Geoheritage (2017) 9:49–57
DOI 10.1007/s12371-016-0176-1

ORIGINAL ARTICLE

Evaluation of the geological heritage of the Dray Nur and Dray Sap waterfalls in the Central Highlands of Vietnam

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Received: 2 August 2015 / Accepted: 3 March 2016 / Published online: 28 March 2016

Abstract The Central Highlands in Vietnam are well known for their large basalt plateau and their natural touristic resources with impressive landforms, such as ancient volcanoes, lakes and waterfalls, which are the result of volcanic activities, and of which the waterfalls are especially spectacular scenically. The Dray Nur and Dray Sap waterfalls located on the Serepok River of Dak Lak and Dak Nong provinces, respectively, are remarkable landscapes with a significant aesthetic value. Not only are these waterfalls well known as tourist attractions, they are also noted for a system of impressive geological objects, including basalt columns beneath torrential waterfalls, contemporaneous columnar and pillow basalts, fan-shaped columnar structures, collapsed wells, cliffs formed at the base of basalt columns, and the boundary between columnar basalts and Jurassic sediments. The aim of the study reported here is to demonstrate the relevance of this site as a geomorphological and geological heritage site, according to current inventory and evaluation methods. The results show that the Dray Nur and Dray Sap waterfalls include 10 inventoried geo-points, relevant to four key themes, namely science, culture, education and tourism. The ultimate goal of the study is to use these results as justifications for the conservation of the area.

Keywords Vietnam · Geosite · Columnar basalt · Jurassic · Waterfall · Natural environment

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Introduction

Geological heritage sites with outstanding values for science, education, aesthetics and economics are regarded as special natural resources (Gray 2004). They consist of special geological and geomorphological sites with rocks, minerals, fossils, soils, landform and landscapes that are both the products and records of the evolution of the planet Earth and, as such, form an integral part of the natural world (Eder and Patzak 2004). Geological heritage, a type of nonrenewable resources, therefore, should be protected, conserved and sustainably used.

A system of criteria that concern the evaluation of the geoheritage has been proposed and related to different values such as intrinsic, cultural, aesthetic, economic, research, educational and functional (Gray 2004). However, the value of the geoheritage sites depends on geological objects, which can be used for evaluation purposes through an open system of qualification. Geological objects may present different contents that display heritage values and depend on the meaning of their attributes. As pointed out by Carreras and Druguet (1998), 'the diversity of contents and the different protection criteria leads to the existence of a great variety of legal regulations'. Thus, geological heritage should be protected all over the world, as its objects with different contents may be or not at risk, depending on a wide range of factors, most of them not related with its contents.

Vietnam possesses many beautiful natural landscapes that show a great potential as natural heritages. Since the 1990s, UNESCO has listed a number of natural World Heritage sites, such as Ha Long Bay (designated in 1994 and 2000), Phong Nha-Ke Bang National Park (designated in 2003), Trang An Landscape Complex (designated in 2014) and Dong Van Karst Plateau Global Geopark (designated in 2009) (Fig. 1a). However, many other geological sites of potential

