Title

Recommendation system to determine suitable and viable hiking routes. A prototype application in Sierra de las Nieves reserve nature (southern Spain)

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Abstract

This paper describes a system for recommending hiking routes to help manage hiking activities in a protected area. The system proposes various routes, based on five criteria that maximize some aspects of hikers' requirements (by analyzing the viability and difficulty of the trails) and also those of protected areas managers (by proposals to relieve congestion in areas already used for hiking and to promote awareness of new ones, as a contribution to environmental education).

The recommendation system uses network analysis, multi-criteria decision analysis and Geographical Information System by free software tools: PgRouting, PostgreSQL and PostGIS. This system has been tested in Sierra de las Nieves reserve nature (Andalusia, Spain). Of the 182 routes obtained by the system, 62 (34%) are considered viable for hikers in Sierra de las Nieves, taking into account the type of user most likely to visit this protected area. Most routes have a high difficulty level, which is coherent with the mountainous character of the protected area.

Keywords

Recommendation system, PosgreSQL, PgRouting, PostGIS, A* algorithm, Hiking, Routes, Network analysis, Multi-criteria decision analysis, GIS, Recreation, Tourism.

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1. Introduction

Walking and hiking are major outdoor recreational activities in western societies (Eurostat, 2012 and Statista, 2014) and have a positive impact on well-being and fitness (WHO, 2010). There is a relation between the physical environment and physical activity (Brownson, Hoehner, Day, Forsyth, and Sallis, 2009), increasingly due to the access and quality of recreational areas (Handy et al. 2002; Saelens and Handy, 2008).

Since the 1970s, tourism-sport activities in the natural environment in Spain have become increasingly popular (García, 2006). Thus, according to a report published by the Centre for Sociological Investigation (CIS, 2010) and the National Sports Council (CSD, 2015), hiking has been increasing over the recent years and has overcome by cycling and swimming in user numbers. Moreover, the number and the surface area of protected areas worldwide increased considerably during the twentieth century (Wall and Fredman, 2007), and today they are commonly used for a variety of leisure and recreation activities (Farias, 2011).

Popular recreational activities in protected areas include the contemplation of nature and landscape, cultural visits, environmental education and sports activities, among which hiking is the most popular (Farias, 2011). The latter activity should be assessed not only in terms of its sports-related characteristics, but also bearing in mind other motivations – cultural, patrimonial, ecological, etc.- of which give rise to a specific type of hiker in this paper we will refer to as a "tourist hiker". Hiking can promote the recovery of traditional paths and tracks, the enjoyment of natural areas and the revival of struggling local economies (Benayas, 2000). These considerations have led the popularity of hiking to grow at rates well above those observed in other leisure activities in the natural environment.

The growing of activities such as the hiking can generate problems of overcrowding in certain areas and at certain periods of the year. It can generate a saturation effect and a negative perception towards tourism (Boller et al, 2010, Farias, 2011, Santana and Hernández, 2011).

The problems of overcrowding in protected areas are even greater because they affect the quality of the environment and because they can have negative repercussions on the development of tourism in the area.

Hiking in protected areas requires certain facilities and infrastructures. On the one hand, this may impose restrictions on hikers' freedom to roam throughout the natural environment, but on the other hand, restrictions are necessary to maintain the viability of the system for these same users. For instance, the managers of protected areas need tools with which to create hiking trails and meet the demands of visitors to these areas. In this regard, studies based on geographical information sciences, such as those conducted by Tomczyk and Ewertowski (2013), Hawes et al. (2013), Clius et al. (2011), Marion et al. (2006) and Rand (2004) have analyzed the management of natural spaces and recreational trail usage. For hiking in particular, only a few methodological studies have been performed, chief among which are the generic studies by Ocaña and Galacho (2002) and Ocaña et al. (2008), on the user capacity of the territory. More specifically, investigations have been carried out by Luque (2003, 2004), Marion and Leung (2004) and Galacho et al. (2011), including proposals for assessing the suitability of trails for hiking.

In the context of geographic information sciences, geographic information systems (GIS), network analysis and multi-criteria decision rules are key elements in the creation of hiking trails. Network analysis is based on graph theory, that is, on the connection between one location and another by means of search algorithms acting on a set of nodes and edges. This type of technology has been applied in natural areas to create 4x4 routes (Snyder et al., 2008) and hiking trails (Morris and Barnard, 2008; Kammoun et al., 2010). Multi-criteria evaluation (Malczewski, 1999) is based on rules helping the analyst to select the most suitable decision from various equally valid solutions. In this way, too, studies have been carried out regarding the creation of different types of routes, such as those for road transport (Park et al., 2007), railways (Kosijer et al., 2012), urban traffic (Chmiel et al., 2011) or livestock (Cazorla et al., 2008).

At present, there are many studies on tourism and sport related activities in natural areas using the previously mentioned technologies, however not in a joint way or in an integral way in protected areas. The inclusion of these techniques in a single computing environment provides a powerful tool for creating routes, making decisions and managing protected areas. A tool based on GIS, network analysis and multi-criteria decision analysis to create hiking routes derived from a web-based recommendation system would help to the managers to identify and to recommend hiking routes that provide access to the main features of the protected area and, at the same time, enable appropriate protection.

Nowadays, the recommendation systems are widely used in touristic activities. The smartphone, via GPS, advises on possible topics of interest to users (Gavalas et al, 2013). Therefore, the geolocation of the user is a basic feature in some types of recommendation system. There are systems that use the GPS technology to detect movement patterns and the durations of visits to recommend other options to its users (Kitayama, Ozu and Nakayima, 2015; Orellana et al, 2012) or to calculate the structure and use of hiking trails in recreational areas to know the real use of the pathway in protected areas (Taczanowska et al. 2014).

Most recommendation systems base their results on user's preferences and not necessarily on the characteristics of the natural areas and qualified criteria. Moreover, overcrowding of some trails must be reduced by diverting some hikers to other areas in order to minimize the impact on the environment.

The aim of this paper is to design a recommendation system to propose routes to tourist hikers based on qualified criteria and using geographic information sciences (GIS, network analysis and multi-criteria decision rules). Those criteria take into account the natural characteristics of the tracks to satisfy the user's preference; the viability of the routes according to the conditions of tourist hikers; and the type of trails to include preferential path of the hikers. All this leads to increasing the diversification of the trails and reducing overcrowding.

The test site used was Sierra de las Nieves Nature Reserve because the users are tourist hikers with environmental or general leisure interests, and the management of the area is difficult due to the scarce human and material resources. Furthermore, the managers of the protected area collaborated with the university via a project funded by the regional and national government.

