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Methodological Proposal for the Inventory and Assessment of Geomorphosites: An Integrated Approach Focused on Territorial Management and Geoconservation

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ABSTRACT

Geoconservation has been growing in importance within the environmental management context. The conservation of geological heritage is being more and more recognised as an essential issue in nature conservation. Inventories of geosites are considered basic steps in geoconservation strategies and constitute a tool to support management considering the sites' values, use potential and risks of degradation. There are dozens of proposed methods to create inventories and to perform qualitative and quantitative evaluations of the sites and there are still discussions concerning the issues of how to select and evaluate sites and provide management guidelines. Geomorphosites are geosites with geomorphological nature and it is a category that presents some peculiarities highlighted in the literature. This work aimed at proposing a method for inventorying and assessing geomorphosites designed for territorial management focused on the use potential of the sites, divided into scientific, educational and geotouristic uses, the promotion conditions and the risks of degradation. The method was applied to the southeast coast of Rio de Janeiro State, Brazil, which has a high geomorphological diversity. The result was the creation of an inventory of geomorphosites in which all sites were described and quantitatively assessed, creating a product that can be easily applied in the management of the sites. The objective of this work was to contribute to the methodological discussions and to strengthen the insertion of geoconservation on territorial management.

Keywords: Geomorphosites, Inventory, Methodology, Geoconservation

INTRODUCTION

The scientific interest in geoheritage has been growing significantly in the last decades and many initiatives of protection and promotion are being carried out all around the world (Reynard and Brilha 2018). The emergence of geoconservation as a new geoscientific domain concerned with the conservation, management and sustainable use of geodiversity elements, although recent, is becoming an essential topic within public policies, scientific research, nature conservation etc. (Brocx and Semeniuk 2007; Henriques et al. 2011; Brilha 2017).

Geodiversity, as defined in Gray (2013) corresponds to the "*natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscape"*. The importance of geodiversity can be seen in different contexts and perspectives, such as ecosystem services (e.g Gordon et al. 2012; Gray 2013; Gray et al. 2013), biodiversity conservation (e.g Parks and Mulligan 2010; Comer et al. 2015; Hjort et al. 2015) and territorial management (e.g Pereira et al. 2013; Pellitero et al. 2014; Santos et al. 2017). Therefore, since the physical environment is the basis for the development of human societies and biodiversity, it is clear that geodiversity should occupy a more central role in environmental management issues (Brilha et al. 2018).

Ecosystem services are *"the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life"* (Daily 1997). The Millennium Ecosystem Assessment (2005) defined four categories for ecosystem services: regulating, supporting, provisioning and cultural. Within this context, Gray (2011) highlighted the values derived from the abiotic environment (geodiversity), referring to them as geosystem services. Gray et al. (2013) "updated" the term to abiotic ecosystem services and included the knowledge services within the cultural services. This new category concerns the understanding of Earth's history, history of research, environmental monitoring and forecasting, geoforensics, education and employment. Gordon et al. (2012) highlighted that geodiversity also provides the knowledge to help society to adapt to new climate conditions and to mitigate the effects of natural hazards, enhancing the importance of the knowledge services and geodiversity as a whole in territorial management.

Taking into account the relevance of knowledge services, two other concepts must be emphasised: geoheritage and geosites. According to Reynard (2009), there are two approaches to define geosites, a broader one and a more restrictive one. Authors such as Panizza (2001) presented a broad definition in which geosites refer to *in situ* occurrences presenting a specific value (scientific, ecological, economic, cultural or aesthetic) due to human perception or exploitation. A more restrictive definition was proposed by Grandgirard (1999), in which geosites are geological objects presenting a particular relevance for the understanding of Earth's history. Reynard (2005, 2009) proposed to distinguish a central (scientific) value and several additional values for geoheritage sites. According to Brilha (2016), geoheritage refers to occurrences with high scientific value. These occurrences may be *in-situ* or *ex-situ* (e.g minerals, rocks or fossils in a museum collection). The *in-situ* occurrences should be called geosites if they have a high geoscientific importance and geodiversity sites if their geoscientific importance is not so high but they present other interests (see Brilha 2016 for other related concepts). Therefore, the concepts of geoheritage and geosites are directly associated with the knowledge services, being part of the culture services category.

There are still discussions in the geoconservation community about the proposal of Brilha (2016). However, independent of the approach (broad or restrictive), geosites are valued occurrences of geodiversity elements that should be managed in order to be protected from degradation or destruction. To answer the question on how should geosites be selected for protection, inventories are being carried out in many countries. Most of the initiatives were based in Europe (e.g Wimbledon and Smith-Meyer 2012), but national or regional inventories are now being developed in many other parts of the world, such as Brazil (e.g Santos et al. 2016; Garcia et al. 2018; Ferreira et al. 2019), Ethiopia (e.g Megerssa et al. 2019), Morocco (e.g Beraaouz et al. 2019), Egypt (e.g Khalaf et al. 2019), Mexico (e.g Silva-García et al. 2019), Vietnam (e.g Phuong et al. 2017) and others.

An inventory must be well-structured and based on a reliable methodology, otherwise relevant geosites may be undervalued or even unidentified. According to Lima et al. (2010), the objective of the inventory must be clear and, in order to define this objective, four issues must be considered: the topic (i.e subject or theme); the value (e.g scientific, educational, touristic etc.); the scale (i.e the geographical area covered by the inventory); and the use (i.e the purpose of the inventory). The criteria must be transparent and in accordance with the assessed values, allowing an unbiased selection, and the subjectivity degree must be as low as possible (Brilha 2018). Concerning subjectivity, Bruschi et al. (2011) applied a statistical approach to identify the most significant criteria and proposed a parametric method based on objective and clearly defined criteria. An interesting contribution of the work of Bruschi et al. (2011) was to show that a higher number of criteria does not imply a better quality of the assessment.

The benefits of geodiversity elements for society are usually associated to mineral resources that are exploited. However, there is a growing understanding that the benefits go way beyond quarrying and mining activities and many other values and uses of geodiversity are being recognised. Brilha (2018) highlighted three ways in which geodiversity elements are used other than the exploitation of mineral resources: scientific, educational and touristic uses. The use of geosites to continue evolving geoscientific knowledge is essential to ensure the development of human societies. Educational and scientific uses are related, since an important use of geosites is preparing new generations of geoscientists. Additionally, the educational use is also important for schools and science communication. Finally, many geodiversity elements may be used for tourism and leisure, which highlights the possibility of sustainable economic development.

The scientific value is usually addressed as the main/central value (e.g Reynard 2005, 2009; Coratza and Giusti 2005; Pereira and Pereira 2010; Brilha 2016; Reynard et al. 2016), while other values (ecological, cultural, educational etc.) are treated as additional values. The method proposed by Coratza and Giusti (2005), focused on the assessment of the scientific value, emphasised its importance in contexts such as territorial planning, environmental impact assessment and protection of the natural heritage. They also highlighted that the additional values, even when not directly related to geoscientific aspects, may enhance the scientific value. Other proposals recognised the importance of other values in the assessment of the scientific, such as Bollati et al. (2015), who included the ecological value or Panizza and Piacente (2005), who integrated the cultural relevance into the scientific value. Zouros (2007) assessed both the educational and the scientific values together. Therefore, even when treated separately, the additional values may be directly associated with the scientific value.

The educational use is important both in formal education and in informal activities, such as science communication. The method presented by Bollati et al. (2012) is focused on educational purposes, which are important due to the fact that processes modifying the landscape affect and are affected by human activities, so the knowledge about this interaction should be spread in the society as a whole. A very interesting example concerning this issue was presented by Coratza and De Waele (2012), who focused on natural hazards and highlighted that making it understandable to the wider public may be an effective way to reduce losses. Another research with high educational potential was presented by Clivaz and Reynard (2018), who made an approach about “invisible geomorphosites”, which are geomorphological sites that are no longer visible today due to human activities. By using these sites for educational purposes, it is possible to raise awareness on how human activities can alter landscapes.

Promoting tourism activities is often the main goal of geosites’ inventories (Mucivuna et al. 2019). Geotourism is a new and specific form of tourism focused on geology and landscapes (Newsome and Dowling 2010), with the aim to provide geoscientific information to visitors and contribute to the conservation of geodiversity through appreciation and learning about Earth’s history (Hose 2012; Dowling 2013). The importance of geotourism for the socio-economic development of local communities was highlighted by Farsani et al. (2011), who focused their analysis in rural areas. However, works such as the one presented by Pica et al. (2016) show that even urbanised areas may benefit from the development of geotourism. A method for assessing the tourist value of geosites is presented by Pralong (2005), who considered four values/parameters in the assessment: scenic, scientific, cultural and economic. This proposal shows how the scientific value can be relevant for the development of economic and sustainable activities.

Systematic inventories are the basis of geoconservation strategies (Henriques et al. 2011; Brilha 2016) and the absence of inventories or the inadequate management of geoheritage may lead to damage or even total destruction of geosites (Lima et al. 2010). Therefore, inventories usually include the assessment of risks of degradation, which is essential for the correct management of the geosites. Concerning this subject, the work of García-Ortiz et al. (2014) must be highlighted for being dedicated to the assessment of risks of degradation. The authors identified a lack of standardised terminology and method and proposed a method based on the concepts of sensitivity, fragility and vulnerability (anthropic and natural). This is an interesting approach for presenting the risks of degradation related to the intrinsic characteristics of the geosites and external factors that may also impose threats, including issues related to the public use of the sites.

Most of the methodological proposals for creating inventories include a quantitative step, when scores are given to evaluate the values of the geosites (e.g Bruschi and Cendrero 2005; Coratza and Giusti 2005; Zouros 2007; Lima et al. 2010; Pereira and Pereira 2010; Bollati et al. 2013; Brilha 2016; Reynard et al. 2016). Brilha (2016) stated that the quantitative assessment is only necessary for inventories in large territories. For small areas, this step is not required, since the characterisation and qualitative assessment is enough to support geoconservation strategies. The quantitative assessment aims to reduce subjectivity and helps decision-making by managers, especially when dealing with dozens or even hundreds of geosites. The quantitative assessment is done by the selection of criteria and the attribution of scores to each of them.

