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Article

GEOMORPHOLOGICAL, LANDSCAPE AND CULTURAL HERITAGE OF "SERRA DO ALVÃO": INTERPRETATION, ASSESSMENT AND THREATS

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Abstract: The analysis of the morphological features can be framed in different temporal and spatial scales, depending on the specific objectives and methodologies of the various scientific fields that find in them a valuable source of information. The inventory and assessment of the geomorphological heritage may be based not exclusively in geophysical factors, but also in its contribution to the structuring of the biosphere, in its interrelation with other types of heritage or even in its potential for research or education purposes. In this article, we proceeded to the selection of a set of geomorphosites, at different scales, in Serra do Alvão (northern Portugal), seeking to demonstrate the importance of the broad lines of relief and intermediate and detailed landforms to the organization of the cultural landscape. Based on a questionnaire applied to a sample of 104 persons, it was intended to assess the value of the geomorphosites, concerning the scientific, preservation, use, cultural and educational dimensions.

Keywords: Geomorphosites; Geomorphosites assessment; Alvão (north of Portugal).

1. Introduction

The different definitions associated with the concept of geomorphological heritage reflect different valuation criteria **[1]** which stem from the theoretical and methodological framework of each subject area and the specific objectives of each research work **[2]**. The meanings of the geomorphological heritage concept narrower in scope or more integrator prove to be equally useful and necessary, serving its different application purposes **[3].** Besides the physical characteristics, the value of a particular geomorphosite depends, as well of its role in structuring the ecosystem and complexity of the biosphere, its interrelation with other heritage typologies and its potential for research or education **[4,5]**. Inventory and evaluation processes of geomorphosites value should not focus solely on the intrinsic quality of the local geomorphological interest since they also serve the purpose of substantiating the definition of protection levels, conducting educational and recreational activities, as well as reflect its potential to generate economic activities **[6]**. Consequently, the valuation of the geomorphosites should also include its use value and its vulnerability to potential threats in order to sustain the proposal of guidelines for its use and the definition of policies and protective measures. Considering the multiple intentions of the evaluation of geomorphosites, the scientific criteria of geophysical nature are insufficient and it is also essential to take into account the relationship between geomorphological heritage, local communities and their "users / consumers."

This work will sustain itself in the paradigms of multidimensional and interdisciplinary evaluation of geomorphological heritage and its valorization within a geosystemic reading of relations between geomorphology and cultural landscape **[7,8]**. Two central objectives guided the

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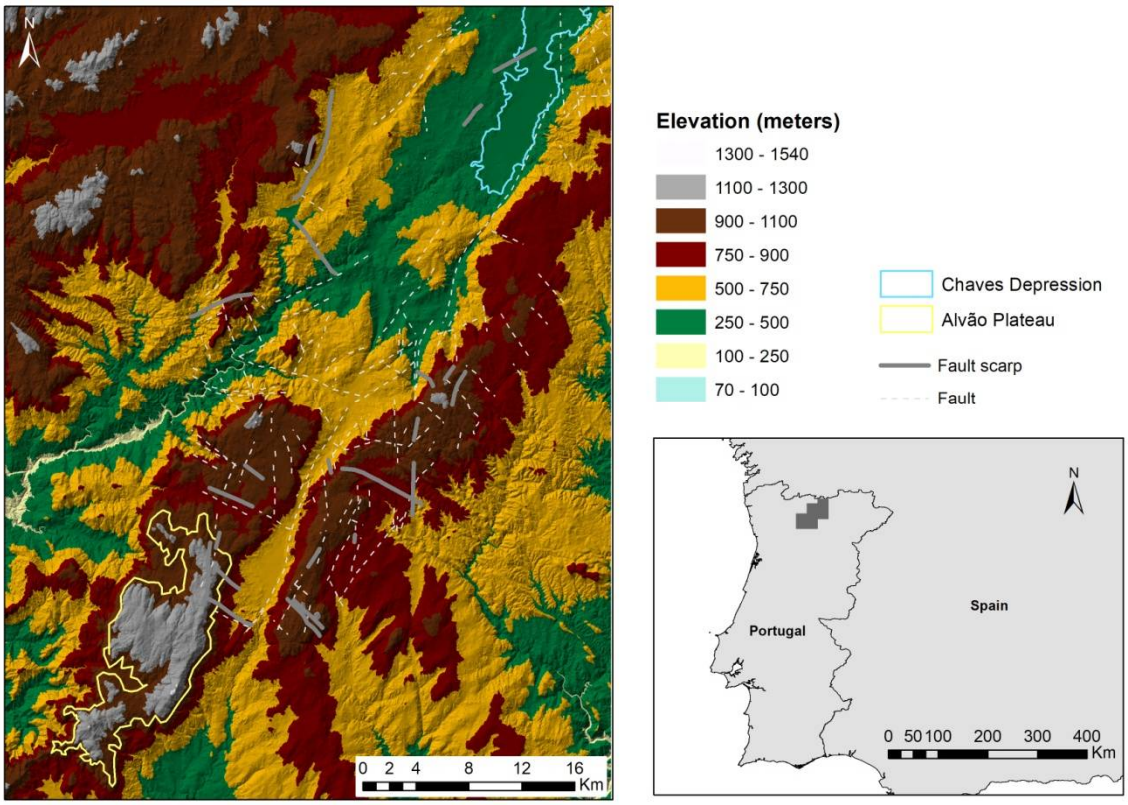
methodological choices made: (i) choose a set of landforms at different scales, representing the regional geodiversity of a geophysical point of view; (ii) assess the value of the geomorphosites, concerning the scientific, preservation, use, cultural and educational dimensions based on a questionnaire applied to a sample of 104 persons.