2. Methodology

The recommendation system proposed in this paper recommends hiking routes by network analysis, multi-criteria decision analysis and Geographical Information Systems or GIS (Fig 1). GIS stores the necessary information of each trail section for the system. The multi-criteria evaluation choose the most adequate trail section for the recommended route according to different criteria related to the suitability of the terrain, management and physical difficulty. Network analysis allows, using A* algorithm in this case, to find the route connecting the start point with the end point (Rolland, 2012).

The recommendation system was implemented in a Linux OS, consisting of a web portal (http://recomendador-rutas.HUM776.uma.es/rutasRecomendadas.html) connected to a PostgreSQL object-relational database with PostGIS spatial database, where the geographic information is stored. The pgRouting extension is added to PostgreSQL, which enables the search algorithm to be used and network analysis performed.

The web portal was designed in accordance with the standards set by the Open Geospatial Consortium (a foundation that ensures the interoperability of open systems and standards in the field of GIS and the internet), and therefore the information generated is compatible with other universal platforms. The routes offered to the user can be downloaded as a map (*.jpg) or as a track (*.kml and *.gpx). These formats allow to any mobile device with geolocation capabilities can be used to follow the route proposed by the recommendation system.

The datasets stored in the PostgreSQL database are read and managed by means of the PostGIS extension. Each row in the database represents a trail or section of the route (or path segment) and for each section attributes are defined in accordance with the criteria required to determine and subsequently evaluate each route. For the purposes of this study, a section is defined as each unit of the trail between two junctions (Vías and Ocaña, 2014).

2.2. System criteria for recommending routes

The routes proposed by the recommendation system must meet various criteria and be viable in terms of their performance. This is ensured by means of a two-stage process:

- Analyze the suitability of the route by connecting trail sections that optimize the characteristics of the environment, applying various criteria
- Determine the viability of the route obtained, in terms of the time required for completion and determine its difficulty.

2.2.1. Assessing the suitability of the routes

Route suitability was evaluated by applying the criteria below. These are criteria based on user's preferences (B and C) because they use those natural characteristics that are most interesting for the tourist hiker, on the management of protected areas (D and E) because they use the type of tracks to reduce the overcrowding, or both users and managers (A).

A. Choice of the start point and end point of the route.
B. Suitability of the sections that constitute the route.
C. Circularity of the route.
D. Inclusion or not inclusion of the trail section in the Public Use Programme (PUP).
E. Inclusion or not inclusion of the trail section in the livestock trail.

For **criterion A**, the possible start points must allow quick and easy access to the hiking trail. Greater weight was assigned to those points, which were close to an urban area, a Public Use Programme facility or a car parking area. End points represent landmarks of the natural area (as a peak, a monument, a special tree, a spring, etc) but greater weight was assigned to those that show unknown zones with high environmental values.

With respect to **criterion B**, we used the methodology proposed by Vías and Ocaña (2014) to assess the suitability of trail sections. This method takes into account the suitability of each one of trail sections of the network based on:

- the 'hikability' of the section, which determines the natural suitability of the trails for hiking. This factor take into account the following parameters: Surface types (type of material of which the trail is constituted), Type of trail (this concerns the width and the type of trail preferred by hikers), Slope (average slopes of the trail sections) and Slope obstacle (amount of trail distance with a continuous steep slope that a hiker must cover in a given section)

- its landscape or natural interest or attraction as a means of exploring the territory. This factor was obtained by the biological or ecological factors and landmarks of environmental, cultural or ethnographic interest

- the land management performed in this area, related with the planning of public spaces, according to the level of protection afforded to different areas of the test site.

Criterion C takes into account the proportion of the trail distance that must be repeated, i.e., whether it is basically circular or linear. The latter case (in which the same trail must be hiked to return to the start point) is considered less suitable than one beginning and ending at the same point without passing along the same sections twice. This criterion can only be assessed when the trail search algorithm has produced a firm proposal.

Criterion D penalizes a route that makes use of sections that are already offered on PUP trails. The purpose of this criterion is to avoid overloading existing trails and facilities and to expand the land surface that can be used for hiking – this aim coincides with those of the PUP itself. Accordingly, the greater the number of sections used in the route that do not form part of the PUP trail network, the more suitable the trail in question.

Criterion E penalizes sections that do not coincide with a livestock trail, according to the catalogue of such trails published by the regional government. The purpose of this criterion is to take into account the Natural Resources Management Plan for Reserve natures (Junta de Andalucía, 2004), at least in part, in order to maximize the benefits derived from public recognition of this category of trail.

2.2.2. Viability of a proposed route

The viability of each proposed route was calculated taking into account its difficulty and foreseeable duration. The viability was calculated using the next formula proposed by Colorado (2001), based on the hours needed to do a route, which take into account the length of the trail, the accumulated height gain and the estimated average speed of the hiker.

The length of the route was determined by applying the PostGIS extension incorporated into the relational database. To ascertain the height gain, the database also required information on the altitude of the terrain; this was obtained from a MDE developed ad-hoc for this project from the information contained in the Topographic Map of Andalusia (scale 1 /10,000).

The recommendation system was designed to improve the management of natural areas and, therefore, improve the development of tourism in a certain region. Therefore, the prototype user is a tourist-hiker. According to Bohannon and Andrews (2011), the average speed of a hiker varies between 2-6 km/h. By carrying out interviews to members of the Grupo Alpino Pinsapo mountaineering club (part of the Malaga Excursionist Society), whose experiences served to differentiate between a tourist-hiker and a sporty-hiker, we estimated the average speed of a mid-level hiker (touristic-hiker). This type of hiker has a horizontal speed of 4 km/h and a vertical speed of 400 m/h (values between 2-6 km/h for distance and 0-1000m/h for stepped). i.e. on a route of 10 km, a hiker would take 2,5 hours (2h 30 min), and on a route of 600 m difference, a hiker would take 1,5 hours (1h 30 min).

From these speeds, the total time needed to complete the route was calculated by the following formula:

If Th > Tv ➔ $Time = Th + \left(Tv/2\right)$ If Tv> Th ➔ $Time = Tv + \left(Th/2\right)$

Time is the estimated time duration of the route. Th (the horizontal time) is the time required to travel a certain distance, and Tv (the vertical time) is that needed to overcome a given height difference.