Among all categories of geosites, geomorphosites are those that have geomorphological nature (Panizza 2001; Reynard et al. 2009). Many methods for inventorying and assessing geoheritage are specifically focused on geomorphosites (e.g Bruschi and Cendrero 2005; Coratza and Giusti 2005; Pralong 2005; Serrano and González-Trueba 2005; Zouros 2007; Pereira et al. 2007; Bollati et al. 2013; Comănescu et al. 2012; Kubaliková 2012; Reynard et al. 2016). Geomorphosites are recognised for having three peculiarities in relation to other categories: the imbrication of spatial and temporal scales, the dynamic dimension and the aesthetic dimension (Reynard et al. 2009). Santos et al. (2019) evaluated how these specificities influence the assessment of geomorphosites and concluded that they should be taken into account in order to prevent mistakes and misjudgements with the final result. These authors also highlighted the importance of the ecological and cultural values for geomorphosites, which are not specificities but are highly relevant in geomorphological contexts. Geomorphosites can be considered as the category with the broadest set of associated values (Coratza and Hobléa 2018).

Mucivuna et al. (2019) presented a research of great importance concerning methodological issues on the creation of inventories and the qualitative and quantitative assessment of geomorphosites. These authors performed a review of dozens of articles in order to analyse how the methods are being applied. First, concerning the qualitative assessment, they concluded that the methods should be more systematic since many are not transparent with the procedures and criteria used to select and describe the geomorphosites (70% of the analysed articles did not specify the criteria used to select geomorphosites and 44% of them did not present standardised methods), making it difficult to reproduce them. Second, concerning the quantitative assessment, there is confusion on how and which criteria should be used, since problems like using the same criteria with different aims or overlapping criteria are common. Their research also showed that there are many methods published as "new", which are highly similar to previously existing methods.

The aim of this work is to present a method for inventorying and assessing geomorphosites, advancing in issues that still need improvements, like how to assess different values in an integrated manner and how to deal with the specificities of geomorphosites in assessment procedures. It assesses the scientific, educational and geotouristic values as representative of the use potentials of the sites. It also assesses the conditions for promotion and the risks of degradation. The objective is to create a product to support environmental management, focused on the geoconservation and sustainable use of geomorphosites. The method was applied to the southeast coast of Rio de Janeiro

State, Brazil, which is a region of high geoscientific relevance and an important touristic destination.

STUDY AREA

The proposed method was tested in the southeast coast of Rio de Janeiro State, Brazil (Fig. 1), which is inside the territory of the proposed *Costões e Lagunas* (cliffs and lagoons) geopark. The area is recognised for its high geodiversity and it has been the target of multiple geological and geomorphological studies for decades (e.g Martin et al. 1996; Turcq et al. 1999; Thomaz-Filho et al. 2005; Schmitt et al. 2016) It is also one of the most important tourist destinations of the whole country due to the high number of beaches with great scenic beauty.

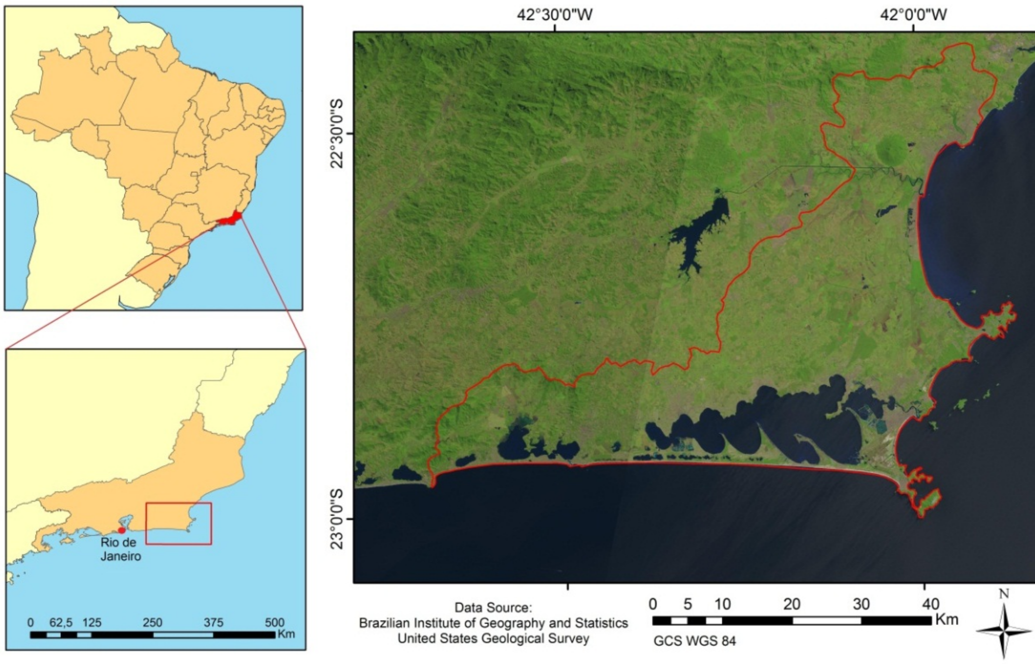


Fig. 1: Location of the study area – southeast coast of Rio de Janeiro State, Brazil.

The geomorphological setting of the area is determined by processes with very different spatial and temporal scales, ranging from tectonic movements related to the opening of the Atlantic Ocean to Holocene sea level variations and anthropic activities (Martin et al. 1996; Castro et a. 2014; Schmitt et al. 2016). Ten types of geomorphological units were identified in the study area, namely: coastal massifs, alkaline massifs, double barrier-lagoon systems, palaeolagoons, marine terraces, cliffs and palaeocliffs, lagoonal spits, dune fields, beaches and cultural landscapes (anthropic landforms).

The coastal massifs (Fig. 2A) are related to the tectonic movements related to the opening of the South Atlantic Ocean, between the Upper Jurassic and Lower Cretaceous. In this context, a series of rifting processes uplifted the mountain ranges which are, nowadays, parallel to the Atlantic Ocean coastline and the lower coastal massifs (Asmus and Ferrari 1978; Zalán and Oliveira 2005). The alkaline massifs are part of the magmatic alignment called *Poços de Caldas-Cabo Frio*, which consists of several massifs composed of alkaline rocks stretching for more than 480 km in an east-west direction.

The genesis of this landform is related to the movement of the South-American plate over a hotspot (Thomaz-Filho et al. 2005).

During the Quaternary, sea level variations were responsible for the genesis of several features in the coastal plain (Martin et al. 1996). The portion of the coastline facing south is characterised by the presence of a double barrier-lagoon system. The inner barrier was formed during the Pleistocene transgressive event, around 123,000 years BP, when the Araruama Lagoon was formed. During the following regression, many lagoons passed through drying processes and wilted or even disappeared, originating a series of palaeolagoon deposits which are present in today's coastal plain (Fig.2B). The external barrier was formed during the Holocene Maximum Transgression, around 5,100 years BP, when a series of lagoons were formed between the inner and the external barriers. Sea level oscillations during the Holocene are also responsible for the existence of marine terraces and palaeocliffs (Fig. 2C), which were originated by coastal processes but are now located above sea level, no longer being affected by these processes.

At present, the region is marked by a climatic peculiarity. While most of Rio de Janeiro State is characterised by a humid tropical climate, the southeast coast has a semi-arid climate. The main reasons for this peculiarity is the geomorphological setting, since the region is a coastal plain distant from the mountain ranges that "block" humidity from the ocean and it is affected by upwelling phenomena, in which cold waters from the Malvinas current come to the surface, inhibiting the formation of clouds (Barbiére 1975). This climatic peculiarity allows the establishment of dune fields (Fig. 2D), which are mainly aligned with the predominant NE winds. These dune fields are formed by a "simple" process: waves in the ocean deposit sand in the coast and the winds remove the fine sediments, depositing them in the coastal plain (Fernandez et al. 2009).

Other interesting geomorphological features related to the climatic peculiarity are the *Salinas* cultural landscapes (Fig. 2E). Due to the lack of rains and intense insolation, the production of salt by natural evaporation in tanks took place as a historical economic activity. This economic activity created an anthropic landform characterised for being totally flat, eventually with shallow water. These landscapes are now recognised as a cultural heritage of the region.

The Araruama Lagoon is the largest hypersaline lagoon in Brazil and one of the largest in the world (Debenay et al. 2001). Its northern shore is composed of basement rocks while the southern shore is the inner barrier, formed during the Pleistocene. Wind-generated waves are responsible for the formation of a series of cuspate spits (Fig. 2F) with a northwest orientation inside the lagoon, in conformity with the predominant NE winds. These winds generate waves that have an angle between their crests and the shoreline, creating a sediment flux, since the southern shore is a sand barrier. When high-angle waves reach a perturbation in the shoreline, the changes in the angle provokes, initially, an increase in the sediment flux in the inflection point, causing erosion. Then the angle becomes continuously smaller, causing a decrease in sediment flux and, consequently, accumulation in the crest of the feature. As the spit grows longer, it creates a "shadow-zone" for the main wave action downdrift. It allows the activity of weaker waves that create a counter-debris stream filling the cavity between the spit and the shore. Another spit is formed, then, by the same processes occurring beyond this "shadow-zone”. This type of process is described in works such as Zenkovitch (1959) and Ashton et al. (2001).

Finally, the region is characterised by a great variety of beaches with high scenic beauty. Because of that, tourism is the main source of income in most of the municipalities. Due to local conditions, there are several types of beaches. The coastline facing south, for instance, presents great barriers with a clear east-west orientation (Fig. 2G). The coastline facing east, in the other hand, presents several coves (Fig. 2H) and beaches with different shapes and morphodynamic profiles.