1.1. Location and geomorphological framework of the study area

The study area is located in northern Portugal and integrates autochthonous terranes from Central Iberian Zone (ITCZ) and parautochthonous terranes of Galicia-Trás-os-Montes Zone (ZGTM), particularly its SE branch (Ribeiro, 2011a) characterized by a considerable heterogeneity in lithology.

Figure 1. Location map of the study area



The vast majority of metasediments is part of autochthonous metasedimentary and subautochthonous units, in particular the lower Marão-Douro group. Only the quartz formation is part of the north-eastern group of Trás-os-Montes. The bigger carriage unit is only represented by a sedimentary unit, although extensive. This is the pelitic-greywacke formation of the lower Silurian, unit that integrates complex parautochthonous units of bigger carriage **[9].**

Parallel to the metasediments outcrop different types of granitoid rocks, which is the predominant type of rock. They settled fundamentally and successively during and after the last stage of Variscan ductile deformation (D3) **[10]**, among which are highlighted the sin-D3 granites, as Pisões Granite (coarse-grained two-mica granite); Borbela granite (fine to medium grain two-mica granite, locally, with biotite or muscovite); Vale das Gatas Granite (GVG) (medium to coarse granite, porphyritic two-mica); and post-D3 granites, whose installation is associated with the displacement **[11-12]**, among which are the Águas Frias-Chaves granite, biotitic, medium porphyritic rough grain and Plutão of Vila Pouca (PVP) in the south, discordant in relation to sin-D3 structures. This corresponds to a laccolith which resulted in two major magmatic intrusions: (i) the intrusion of Vila

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Pouca granite (GVPA), with laminar geometry (threshold) of magnetic foliation inclined outwardly of the pluton and NNE-SSW orientation; (ii) Salted intrusion of granite stones (GPS) corresponding to the magnetic last pulse and forms the majority of the pluton. It is medium grain porphyroid granite, characterized by the presence of microgranular tonalite enclaves and granodiorites often accompanied by veins with NNE-SSW direction coincident with the main fracturing. The geochronological data U-Pb and isotopic (Rb-Sr and Sm-Nd) show an age of 299 ± 13 Ma, obtained by the U-Pb method (**[11,12]**.

The area is part of a structural context dominated by Régua-Chaves-Verin fault The fault corresponds to a late-hercynian left displacement, belonging to the same fault system of Manteigas-Vilariça-Bragança and being sub-parallel to it, with a general orientation NNE-SSW, being located about 60 km west. The structural complexity associated with displacements forms at the regional level, a fault system that extends for several kilometers wide, a complex set of high tectonic blocks by compression (Serra do Alvão) and basins depressed by traction. Some depressions are developed between fault segments and are called the pull-apart (as, for example The Bacia de Telões at orient of Serra do Alvão), others are associated with bends in the faults producing divergences (releasing bends), as for example, the Bacia de Chaves.