Therefore, if, for instance, the route has 10 km and a difference of 100 m, Time is equal to 2,625 hours (2h 37 min). Otherwise, if the distance is 5 km and the difference is 1000 m, Time is equal to 3,125 hours (3h 07 min).

The estimated difficulty of the route (Table 1) is offered as a guide to hikers and also constitutes a limit for the development of routes, in that routes with an estimated duration of over nine hours are not proposed. This limit was set taking into account the time that the average hiker is prepared to dedicate to this activity. According to the previous paragraph, the route of the first example would have a Low difficulty and the second route a Medium difficulty.

2.3. Recommendation system operation: multi-criteria algorithm

The use of search algorithms to design routes or itineraries is, generally, a common practice in network analysis, but in the field of hiking this approach has only recently been adopted (Rees, 2004; Akasaka and Onisawa, 2008; Nadi and Delavar, 2010).

The multi-criteria approach of the algorithm minimizes the costs associated with each of the criteria and objectives (start and end points) that must be addressed in determining a recommended route. With this goal in mind, the approach adopted is streamlined and focused on achieving the minimum cost, which is represented by the algorithm A* (Hart et al., 1968).

The pgRouting library implements this algorithm and also enables us to modify the standard cost (distance) to be minimised by applying various criteria (such as the sum of weights) in order to resolve the initial problem. The viability of a route is maximised, within an algorithm focused on minimising, by inverting the value obtained before including it in the total cost. The route calculation is performed in one of the following steps, depending on whether the route is in one direction or the other.

2.3.1. Phase 1: outward

During the outward leg of the route, the viability value for each of the criteria described in paragraph 2.2.1 is positive.

For criterion A, accessible proximity to the route starting point(s), various aspects are predominant, namely proximity to urban centres, parking areas and PUP infrastructure.

For Criterion B, viability of the route, a weighted average is determined section-by-section, to obtain the overall percentage with respect to theoretical maximum values. For example: for a route with a length of 400 m, composed of 2 sections (Section 1, 100 m, suitability = 0.8; section 2, 300 m, suitability = 1.2), the weighted average viability is calculated as 0.8*(100/400) + 1.2*(300/400) = 1.1, which with respect to a theoretical maximum of 1.73 produces an overall viability rating of 63%.

Criterion C, circularity of the route, is calculated as the percentage of the total route length in which the same section is not repeated. For example, if there are 800 m of non-repeated sections, in a total route length of 1000 m, the circularity value will be 80%.

Criterion D, whether or not the route forms part of the Public Use Programme (PUP), is calculated as the percentage of the route length that is not in the PUP, and is stated as a positive value.

Criterion E, the percentage of the route that forms part of a livestock track, is taken into account as a positive value.

These five criteria are used to assess the route as a weighted linear sum obtained by the following equation. The weights were assigned according to their importance for creating routes. The A criterion is for both hikers and managers, therefore is the most important. The B and C criteria are related to the tourist hikers and, therefore, they have a significant weight in

the recommendation system because it is a tool for themselves. And the D and E criteria have the least weight because they are complementarians to the A criterion from the point of view of the management. All criteria are normalised and their values are stated in the interval [0,1]. With this normalisation, the maximum score possible is 15.

Route viability = (5 x A) + (4 x B) + (3 x C) + (2 x D) + (1 x E)

2.3.2. Phase 2: return

If the outward leg of the route is less than 10 km in length, the same criteria are applied as in the first leg, i.e., there is a high penalty for repeating a section.

If the route is 10-16 km long, the above penalty is reduced, while that for the overall length is increased.

If the route is 16-21 km long, repeated sections receive very little penalization; the main parameter taken into account is the total distance.

If the route length exceeds 21 km, only the distance is taken into account.

Therefore, depending on the points of origin and destination chosen, the return sections of the route proposed may be more or less focused on the original criteria of the recommendation system. When the start and end points are far apart, the route is less likely to obtain a high score.

3. Application to Sierra de las Nieves Nature Reserve.

The study area selected to test the proposed methodology is Sierra de las Nieves. It is a protected area by the regional government of Andalusia as a Nature Reserve and according to the IUCN categories it is similar to a Strict Nature Reserve. It also forms part of the Natura 2000 network of the European Union as a Special Area of Conservation (Habitats directive) and Special Protection Area (Birds directive). Moreover, it is a Biosphere Reserve of the UNESCO.

It was chosen for various reasons. First, this nature reserve is the subject of an R&D project being implemented by the University of Malaga ("Development of a method to assess the recreational capacity of protected areas", funded by the Spanish Ministry of Science and Innovation, Project No. SEJ2007-67690, and by the Regional Ministry of Innovation, Science and Enterprise, Project No. P07HUM-03049), in collaboration with various agencies, including the Department of the Environment in the province of Malaga and the Governing Board of Sierra de las Nieves Reserve nature. These various levels of input have enabled different synergies to be established during this research.

Second, because it involves two important natural environment/tourism resources, namely Mount Torrecilla, which at 1917 m is the highest in western Andalusia, and a large population of Spanish fir (*Abies Pinsapo*, which in 2010 was included on the IUCN Red List of threatened

species). These two elements of the area constitute the main attraction for many of the hikers who visit this natural environment.

The third reason is the park's ease of access for many walkers, from the tourist resort areas of the Costa del Sol and from the cities of Malaga and Seville (which have a joint population of 1.5 million inhabitants). Finally, this reserve is the object of a public use programme (PUP) in which hiking-related activities are constantly evolving. In fact, the routes proposed by the application presented in this paper are complementary to the trail network published in the Sierra de las Nieves Reserve Nature PUP, which stipulates the need to address some of the criteria presented in this article.

3.1. Characteristics of the hiking in Sierra de las Nieves

Sierra de las Nieves is a mountainous area (Fig. 2) formed by Jurassic limestone in the northern and central part, which determine a steepness relief. In the southern part of the test site, there are Paleozoic materials (peridotites and schist) that generate a relief smoother or lower slope and therefore there are a greater number of trails. The roughness of the relief has led to the land mainly being taken up by forest and the human influence is very low. Since 1989, this mountain range is a protected area and this has led to an increase of the tourist activity in the zone.

Knowledge of users' motivations is fundamental for understanding the demand for recreational facilities and, at the same time, a valuable tool for developing effective management measures (Arnegger, Woltering and Job, 2010; Saepórsdóttir, 2010; Farias, 2011) and also for estimating the perceptions of overcrowding. The surveys are usually the way to understand both motivation and perceptions of overcrowding. In this way, overcrowding perceptions, being subjective judgments by individuals, depend on a wide variety of social and/or psychological factors, including the type of user, the activity performed and the environment in which it takes place (Graefe and Vaske, 1987).