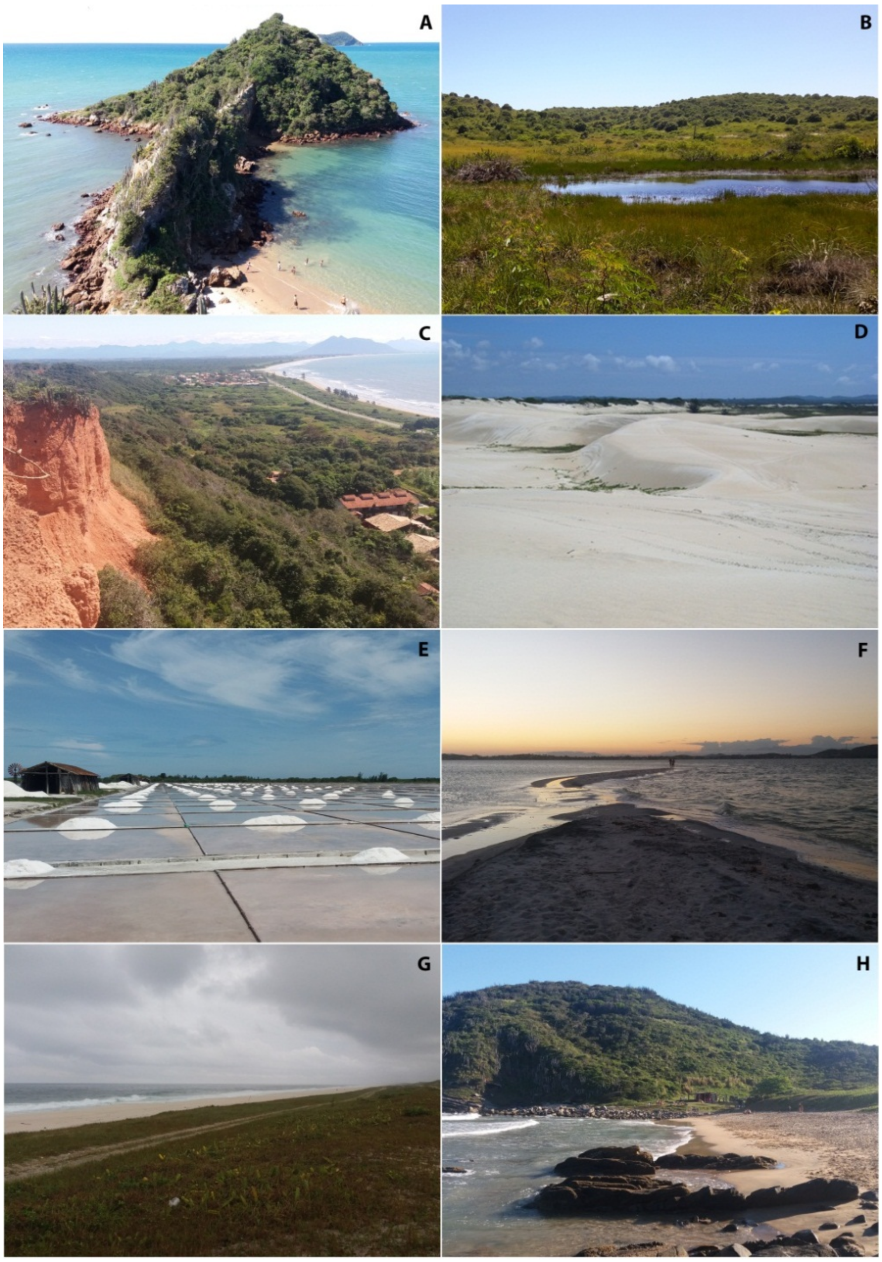


Fig. 2: (A) Coastal massif in Pai Vitório Point; (B) Wetlands related to palaeolagoons in Armação dos Búzios; (C) Palaeocliff above current sea level; (D) Peró dune field; (E) *Salinas* cultural landscape; (F) Edge of a cuspate spit in Araruama Lagoon; (G) Coastal barrier in Massambaba beach; (H) Cove beach in José Gonçalves. (photo D: Kátia Mansur; all other photos: Daniel Santos).

METHODOLOGICAL PROCEDURES

The method was divided into three main steps: preliminary assessment, characterisation and quantitative assessment. The first consists of the selection of geomorphosites to be included in the inventory and the two further steps are the complete assessment of the site.

Preliminary assessment

The pre-selection is one of the most unclear steps in the methods proposed so far (Pereira and Pereira 2010; Reynard et al. 2016; Sellier 2016; Mucivuna et al. 2019). Geodiversity comprises all elements of the physical environment and, as highlighted by Brilha (2016, 2018), choosing the ones that must be conserved for the benefits of present and future generations is a major challenge in geoconservation. Therefore, when a method is not clear about the procedures, it becomes hard, sometimes impossible, to reproduce it in other areas, resulting in the creation of new methods instead of using previous ones (Mucivuna et al. 2019).

Some works, such as Coratza and Giusti (2005) and Serrano and González-Trueba (2005), present indications on how to select the sites that will be evaluated. Coratza and Giusti (2005) highlighted the use of GIS in this step, using geomorphological maps and DTMs for an initial investigation. The method of Serrano and González-Trueba (2005) used geomorphological maps as basic tools to identify geomorphosites. Both works state that the knowledge about the geomorphological setting of the area is crucial for the inventory. However, the parameters used for selecting the sites are not clear enough to be reproduced by other researchers, since there is still a high degree of subjectivity.

The method proposed by Pereira and Pereira (2010) is one of the first to present a pre-selection phase, in which potential geomorphosites are identified and qualitatively evaluated under a clear set of criteria. The identification is based on a geomorphological survey of the area through bibliographic research and fieldwork. The scientific relevance, aesthetic component and the links with cultural and ecological elements are the criteria used in this stage. The preliminary evaluation consists of a qualitative assessment of the scientific, ecological, cultural and aesthetic values and parameters of use and management, including need of protection. The final selection is based on the performance of the sites in this first evaluation.

The method proposed by Brilha (2016), designed not only for geomorphosites but for any category of geosites, also proposes a clear pre-selection phase. This author presented a conceptual review and its method is divided in sites with scientific value (geosites) and sites with educational and touristic relevance (geodiversity sites). The pre-selection phase consists of bibliographic review followed by fieldwork, when the sites are characterised and evaluated taking into account their representativeness, integrity, rarity and scientific knowledge if they are potential geosites; and their didactic potential, geological diversity, accessibility, safety, aesthetic component and interpretive potential if they are potential geodiversity sites.

Sellier (2016) focused on the geomorphological context, bringing the idea that an inventory should provide an overview of the geomorphology of the study area. Reynard et al. (2016) followed this idea, proposing a selection method divided in four steps: (1) definition of the main geomorphological contexts (morphostructures, geomorphological processes etc.); (2) creation of a preliminary list of landforms including each geomorphological context; (3) classification of the landforms based on spatial and temporal criteria; (4) selection of geomorphosites, with the creation of a list that is representative of the geomorphology of the study area, covering the diversity of landforms and the morphogenetic phases.

The methodology proposed here starts with a pre-selection phase, called Preliminary Assessment. It is based on the main issues highlighted on previous proposals and is divided in the following steps:

1. Following Sellier (2016) and Reynard et al. (2016), the first step is the definition of the geomorphological contexts of the area. Serrano and González-Trueba (2005) used geomorphological maps as basic tools to select geomorphosites. However, especially in large countries, like Brazil, there is a lack of data in many areas and developing geomorphological maps as a mandatory condition for creating inventories is unfeasible for being time consuming and for the significant elevation of costs. Therefore, we endorse that geomorphological maps should be used but, if they do not exist in an area, this first step must be done with other materials (remote sensing products, other thematic maps, bibliographic and field survey etc.).

2. Selection of sites in each context considering the representativeness of the landforms. Following Reynard et al. (2016) proposal, this step must take into account spatial and temporal criteria, so that the inventory may cover both the geomorphological diversity and the morphogenetic phases. The sites must be selected by their scientific relevance, but also by their educational and touristic use potentials, as in Brilha (2016). This step ends up with the creation of a preliminary list of sites.

3. Assessment of the sites according to the parameters and scores displayed in Table 1. This step was mainly based on the work of Pereira and Pereira (2010), with some modifications on the parameters. The main goal of this step is to avoid the inclusion of non-relevant sites in the following procedures (characterisation and quantitative assessment), which are time consuming and demand a lot of effort. Only the sites with high scores are selected. There is not a specific score to be achieved. The evaluator can decide what the minimum score is taking into account specific issues of his work. The only recommendations are: sites with Very High rarity must be chosen; Sites with low scores on Additional Parameters and Use and Management Parameters, but high values on the Central Parameters, should not be excluded; and there must be at least one site representing each geomorphological context. By the end of this step, a final list is created with the sites that will be included in the inventory.

Table 1: Criteria and scores for the Preliminary Assessment of sites.

Criteria		Assessment
Central Parameters	Representativeness Integrity Rarity Scientific knowledge	1 – Low 2 – Medium 3 – High 4 – Very high
Additional Parameters	Ecological relevance Cultural relevance Aesthetic relevance	0 – None 1 – Low 2 – Medium 3 – High
Use and Management Parameters	Accessibility Safety Infrastructure Visibility	1 – Low 2 – Medium 3 – High

Characterisation and quantitative assessment

After the preliminary assessment, each selected site passes through a process of characterisation of its geomorphological aspects, associated interests and use and management issues. This step is not only essential for the final results, but also to provide the necessary information for the quantitative assessment. Similarly to the preliminary assessment, previous proposals were analysed in order to propose the method used in this work.