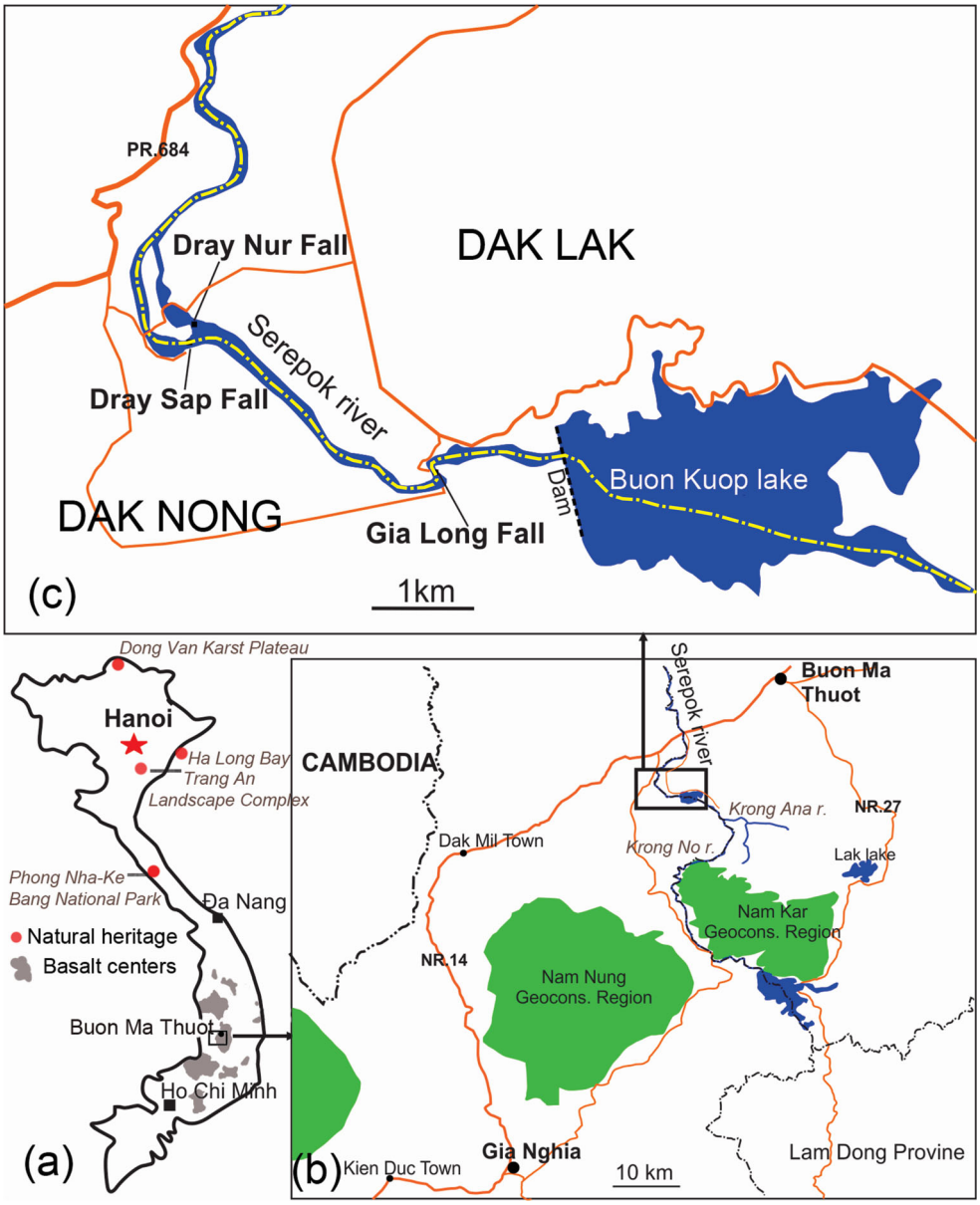

Fig. 1 **a** Map of Vietnam with natural heritages that have been recognised by UNESCO and basalt centres; **b** Buon Ma Thuot area; **c** Location of the Dray Nur and Dray Sap waterfalls

heritage value have not yet been defined and recognised in Vietnam.

The Central Highlands, part of South Central Vietnam, have a number of beautiful natural sceneries, such as relatively untouched forests, waterfalls and spectacular views, in contrast to other areas still scarred by twentieth century war. The Central Highlands is a huge basalt plateau formed during periods of powerful volcanic activity from the Neogene to the Quaternary. Consequently, impressive landforms, such as ancient volcanoes, lakes and waterfalls, formed by volcanic activities have created the typical landscapes in the Central Highlands. However, no systematic geosite inventory has been carried out in this area.

The goal of this present study is to carry out an inventory of the site features in the Dray Nur and Dray Sap waterfalls and then evaluate them within the framework of a potential geological heritage site in order to support the definition of geoconservation strategies.