2. Materials and Methods

The geomorphological interpretation of the study area is the support of a reasoned selection of geomorphosites at regional level **[13]**, which took into account the major morphological features, intermediate and detailed forms, the latter primarily related to granitic landforms of Serra do Alvão. This selection was based on qualitative methods **[14]**, according to criteria: (i) representativeness of the landform as morphogenetic process; (ii) the morphodynamics witnessed periods; with potential to contribute to the reconstruction of paleoenvironmental conditions; (iii) the current morphodynamic; (iv) the importance to the shaping of the cultural landscape and (v) use value. The analysis of the influence of geomorphological conditions on the landscape mosaic was based on the correlation between morphological and structural characteristics, land use patterns, especially with regard to agriculture, forestry and grasslands, and settlement models.

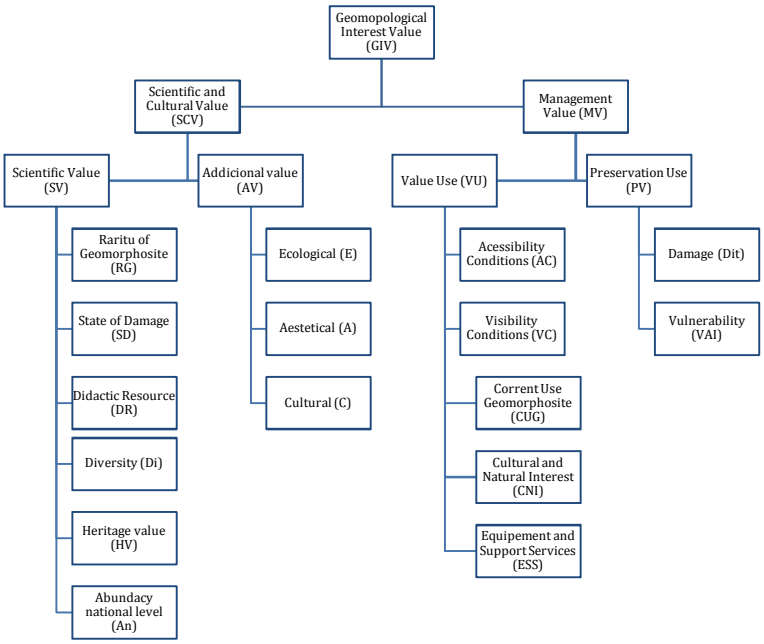

Figure 2. Flow chart of use methodology

After selection of the geomorphosites according the above-stated criteria, a questionnaire was applied to a group of 104 inhabitants, aiming to analyse the perception in what concerns to different values of the geomorphosites.

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The option by this methodological toll comes in line with Pereira et al, 2007, in which it is consider: (i) the scientific and cultural value (SCV); (ii) the management value (MV) e (iii) o geomorphologic interest value (GIV). GIV results from the sum of the scientific value and the additional value (fig. 2).

SCV results from the sum of the scientific value (SV) and additional value (AV). SV results from the sum of the following parameters: (i) rarity of the geomorphosite (RG), (ii) state of damage (SD); (iii) representativeness as didactic resource (RDR); (iv) diversity (Di); (v) heritage value (HV) and (vi) abundance at national level (An). AV results from cultural (C), aesthetic (A) and ecological (E) value.

MV was calculated from the sum of the value of use (VU) and the preservation value (PV). The value of use (VU) results from the sum of: (i) accessibility conditions (AC); (ii) visibility conditions (VC); (iii) current use of geomorphosite (CUG); (iv) other cultural and natural interests (CNI) and (v) equipment and support services (ESS). The value of preservation (PV) implies the quantitative evaluation of the parameters of damage (impacts to date) (Dit) and vulnerability to anthropogenic impacts (impacts due to the use of geomorphological sites) (VAI). Finally, GIV resulted from the sum of SV and MV.

3. Results

3.1. The regional geodiversity and geomorphosites

The landscape organization shows, even in a first reading at the regional level, the decisive influence of the landforms, as shown in Table 1, which organizes the scientific criteria of geomorphological and landscape character, which supported the selection of geomorphosites associated with the major morphological features, namely the plateau of Serra do Alvão, depressions and fault scarps.

Table 1. Scientific and landscaped criteria for selection of geomorphosites associated with major relief lines.