In Sierra de las Nieves Nature Reserve, 23000 users were counted over a year (Gómez, Luque and Peláez, 2016), which it represents a medium to low influx of hikers according to Muñoz (2008). According to the number of hikers, Gómez, Luque and Peláez (2016) carried out a survey to 345 persons (from October 2010 to June 2011) to analyze the type of user, motivation and overcrowding perception of each hiker in Sierra de las Nieves. The results allowed them to classify the hikers as tourist-hiker, which means that their motivation was more about enjoying nature rather than becoming fitter in natural surroundings. The motivation related to enjoying and gaining knowledge about the nature accounted for 37.3% of the cases and 11.6% of the hikers prefer it for the sport. Furthermore, the overcrowding perception due to tourist hikers was higher than of sporty hikers, approximately 30% and 10 % respectively (Gómez, Luque and Peláez, 2016).

3.2. Datasets used for the test site

Application of the multi-criteria algorithm depend on start and end points located in the test site (Fig. 3). Fourteen start points were identified, but only eight are strongly recommended, because they are easily accessible by car, are close to main roads or towns, or are located in areas where hiking activity is encouraged in order to relieve congestion elsewhere. On the

other hand, a total of 326 end points were located, of which 13 were considered especially suitable.

These landmarks were selected after consulting the 1/25,000 National Topographic Map, published by the Geographical Survey of Spain[1] (IGN: Instituto Geográfico Nacional), and the websites www.conocestusfuentes.com and www.espeleomalaga.com.

The graph used by the algorithm to find the optimal route and stored in the PostgreSQL database was created from feature datasets obtained from the Topographic Map of Andalusia (scale 1/10,000) in ESRI Shapefile format, published by the Cartographical Survey of Andalusia[2] (IECA: Instituto de Estadística y Cartografía de Andalucía). The attribute table of the dataset contains different types of information, and for our purposes, only the roads and trails were selected. This cartographic database was revised and modified by Vías and Ocaña (2014), eliminating disconnected routes and connecting other possible routes by adding sections obtained from the information gathered at www.wikiloc.com and from interviews with mountaineers familiar with the study area.

4. Results.

The hiking route recommendation system proposed 364 of the 785 trails that have been mapped (46%). The trails most often recommended by the algorithm are concentrated in the central part of the study area (Fig. 4), because they are the most useful for connecting the northern and southern parts of the reserve nature, but they are not necessarily the most suitable for hiking.

The search algorithm considered 182 routes. Of these, only 62 (33%) were considered viable, in terms of their estimated difficulty (i.e., duration). Those classified as non-viable had an average duration of 16 hours and an average length of 50 km (Table 2). These values are considered excessive, as they exceed the time/distance acceptable to tourists-hikers in settings such as this reserve nature. Such routes would be more appropriate for athletes-hikers expecting to exert high levels of physical activity. However, this type of visitor is not predominant among those who enter the reserve nature (Ocaña, Larrubia and Navarro, 2013; Gómez, Luque and Peláez, 2016). Therefore, we propose as viable routes those with a duration not exceeding nine hours, and, within these, we differentiate between high, moderate and low difficulty (Table 2).

The average suitability values of the routes obtained (table 2) do not present significant differences. The range of suitability vary from 0 to 15 and the average values are around the middle: 7. However, there is a logical sequence in the mean values for length, slope and duration for any type of route (table 2). Thus, the greater the difficulty, the greater the distance, the height gain and the time required to complete the route.

Of the 62 recommended routes, 41 (66%) are classed as highly difficult, 16 (26%) are moderately difficult and 5 (8%) present little difficulty (Fig. 5).

[1] http://centrodedescargas.cnig.es/CentroDescargas/index.jsp
[2] http://www.juntadeandalucia.es/institutodeestadisticaycartografia/lineav2/web/

Among all the routes recommended, nine were selected for detailed analysis (Table 3), in view of their high level of suitability for routes, and these are graded as High, Moderate and Low difficulty. These routes are shown in Figure 6.

Of the routes proposed, those considered to be most suitable originate from five of the eight preferred route starting points. These routes are all in areas of high environmental quality within the reserve nature, but to date, these areas have received little attention in the park's management plans. The proposed routes would meet several of the objectives specified in the management plans, opening up new sectors of protected terrain and reducing overcrowding in others of similar environmental quality.

Of the nine routes proposed, seven are located in the southernmost part of the reserve nature, while the other two are in the north. These routes, as well as being optimal in terms of suitability, fulfil one of the main priorities stipulated for them, that of relieving the pressure of visitor numbers in the central area of the park and presenting areas of the reserve nature that are relatively unknown and of high environmental value, such as the Bornoque woodland, containing oaks and endemic pines.

The three routes classed as highly difficult have comparable levels of intrinsic suitability. The route extending from the Quejigales recreation area to Sierra de la Hidalga passes through a sector of great scenic beauty and contains two of the most important areas of *pinsapo* (Spanish fir) woodland, on the northern slopes of Sierra de las Nieves. Spectacular views extend from the summits of Sierra Hidalga toward the Ronda plain, containing the town of the same name with its historical and cultural riches. The other two routes with a high degree of difficulty both start from the same point, the entrance to the reserve nature, and continue along the forest track that leads from Monda to Istán. One of these routes climbs to the summit of mount Aranda, at 1050 m above sea level, while the other takes the hiker to the Montecilla spring, where water from the Río Verde emerges and flows toward the Concepción damming.

The medium difficulty routes are very similar to those described in the previous paragraph; they start from the same point, or nearby, and lead toward another peak, mount Gaimón, with similar characteristics to that of Aranda, and toward the Montecilla spring.

Two of the low difficulty routes start from the site proposed for the '*Pecho de Venus* ' visitor centre at Tolox, in the southern part of the park, and lead toward mount Aranda and the Rejía waterfall. These routes are classed as low difficulty due to their proximity to the end points of the routes; however, they are not actually operational, as the visitor centre has not yet been constructed.

The final proposed route, also of low difficulty, is located in the northernmost part of the park. This area is relatively unknown and indeed, enigmatic; nevertheless, it has considerable scenic value, with outstanding features such as the Lifa tower, the gorge of the same name and one of the sources of the river Turón, located at a point of outstanding natural beauty.