The Study Area

The Serepok River in the Central Highlands is at the confluence of two tributary rivers, named the Krong Ana and Krong No, meaning female and male, respectively, in Ede ethnic language. When it flows towards the boundary between the Dak Lak and Dak Nong provinces, the Serepok River divides into two branches, flows down the Dray Nur and Dray Sap waterfalls, and is then joined together again to the north (Fig. 1c). The Dray Nur and Dray Sap waterfalls, which are

considered as the most majestic waterfalls in the Central Highlands, are located about 25 km to the southwest of Buon Ma Thuot city, along the national highway (NR) 14 (Fig. 1b). Although these waterfalls are situated in two different provinces, they are quite close together and jointed by two suspension bridges and a short walkway.

The Dray Nur and Dray Sap are impressive waterfalls with similar sizes, spanning a width of ca. 150 m, a height of ca. 30 m and a length of ca. 250 m. The wall of water plunging down to the basalt columns creates an impressive natural marvel (Figs. 2f and 3f). The interference of the white water and the dark basalt rocks, whose structure is columnar and diversely oriented, creates an unsteady feeling. The water falling from the top of a giant basalt column wall represents one of the most rare and spectacular landscapes, not only in Vietnam but also worldwide. Behind an amazing veil of mist, like a mirror of smoke, there are several small caves in the deep cliff at the bottom of columnar basalts created by undercutting of the cliff, but hidden behind the waterfalls (Fig. 2b, g). Looking out from the caves is a spectacular scene composed of looming shadows of trees, with tottering blocks of rocks displayed through long water walls.

The Dray Nur and Dray Sap waterfalls have become attractive tourist destinations (Fig. 2g, h), with pronounced hanging basalt columns beneath a ca. 30-m-high waterfall. The basalt columns were generated under geological conditions which affected their aspect, petrology and structure. The basalt cooled rapidly from the outside towards the centre, causing shrinkage cracks to form either a hexagonal pattern or sometimes 3- or 12-sided shapes. The shape of the columns is attributed to tensional stress (Bates and Jackson 1984).

The combination of basalt columns and a waterfall is not unique in the world, but the basaltic rocks in the Dray Nur and Dray Sap waterfalls are regarded as an original feature, because of the presence of geological objects related to basalt magmatism, such as columnar basalt and pillow basalt together in one place, as well as fan-shaped columnar structure, collapsed wells, cliff undercutting in the bottom of basalt columns and the boundary between columnar basalts and Jurassic sediments. In addition, these waterfalls are quite close together and connected by two suspension bridges (Fig. 3a, c) and are ranked among the top scenic geotopes in the Central Highlands of Vietnam.

Geological Setting

Although the Dray Nur and Dray Sap waterfalls are famous primarily for their extraordinary natural beauty, they also provided geological data on the history of the Earth's crust during the Neogene-Quaternary periods. Over this interval, intraplate volcanism was widespread in East and Southeast Asia, forming basalt plateaus associated with pull-apart and extensional rifts (Barr and MacDonald 1981; Whitford-Stark 1987). The basaltic centres in Vietnam occupy an area of ca. 23,000 km^2, mainly distributing in Phuoc Long, theCentral Highlands and the North (Hoang et al. 1996; Hoang and Flower 1998; Bat et al. 2002; Fedorov and Koloskov 2005).

For most of the volcanic centres, there are two eruptive episodes including (1) an early series formed by high SiO_2, low FeO* quartz and olivine tholeiites that are large melt fractions of refractory (lithosphere-like) mantle, and (2) a later series made up of low SiO_2, high FeO* olivine tholeiites, alkaline basalts and basanites that are smaller melt fractions of more fertile (asthenosphere-like) mantle (Hoang and Flower 1998). The basalt rocks in the Dray Nur and Dray Sap waterfalls belong to Buon Ma Thuot centre, one of five basaltic centres in the Central Highlands.

