Proceedings of the XVI ECSMGE
Geotechnical Engineering for Infrastructure and Development
ISBN 978-0-7277-6067-8

doi:10.1680/ecsmge.60678

Interaction between infrastructures and karst. Protekarst analysis method

L'interaction entre les infrastructures et le karst. La méthode d'analyse Protekarst

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ABSTRACT This paper presents the Protekarst method, by which karst protection zones can be mapped after quantifying their main geological, botanical, zoological, scenic, archaeological, hydrogeological, economic and social characteristics. The method was applied to a sierra in southern Spain. We describe the contribution made by the method to the design of new road infrastructure, and show that it enables us to compare alternative routes, to evaluate the impact made on karst values by previous road construction and to select suitable routes for paths or trails that pass through karst areas of special interest.

RÉSUMÉ Cet article présente la méthode Protekarst, par lequel les zones de protection karstiques peuvent être cartographiées après avoir quantifié leurs principales caractéristiques géologiques, botaniques, archéologiques, hydrogéologiques, économiques et sociaux, et leurs faune et paysage. La méthode a été appliquée à un massif dans le sud de l'Espagne. Nous décrivons la contribution apportée par cette méthode au développement de nouvelles infrastructures routières, ce qui permet la comparaison d'itinéraires alternatifs, l'évaluation des impacts occasionnés sur les valeurs karstiques par les routes construites auparavant et la possibilité de tracer des parcours appropriés pour les chemins ou sentiers qui passent à travers des zones karstiques d'intérêt particulier.

1 INTRODUCTION

The term karst is applied to certain geological formations in which the pores and fractures in rocks are widened by the action of water, creating conduits, caves and a characteristic landscape, both superficial (exokarst) and underground (endokarst). There are two major groups of karstifiable rocks: evaporites (gypsum and salt) and carbonate rocks (limestones, dolomites and marbles).

Karst is a significant part of our natural and cultural heritage, presenting important scientific value (biological, geological, hydrological, hydrogeological and archaeological), cultural value (the remains and artefacts of our ancestors, cave paintings and scenic values) and socio-economic value (agriculture, forestry, mining, extraction from quarries, tourism and various uses of stored water).

The activities carried out in and around karst subject it to various pressures that can have adverse effects. For example, quarrying, road construction or the dumping of inert waste and other materials can produce the destruction of external karst forms or of cavities, as well as irreversibly altering natural cycles and flows. Similarly, forest fires and agriculture can cause changes in nutrient flows between the soil and the endokarst. Furthermore, the introduction of contaminants into the karst system provokes changes in groundwater quality.

The protection of karst forms part of the global defence of the conservation of geodiversity, biodiversity and, in general, of our heritage in its broadest sense. Therefore, a methodological framework is needed so that different areas of protection can be defined and karst systems in general safeguarded. Such a framework is provided by the Protekarst method.

In Andalusia (southern Spain), large areas are characterised by the presence of limestone mountain ranges, which are spectacularly rugged in places and not only contribute to the beauty of the landscape but also present other values that are very important to preserve when the construction of new transport infrastructure is considered. For example, geomorphological values include such emblematic sites as the exokarstic forms of Torcal de Antequera and various enclaves within the Serrania de Ronda, between the provinces of Málaga and Cádiz, as well as unique cave systems such as those of Nerja and Hundidero-Gato and the sinkholes in Sierra de las Nieves and Sierra de Líbar. Furthermore, the botanical and zoological values in this region are of major importance in some areas, with plants that only flourish in association with certain carbonate geological formations. Finally, there are various cavities that contain archaeological remains, as well as important populations of bats and other cave fauna.

But, above all, it is the hydrogeological values, the fundamental role played by karst aquifers in response to water demands, and the need to maintain water flow in river system which most strongly emphasise the need to take precautions to ensure that future linear infrastructure projects have no adverse effect on water quality or aquifer functioning. The experience of recent projects such as the high-speed rail tunnels through the Valle de Abdalajís mountain (province of Málaga), which have provoked a drastic fall in water reserves and a probably irreversible change in drainage points and in directions of groundwater flow, highlight the need for the utmost precaution to be taken, and to acquire sufficient understanding of the terrain before embarking on new infrastructure projects that may impact on karst values.