Geomorphosites	Selection Criteria	Geomorphologic framework	Use value
Alvão plateau	Existing scientific knowledge about the morphogenesis Morphology demonstrative capacity associated with shutdown failures	Importance of tectonics in the morphology of the area in study, with is very conditioned by the transform fault Ourense-Basin Lousã in the Régua-Chaves-Verin sector. The fault of orientation predominantly NNE-SSW moved with a strong component up to the end of the Westphalian (Upper Carboniferous). Between the upper Carboniferous and the lower Permian, the fault came to have to have an important component of left motion. Posteriorly to the beginning of the upper Triassic, parallel disconnexions to the fault were reactivated as extensional faults (J. Baptista, 1998). Between the Eocene and the lower Miocene occurs the Pirenaica compression, reactivating the NE-SW and NNE-SSW systems faults, in normal faults and / or in transtensives disconnexions (?), with a large normal component. From the upper Miocene occurs the Betic compression, reactivating the segments towards NNE-SSW stairc Despite the importance that the Hercynian movements had in the study area, there's no doubt that existing morphological features are related to more recent movements. At the end of the Miocene, the direction of the maximum stresses of the Iberian Peninsula would be NNW-SSE. During the Quaternary, the collision between the Iberian Peninsula and Africa	Productive Leisure /tourism Ecological
Chaves depression			

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		comes to have different characteristics depending on the collision zone: the sea, continental shelf or the continental sector (Gibraltar area). In the study area, recent movements generate new faults and reactivate inherited faults. Furthermore reverse faults are generated in a compressive regime, normal faults in extensional regime and numerous flaws with varied styles, but reflecting the disconnecting regime with disconnecting rates of 0.2 and 0.1 mm / year [15].	
Alvão /Falperra fault scarp			

It is usual the association between the presence of granitoid rocks and the existence of natural areas of high landscape and ecological value through the development of a variety of processes at different scales, with geomorphological interest. The thors are frequent, as well as the presence of forms of detail as sinks, tafone or grooves across the Serra do Alvão (Table 2). It appears that many of these forms have their genesis under the mantle changes in microenvironmental conditions more favorable to the development of morphogenetic processes related to the advancement of change mechanisms. Except for the cold climate zones under the alteration of the mantle the thermal stability and higher humidity values enhance such processes.

Table 2. Types of detailed landforms, selection criteria and threats to use value.

Geomorphology aspects	Selection Criteria	**Current active geomorphological processes**	Use value
Linear grooves / slots	Detailed demonstrative capacity of the forms genesis and evolution in granitic areas	Predominance of chemical weathering processes associated with water erosion	Scientific Didactic Touristic
Parallel grooves			
Gnammas (weathering pits)		Primary action of hydrolysis as well as hydration / dissection action by cumulative effect of thermal deviations and indoor / outdoor hygrometric. Exposure to intense surface evaporation, wherein any wall sinuous creates differences in moisture and accelerates the process of evolution of these forms.	
Tafoni			
Thors		Genesis under the change in macro environmental conditions favourable to the development of morphogenetic processes related to the advancement of change mechanisms. Importance of the existence of a web of faults and fractures that dictate the sectors where change front acts preferentially taking advantage of the greater water circulation in these sectors. The mineralogical differences further generate differential changes by varying of the susceptibility to weathering, as well as, internal geodynamic processes, by subjecting the rock material to force concentration, in particular, in the elastic installation phase originating subspheric and fracturing alvioli.	
Zoomorphic and anthropomorphic		Conjugation of morphogenetic processes of different typologies of the detail shapes.	

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forms			

The explanation of some forms is related to the existence of a network of faults and fractures that dictate the preferred sectors of the front change operation, taking advantage of the greater water circulation in these areas. However, mineralogical differences generate differential change by varying susceptibility of weathering. Internal geodynamic processes, by subjecting the rock material to the concentration of forces in particular in the elastic installation phase originate sub spherical cavities **[16]**. It is not consensual the explanation of some smaller shapes, as is the case of tafoni (tafone in the singular) (fig. 3).

Figure 3. Tafone sketch in lateral wall and base. Please note the presence a quartz intrusion (left). Tafone sketches in lateral wall (right).