The Buon Ma Thuot plateau occupies an area of about 3800 km^2 in the largest basaltic plateaus in the Central Highlands of ca. 14,500 km^2 (Hoang et al. 1996; Hoang and Flower 1998; Bat et al. 2002). While still reflecting two major phases, their eruptive stratigraphy differs significantly from that recorded in most of the centres. The early phase of Buon Ma Thuot activity was dominated by alkali basalts, which are succeeded (mainly) by olivine tholeiites that were dated at 8.7–4 Ma. Both alkaline basalts and tholeiites in this phase vary from aphyric to olivine and augite phyric, and generally lack plagioclase phenocrysts. The later phase, in the upper part, has been dated at <2–0.3 Ma and consists of alkali basaltic flow intercalated with thin flows of olivine and quartz (rare) tholeiites, all, except for the tholeiites, showing prominent olivine microlites in the groundmass (Hoang et al. 1996; Hoang and Flower 1998). According to Hoang et al. (2013), the basaltic plateau in Buon Ma Thuot was generated in the regional post extrusion stress field, thus, potentially resulting in the columnar basalts in the Dray Nur and Dray Sap waterfalls.

The columnar basalts in the research area were formed during the later eruptive phase by alkali basalts and olivine tholeiites. Their chemical compositions, analysed by XRF, show SiO_2 contents ranging 44.87–53.16 wt%, 10.69–11.50 wt% of FeO* content and 1.77–2.46 wt% of TiO_2.

Methods

Inventory

The inventory method is a tool used to list the heritage assets, recognise their value and subsequently promote them. Singular and/or monumental features are attributes that one tries to identify in each inventoried asset in order to enhance its value and justify its protection (Reis and Henriques 2009). The method that was used

Fig. 2 Characterised heritage sites with geomorphological and geological values. **a** Collapsed well in basalt columns, **b**, **c** fan-shaped structure in basalt columns and undercutting in the bottom of basalt columns, **d** basalt columns as seen from straight above, **e** boundary between columnar basalt and Jurassic sediments, **f**, **g** general view of the Dray Nur waterfall and **g** undercutting in the bottom of the basalt columns

for the Dray Nur and Dray Sap waterfalls is based on (1) the International Scientific Committee on Cultural Landscapes of International Council on Monuments and Sites (ICOMOS), Cultural Landscape inventory sheet proposal (http://www.icomos.org/landscapes/inventory_card.htm), and (2) the International Union for the Conservation of Nature (IUCN) (http://cmsdata.iucn.org/downloads/geology.pdf), global framework for Geological World Heritage which has advanced the characterisation of the typology associated with geological heritage, as used in several countries to inventory and evaluate geological and geomorphological sites (Dingwall et al. 2005).

The geosite identification should follow the definition of geological framework and be adapted to the local reality. There are three simple criteria generally selected in each framework including representativeness, scientific relevance and integrity (Lima et al. 2010). For the work reported here, inventoried structures and proposals were followed, with a typology considering several criteria, such as geomorphological, geochemical, geophysical, geological history, palaeontology and/or palaeobiological, pedological,

Fig. 3 Characterised heritage sites with geomorphological and geological values (*continued*). **a**, **c** Two suspension bridges connecting the Dray Nur and Dray Sap waterfalls together; **b** bedding structure of Jurassic sediments of La Nga Formation occurring in the Serepok River; **d**, **e** columnar basalt and pillow basalt boundary; **f** general view of the Dray Sap waterfall

palaeoclimatic, impact crater, marine, submarine, metalogenetic, metamorphic, sedimentary and igneous, among others.

Evaluation

Geomorphological and geological characterisations are enough to achieve the aim expressed for the inventory of a geosite. But, as this geosite is a truly geological heritage site, it is convenient to enlarge the characterisation and include the assessment of its potential use. According to Brilha et al. (2005), the geological heritage of geosites may contain one or more geodiversity element of exceptional scientific, educational, cultural, touristic or other value. The attribution of the value to these sites would be able to demonstrate their possible or effective utilisation. Thus, it is necessary to have both a large body of scientific knowledge on the site and a selection of elements to attribute value, so that one can evaluate each geosite objectively, with little or no subjectivity.