The use of descriptive cards for the characterisation is common (e.g Serrano and González-Trueba 2005; Pereira and Pereira 2010) and it is an effective way to standardise the information. Other authors (e.g Brilha 2016; Reynard et al. 2016) do not use descriptive cards, but clearly describe which information must be included. For this work, a descriptive card is proposed (Table 2), being mainly based on the work of Serrano and González-Trueba (2005) and considering issues highlighted in other works. The spatial classification is based on Grandgirard (1999) and Perret (2014) (Fig. 3). This classification is related to the spatial complexity of the geomorphosite according to the processes and landforms, being also important for the creation of a vector database in GIS, which is not mandatory, but strongly recommended. However, different from some authors (e.g Pereira and Pereira 2010; Rodrigues 2013; Migón and Pijet-Migón 2017), viewpoints are not considered as geomorphosites in this work, being considered a place to visualise geomorphosites or landscapes. Geomorphosites are geomorphological features presenting certain values that the viewpoints themselves do not have, since they can even be totally man-made (in accordance with Santos et al. 2019).

Table 2: Characterisation of geomorphosites including the quantitative assessment results.

Identification	Name
	Location
	Property
	Eventual use limitations
Geomorphology	Thematic classification (coastal, aeolian, glacial, tectonic etc.)
	Spatial classification (according to Figure 3)
	Size/ Area
	Altitude
	Landforms: active and inactive (when applicable)
	Processes: active, inactive or passive evolving geomorphosite (based on Pelfini and Bollati 2014) (when applicable)
	Morphogenesis (morphogenetic history)
Associated interests	Brief explanation of each associated interest (high geodiversity, other areas of geosciences, ecological, cultural etc.)
Use and Management	Access (from closest city or village): Public/ private transport; Trails; Access to wheelchairs (takes into account the possibility of existence of different specific viewpoints).
	Safety. Takes into account the type of visitors, size of groups and inherent risks of the site.
	Observation conditions.
	Interpretive potential and existence of interpretive material.
	Infrastructure on the site.
	Regional touristic infrastructure.
	Integrity and protection status.
	Fragility.
	Natural and anthropic vulnerability.
Quantitative assessment	Graphic presenting the quantitative assessment results
Photos	
References	

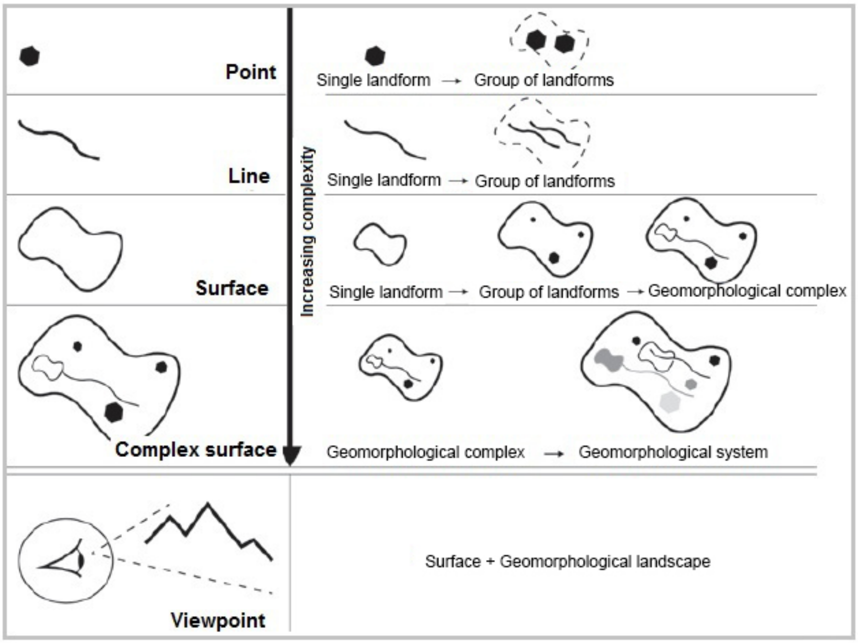


Fig. 3: Spatial classification of geomorphosites (translated from Perret 2014).

The quantitative assessment is still a subject of discussion, with dozens of different methods proposed so far (Mucivuna et al. 2019). A basic idea is that the methods must be in conformity with the aim of the inventory. A method focused on creating an inventory of sites with scientific relevance, for instance, would not consider parameters such as aesthetic value. An inventory focused on geotourism, on the other hand, would definitely take this parameter into account, since the aesthetic dimension is quite important to attract tourists and raise awareness about the importance of geomorphology for the society as a whole (Goudie 2002). Therefore, the parameters included in a method must have a direct connection with the aim of the inventory.

The method proposed here is focused on the use potential of the site, dividing it into three types: scientific use, educational use and geotouristic use. Besides that, the method is intended to assess the promotion potential of the site, which is the assessment of the visiting conditions in order to find out if the site is suitable to be promoted for visitors or if it needs managing actions before. Finally, the risks of degradation are also quantitatively assessed, since this is a fundamental issue in geoconservation. Therefore, three values are assessed to represent the use potential, namely the scientific, educational and geotouristic values. The ecological, cultural and aesthetic values are used as parameters to assess the use values and are also displayed as additional values in the final result because of their importance for geomorphosites.

Despite the existence of different methods because of their different aims, it is clear that many of the criteria used are similar. Pralong (2005), for instance, presented a method to assess the tourist potential of sites and included, among others, the scientific value as a parameter. Bollati et al. (2012) presented a method focused on educational purposes and also included the scientific value as a part of the assessment. The same was done by Coratza and Giusti (2005) in their method focused in territorial planning, environmental impact assessment and protection of the natural heritage. Due to the importance of the scientific value, authors such as Pereira and Pereira (2010), Brilha (2016) and Reynard et al. (2016) put it as central values in their methods, while other values are considered as additional.

Considering that the method proposed here is focused on the scientific, educational and geotouristic use of the sites and that methods proposed so far use similar criteria despite having different aims, a set of criteria was selected to assess these values, being called Basic Parameters. Considering the work of Bruschi et al. (2011) that shows that a high number of parameters does not translate into a more accurate assessment, the choice of the Basic Parameters considered some of those most used in previous proposals, being careful not to use parameters that are too similar.

The Basic Parameters are: representativeness, integrity, rarity, geodiversity, interpretive potential, scientific knowledge and observation conditions. They were chosen for being present in some of the most important existing proposals (e.g Pereira and Pereira 2010; Brilha 2016; Reynard et al. 2016). The palaeogeographic value was considered part of the representativeness, since landforms with palaeogeographic value are actually representing a part of the history of the Earth, and thus do not need to be assessed separately.

Some proposals include the ecological value as part of the scientific value and highlight its importance for educational and touristic purposes (e.g Panizza 2001; Pralong 2005, Bollati et al. 2012). For this reason, it was also included in the assessment. The cultural value was also included for considering the importance of cultural geomorphology; so it was not considered only an additional value, but part of the scientific and educational values. The importance of the cultural value for geotourism is also stressed in previous works (e.g Pralong 2005; Coratza et al. 2016). However, sites presenting relevant ecological and cultural values are not so common; so it was decided to consider one or the other in the assessment instead of both. Finally, the aesthetic value was included especially due to its importance for geotourism, but also for presenting relevance in educational activities, since the aesthetic dimension also attracts the attention of students and people taking part in educational projects. It is important to highlight that these values (ecological, cultural and aesthetic) are used to assess the scientific, educational and geotouristic values but must also be presented as additional in the final results.

The same parameters were used to assess different values, but it would be wrong to consider that they always have the same importance. For this reason, a weighting scheme was proposed to assess the scientific, educational and geotouristic values, as displayed in Table 3. The indicators to assess the basic parameters are presented in Table 4 and the additional values in Table 5.

Table 3: Parameters to assess the scientific, educational and geotouristic values and the weighting scheme.

	Scientific value	**Educational value**	**Geotouristic value**
Representativeness	30%	20%	10%
Integrity	20%	10%	15%
Rarity	15%	10%	10%
Geodiversity	5%	5%	5%
Interpretive potential	0%	15%	15%
Scientific knowledge	10%	10%	0%
Observation conditions	10%	15%	15%
Ecologic or cultural value	10%	10%	10%
Aesthetic value	0%	5%	20%

Some methods for the assessment of geomorphosites present different weights to calculate the final values; however, their authors do not justify the reasons for that (Mucivuna et al. 2019). In the method proposed here, the weightings were applied in order to stress that some parameters have higher importance than others.

Representativeness, integrity and rarity are three of the most used criteria to assess the scientific value of geosites (Mucivuna et al. 2019), so they have a higher importance for the scientific value in the proposed method, adding up to 65% of the total. These criteria have a slight lower relevance for the educational and geotouristic values because other criteria were considered equally or more important (interpretive potential and observation conditions). The aesthetic value is considered the most important for the geotouristic value due to the attractiveness of the aesthetic dimension for the public in general. Scientific knowledge represents the current scientific use of the site and the weight of 10% was given to address that fact; it is not higher because it is common that sites have a high potential but are not yet very used. Geodiversity is considered because the variety of elements may be an interesting characteristic, but, since it is not "mandatory" to have diversity of elements to be important, the weight given to this parameter is low.

Table 4: Indicators to assess the basic parameters.