If a group of authors suggests the shape as having a fully subaerial genesis **[17]**, others admit the possibility of a previous stage in the development of these forms (sub edafic and subaerial evolution) **[18]** and also linked to the installation of the rock mass (elastic phase) **[19]**.

In addition to the mineralogical characteristics of the rock, are still important the tension forces in tafone genesis of: (i) lithostatic and (ii) tectonic, giving rise to deformations and ruptures that condition, therefore, the structural characteristics and lithological discontinuities, and that will influence the weathering process. The active area is split into small and numerous active fronts, which continue to serve the breakdown processes, leading to a weathering hive, allowing each unit to evolve without a relation to others. The hydrolysis action is of paramount importance and the action hydration / dissection by cumulative effect of indoor/outdoor thermal and hygrometric deviations. Exposure to intense surface evaporation places, wherein any wall sinuosity creates differences in moisture, accelerates the development of these forms. Earlier begin a rapid and localized breakdown of the rock blade or grain, forming two surfaces, an inactive, which keeps the above characteristics of the phenomenon, and an active, advancing into the block, increasing its dimensions.

These forms are more common in the study area in leucocratic granites and porphyroid, where one can observe mega crystals potassium feldspars and muscovite which is the predominant mica. Particularly common is the presence of sinks (fig. 4).

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Figure 4. Example of a complex form of sinks and tafone outlines in leucocrate granite, coarse-grained porphyritic with the presence of feldspar megacrystals - eastern slopes of Serra do Alvão.

It is very present forms in granitic areas, assuming different names, varying according to the language and the area of the globe. May be defined as cavities or bowls as rock excavated in the solid rock bed, generally circular, oval or elliptical (Twidale, 2002). They are shapes that allow the retention of water which usually disappears by evaporation (Fig. 5).

Figure 5. Elliptical shape sink. Note the protrusion of a small quartz strand more resistant to the advance of the weathering (left); Set of sinks in different evolution states (right).

Water is the principal agent of weathering **[20]**. In some cases, there appears to be a relationship between the shape and the structure; in other this relationship is not so clear, so there are different interpretations related to its genesis. This is related to epigenetic reasons, subaerial or soil, as well as with other linked to internal geodynamic elements, associated with structural aspects and rock mass installation.

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Figure 6. Elliptical shape sink. Note the protrusion of a small quartz strand more resistant to the advance of the weathering (left); Set of sinks in different evolution states (right).

Although in small number, are also present in the study of area grooves, also known as channels and runnels, or gutters, grooves or flutings. Morphologically resemble roof gutters. The presence of the flutes over the downhill slightly inclined rocky surfaces results from granular rock breakdown leading to deepening the grooves.

Are still frequent "bolideira" stones or oscillating blocks or isolated blocks. Without a complex genesis of important morphological meaning, are recurrent forms in granites and many generate interest and curiosity in the population when give rise to animal related forms, such as turtles or anthropomorphic (fig. 6).

3.2. Evaluation of selected geomorphosites

Table 3. Scientific value (SV) of geomorphosites.

		Scientific Value (SV)					
		RG (0-1)	**SD (0-1)**	**RDR (0-1)**	**Di (0-1)**	**An (0-0,5)**	**SV**
Major landforms	Alvão Plateau	0.7	0.6	0.6	0.7	0.2	2.77
	Chaves Depression	0.8	0.7	0.7	0.8	0.2	3.21
	Alvão /Falperra scarp	0.4	0.3	1.0	0.5	0.1	2.30
Intermediate landforms	*Tors*	0.5	0.2	1.0	0.3	0.1	2.17
Detailed landforms	*Tafoni*	0.4	0.2	0.7	0.7	0.1	2.09
	Complex forms (*tafoni*/sinks)	0.6	0.3	0.6	0.7	0.1	2.32
	Gnammas (weathering pits)	0.4	0.1	0.9	0.4	0.1	1.90
	Grooves	0.5	0.1	0.9	0.1	0.1	1.70
	Anthropomorphic forms	0.7	0.1	0.8	0.1	0.2	1.90

The main geomorphological features, particularly the Alvão plateau and the depression of Chaves, show the higher values of SV. The parameters of rarity (VR), diversity (Di) and the representativeness as didactic resource (RDR) are the ones that contributed the most to this result. It is remarkable that the major geomorphosites, particularly the Chaves depression and the Alvão

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plateau, are understood as areas highly exposed to damage (SD value 0.6 and 0.7, respectively). When queried about the main threats, depopulation, forest fires, agricultural abandonment, expansion of monocultural stands, occupation of land with agricultural potential for other uses and construction of communication infrastructure with scenic impact are the most reported factors.