5. Discussion

Of all the routes examined by the algorithm, 66% were classed as non-viable because they exceed the levels of distance and difficulty considered appropriate for average hikers. This high proportion of rejected routes is understandable in view of the terrain in the study area, which is very rugged and contains the highest peak in western Andalusia. Therefore, this reserve nature may be considered more appropriate for athletic users than for less committed hikers. The proportion of viable routes classified as highly difficult is also consistent with the nature of the terrain; in other words, the ruggedness of Sierra de las Nieves increases the degree of difficulty of the hiking trails recommended, compared to those in less physically-demanding areas. In consequence, only five of the routes recommended by the system are classed as presenting little difficulty to average hikers.

The maps show that a greater use of hiking trails in the central area of the reserve nature (Figure 4) does not actually produce an optimal implementation of the criteria established for the recommendation system (Figure 6). In consequence, the system does not recommend trails in the central sector of the study area, despite the presence of important end-point features such as the Caina canyon or the Alcazaba elevation, primarily due to the absence of start points for routes in this sector, and to the PUP trails already established here; the system, thus, takes into account the existing presence of routes proposed by the administration, which confirms the correct functioning of the recommendation system proposed in this paper.

Of the nine results presented, two (H1 and L2) fail to meet the criterion of route circularity, being linear or nearly linear. This is due to the virtual absence of trails or tracks in Sierra Hidalga, in the northern part of the study area (see map in Figure 4). This fact precludes the creation of various possible routes toward the end points located in this northern area; nevertheless, due to the high values obtained for the remaining criteria, H1 and L2 are included as routes presenting high levels of suitability.

The values of trail length, height gain and, above all, time required for each of the routes proposed in this paper are consistent with the difficulty levels assigned. The highest values for route distance and height gain are associated with routes classed as highly difficult, and the lowest ones, with those presenting little difficulty. There are only two exceptions to this pattern, namely H1 and M2 (Table 3), for which the height gain values are contradictory; however, even in these cases, the time required to complete the routes is consistent with their degree of difficulty.

6. Conclusions

The recommendation system presented in this paper is a tool for creating hiking trails through areas that have not previously been considered in management plans for the public use of protected areas, thus contributing to the management of tourism/sports activities in the natural environment. This system, moreover, offers hiking itineraries of varying levels of difficulty, so that users with different levels of physical fitness can explore and better understand this protected area.

In this paper, the recommendation system uses open and public databases with the objective of minimizing the costs. This decision allows applying the methodology quickly in other areas to facilitate the tasks of protected area managers, but has the problem that it depends on the accuracy of the public data to validate the information derived from the recommendation system. Nowadays, the advancement of technology means that the accuracy of the information published today has enough quality to obtain results close to reality, although not exempt from small errors.

In many cases, the objective of hiking is to reach a particular landmark, but the return becomes monotonous because it does not provide new information. This recommendation system use a criterion to keep the hiker interested during the whole route. This tool encourages the creation of circular routes, which allows maintaining the degree of adventure or exploration by not having to return by the same path. The routes obtained are circular (i.e. L1, L3, M1, M2, M3, H3, in figure 6) or semicircular (i.e. H2 in figure 6) in a high percentage and only in a few cases are linear (i.e. L2, in figure 6) or quasilinear (i.e. H1, in figure 6).

One of the tasks of the management of the protected areas is to reduce the impact that the human activity could have in those areas. In this sense, the use of criteria that allows the diversification of hiking to others areas would help to reduce problems related with overcrowding in specific zones. This system recommends routes in areas that are not normally used for hiking and would allow minimizing the overcrowding of some areas in specific periods. In addition, it recommends hiking in zones not very well-known, but with high environmental value according to the knowledge of the experts.

This recommendation system must be used before visiting a place for hiking, as it is necessary to plan the route. Smartphones are a widely used technology among tourists, allowing the use of geolocations to facilitate the decisions of consumers of a product, in this case hiking. Therefore, a new app that allows knowing the location of a certain user of the recommendation system would simplify the task of choosing the starting point, since the GPS of the smartphone would do that function. This task will be developed in the future within the framework of the researches that are being carried out in the research group.

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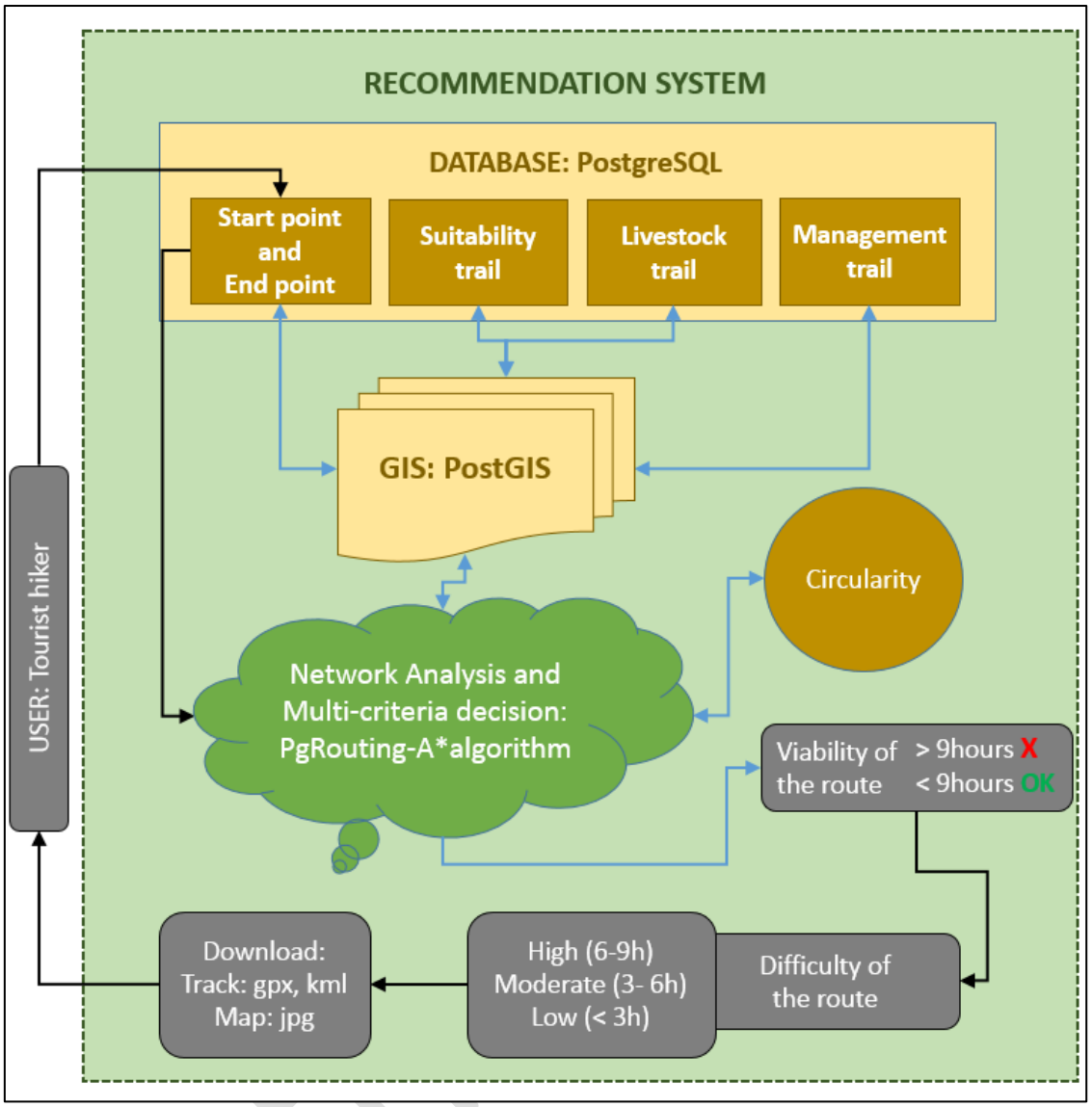