2 METHODOLOGY

The Protekarst method that we propose is based on the generation of thematic maps of characteristic values of karst. When these are integrated, it will enable us to create a protection map classifying different areas in terms of their protection requirements, from "very low-grade protection" to "very high-grade protection". The method consists of the following steps (Figure 1):

a) Define karst values. The following karst value areas were selected: geology, flora, fauna, landscape, archaeology and hydrogeology, together with economic and social values.

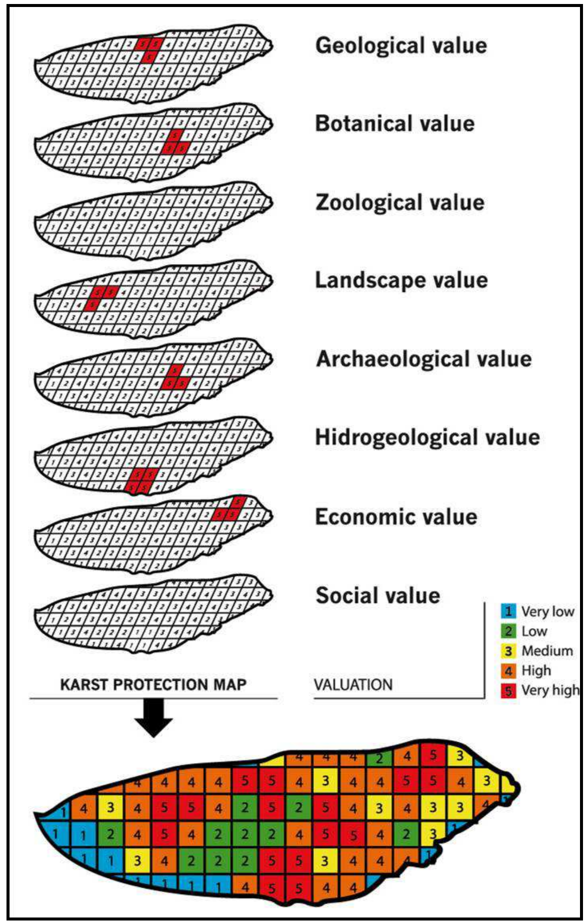

Figure 1. Summary of the Protekarst method.

b) Quantify the different values. A specific, different methodology is proposed for each of the values selected, such that, for each karstic massif, eight georeferenced thematic layers will be obtained, showing the zonal distribution of each value, scored from 0 to 5, from lowest to highest importance in terms of protection. The complete methodology for quantifying each value can be consulted at Junta de Andalucía-Universidad de Málaga (2014), Project G-GI3000/IDIM. For example, the geological value is obtained from three variables: geological heritage, geodiversity and karst geomorphology.

c) Obtain the karst protection map. The karst protection map is obtained from the superposition of the above-described thematic layers, using a GIS. This process generates a map in which each cell or pixel is associated with a corresponding valuation index, consisting of the eight cell values for each layer overlay (Figure 1). This information is then used to derive the karst protection map, differentiating the required degree of protection from lowest (1) to highest (5). The protection is then quantified as follows:

1) If a pixel has at least one value of 5, it is assigned a value of 5 on the protection map.

2) If a pixel has at least two values of 4, it is assigned a value of 4 on the protection map.

3) If a pixel has at least three values of 3 or two values of 3 and one of 4, it is assigned a value of 3 on the protection map.

4) If these conditions are not met, the mean value of the pixels is calculated. The result will be between 1 and 2.5:

Pixels with values from 1.5 to 2.5 are assigned a value of 2 on the protection map.

Pixels with values of less than 1.5 are assigned a value of 1 on the protection map.

3 RESULTS. APPLICATION OF THE METHOD TO SIERRA DE MIJAS

Sierra de Mijas (Figure 2) lies in the southern part of the province of Málaga, in southern Spain. It has an area of about 90 km^2 and it is composed almost entirely of Triassic limestone and dolomitic marbles corresponding to the Alpujárride Complex within the Internal Zone of the Betic Cordillera.