This research has used three criteria, including science, education and tourism, to select representative geosites in the Dray Nur and Dray Sap waterfalls. A scientific criterion is exhibited by three sub-criteria of representativeness, singularity and proximity. Here, the representativeness sub-criterion is related to the appropriateness of the geosite to illustrate a geological process that brings a meaningful contribution to understand a geological topic, process or feature; the singularity sub-criterion regards the number of similar occurrences of a geological process or feature on a specific area; the proximity sub-criterion considers the possibility of having different relevant geological processes or features that might be integrated in the same geosite. The educational and touristic criteria that follow the proposed evaluation system from Rocha et al. (2013) and Reis and Henriques (2009) were used for values or contents displayed by geological objects.

The evaluation system of Rocha et al. (2013) selects criteria for the potential of education and tourism and evaluates them by comparative ranking system in a scale of one to five points according to Braga (2002).

Reis and Henriques's (2009) method does not use a quantitative ranking system. The method is a simple and objective way to visually show the qualitative relevance of the

geological heritage basing on an integrated approach of the two variables previously described: relevance grade and abstract perceptiveness. There are four ranks of content value including rank I, represented by indicial contents; rank II, displayed by documental, iconographic, and symbolic contents; rank III, exhibited by conceptual and scenic contents; and rank IV, referring to universal content.

Cataloging Data

According to the inventory method established by Lima et al. (2010), ICOMOS and IUCN, 10 geo-points within the Dray Nur and Dray Sap waterfalls have been established (Fig. 4) and correspond to the following types of heritage:

- Geomorphological, due to the scenic beauty of the impressive waterfalls cascading over basalt columns (geo-point 5, Fig. 2f, h; and geo-point 10, Fig. 3f) and of the two suspension bridges connecting Dray Nur and Dray Sap waterfalls (geo-point 6 and 8; Fig. 3a, c)
- Petrological, due to the occurrence of basalt columns beneath the torrential waterfalls (geo-points 3, 4 and 5; Fig. 2d–g); contemporaneous columnar basalts with pillow basalts (geo-point 9; Fig. 3d, e)
- Tectonic, due to the appearance of fan-shaped columnar structure (geo-point 2; Fig. 2b, c), collapsed well in the cluster of basalt columns (geo-point 1; Fig. 2a), and cliff undercutting in the bottom of the basalt columns (geo-point 2, 5 and 10; Fig. 2b, g)
- Sedimentary, due to bedding structure of the Jurassic La Nga Formation exposed in the bottom of Serepok River (geo-point 7; Fig. 3b)
- Stratigraphical, due to boundary between columnar basalts and Jurassic sediments of the La Nga Formation (geo-point 4; Fig. 2e)
- Hydrogeological, due to the accumulation of freshwater in the Serepok River, supplying water resource to waterfalls and hydroelectric dam about 4 km away from the falls (geo-point 7; Fig. 3b)

Assessment

Although Dray Nur and Dray Sap waterfalls are the famous sites in the Central Highlands, which is also well known for the vast scientific documentation concerning the large regions of 'diffuse basalt eruptions' (Hoang and Flower 1998), they have not been the subject of a systematic inventory of geosites.

The scientific relevance of the Dray Nur and Dray Sap waterfall was well demonstrated in the geological setting section and as such the scientific use for these waterfalls is quite clear. However, their potential educational and touristic uses need to be assessed. The combined criteria to analyse and assess their potential use in education and tourism are presented in Table 1 and were selected from the open system proposed by Rocha et al. (2013).