Representativeness	0.25: The site represents a form or process of the regional geomorphological context.
	0.5: The site is the best example of some geomorphological unit of process of the regional geomorphological context.
	0.75: The site represents a clear relation between forms and processes or the site has palaeogeographic relevance.
	1.0: The site represents a clear relation between forms and processes and the site has palaeogeographical relevance.
Integrity	0.25: The forms and/or processes are significantly altered.
	0.5: The forms and/or processes are significantly altered, but it is still possible to clearly recognize and analyse them.
	0.75: The forms and/or processes are not intact, but are not significantly altered.
	1.0: The forms and/or processes are intact.
Rarity	0. 25: The site represents a common form/ process in the area.
	0.5: The site is the best example of a common form/process in the area.
	0.75: There are few examples of the form/process represented by the site.
	1.0: The site is the only occurrence of the type in the study area.
Geodiversity	0.25: The site represents a geomorphological complex.
	0.5: The site represents a geomorphological system.
	0.75: The site presents relevant elements beyond geomorphology (other aspects of geodiversity).
	1.0: The site presents three or more relevant elements beyond geomorphology (other aspects of geodiversity).
Scientific knowledge	0.25: There is scientific material available (monographies, abstracts, simple reports etc.).
	0.5: The site was used for the development of master dissertations or it is currently used for the development of not yet published research.
	0.75: There are works about the geomorphological features of the site published in national journals or books with national relevance or the site was used for the development of doctoral theses.
	1.0: There are works about the geomorphological features of the site published in international journals or books with international relevance.
Observation conditions	0.25: The observation of the elements is very hard, depending on specific conditions.
	0.5: The observation of the elements is hard, but it does not depend on specific conditions.
	0.75: There are few difficulties for the observation of the elements.
	1.0: There are no obstacles for the observation of the elements.
Interpretive potential	0.25: Suitable only for students of geosciences.
	0.5: Some basic geoscientific knowledge is necessary to interpret the site (scholar level).
	0.75: Suitable for youth and adults.
	1.0: Suitable for any group, including children.

Table 5: Indicators to assess the Additional Values.

Ecological value	0.25: The geomorphological unit represented by the geomorphosite has direct relationship with some biotic aspect.
	0.5: The geomorphological unit represented by the geomorphosite has direct relationship with some special biotic aspect (rare, endemic, threatened etc.).
	0.75: The site shows a clear conditioning of geomorphology over some biotic aspect.
	1.0: The site represents a special case of relationship between geomorphology and biodiversity.
Cultural value	0.25: There are elements with cultural importance, but not directly related to the geomorphological setting.
	0.5: There are elements with cultural importance directly related to the geomorphological setting or the site has economic importance.
	0.75: The site is/was occupied or is highly relevant for some traditional community or the site was used for the development of a geomorphological model.
	1.0: The main geomorphological feature is anthropic, or represents an icon of a people/region, or is highly relevant for the history of geomorphology.
Aesthetic value 1: Visualisation conditions	0.25: There are significant difficulties to visualize the site, being impossible to see it in its totality.
	0.5: There are significant difficulties to visualize the site, but it is possible to see it in its totality.
	0.75: The site can be seen with no difficulties, but only from specific viewpoints.
	1.0: The site can be seen with no difficulties without the need of going to specific viewpoints.
Aesthetic value 2: Conservation	0.25: Site highly altered/ degraded.
	0.5: Site partially altered/ degraded.
	0.75: Site with alterations but with low influence on its aesthetics.
	1.0: Site in very good state of conservation.
Aesthetic value 3: Aesthetic dimension	0.25: Low (the aesthetic dimension does not contribute to attract visitors).
	0.5: Medium (the aesthetic dimension may be attractive to a specific public).
	0.75: High (the aesthetic dimension may highly contribute to attract visitors).
	1.0: Exceptional (site already widely recognised by its aesthetic dimension).
Aesthetic value	(AV1 + AV2 + AV3)/3

The aesthetic value is one of the most subjective, being difficult to quantify. The parameters proposed here take into account not "how beautiful the site is", since it would be impossible to answer this question with a score. Assessing the visualisation conditions is considered part of the aesthetic value because the method is focused on the use potentials of the site, so sites where the fruition of the aesthetic dimension is facilitated should have higher values. The conservation is also taken into account because a degraded site loses its characteristics, which may influence its aesthetics depending on the degree of alteration. Finally, the aesthetic dimension parameter is the most subjective one, since it depends more on the evaluator. This parameter is assessed based on the potential of the site to attract visitors due to its aesthetics, with the highest values being given to the sites that are already recognised by the wide public.

After the assessment of values, comes the assessment of use and management parameters, which are divided into Promotion and Risks of Degradation. Similarly to Reynard et al. (2016), use and management characteristics are not considered values of the sites. However, different from the cited authors, it does not mean that they should not be quantitatively assessed. It is only important to make it clear that this is an assessment of the current conditions for use and risks of degradation and it may change if management actions are taken. In fact, this is the point in performing this quantitative assessment: to provide a tool for managers that make it easier to identify sites that need attention, such as sites with high values and high risks of degradation or inadequate conditions to receive visitors.

Table 6 presents the indicators to assess Promotion parameters, which are: access by public transport; access by private transport; need for walking/hiking; natural risks; human risks; safety for groups; infrastructure in the site; regional touristic infrastructure. All parameters were considered equally important; so no weighting is proposed for this assessment (the total value is the arithmetic mean). Table 7 presents the indicators for the Risks of Degradation, being: legal and indirect protection; access; fragility; anthropic vulnerability; natural vulnerability; use conflicts. The weighting for these parameters is presented on Table 8.

The main inspiration for the assessment of Risks of Degradation was the work of García-Ortiz et al. (2014). The parameters “access” and “legal and indirect protection” were inspired by the work of Brilha (2016).

Table 6: Indicators for the assessment of Promotion parameters.

Access by public transport	0.25: Low frequency and distant from the site.
	0.5: Low frequency but close to the site.
	0.75: Frequent but distant from the site.
	1.0: Frequent and close to the site.
Access by private transport	0.25: Need of specific vehicles.
	0.5: It is possible to visit with regular vehicles.
	0.75: Good roads and parking area or parking area for bus. .
	1.0: Good roads and parking area for bus.
Need for walking/ hiking	0.25: Hiking with technical difficulties.
	0.5: Long and technically easy walk or short and technically easy walk, but inaccessible for disabled visitors.
	0.75: Short and technically easy walk, accessible for disabled visitors.
	1.0: No need to walk.
Natural risks	0.25: Dangerous environment, with risks of serious accidents.
	0.5: Small risk of accidents or risk of serious accidents due to inadequate behaviour.
	0.75: Small risk of accidents due to inadequate behaviour.
	1.0: Safe environment.
Human risks	0.25: Problems related to violence.
	0.5: Site located along dangerous road.
	0.75: Site with no safety infrastructure.
	1.0: Safe environment (site has safety infrastructure or does not need any).
Safety for groups	0.25: Group visits demand special care.
	0.5: Safe for small groups.
	0.75: Safe for groups of adults.
	1.0: Safe for groups with children.
Infrastructure in the site	0.25: Site with eventual infrastructure (high season, weekends etc.).
	0.5: Site with interpretive infrastructure but no other infrastructure for visitors.
	0.75: Site with infrastructure for visitors (bathrooms, shops etc.).
	1.0: Site with both interpretive and visiting infrastructure.
Regional touristic infrastructure	0.25: The closest city/village with touristic infrastructure is less than three hours away by car/bus.
	0.5: The closest city/village with touristic infrastructure is located around one hour away by car/bus.
	0.75: The site is located in the surroundings of a city/village with touristic infrastructure.

	1.0: Site located within a city/village with touristic infrastructure.

Table 7: Indicators for the assessment of Risks of Degradation.

Legal and indirect protection	0.25: Site located in protected area with no control of access, but with the presence of communities, associations or groups that effectively protect the site.
	0.5: Site located in protected area with no control of access or site with no legal protection but with the presence of communities, associations or groups that effectively protect the site.
	0.75: Site with no legal protection and with reduced action of communities, associations or groups protecting it.
	1.0: Site with no legal or indirect protection.
Access	0.25: Access by long walk with no technical difficulties or short walk with technical difficulties. The walk starts in non-paved road, but accessible by bus.
	0.5: Site located close to non-paved road, but accessible by bus. May include short and easy walk.
	0.75: Access by long walk with no technical difficulties or short walk with technical difficulties. The walk starts in paved road, easily accessed by car or public transport.
	1.0: Site located close to paved road, easily accessed by car or public transport. May include short and easy walk.
Anthropic vulnerability	0.25: Forms/processes vulnerable to large scale interventions on the site or related areas, but with no problems related to visits.
	0.5: Forms/processes vulnerable to small scale interventions on the site or related areas, but with no problems related to visits.
	0.75: Forms/ processes vulnerable to visits, with the need of special cares (infrastructure, rules, guides etc.).
	1.0: Forms/processes highly vulnerable to visits, being restricted to authorised people.
Natural vulnerability	0.25: Possibility of small alterations on the forms or processes of the site by geomorphological or climatic processes not related to the site.
	0.5: Possibility of significant alterations on the forms or processes of the site by geomorphological or climatic processes not related to the site.
	0.75: Possibility of partial destruction of the forms or processes of the site by geomorphological or climatic processes not related to the site.
	1.0: Possibility of total destruction of the forms or processes of the site by geomorphological or climatic processes not related to the site.
Fragility	0.25: Low risk of degradation due to inherent geomorphological conditions of the site.
	0.5: The geomorphological processes of the site are gradually destroying it (at the human or historical temporal scale).
	0.75: Possibility of total destruction of the site in case of extreme events.
	1.0: Risk of total destruction in a short period of time due to processes inherent to the site.
Use conflicts	0.25: There are use conflicts affecting or preventing the scientific, educational or geotouristic uses, but they do not impose risks to the site.
	0.5: There are use conflicts imposing risks to the site.
	0.75: There are projects that may destroy the site if put into practice.
	1.0: The current use or imminent changes may destroy the site in a short period of time.

Table 8: Weighting of the risks of degradation parameters.

Legal and indirect protection	25%
Access	10%
Anthropic vulnerability	15%
Natural vulnerability	15%
Fragility	25%
Use conflicts	10%

For the assessment of the risks of degradation, García-Ortiz et al. (2014) proposed using the concepts of fragility and vulnerability (natural and anthropic) as the basis. Because of that, these parameters were considered more important than the others, together with the legal and indirect protection, since this protection directly affect the status of the site. Site access was included because sites that are easily accessed have higher chances of being degraded (Brilha 2016). Finally, use conflicts consider that some actual uses or projects may be responsible for the degradation of sites.