Figure 1. Scheme of the methodology. The arrow establish the direction of the connection between elements of the recommendation system.

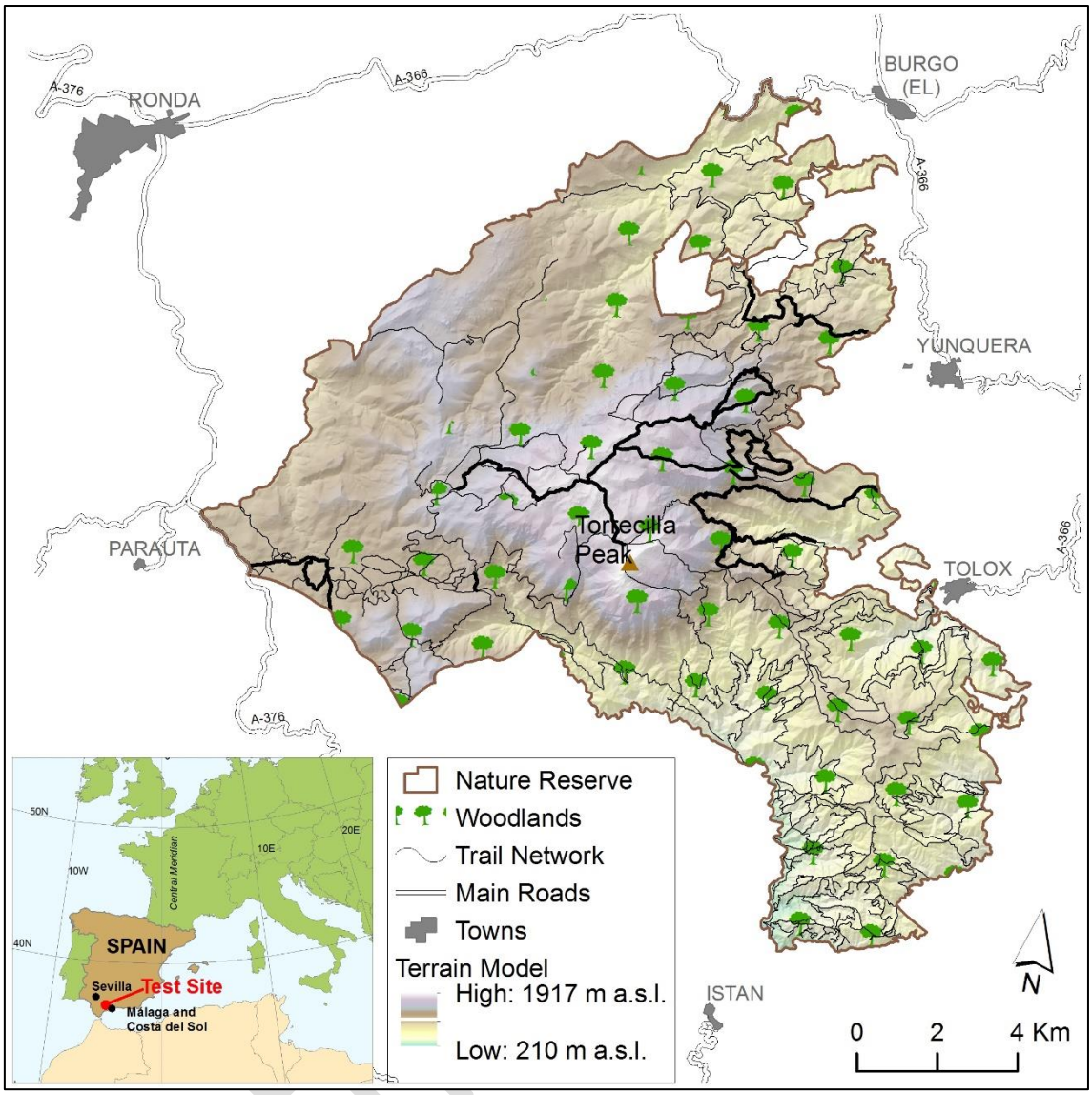

Figure 2. Location and characteristics of the study area (Sierra de las Nieves natural reserve). The trails included in the public use programme are highlighted in bold.