To assess the potential for educational use, we have selected six of the seven criteria, such as accessibility, associated resources, viewing conditions, educational content, fragility and representativeness. These criteria were evaluated on the basis of a scale of one to five points, proposed by Braga (2002), and used by Rocha et al. (2013). The significance of

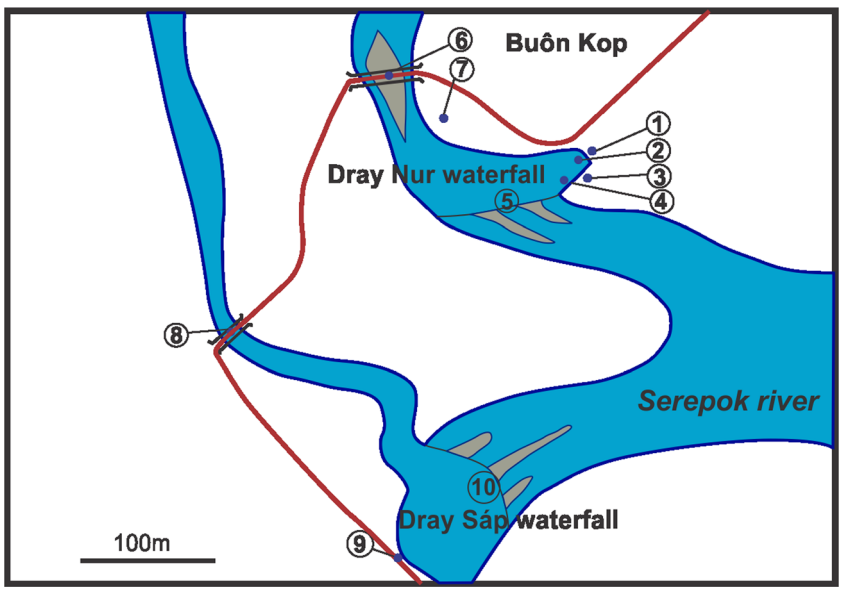

Fig. 4 Location of the geo-points in the Dray Nur and Dray Sap waterfalls. (*1*) collapsed well in basalt columns; (*2*) fan-shaped structure in basalt columns; (*3*) basalt columns as seen from straight above; (*4*) boundary between columnar basalt and Jurassic sediments; (*5*) Dray Nur waterfall; (*6*) bridge in the Dray Nur waterfall; (*7*) bedding structure of the Jurassic sediments of the La Nga Formation; (*8*) bridge in the Dray Sap waterfall; (*9*) columnar basalt and pillow basalt boundary and (*10*) Dray Sap waterfall

Table 1 Assessment of potential use for education and tourism of the Dray Nur and Dray Sap waterfalls according to Rocha et al. (2013)

Criteria for potential educational and touristic uses	Point	Description and assessment for the waterfalls	Point
(1) Accessibility (Ac) criterion (possibility to easily reach the geosites)			
Direct access by municipal/national road	5	The waterfalls are located along national highway (NR) 14 and distant about 1.5 km from provincial road (PR) 684 and could be directly accessed by bus on asphalted road.	5
Direct access by a pathway or a paved road	4		
Direct access by a pathway or a non-paved road	3		
Less then a 1 km distance from any pathway	2		
More then a 1 km distance from any pathway	1		
(2) Association with other resources (Ar) criterion			
Association with other features up to 500 m distance	5	The waterfalls include two independent Dray Nur and Dray Sap waterfalls with distance of approximately 0.5 km. A convenient way to travel from one to another is two suspension bridges and paved road of columnar basalt. There are other smaller waterfalls named Gia Long and Buon Kuop hydroelectric lake that is located about 4 km to the west of these waterfalls.	3
Association with other features up to 1000 m distance	3		
No associated features	1		
(3) Educational content (Edu) criterion			
Clearly exemplifies educational contents to any teaching level and to the general public	5	The geological objects, such as basalt columns beneath torrential waterfalls, contemporaneous columnar and pillow basalts, fan-shaped column structure, collapsed well, cliff undercutting in the bottom of basalt columns and boundary between columnar basalts and Jurassic sediments, are regarded as examples of educational contents to any teaching level and to the general public.	5
Clearly exemplifies educational contents to any teaching grade	4		
Clearly exemplifies educational contents for graduate and post-graduate studies	3		
(4) Spectacularly (Spe) criterion			
Used for national tourism iconography	5	The Dray Nur and Dray Sap waterfalls are regarded as typical prospects of the Central Highlands of Vietnam because of marvelous water flows and imposing wall of columnar basalts.	3
Used for local tourism iconography	3		
Not used for tourism iconography	1		
(5) Fragility (Fra) criterion (linked to the negative impacts of anthropogenic activities)			
Decametric dimension sites hardly affected by anthropogenic activities	5	The water resource coming to these waterfalls could be effected in disadvantage by developing more hydroelectric dams on the Serepok River.	3
Decametric to metric dimension sites moderately affected by anthropogenic activities	3		
Metric dimension sites easily affected by any anthropogenic activity	1		
(6) Viewing conditions (Vie) criterion (presents the quality of the geosite visualisation)			
Exceptional viewing conditions (to the fullest extent and easily observable)	5	The viewing conditions are in the full extent of the geosites with the opportunities to directly observe and study all geological objects.	5
Good viewing conditions (to the fullest extent but with some difficulty)	4		
Median viewing conditions (not observable in the fullest extent)	3		
(7) Representativeness (Rpr) criterion			
Best example in Vietnam of a geological process or feature	5	This is the best example in Vietnam of geological process of basaltic magmatism.	5
Best example in the Central Highlands of a geological process or feature	4		
Representative of various geological contexts	3		