Therefore, the quantitative assessment presents, for each site, a score for their values where the scientific, educational and geotouristic values represent the different use potentials; and the ecological, cultural and aesthetic values are presented as additional values. Besides that, the conditions for use and the risk of degradation are tabulated, representing the visiting conditions and the need of conservation measures. So, the quantitative assessment allows the identification of different values for the sites, their visiting conditions and their actual and potential threats.

RESULTS

Preliminary assessment

After the definition of the main geomorphological contexts (described in the Study Area topic), 41 sites were selected to be in the preliminary list. Seven sites were directly chosen to be in the final list for their rarity, since they are the only ones representing their context. Despite being chosen for their rarity, all of these sites achieved high scores in the Central Parameters, which guarantee their relevance. One site achieved high score but had to be removed for the lack of data. Another site with a high score in the Central Parameters was removed because of Use and Management issues, since it is located in a private area and the owners do not allow visitors.

Considering that 16 is the maximum possible value in the Central Parameters and that some contexts, such as Beaches and Coastal Massifs, had too many sites, a threshold of 12 was defined as a boundary. Therefore, sites with less than 12 points were not included in the inventory. This arbitrary value was selected taking into account the overall scores of the sites, since many similar sites had scores around 10 and only a few achieved 12 or more. Only two sites were selected with less than 12 points (both achieved 11): one because of its exceptional cultural value and another for being at high risk of degradation, being considered a very interesting site to analyse environmental impact issues.

From the preliminary list with 41 sites, 20 were selected to be in the inventory (Table 9).

592 Table 9: Geomorphosites included in the inventory after the preliminary assessment.

Site	Geomorphological Context	Spatial Classification	Features	Processes
Espinho Wetlands	Double barrier-lagoon System	Surface – Geomorphological System	Coastal barriers; lagoons; wetlands; foredunes; parabolic dunes	Coastal processes (active and inactive)/ lagoonal sedimentation; aeolian processes (active)
Dama Branca Dune Field	Coastal dunes	Surface – Geomorphological Complex	Foredunes; barchans; barchanoids; parabolic dunes; parabolic megaform dune; nebkhas	Aeolian processes (active)
Ponta Negra Promontory	Coastal massifs	Surface – Single landform	Rocky promontory between coastal barriers	Tectonic processes (inactive)/ slope processes (active)
Cabo Frio Island	Alkaline massifs (island)	Surface – Geomorphological System	Island with secondary features within: beach, climbing dunes and *sambaquis* (anthropic pre-historic deposits of sea shells)	Tectonic processes; anthropic processes (inactive)/ coastal processes; aeolian processes (active)
Peró Dune Field	Coastal dunes	Surface – Geomorphological complex	Foredunes; parabolic dunes; barchanoids; nebkhas; climbing dunes; deflation zone	Aeolian processes (active)
Sapiatiba Hills	Coastal massifs	Surface – Single landform	Massif bordering Araruama Lagoon	Tectonic processes (inactive)/ denudational processes (active)
Vermelha lagoon	Coastal lagoon; Cultural landscape	Surface – Geomorphological System	Double barrier-lagoon system; Anthropic landform originated by the *Salinas* (areas of salt production)	Coastal processes; anthropic processes (active)
Cliffs and Palaeocliffs of Rasa Beach	Coastal cliffs	Points – Group of landforms	Active cliffs; inactive cliffs (located above current sea-level)	Marine erosion (active and inactive); sea level variations
Palaeolagoon of Reserva Tauá	Palaeolagoons	Surface – Single landform	Plain composed of palaeolagoon deposits (mainly coquines)	Lagoonal sedimentation (inactive); sea level variations
José Gonçalves Marine Terrace	Marine terraces	Surface – Geomorphological complex	Marine terrace; beach	Coastal processes (marine deposition) (active and inactive)
Pai Vitório Point and Stone Mangrove	Coastal massifs (aligned ridge)	Surface – Geomorphological System	Aligned hills; talus deposits	Tectonic processes (inactive); differential erosion
Tartaruga Beach	Erosional beaches	Line – Single landform	Beach with high rates of coastal erosion; mitigation structures	Marine erosion (active); anthropic processes
Araruama Lagoon Spits	Lagoonal spits	Surface – Group of landforms	Lagoonal spits	Lagoonal processes (intralagoonal waves) (active)
Tucuns Dune Field	Coastal dunes; Environmental impacts	Surface – Geomorphological complex	Coastal dunes affected by urbanisation	Aeolian processes; anthropic processes (active)
Ferradura Beach	Beaches	Line – Single landform	Cove beach with a well-rounded format and a narrow bay entrance	Wave diffraction
São João Hill	Alkaline massifs (hill)	Surface – Single landform	Hill surrounded by coastal plain	Tectonic processes (inactive)/ Denudational processes (active)
Double Barrier-Lagoon System of Jacarepiá	Double barrier-lagoon system	Surface – Geomorphological system	Coastal barriers; lagoons; wetlands;	Coastal processes (active and inactive)/ lagoonal sedimentation;

			foredunes; intralagoonal spits	aeolian processes (active); intralagoonal waves (inactive)
Papagaios Island	Coastal islands	Surface – Geomorphological system	Island with secondary denudational forms within	Tectonic processes (inactive)/ Marine erosion on rocky coasts
Saquarema Promontory	Coastal massifs	Surface – Single landform	Rocky promontory with a cave within	Tectonic processes; marine erosion (inactive); slope processes (active)
Foredunes and Secondary Dunes of Massambaba	Coastal dunes	Surface – Geomorphological system	Foredunes; parabolic dunes; coastal barriers; lagoon	Aeolian processes; overwash (active)

Characterisation and quantitative assessment

After the preliminary assessment, all sites were characterised and quantitatively assessed. Fig. 4 displays a map with the location of the sites and the results of the quantitative assessment, highlighting the main values of the site and information concerning the promotion and risks of degradation. Besides the map, Table 10 shows an example of how a geomorphosite is presented in the inventory. Therefore, the inventory consists of a list of geomorphosites with their geomorphological aspects, associated interests and use and management characteristics fully described.

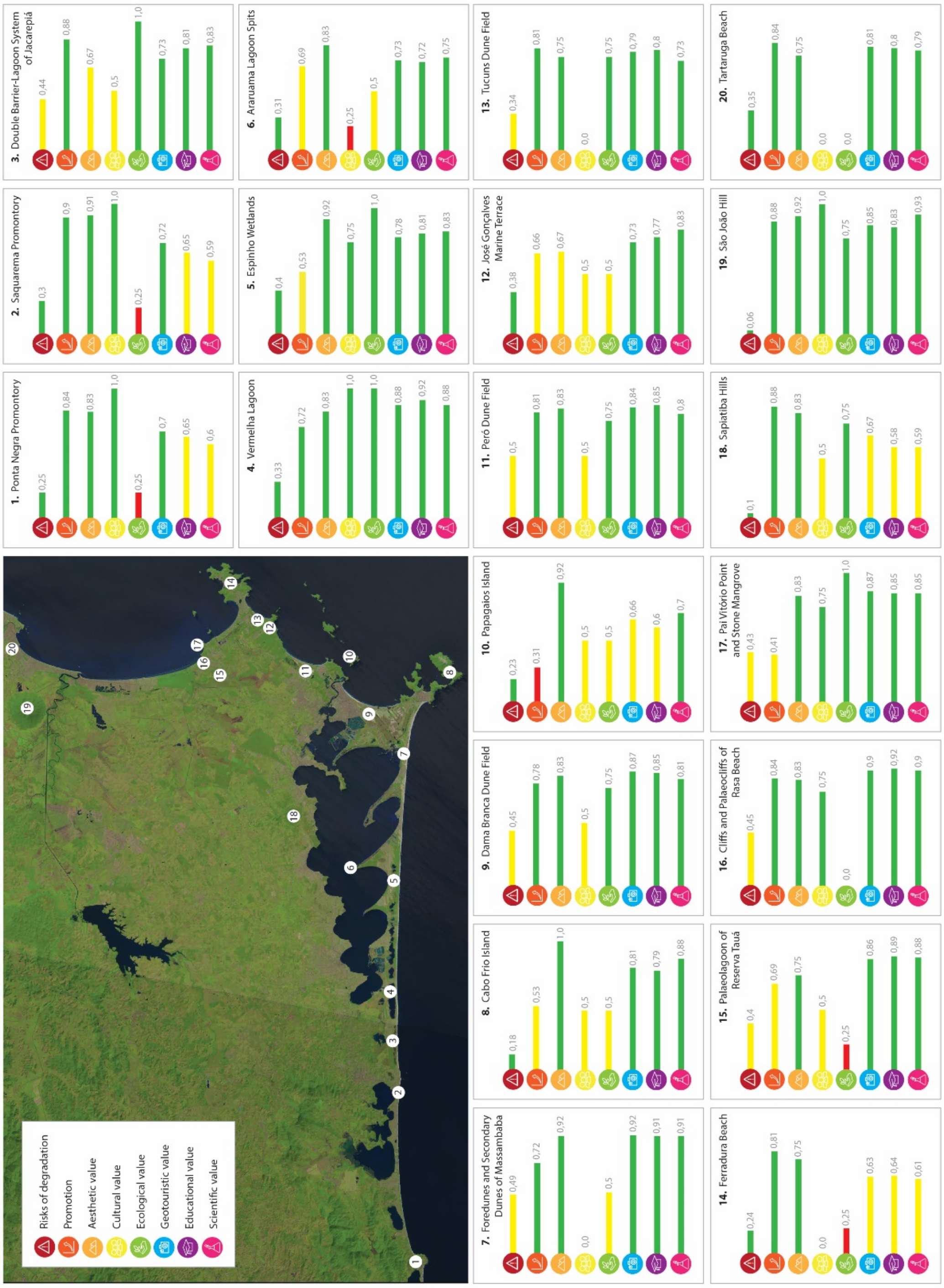
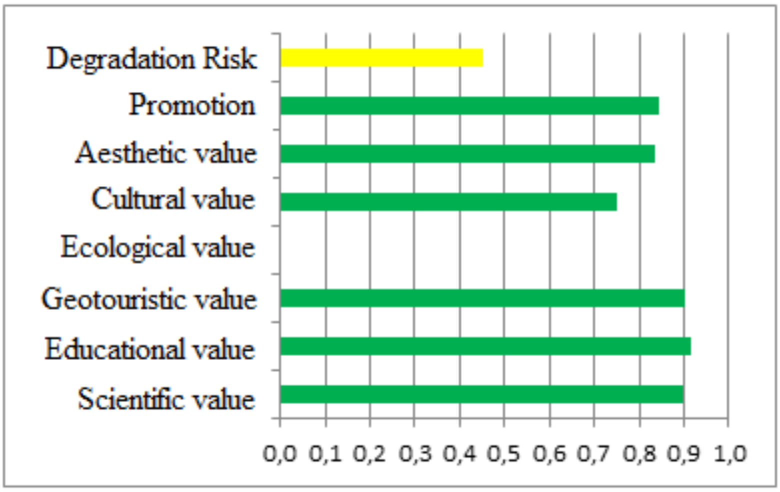


