations show that the site performed favourably in accessibility (EcV1), receiving a score of 7 from all three decision-makers, whereas present tourist infrastructure (EcV2) and local products (EcV3) received lower scores of 3 from all three decision-makers. Considering the criterion weights, EcV2 had the highest weight (0.461), followed by EcV1 (0.328) and EcV3 (0.211). Thus, the relatively favourable economic ranking of Baksı Meanders is mainly associated with its strong accessibility performance, which partly offsets its weaker performance in existing tourism infrastructure and local-product provision. More importantly, the resulting “high” classification reflects the relative position of Baksı Meanders among the 14 evaluated geosites rather than a high absolute level of current tourism development. Its comparatively low scores for tourism infrastructure and local products indicate that the site still has important limitations in terms of its present economic use. Accordingly, landscape and drone photography should be considered potential opportunities for future geotourism development rather than factors explaining the site’s current economic value. The Aydıncık Amber Mining Area also presents potential for the development of amber-related geoproducts; however, any such economic use should be considered strictly within a geoconservation framework. Further extraction of amber from the geoheritage site may adversely affect site integrity and scientific value and should therefore not be encouraged unless it is legally permitted, scientifically justified, carefully controlled, and demonstrably compatible with conservation requirements. Where appropriate, locally produced crafts, replicas, interpretive products, or legally and sustainably sourced or previously extracted material may provide alternative means of generating local economic value while minimizing direct pressure on the geoheritage resource.

Finally, geosites classified as having low or medium importance may be considered as potential components of secondary geotourism routes, provided that site-specific conditions are suitable. Their inclusion in such routes should not be based solely on importance scores but should also consider accessibility, carrying capacity, visitor safety, site sensitivity, land ownership, and conservation requirements. In other words, geosites at this level can be used as supporting landscape stops, with a planning where primary and secondary geosites form the main backbone of the ideal route. Furthermore, to enhance the educational and geotourism value of these geosites, various infrastructure deficiencies (accessibility, facilities, guiding and interpretive panels, etc.) need to be addressed, as suggested for geosites with high priority. Overall, this study presents new evidence in the literature by introducing an area where geoheritage assessment has not been previously studied and by utilising current methodological approaches. Moreover, the results of this study may provide practical decision-support information for stakeholders, including practitioners, policymakers, and planners, by contributing to the development of a broader geosite inventory and catalogue for Bayburt, supporting preliminary assessments of the region’s future geopark potential, and guiding geotourism development. However, the present findings should be regarded only as preliminary decision-support input and should not be interpreted as sufficient evidence for the establishment of a geopark. A comprehensive geopark assessment would additionally require a more complete geosite inventory, evaluation of site representativeness and integrity, an appropriate management structure, local stakeholder participation, accessibility assessment, conservation planning, and sustainable development considerations.

Despite the contributions of this research, several limitations should be acknowledged. First, the quantitative evaluation of the geosites was based on the judgments of a three-member expert panel. Although the selected experts had relevant expertise, the limited panel size may restrict the diversity of judgments represented in the evaluation. Future studies could include a larger and more diverse expert group and examine the extent to which changes in panel composition affect criterion weights and geosite rankings. Second, the 14 geosites evaluated in this study do not represent an exhaustive inventory of the geoheritage resources of Bayburt Province. Rather, they comprise the sites identified, documented, and examined within the scope of the present research through fieldwork and a review of the relevant literature. Therefore, the findings and rankings should be interpreted as being limited to these 14 geosites and should not be generalized to the entire geoheritage diversity of Bayburt Province. Future research should develop a more comprehensive provincial geosite inventory and subsequently reassess the identified sites within a broader comparative framework. A further limitation concerns the robustness of the rankings with respect to changes in criterion weights and the λ coefficient. In the present study, criterion weights were derived from the F-PIPRECIA procedure and the λ coefficient was determined according to Equation (37); therefore, an additional scenario-based sensitivity analysis was not performed. Consequently, the stability of the rankings under alternative weighting structures or λ values was not explicitly tested. Future studies could address this issue by systematically varying criterion weights and λ values and examining the resulting changes in geosite rankings. Along with the stated limitations of the research, some suggestions are offered to future researchers. Firstly, the topic of inventory and cataloguing could be researched and adopted for further geoheritage assessment studies in Bayburt province. Secondly, studies could be conducted to measure the familiarity of local residents with concepts such as geoheritage, geotourism, and geoconservation. In conclusion, this study provides valuable insights into the assessment and sustainable use of geoheritage, underscoring the need for in-depth field research on this topic.