the criteria is to provide clear evidence of the educational relevance of these waterfalls for geological education, when used as an educational resource according to activities integrated in a curriculum (Henriques et al. 2012).

The assessment of the potential touristic use is based on five criteria, including accessibility, associated resources, educational content, fragility and scenery. The presence of spectacular scenic aspects is commonly regarded as the first suggestion of the geotouritic potential of a geosite, once landscapes are at the top of the hierarchy of the features of geotouristic interest (Newsome and Dowling 2006). The 'spectacularity' criterion that is of significant importance for evaluating the touristic potential is assessed on the basis of the actual use of a geosite as an icon in tourism strategies, campaigns and documents (Braga 2002, as exemplified in the research of Rocha et al. 2013). However, the Dray Nur and Dray Sap waterfalls have not yet been established as a geosite and for geodiversity conservation. According to Gray (2008) geodiversity can be used as a basis for the development of geotourism activities. So, in order to promote the use of the

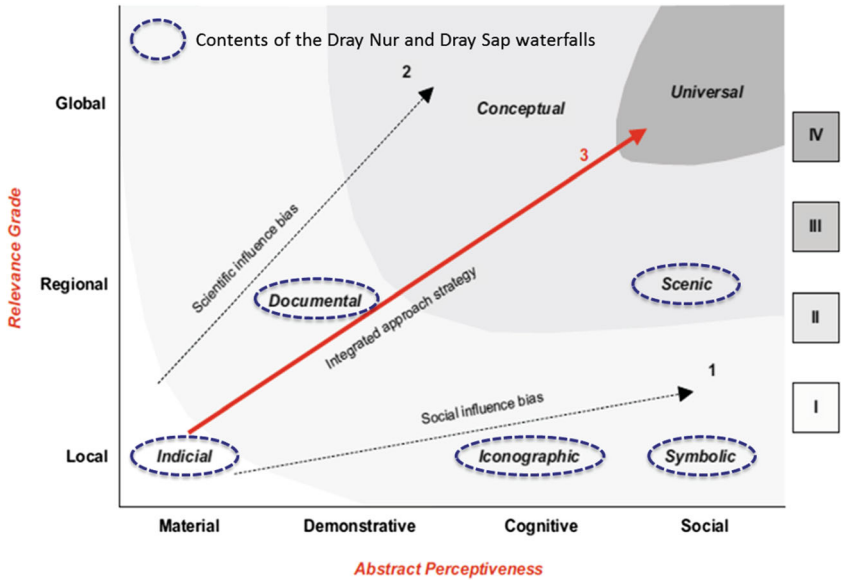

Fig. 5 Evaluation system for the contents of the Dray Nur-Dray Sap waterfalls (according to Reis and Henriques 2009)

waterfall's geosites and geodiversity, several resources, such as a geosites map, textbook and informative panel, need to be developed and addressed to the general public, schools or universities.