Fig. 4: Geomorphosites and quantitative assessment results. The colours of the bars indicate the degree of relevance: green is high (higher than 0,7), yellow is medium (between 0,4 and 0,7) and red is low (below 0,4). The risks of degradation follow the opposite: the lower the better.

Table 10: Example of geomorphosite fully described in the inventory.

Identification	**Name**	Cliffs and Palaeocliffs of Rasa Beach
	Location	Praia Rasa – Armação dos Búzios/ Cabo Frio (State of Rio de Janeiro): 24K 7483412 194706 (UTM WGS-84)
	Property	Public
	Eventual use limitations	No limitations
Geomorphology	**Thematic classification**	Coastal; Palaeogeographic
	Spatial classification	Points – Group of landforms
	Area/ Size	Punctual occurrences with different dimensions
	Altitude	From sea-level to about 35 meters.
	Forms	Active and inactive cliffs; abrasion platforms.
	Processes	Marine erosion; Sea-level variations.
	Morphogenesis (chronology)	Cliffs are formed in places of the shoreline where rocks or sediments impose resistance to wave action, so marine erosion originates vertical or sub vertical forms. The cliffs in this geomorphosite are composed of sedimentary rocks from Barreiras Formation. There is one active cliff and at least four well represented inactive cliffs, which are related to the transgressive phase that occurred around 5100 years BP, when the sea level was around three meters higher than at present (Castro et al. 2014). The active cliff is classified as a *Cliff with horizontal shore platform* (Davidson-Arnot 2010), which means that the retreat of the cliff by marine erosion leaves behind a horizontal platform that is also subject to erosion, being vertically lowered. This abrasion platform is composed of debris from the sedimentary rocks, witnessing the retreat movement of the cliff.
Associated interests	Palaeogeographical interest for the sea level variation records; sedimentological interest for the outcropping of sedimentary rocks from Barreiras Formation; cultural interest for the presence of a *Quilombola* traditional community in the area.	
Use and management	**Access**	The access is through the Rasa Fishing Colony, in the entrance of Armação dos Búzios municipality. There is a bus stop nearby. The site can be visited by disabled people.
	Safety	There are no major risks.
	Observation conditions	Both active and inactive cliffs are easily visualised, as well as the abrasion platform.
	Interpretive potential	The interpretive potential is high since the processes that originated the inactive cliffs can be observed in the active cliff. There is a panel of the *Caminhos Geológicos* (Portuguese for "geological paths") project explaining the evolution of the landscape in the area.
	Site infrastructure	There is a parking area accessible for buses.
	Regional touristic infrastructure	The municipality of Armação dos Búzios is one of the major touristic destinations of Brazil, presenting a well-developed infrastructure for visitors.
	Integrity and protection status	The site is well conserved. There is no legal protection, but the traditional communities that inhabit the area contribute to the protection.
	Fragility	The process of marine erosion is constantly affecting the active cliff. However, its rate is too low to be considered as a factor enhancing the fragility of the site.
	Vulnerability	The high rate of urban growth is the main factor of anthropic vulnerability. There are houses being built above the palaeocliffs and the continuation of this process could impose damages and/or affect the scientific, educational and geotouristic uses. The palaeocliffs are subject to mass movements, enhancing the natural vulnerability.

Quantitative Assessment	
Photos:	 (A) Active cliff in the front/left and palaeocliffs in the back (photo: Daniel Santos); (B) Sedimentary rocks of Barreiras Formation exposed in the active cliff (photo: Kátia Mansur).

References:

Castro JWA, Suguio K, Seoane JCS, Cunha AM, Dias FF (2014) Sea-level fluctuations and coastal evolution in the state of Rio de Janeiro, southeastern Brazil. An Acad Bras de Cienc 86(2):671–683

Davidson-Arnot R. 2010. Introduction to coastal processes and geomorphology. Cambridge University Press, New York

The quantitative results displayed on Fig. 4 allow a quick identification of the main values of each geomorphosite, as well as its suitability for the promotion of its use and its risk of degradation. It is important to highlight that this value only indicates a situation and it is not enough to provide a diagnosis. This is why it is important to present the quantitative assessment together with the characterisation, allowing the understanding of the achieved values and eventually the proposition of actions to enhance the potential of use and to guarantee the conservation of the sites.

For instance, the Cliffs and Palaeocliffs of Rasa Beach geomorphosite (Table 10) shows high scores for most values (except ecological value, which is zero). Thus, the site has a good use potential and also cultural relevance. Besides that, the promotion parameter is also high, showing that the site can be considered ready to be used. However, the risk of degradation is medium. The value itself does not say a lot, it only highlights that there could be problems. By reading the description, it is clear that the problem is related to the high rates of urban growth in the region, enhancing the anthropic vulnerability of the geomorphosite. Therefore, there are no problems concerning the visits, since the site is not vulnerable to this type of activity, but measures should be taken to prevent damages related to urban growth.

Another interesting example is the Espinho Wetlands geomorphosite, which is marked by high values and low degradation risk, which is a very good situation for scientific, educational and geotouristic uses. However, the promotion parameter is medium, showing that there are difficulties for the use. Again, the reasons for the lower score are provided in the characterisation (Table 11), which shows that the problem is related to the access and the safety. Therefore, in order to exploit the use potentials of the site, solving these issues is crucial.

Table 11: Description of Access and Safety of the Espinho Wetlands geomorphosite, showing the problems for the promotion of the site.

Access	The site is accessed through Figueira Road (RJ 102), in the proximities of Caiçara village. There are no signs indicating the existence of the geomorphosite, neither a parking area nor bus stop nearby. A walk through a trail amidst thorn bush is necessary to reach the site, making it difficult for disabled visitors. (*Espinho* stands for thorn in Portuguese)
Safety	The absence of a parking area enhances the risks for visitors because the site is located in a high speed road. The site itself does not present risks.

It is possible to observe that most of the geomorphosites achieved high scores for the scientific, educational and geotouristic values. Only five did not achieve high scores in all of them. Some sites, such as Cabo Frio Island and São João Hill were exceptional, with high values in all of the parameters. This fact can be explained by the preliminary assessment that guaranteed that only relevant sites were selected to be in the inventory; so, logically, it does not have sites with low scores.

It is also possible to observe that most of the sites have low risk of degradation. Eight of them were considered with medium risk and none with high risk. The reason for this fact is that the geomorphosites in this inventory usually do not present significant fragility and the anthropic vulnerability is related to high impact actions, such as urban growth. Lower impact activities, such as visiting, do not represent a significant rise for the vulnerability.

DISCUSSION

The importance of geosite inventories as a tool for environmental management have been highlighted in many works (e.g Fuertes-Gutiérrez and Fernandez-Martínez 2010, 2012; Fassoulas et al. 2012; Poiraud et al. 2016; Santos-González and Marco-Reguero 2019; Selmi et al. 2019). Land use management in a geoconservation context requires tools that can be easily interpreted by managers which are not always experts in geosciences (Coratza and Regolini-Bissig 2009; Fuertes-Gutiérrez and Fernandez-Martínez 2012). The intention of the proposed method was to develop an inventory of geomorphosites to be used as a tool for managers, considering their values, potential uses, promotion and risks of degradation. It was achieved through the integrated quantitative results (easily interpreted) and a full “diagnosis” of the site. Therefore, more than simply ranking, the quantitative assessment proposed here is intended to support the identification of management priorities at each site. The method does not intend to create rankings because it could lead to the dangerous conclusion that the sites at the bottom of the ranking are not so important. All sites selected in the preliminary assessment are important and they are different from each other (from massifs related to tectonic events to coastal barriers related to sea level variations). So, the outcomes of the quantitative assessment intend to provide information about each site and help in the establishment of priorities and guidelines for the sites themselves, without creating comparisons among them.

The work of Mucivuna et al. (2019) highlighted a very important issue: there are already many published methods for creating inventories and most of them only have a small impact on the scientific community. Many methods were not reproduced by other research and some were successfully reproduced in other contexts (e.g Tavares et al. 2020, who applied the method presented by Brilha 2016 in Brazil). So, what is the need of proposing new methods if there are already too many and some have proven to be capable of being reproduced? The answer is simple. Despite the existence of dozens of methods, most were created for specific situations and there are still discussions to be performed in order to develop a more universally accepted method. The aim of this article is not at all proposing this universal method, but to bring the debate forward in order to contribute in this context of methodological development.