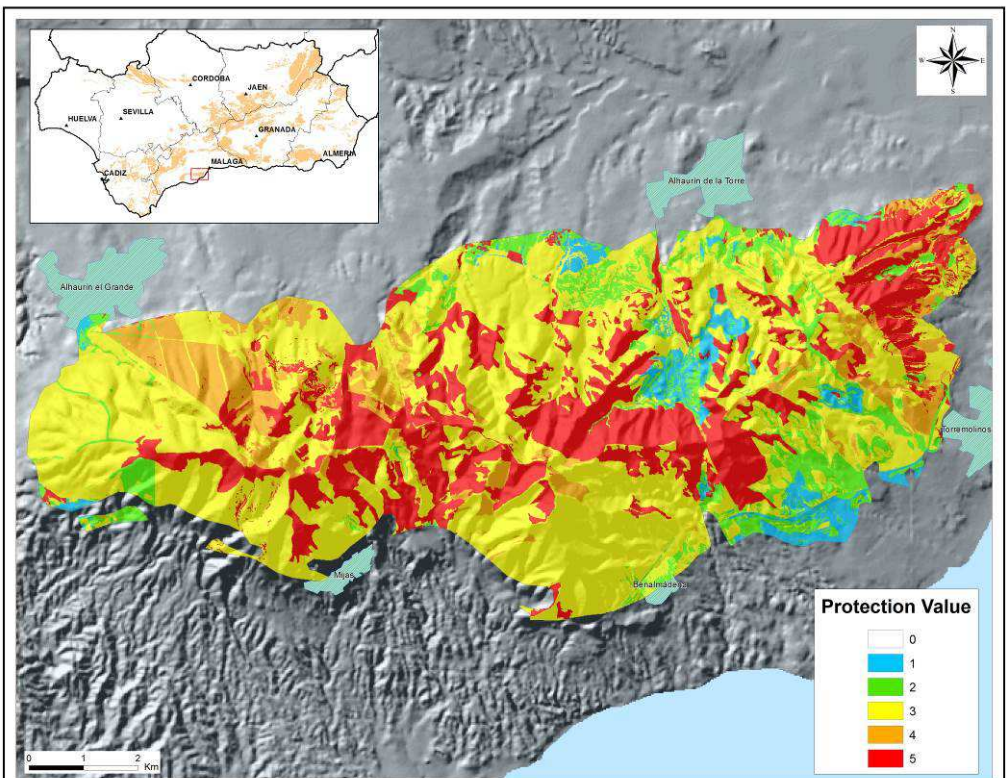

Figure 2. Protection zones for Sierra de Mijas.

Areas of very high protection (level 5) represent 26% of the surface area of the sierra and correspond, in general, to areas with very high scores for botanical and scenic parameters (Figure 2). In addition, there are some small areas with the same protection value on the northern edge of the sierra, which correspond to irrigated plots (high economic value) and an area in the central-eastern part of the sierra, containing Cueva del Toro, which has been declared an Element of Cultural Interest (high archaeological value).

Areas of high protection (level 4) represent only 9% of the land surface and are located mainly in the north-western and eastern sectors of the sierra, where there coincide areas of high scenic, economic and botanical value (Figure 2).

Medium-level protection areas (level 3) are predominant in Sierra de Mijas, occupying 52% of the land surface, and mainly reflect the economic, zoological, scenic and botanical values recorded here.

The areas with low and very low protection values (levels 2 and 1), occupy 4% and 9% of the land surface, respectively. These are areas with very low botanical and scenic scores, and include roads, quarries, urban areas, areas devoid of natural vegetation and areas where the vegetation is mainly nitrophilous.

4 CONTRIBUTION OF THE PROTEKARST METHOD TO THE STUDY OF INFRASTRUCTURES

The Protekarst method can contribute to the study of infrastructures in the following ways:

To evaluate proposed road infrastructure

The method can be used to determine the variation in the overall grade of protection or in the quantification of a specific parameter at different points along the route of the proposed road infrastructure (Figure 3). This allows planners to identify the sectors of the route that affect the most sensitive areas (i.e., those rated at protection levels 4 and 5)

Moreover, the level of protection affected by a given sector of an infrastructure route can be compared with the average values for the entire route and for those of the sierra (Figure 3). Thus, it is apparent whether the area affected by the route in question is above or below the mean protection value for the sierra, and whether the route passes through areas of very high protection value, in terms of a specific value or of the overall level of protection (Figure 3).