According to Reis and Henriques (2009), the Dray Nur and Dray Sap waterfalls would score as Rank III, because of their regional importance and the material, iconographic, symbolic, documental and scenic types of abstract perception. They are positioned between vectors 1 and 3 in the graph, i.e., between that of social influence and that integrated with scientific influence (Fig. 5).

The geological objects that correspond to a local scale content exhibiting a clear relationship between elementary geological processes and their resulting products, and specialised knowledge of particular geological phenomena, are generally regarded as indicial and iconographic contents (Reis and Henriques 2009). The presence of two basalt types (column and pillow) (Fig. 3d), collapse structures (Fig. 2a, b, g) and bedding structure of sedimentary rock (La Nga Formation) (Fig. 3b), suggests their process of formation and origin in an obvious way. These contents are particularly relevant for illustrating the detailed features of geological systems in the past and can be used as illustrations in scientific publications.

The Dray Nur and Dray Sap waterfalls are widely known to the public as famous tourist attractions for their dramatic beauty rather than their valuable geological features. These sites are impressive outcrops where significant geological features are exhibited, but the remarkable features that contribute to attract people are the high value of the scenery and legends associated with the Serepok River. These are now a symbol of the Central Highlands of Vietnam.

The thorough knowledge of the basalt plateau in the Central Highlands enriches the documental content. A highly demonstrative record of the chemical composition and formation of basalts is particularly relevant for the understanding of the significant geological processes involved in this area.

The scenic content refers to a landscape value that is of highly abstract concept, providing a high recreational function in the Dray Nur and Dray Sap waterfalls. Unusual geomorphical features reinforce the aesthetic value of this content (Gray 2004; Brilha et al. 2005); moreover, emergent natural values, such as amenity, quietness or discovery, tend to become relevant components as well. According to the Dak Lak Department of Tourism, Culture, Sport, and Tourism, around half a million visitors area attracted to these waterfalls every year.

Conclusions

The method used here to score sites in a ranking system was conducted using parameters related to scientific, educational and touristic potentials. The high value attributed to the Dray Nur and Dray Sap waterfalls by their classification, as a geomorphosite, should be adequate to show their touristic importance and reinforces their potential for educational and cultural use. The reasons of this evaluation are as follows: the site is of easy access and observation capacity; the diversity of observable elements; the existence of scenic combinations, such as majestic waterfalls, basalt columns, the strength and legends of the Serepok River; and the current touristic use.

Ten geo-points, which were inventoried, related to several types of heritage and are enough to demonstrate that the Dray Nur and Dray Sap waterfalls are a geomorphological-geological heritage site. Seven criteria, including accessibility, association with other resources, educational content, spectacular view, fragility, viewing conditions and representativeness,

were used to identify and characterise their potential educational and touristic uses; these criteria and weightings therefore support their ranking according to their potential uses.

The evaluation of the Dray Nur and Dray waterfalls as a geological heritage was also assessed by their content of geological objects, plotted on a graph of abstract perceptiveness versus relevance grade, according to Reis and Henriques's (2009) method. The result shows their importance due to their scenic beauty, landscape representativeness, culture value, and social and scientific influence, being placed at Rank III, and outranked by sites of regional importance.

The evaluation results show the necessity of conserving, protecting and managing geo-points in these waterfalls, both for their cultural value and their continuing touristic, educational and scientific uses. They can be used to establish priorities for the application of protection measures and to support the definition of geoconservation strategies.

Acknowledgments This work was supported by the project 'Research, comprehensive evaluation on tourist resources and spatial organization for proposals towards tourism development in the Central Highland of Vietnam' (Code: TN3/T18), which is under the key state-level program of 'Science and technology for socio-economic development in the Central Highlands of Vietnam' (Code: KHCN-TN3/11-15). The chemical composition of columnar basalts was analysed by XRF (XRF—1800 Shimadzu) at the Faculty of Geology, VNU University of Science.

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