In what concerns to the intermediate and detailed landforms, the rate is clearly lower. The main identified threats are the forest fires, intensification of pastoral use, vandalism and eventual conflicts between shepherds and educational, leisure, and tourism use.

The major morphological features present the highest values of the additional value (AV). These sites are perceived by the respondents as places of high cultural, aesthetic and ecological values (Table 3). The management value (MV) results from the sum of the value of use (VU) and the preservation value (VP).

Table 4. Additional Value (AV) of the different geomorphosites.

		C (0-0,5)	A (0-1,5)	E (0-1,5)	AV
Major landforms	Alvão Plateau	0.4	1.2	1.1	2.73
	Chaves Depression	0.4	1.3	1.1	2.83
	Alvão /Falperra scarp	0.3	1.1	1.1	2.52
Intermediate landforms	*Tors*	0.1	0.5	0.4	1.01
Detailed landforms	*Tafoni*	0.1	0.6	0.3	1.09
	Complex forms (*tafoni*/sinks)	0.1	0.7	0.3	1.18
	Gnammas (weathering pits)	0.1	0.6	0.1	0.82
	Grooves	0.1	0.2	0.1	0.37
	Anthropomorphic forms	0.1	1.1	0.1	1.31

Table 5. Value of use (VU) of the geomorphosites.

		Value of Use (VU)					
		AC (0-1,5)	VC (0-1,5)	CUG (0-1)	CNI (0-1)	ESS (0-1)	VU
Major landforms	Alvão Plateau	1.3	1.3	0.3	0.2	0.9	4,03
	Chaves Depression	1.4	1.4	0.3.	0.1	1.0	4,22
	Alvão /Falperra scarp	1.3	1.2	0.0	0.1	0.8	3,39
Intermediate landforms	*Tors*	0.4	0.9	0.0	0.0	0.2	1,55
Detailed landforms	*Tafoni*	0.4	0.9	0.0	0.0	0.2	1,60
	Complex forms (*tafoni*/sinks)	0.3	0.9	0.0	0.0	0.2	1,43
	Gnammas (weathering pits)	0.4	1.0	0.0	0.0	0.2	1,61
	Grooves	0.6	0.9	0.0	0.0	0.2	1,73
	Anthropomorphic forms	0.6	0.6	0.0	0.0	0.2	1,48

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The major morphological features present the highest scores of value of use (VU) given that they are places of greater accessibility (AC), visibility (VC), they present other natural and cultural interests (CNI) and present more and better equipment and support services (ESS) (table 4).

When considering the value of preservation (VPR) (Figure 7), which includes the parameters of damage (impacts to date) (Dit) and vulnerability to anthropogenic impacts (VAI), the Chaves depression, the plateau of Alvão and the fault scarp of Alvão and Falperra are the geomorphosites that outstands.