6. CONCLUSION

This study evaluated 14 geosites identified and examined within the scope of the research in Bayburt Province and determined their relative importance across scientific, educational, economic, geoconservation, and additional value dimensions using the integrated F-PIPRECIA and R-WASPAS methods. The findings are strictly limited to these 14 evaluated geosites and should not be interpreted as representing the entire geoheritage diversity or all potential geosites of Bayburt Province. The F-PIPRECIA results showed that rarity (SV2; 0.302), representativeness and visibility (EV1; 0.323), present tourist infrastructure (EcV2; 0.461), legislative protection (GV4; 0.385), and aesthetic values (AAV3; 0.414) were the most influential sub-criteria within their respective main criterion groups. According to the R-WASPAS rankings, G13 (Helva Village Ice Cave) ranked first in scientific and additional values, G14 (Çımağıl Cave) ranked first in educational value, and G12 (Sırakayalar Waterfall) ranked first in both economic and geoconservation values. G12, G13, and G14 were also consistently positioned among the leading geosites across several evaluation dimensions, indicating their comparatively high importance within the set of 14 geosites examined.

The results should not be interpreted as a systematic assessment of all conservation-use problems in Bayburt Province. The principal quantitative analyses are based on expert evaluations of the selected criteria and the resulting relative importance rankings. Therefore, the implications regarding conservation, management, and geotourism use should be regarded as decision-support considerations derived from the comparative assessment of the evaluated geosites rather than as the outcome of a separate and comprehensive field-based assessment of conservation-use problems.

The specific contribution of this study lies in the quantitative and comparative assessment of the 14 geosites identified in Bayburt Province within a common framework comprising scientific, educational, economic, geoconservation, and additional values, together with the integrated application of F-PIPRECIA and R-WASPAS methods to geoheritage assessment. In this respect, the study extends the previously site-specific geological, geomorphological, archaeological, and tourism-related research in Bayburt by providing a structured multi-criteria decision-support framework for the comparative evaluation of the identified geosites. Within this framework, F-PIPRECIA was used to determine the relative weights of the sub-criteria within each main criterion group, whereas R-WASPAS enabled the comparative ranking of the geosites under expert-based uncertainty. The findings may therefore provide preliminary decision-support input for practitioners, policymakers, and planners involved in the development of a broader geosite inventory, geoconservation planning, and geotourism development in Bayburt Province. They may also contribute to a preliminary assessment of the region's future geopark potential; however, the present results do not constitute a geopark feasibility assessment. Such an assessment would require a more comprehensive geosite inventory, evaluation of representativeness and integrity, an appropriate management structure, local stakeholder participation, accessibility and conservation planning, and sustainable development considerations. Future studies should therefore expand the provincial geosite inventory and reassess the identified sites within a broader and more representative framework.

APPENDIX

Table A1: Evaluation of geosites by DMs based on educational value factor.

Geosites	EV1			EV2			EV3			EV4		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
G1	7	7	7	7	7	5	5	5	3	1	1	3

G2	5	3	5	7	7	5	7	7	7	3	1	3
G3	3	3	5	5	5	5	5	5	5	3	3	5
G4	5	5	5	7	7	7	5	3	5	3	3	3
G5	3	5	3	5	5	5	5	5	5	3	3	3
G6	5	5	7	5	5	5	5	5	3	1	1	1
G7	5	5	5	7	7	7	7	7	7	1	1	1
G8	5	5	7	7	7	7	7	7	7	1	1	1
G9	7	7	7	7	7	7	5	5	5	1	1	3
G10	7	7	7	7	7	7	5	5	5	1	1	3
G11	7	7	7	5	5	5	5	5	5	1	1	1
G12	7	7	7	7	7	7	7	7	7	5	5	5
G13	7	7	7	7	7	7	7	7	7	5	5	5
G14	7	7	9	7	7	7	7	7	7	5	5	5

Table A2: Evaluation of geosites by DMs based on geoconservation value factor.