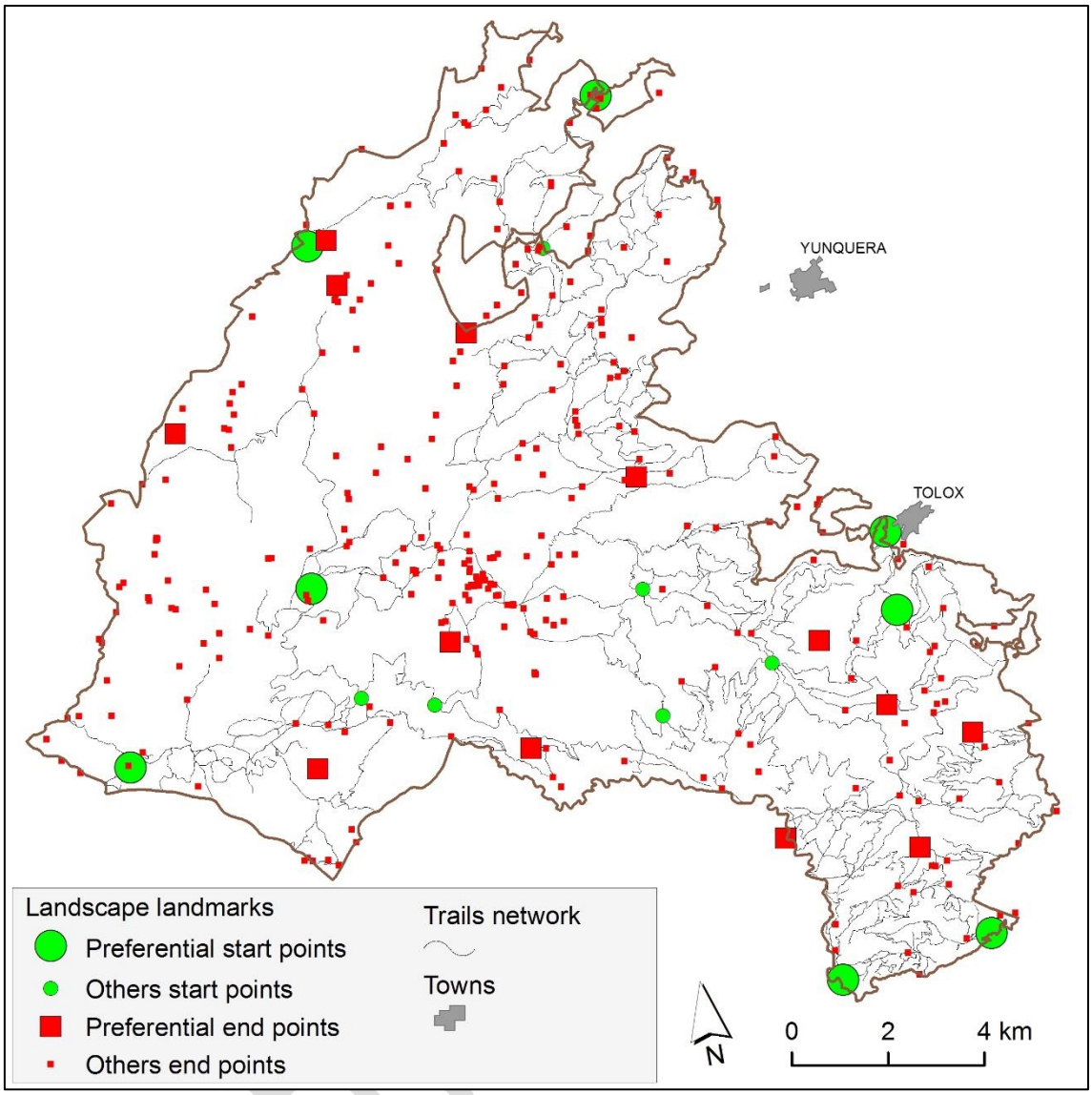

Figure 3. Start and end points and sections of the trail network.

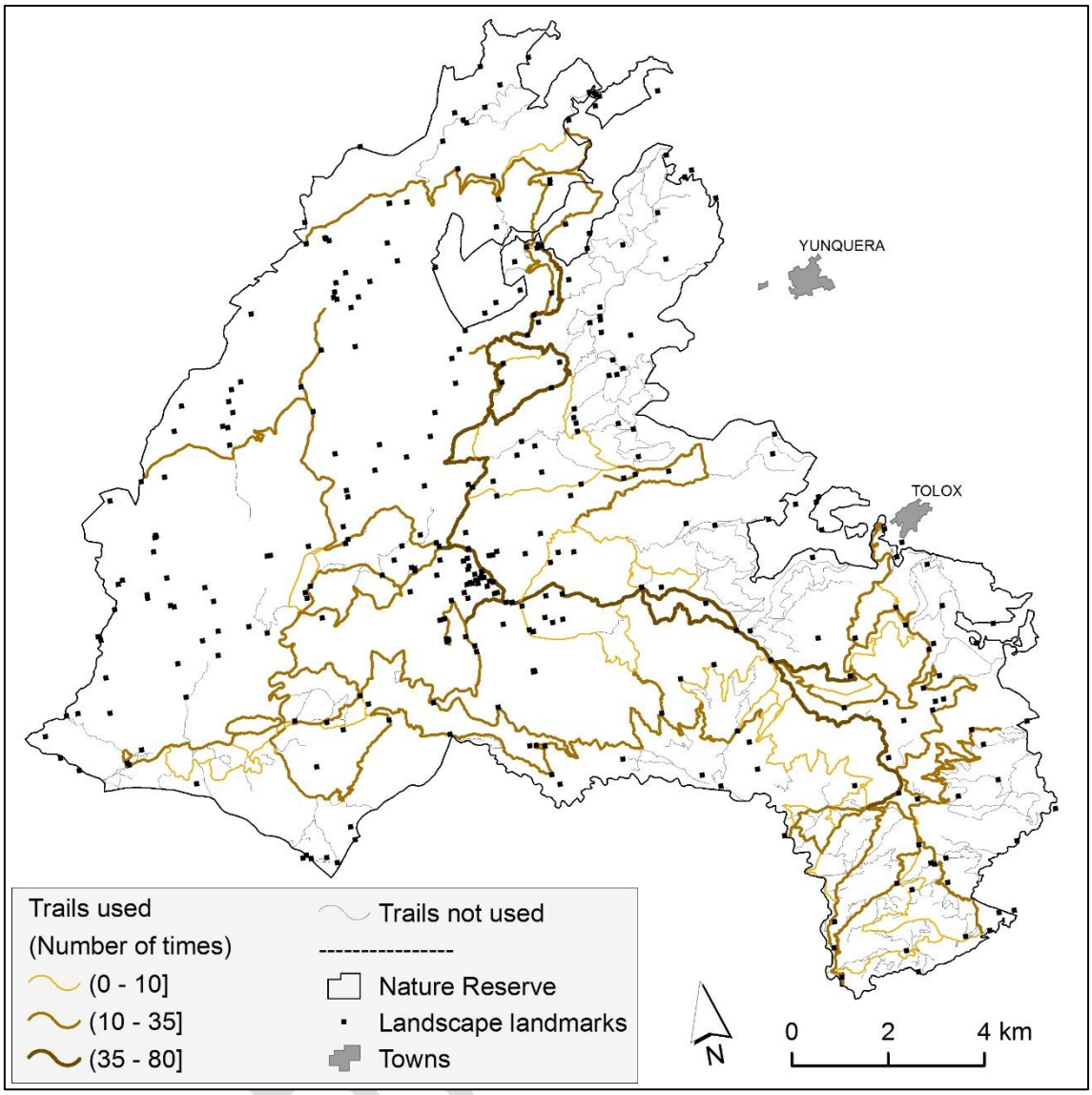

Figure 4. Location of the recommended routes, according to their viability and difficulty.