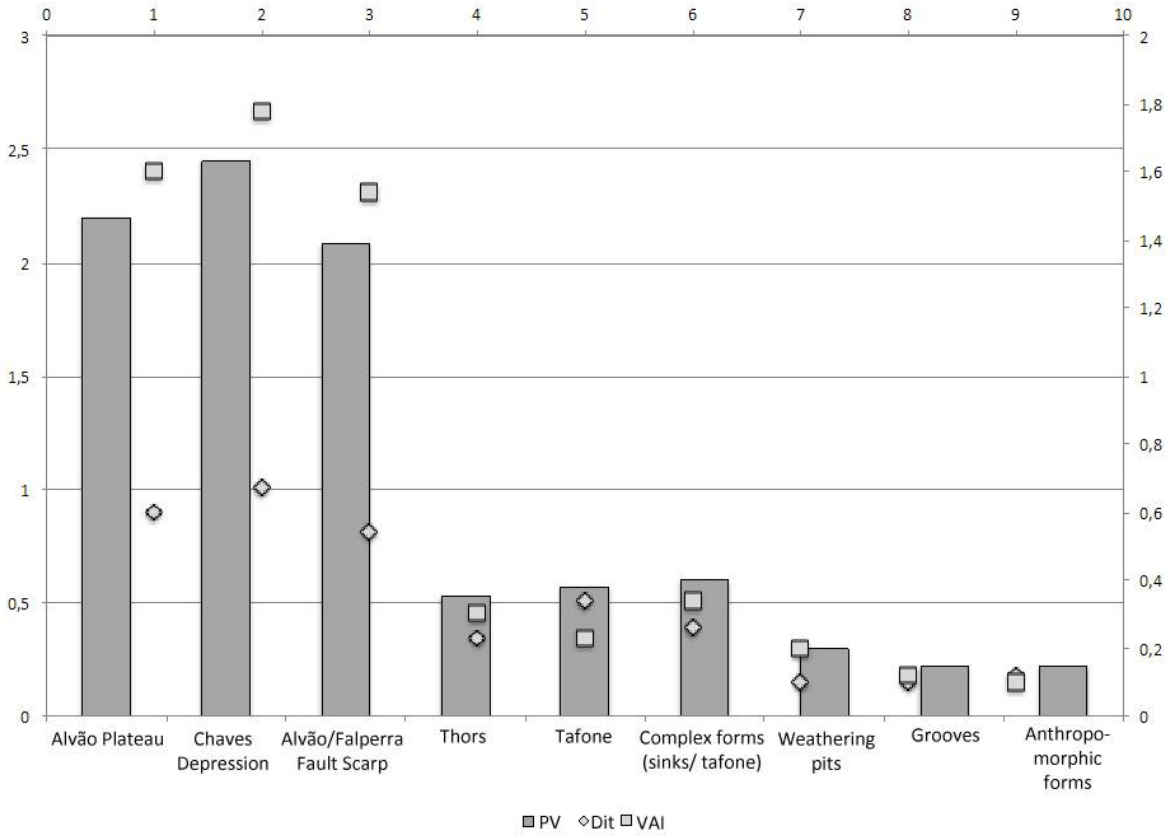

Figure 7. Preservation value (PV) for the different geomorphosites considering the parameters of damage (impacts to date) (Dit) and vulnerability to anthropogenic impacts (VAI).

Table 6. Geomorphological interest value (GIV) obtained from the sum of scientific value (SV) and management value (MV).

		SC (0-1)	AV (0-1)	VU (0-1)	PV (0-1)	
Major landforms	Alvão Plateau	0.7	2.7	2.7	4.0	**15.03**
	Chaves Depression	0.8	3.2	2.8	4.2	**16.3**
	Alvão /Falperra Fault Scarp	0.4	2.3	2.5	3.4	**13.03**
Intermediate landforms	*Tors*	0.5	2.2	1.0	1.5	**7.91**
Detailed landforms	*Tafoni*	0.4	2.1	1.1	1.6	**7.96**
	Complex forms (*tafoni*/sinks)	0.6	2.3	1.2	1.4	**8.43**
	Gnammas (weathering pits)	0.4	1.9	0.8	1.6	**7.05**
	Grooves	0.5	1.7	0.4	1.7	**5.87**
	Anthropomorphic forms	0.7	1.9	1.3	1.5	**7.90**

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Respondents consider that the major geomorphological features are places of high vulnerability to anthropogenic impact (VAI), although they are considered with a medium value of preservation (PV).

The results suggest the major geomorphological features as the sites perceived as having the greatest geomorphological value, especially the Chaves depression (table 6). The results are driven not only by the scientific parameters, but also by the ecological, cultural and value-for-use parameters.

3. Conclusion

Selecting geomorphosites based on a combination of scientific criteria, defined by geophysical point of view, and of its importance in shaping the cultural landscape proved to be a methodology able to increase the recognition of the asset value of landforms.

The major geomorphological features are the sites perceived as having the greatest geomorphological value, especially the Chaves depression. These major geomorphosites, particularly the Alvão plateau and the depression of Chaves, show the higher values of scientific value (SV), as well as of the additional value (AV). These sites are perceived by the respondents as places of high cultural, aesthetic and ecological values. It is remarkable that the major geomorphosites, particularly the Chaves depression and the Alvão plateau, are understood as areas highly exposed to damage. Depopulation, forest fires, agricultural abandonment, expansion of monocultural stands, occupation of land with agricultural potential for other uses and construction of communication infrastructure with scenic impact were the main threats identified.

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