Geosites	GV1			GV2			GV3			GV4		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
G1	7	7	9	5	5	7	7	7	5	1	1	1
G2	3	3	3	3	3	3	7	7	5	1	1	1
G3	3	3	5	3	3	5	5	5	5	1	1	1
G4	5	5	5	5	5	5	5	5	5	1	1	1
G5	3	3	3	5	5	5	7	7	7	1	3	1
G6	5	5	5	5	5	5	5	5	5	5	5	5
G7	7	7	9	7	7	9	5	5	5	3	3	3
G8	7	7	9	7	7	9	3	3	3	1	1	1
G9	1	1	3	1	1	3	7	7	7	1	1	1
G10	3	3	5	3	3	5	7	7	7	1	1	1
G11	5	5	5	5	5	5	7	7	7	1	1	1
G12	7	7	7	7	7	7	7	7	7	5	5	5
G13	7	7	7	7	7	7	7	7	7	5	5	5
G14	7	7	7	7	7	7	7	7	7	5	5	5

Table A3: Evaluation of geosites by DMs based on economic value factor.

Geosites	ECV1			ECV2			ECV3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
G1	3	3	1	1	1	1	1	1	1
G2	5	3	5	1	1	1	1	1	1
G3	5	7	5	1	1	1	3	3	3
G4	5	7	7	1	1	1	3	3	3
G5	7	7	7	5	3	5	7	5	7
G6	5	7	7	3	3	3	5	5	5
G7	7	7	7	1	1	1	1	1	1
G8	5	5	5	1	1	1	1	1	1
G9	7	7	7	3	3	3	3	3	3
G10	3	3	3	1	1	1	1	1	1
G11	5	5	5	1	1	1	3	3	3
G12	7	7	5	5	5	5	5	5	5
G13	7	3	7	5	5	5	5	5	5
G14	7	7	7	5	5	5	5	5	5

Table A4: Evaluation of geosites by DMs based on the assessment of added values factor.

Geosites	AAV1			AAV2			AAV3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
G1	7	7	5	5	5	5	7	7	7
G2	1	1	1	3	5	5	5	5	5

G3	1	3	1	3	5	3	3	3	3
G4	7	7	7	1	3	1	5	7	5
G5	5	7	7	1	3	1	7	7	7
G6	7	7	7	1	3	1	5	5	5
G7	3	3	5	3	3	5	3	3	5
G8	1	1	1	3	3	5	3	3	5
G9	1	1	1	5	5	5	7	7	7
G10	1	1	1	5	5	5	7	7	7
G11	5	5	5	3	3	3	5	3	5
G12	5	5	5	7	7	7	7	7	7
G13	5	5	5	7	7	7	7	7	9
G14	5	5	5	7	7	7	7	7	7

Table A5: Minimum and maximum normalised values and ranking of geosites.

Geosites	SV		EV		EcV		GV		AAV	
	Min-Max N.	Lev.	Min-Max N.	Lev.	Min-Max N.	Lev.	Min-Max N.	Lev.	Min-Max N.	Lev.
G1-Mount Soğanlı Historical Road	0,322	M	0,322	M	0,000	L	0,439	M	0,934	VH
G2-Somarova Tor Topography	0,407	M	0,314	M	0,139	L	0,100	L	0,176	L
G3-Nişantaşı Gorge Valley	0,136	L	0,139	L	0,311	M	0,118	L	0,000	L
G4- Dragon Rocks	0,207	L	0,327	M	0,438	M	0,237	L	0,640	H
G5-Aydıntepe Underground City	0,247	L	0,068	L	0,996	VH	0,300	M	0,719	H
G6-Çiğdemtepe Mound	0,000	L	0,000	L	0,669	H	0,735	H	0,569	H
G7-Aydıncık Amber Mining Area	0,384	M	0,277	M	0,288	M	0,743	H	0,258	M
G8-Çayırözü Fossil Area	0,442	M	0,347	M	0,227	L	0,406	M	0,003	L
G9-Baksı Meanders	0,160	L	0,423	M	0,609	H	0,000	L	0,415	M
G10-Değirmendere Valley and Waterfall	0,421	M	0,423	M	0,055	L	0,188	L	0,415	M
G11-Dikmetaş Dike	0,391	M	0,173	L	0,354	M	0,307	M	0,409	M
G12-Sırakayalar Waterfall	0,819	VH	0,929	VH	1,000	VH	1,000	VH	0,930	VH
G13-Helva Village Ice Cave	1,000	VH	0,929	VH	0,971	VH	1,000	VH	1,000	VH
G14-Çımağıl Cave	0,962	VH	1,000	VH	0,899	VH	1,000	VH	0,930	VH
							Low (L)		0-0.250	
							Middle (M)		0.251-0.500	
							High (H)		0.501-0.750	
							Very High (VH)		0.751-1.000	

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