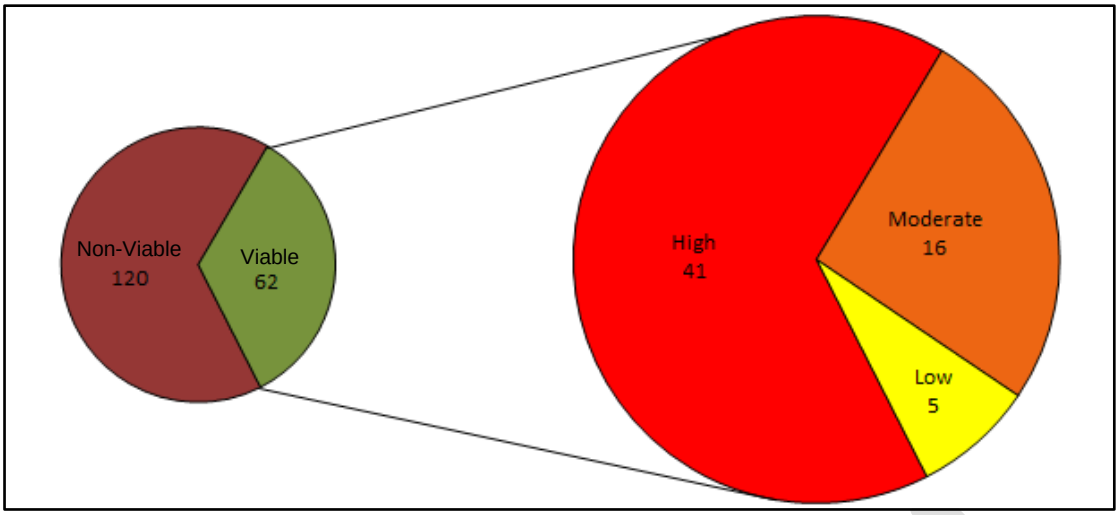

Figure 5. Proportion of routes recommended and classified by degree of difficulty

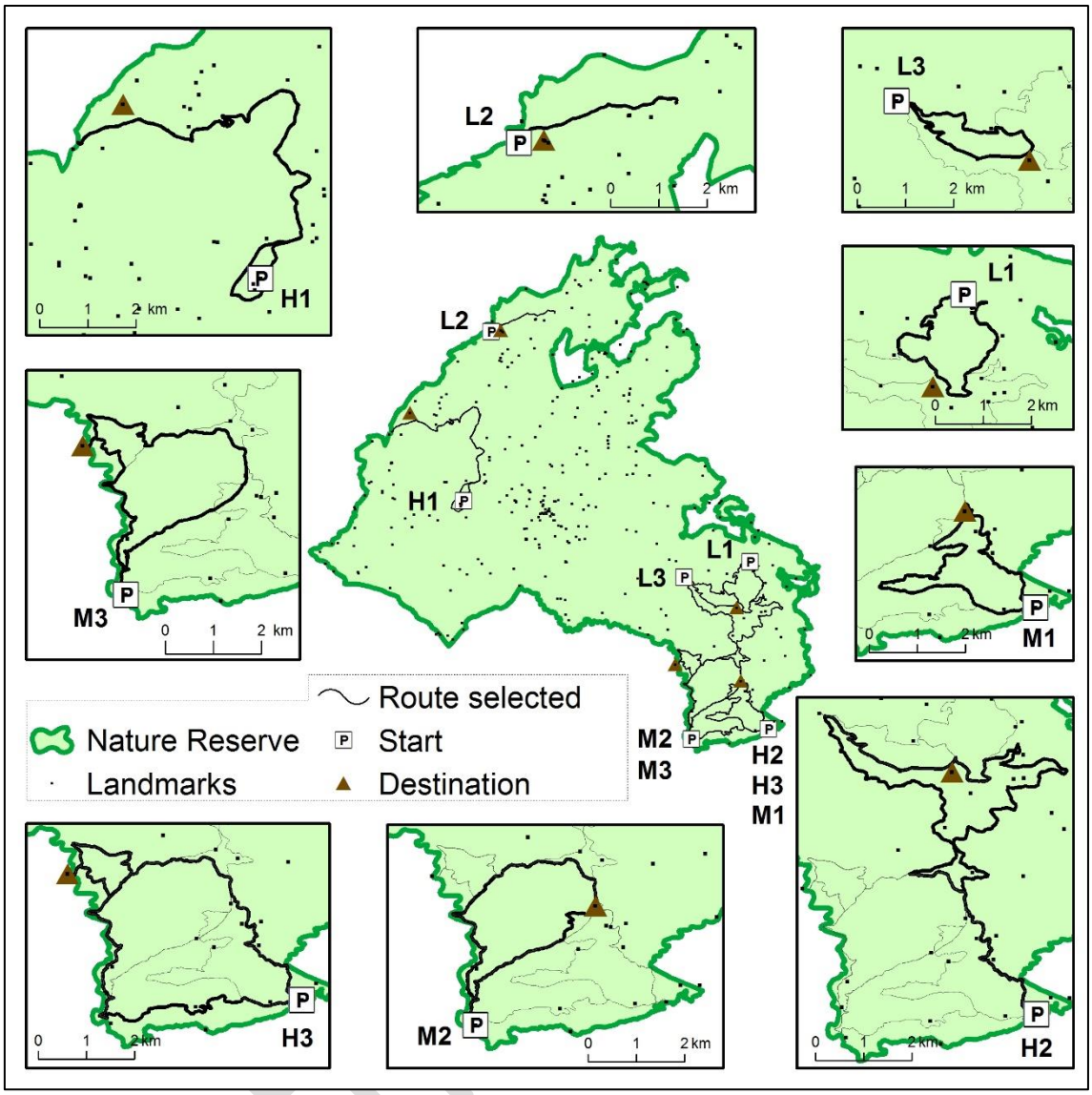

Figure 6. Most suitable recommended routes, according to level of difficulty. Legend. Difficulty: H = high; M: moderate; L = low. Suitability: 1 = first; 2 = second; 3 = third.