To compare alternative routes

For this task, we propose, first, a simplified scoring criterion, by which a threshold of significance is selected for each region of the sierra (value 3). Second, the karst values used in the analysis of alternatives must be identified, because the importance of the different values considered will vary from one area of the sierra to another. Finally, the different profiles must be created and the impact made by each route on the karst values must be determined (Figure 4).

To evaluate significant impacts on karst values by previous infrastructure projects

To assess the impact of construction work on karst values, we must analyse the difference between the initial value and that observed after the construction (including any remedial action taken). For example, the embankments of the A-7 motorway constructed through the south-east sector of the study zone have led to the almost complete disappearance of botanical karst values from the area affected; other aspects, such as scenic values, have suffered serious degradation, not only in the area directly affected by the infrastructure work but also along a much broader part of the southern slope of the sierra. On the other hand, the hydrogeological values of the area have not been affected.

To define suitable routes

The results obtained highlight the potential of the method for the proposal and basic definition of routes or trails through karst areas of special interest.

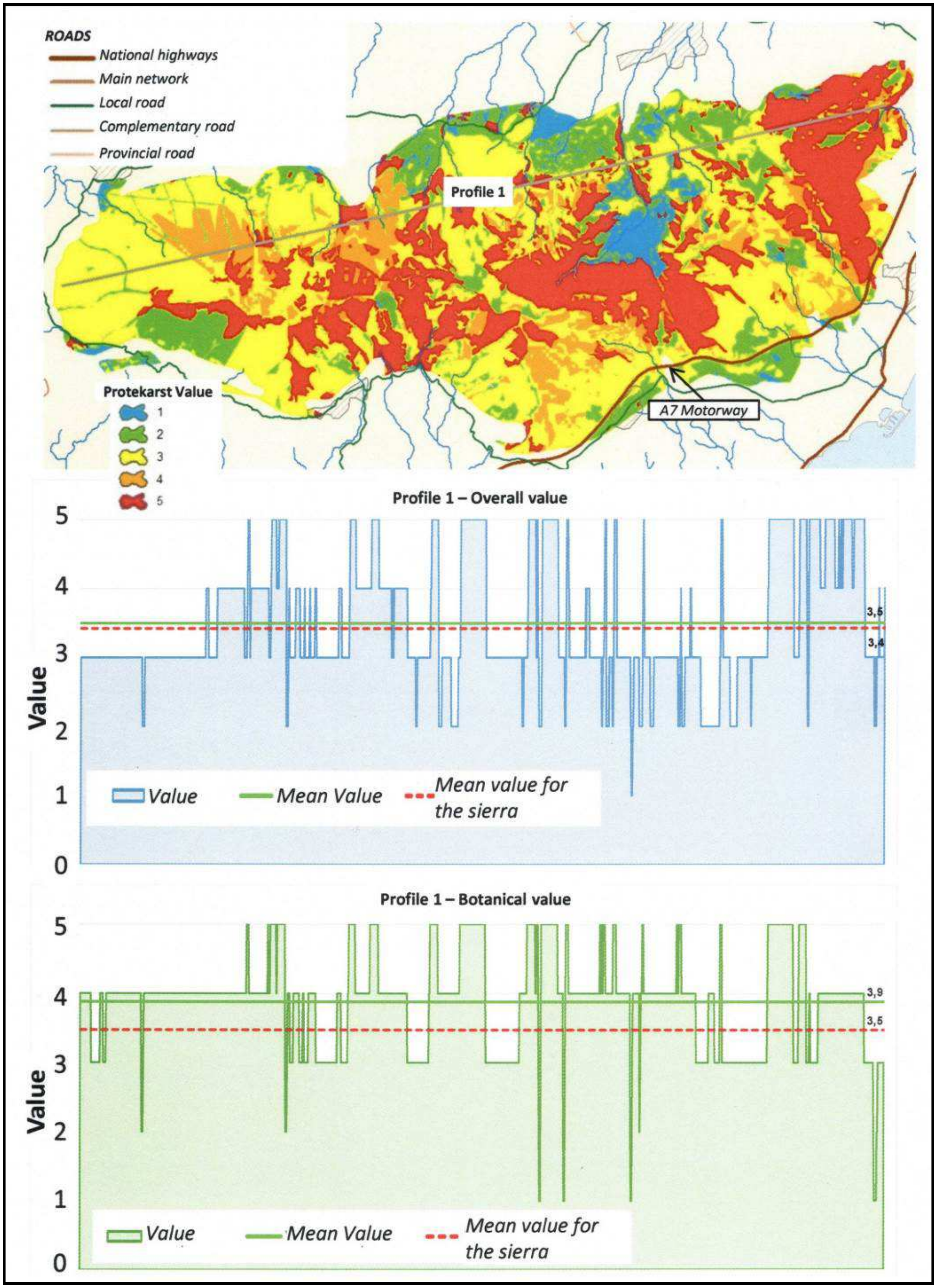

Figure 3. Application of the Protekarst method in a road infrastructure project.

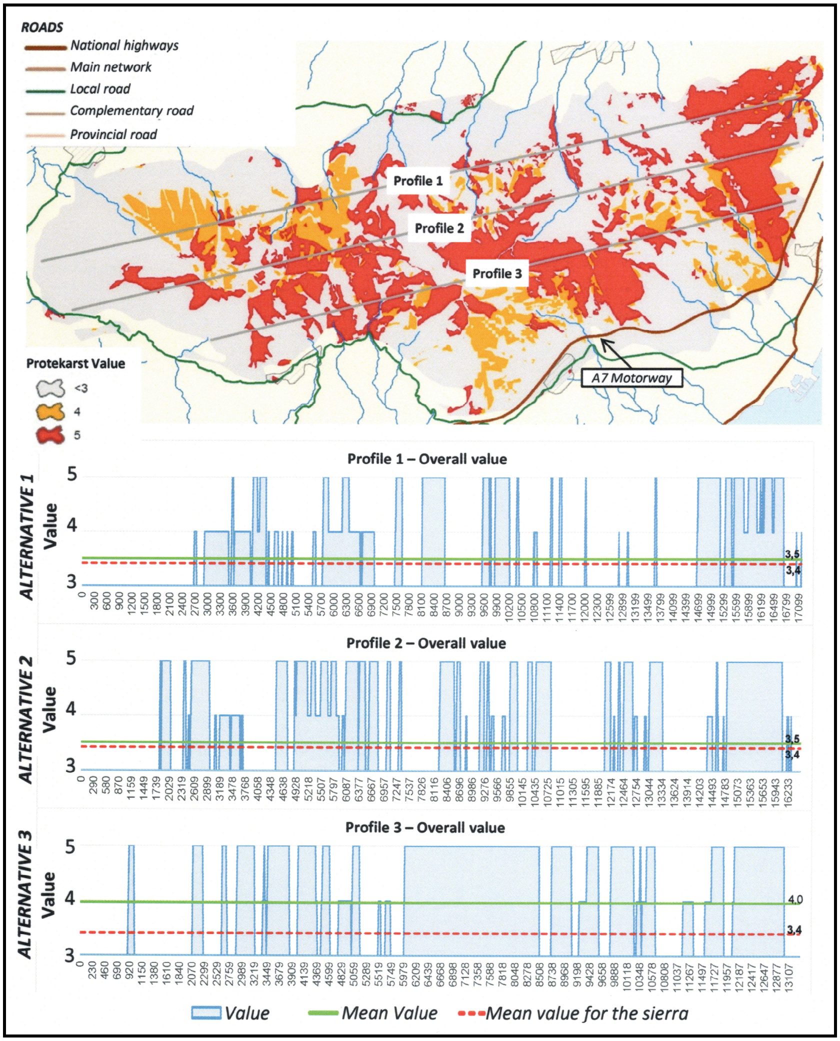

Figure 4. Using the Protekarst method to compare alternative routes.

ACKNOWLEDGEMENT

The authors would like to thank the ERDF of European Union for financial support via project "Desarrollo de una metodología para la protección de las regiones kársticas en relación con las infraestructuras y otras actividades antrópicas (G-GI3000/IDIM)" of the "Programa Operativo FEDER de Andalucía 2007-2013". We also thank all Public Works Agency and Regional Ministry of Public Works and Housing of the Regional Government of Andalusia staff and researchers for their dedication and professionalism

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