The application of the method in the southeast coast of Rio de Janeiro State allowed the identification of geomorphosites in all geomorphological contexts, which was done during the Preliminary Assessment. This is a crucial step because an inventory must present the complete geomorphological setting of the area, allowing the understanding of which units are present and the morphogenetic history of the area (Sellier 2016; Reynard et al. 2016). There are geomorphosites representing coastal massifs related to tectonic movements between the Palaeocene and Pliocene, alkaline massifs related to magmatic events during the Eocene, several features related to sea-level variations during the Quaternary, aeolian features and cultural landscapes. Therefore, by studying the geomorphosites in the inventory, it is possible to have a complete overview of the geomorphological setting of the region.

As highlighted by Lima et al. (2010), methods for inventorying geosites must have clear aims. In fact, the aim of the inventory defines what type of parameters will be assessed. However, it is clear that works focused on the scientific value (e.g Coratza and Giusti 2005;), educational value (e.g Bollati et al. 2012) and touristic value (e.g Pralong 2005) present similar parameters for the assessment, highlighting that these values are actually strongly related with each other. For instance, the high scientific value of a site may enhance the educational value, since it is usually interesting to visit such sites with students. The same can be said about the geotouristic value, since a site can become interesting for visitors due to its scientific relevance. However, using exactly the same method to assess three different values would be wrong and could create incoherencies like including the aesthetic value as a part of the scientific value or the scientific knowledge as a part of the geotouristic value. Even when the same parameter is used, they do not have the same weight depending on the value. For that reason, the proposed method used almost the same parameters for the three values, but with a weighting scheme (Table 3) to modify the results. By doing so, an integrated result was achieved without using too many different parameters, presenting the scientific, educational and geotouristic values and considering that these values represent the use potential of the site.

The method uses weighting to assess the value and the risks of degradation in order to address the fact that some parameters are more important than others, depending on what is being assessed. The values assessed are intangible, since they are related to the human perception, being subjective. One of the main efforts in inventory and assessment methods is reducing this subjectivity, but it is crucial to emphasise that it is impossible to eliminate it. Therefore, the most important is to be transparent in how the criteria are being used and why some criteria have different weight. It is also crucial to highlight that the weighting was essential to differentiate the assessment of the scientific, educational and geotouristic values, since they share most of the parameters.

Santos et al. (2019) highlighted the influence of the specificities of geomorphosites in assessment procedures and there were also taken into account in the development of the method presented here. Concerning the imbrication of temporal scales, the palaeogeographical value was considered part of the representativeness of the sites instead of being assessed separately as in some other methods (e.g Bollati et al. 2012; Reynard et al. 2016). A site that has palaeogeographic value was considered to be representative of some periods of Earth's history in the studied area, so this parameter should be part of the representativeness. This modification was mainly proposed because, when assessed separately, sites with palaeogeographic value tended to have much higher scores than sites showing only active processes, creating an imbalance. By including this parameter as part of the representativeness, these sites still have higher scores, but the disparities were smaller.

The work of Santos et al. (2019) also pointed the importance of the specificities, especially the spatial scale and dynamic dimension, in the assessment of risks of degradation. In this sense, the use of the method proposed by García-Ortiz et al. (2014) proved to be a solution because the parameters used were sufficient to cover all situations where the specificities imposed the need of different approaches. The importance of using this method is due to the fact that other quantitative methods, such as that of Brilha (2016), use, for instance, the distance of the site to areas or activities with potential to cause damage as parameter. Because of the complexity related to the spatial scale and the dynamic dimension of geomorphosites, such parameter was often difficult to apply. Nonetheless, other parameters used by Brilha (2016) were included in the proposed method: the accessibility and the legal protection, which was modified with the inclusion of indirect protection. By applying the concepts of fragility and vulnerability, it was also possible to distinguish between processes directly related to the site and external processes. This is essential for management because, as stated by García-Ortiz et al. (2014), natural processes enhancing the fragility of a site should not be stopped or mitigated, since the natural rhythm of degradation of the site must be respected.

Including the additional values (ecological, cultural and aesthetic) as parameters to assess the scientific, educational and geotouristic values is also an important point of discussion. First, many geomorphosites clearly represent the relationship between geomorphology and biological elements and connecting geodiversity and biodiversity is crucial to strengthen nature conservation actions (Matthews 2014). Also, many methods include the ecological value as part of the scientific value (e.g Panizza 2001; Bollati et al. 2015); for these reasons the ecological value was included in the proposed method. Second, considering cultural geomorphology as an important field of research (see Panizza and Piacente 2008; Reynard and Giusti 2018), it seemed incorrect to only include the cultural value as additional. The links between culture and geomorphology must be emphasised in scientific and educational contexts. Besides that, it may be an important factor to enhance geotourism (Pralong 2005; Coratza et al. 2016). Third, the aesthetic value was excluded from the assessment of scientific value, but included in the educational and geotouristic values. For the educational value, the aesthetic dimension of geomorphosites is a factor that helps to attract the attention, which is essential for educational activities. For the geotouristic value, the aesthetic dimension is usually the most important factor to attract tourists. Therefore, these so-called additional values were included in the assessment of the use values.

Concerning the aesthetic value, the method proposed here considers that it is not possible to quantify the "beauty" of a site; so the parameters used are linked to the possibility of attracting visitors due to the aesthetic value. The difficulty related to the subjectivity in the assessment of the aesthetic value was recognized in many previous works. In order to tackle this issue, authors have been proposing different ways to assess this value. Reynard et al. (2016), for instance, include the existence of viewpoints and parameters to directly assess the aesthetics of the site (colour contrast, vertical development and space structuration), while others, such as Brilha (2016) do not assess it directly, using the touristic use of the site as parameter. The proposed method does not assess the aesthetics directly, but considers visualization conditions, similarly to Reynard et al. (2016); the conservation, since degradation represents an alteration of the aesthetics of the site; and, instead of using the touristic use (as in Brilha 2016), the potential to attract visitors due to the aesthetic dimension is used. It may be more subjective than the touristic use, but it is common to have sites with great scenic beauty which are not touristic destinations. It would not be correct to give a low aesthetic value to such sites.

Clearly differentiating values from use and management characteristics is one of the most important issues when assessing geosites, especially quantitatively. Reynard et al. (2016) stated that characteristics of use and management are not intrinsic values of the sites and, for that reason, are not quantitatively assessed in their method, being only described. However, other methods (e.g Serrano and González-Trueba 2005; Pereira and Pereira 2010; Brilha 2016) quantitatively assess use and management parameters, which is interesting because, despite not being values, the quantitative assessment also constitutes a tool for management as it provides a simple and easily interpreted result, allowing a quick identification of priorities, for instance.

Brilha (2016) uses parameters of use and management to assess the potential educational and touristic uses of geosites. Although this makes sense, since geosites must have good conditions to receive visitors, it seems a problem in the assessment of several sites which are geomorphologically interesting but have problems related to their management. By separating the intrinsic values of the sites from the use and management characteristics, it is possible to identify sites that need attention in order to become a visiting place. In other words, it was more interesting to identify the sites that could become interesting destinations than simply saying that they have low educational or geotouristic use potential, which could, for instance, weaken protective measures.

Finally, it is important to emphasise the importance of the Preliminary Assessment for the selection of relevant geomorphosites in the inventory, avoiding time spent performing complete evaluations of sites that, in the end, would never yield high values and, therefore, use potentials. The results showed that none of the quantitatively assessed sites presented low values and the Preliminary Assessment is the main responsible for that. The proposed method was mainly inspired by the works of Sellier (2016) and Reynard et al. (2016) in what concerns the complete understanding of the geomorphological setting of the area and by Pereira and Pereira (2010) for the assessment of basic, additional, and use and management parameters. This step was crucial to make the whole process of inventorying more efficient.

CONCLUSIONS

The main result of this research consists of the inventory of geomorphosites with full description of their geomorphological and use and management aspects, and the quantitative assessment of their values, promotion potential and risk of degradation. This inventory is intended to be a tool for territorial management, supporting actions of geoconservation and sustainable use of the geomorphosites.

Identifying and evaluating geosites is a basic step in geoconservation strategies and, within the context of abiotic ecosystem services, is a valuable tool to provide a series of knowledge services, ranging from understanding Earth History to teaching society as a whole about elements and processes that directly affect their lives. It is especially important considering the negative effects of natural disasters or the eventual consequences of climatic change. Therefore, geosites must be protected and sustainably used for the benefit of humanity.

Besides the knowledge services, geosites may also be used for sustainable economic development through activities such as geotourism. Inventories are basic tools for managers to identify geosites with high use potentials but still need actions to improve the accessibility or safety issues, for instance. It also helps in the identification of sites that need protective measures. By integrating the characterisation and the quantitative assessment, it was possible to achieve this aim, since the final product provides a diagnosis of the site as well as an easily interpreted quantitative result.

The proposed method differs from previous ones in several aspects. It assesses the scientific, educational and geotouristic values as representative of the use potentials of the sites. The assessment of these values is done through similar parameters, using weights to differentiate them in the evaluation, resulting in an integrated outcome without the need of using too many parameters. It integrates the characterisation and the quantification in order to provide a complete and more easily interpreted product.

Therefore, the quantification is not used to create rankings, but to display the values and the use and management characteristics of each site. The whole procedure considers the specificities of geomorphosites, which is essential to assess the values and risks of degradation without incoherencies or misjudgements. The additional values are used as parameters to assess the use values, which highlights the links between them. Concerning the aesthetic value, which is one of the most difficult to assess due to the subjectivity, the proposed method focuses the assessment not in the quantification of how beautiful the site is, but in the capacity to use the aesthetic dimension to attract visitors and call their attention. Finally, it is crucial to highlight the transparency of the method, allowing the reproduction and critical analysis of each parameter.

Therefore, this work had the aim of proposing a method inserted in the actual context of methodological development, contributing in the discussion and advancing in the achievement of more universally applied methods. Geoconservation has been growing in importance in the last decades and reliable and transparent methods are essential in order to be effectively included in the environmental management agenda.

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