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"Gheorghe Asachi" Technical University of Iasi, Romania

ENVIRONMENTAL MODELLING OF LOW-IMPACT LANDSCAPED PATHS FOR LINEAR INFRASTRUCTURE IN "LAS BATUECAS-SIERRA DE FRANCIA" AND "QUILAMAS" NATURE PARKS (CENTRAL SYSTEM, SALAMANCA, SPAIN)

Antonio Miguel Martínez-Graña*, Pablo Silva, Virginia Valdés, Javier Elez

Department of Geology, External Geodynamics Area, Science Faculty, University of Salamanca, Plaza Merced s/n, 37008, Salamanca, Spain

Abstract

The great degree of human development in recent centuries has generated an environmental problem: the spread of human activities through the landscape without sustainable planning. Currently, most natural areas of the planet that are protected for their natural resources have not been impacted by linear infrastructure. The landscape is one of the natural resources that is adversely affected by linear infrastructure. In this short essay, a methodological procedure is described that is easy to use and cost effective and allows for early stage environmental planning. The method uses environmental assessment maps in which weighted pixel values for landscape quality and visual fragility are predetermined. GIS techniques, such as accumulated costs and driving direction scripts, are used to calculate linear infrastructure routes that have the lowest environmental impact. The optimal path is generated by quantitatively calculating the impact of each map pixel along the route such that alternative routes can be selected prior to construction. This method is a powerful tool for environmental modelling focused on the avoidance of environmental impacts during the assessment phase of a project.

Key words: environmental assessment, GIS, landscape environmental impact, linear infrastructure, nature parks

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1. Introduction

With the emergence of the concept of sustainable development comes the need to include environmental variables in the decision-making process, such that conservation of the environment through protection constitutes a bulwark against increased pressure from the growing needs of human activity and ensures the conservation of natural resources from technical, socio-economic and environmental perspectives. Sustainable development integrates economic growth with resource protection (Bruschi et al., 2015; Fortuna et al., 2012; Ghinea et al., 2017; La Rosa et al., 2013; Masnavi, 2013; Su et al., 2014; Santos-Francés et al., 2017). Landscape preservation is one of the most difficult aspects of land management.

In this context, the strategic environmental assessment process (DOUE L197, 2001) and environmental impact assessments (DOUE L175, 1985) have emerged as preventive tools to be used during the planning, design and implementation phases of projects occurring in natural areas (Bryan., 2013). Environmental modelling of particular parameters of the physical environment (Castronova et al., 2013; Fonseca et al., 2014; Martínez-Graña et al., 2017a, 2017b; Massmann et al., 2014; Welsh et al., 2013) can be used to avoid the environmental impacts of many projects, thus averting the need for future rehabilitation.

* Author to whom all correspondence should be addressed: e-mail: amgranna@usal.es; Phone: +34 923294496; Fax: +34 923294514

Landscape analysis has a dual approach. One studies the total landscape or phenosystem (perceptible part) with indirect methods: identification and distribution of the components of the landscape with interrelation with thematic components of the natural environment (reliefs, vegetation, hydrology…), and the characterization of its attributes (slopes, orientation…). The other approach studies the visual aspect of the landscape, or cryptosystem (intangible part) with indirect methods that assess the natural environment based on aesthetic criteria (beauty) or forms perception: visual, auditory or olfactory sensations (Dunn, 1974; García-Quintana et al., 2005; Klauko et al., 2017; Martin and Otero, 2012; Martínez-Graña and Valdés, 2016a; Van Der Perk et al., 2007). The strategic planning of different human activities should be managed following a method that includes (Laniak et al., 2013; Martínez-Graña et al., 2013a) defining the carrying capacity of the territory, determining the different levels of protection required for important natural features, obtaining input from human activities as prescribed the resilience or land use grade integrating the results with environmental values (Bastin et al., 2013; Martin et al., 2016; Martínez-Graña et al., 2016b, 2018; Martínez-Graña and Gago, 2018; Nativi et al., 2013). A significant environmental impact, especially in nature parks, is linear infrastructure (e.g., roads, power lines, pipelines, forest paths, hiking trails, etc.), which can affect the environmental quality of areas with high biodiversity and geodiversity, requiring the government to protect those areas (Geneletti, 2004; Martínez-Graña et al., 2014; Samarasinghe and Strickert, 2013). Currently there are not many tools to determine a priori the negative impacts of different linear structures such that alternative routes can be identified prior to creating a direct harm to the environment (David et al., 2013; Labarraque et al., 2015; Niţă et al., 2015; Strevens et al., 2008; Von Seht, 1999).

The objective of this paper is to establish a methodology that quantifies the negative impact of linear infrastructure on natural areas. This analytical method allows us to anticipate the negative effects of human activities, subsequently allowing the selection of lower impact alternatives that take into account traditional land use and avoid deterioration of the natural environment. The methodology is conducted by applying different scripts in Geographic Information Systems (GIS) ArcGIS 10.3. The scripts use georeferenced and geospatial analysis to allow the overlaying of thematic maps (e.g., landscape, vegetation, hydrology, etc.) (Afgrawal and Dikshit, 2002; Martínez-Graña et al., 2013b), which subsequently automatically generating respectful paths with environmental conservation.

2. Material and methods

In this paper, the methodology has been applied to two nature parks: Batuecas-Sierra de Francia and Quilamas (Fig. 1). The analysis applied to these spaces takes into account the quality of life of residents within the project study areas, ensures continued access to natural resources and prevents permanent damage to the environment. The methodology also satisfies the needs of current development while avoiding the deterioration of the natural environment and ensuring its continued enjoyment by future generations. This GIS technique is easy to use, low economic effective and ideal for use during the project planning stage. The methodology outlined below gives to environmental stewardship a previous judgment, as objective as possible, which seeks to avoid, reduce or offset the negative effects of human activity and is meant to be utilized as a preventive tool during the planning stage of linear infrastructure projects.

To demonstrate the methodology, a route that passed through two nature parks (Las Batuecas-Sierra de Francia and Quilamas) was selected, beginning in the town of Herguijuela del Campo (NE region) and ending in the town of La Alberca (SW region).

2.1. Analysis of the landscape quality

First, the environmental qualities to evaluate are selected. Then, the landscape impact assessment and maps of the landscape (Fig. 2) are generated. The landscape maps are created by assigning a numerical value between 0 and 256 to each pixel, where pixels with higher values are areas with correspondingly with landscape areas of major importance. The pixel values are obtained by combining GIS environmental quality maps and the landscape visual fragility maps for the study area.

The landscape visual fragility maps use a green colour scale, indicating regions of higher scenic value with dark green pixels and regions of lower scenic value with light green-yellow pixels (Martínez-Graña et al., 2011).

2.2. Calculation of the accumulative cost

To determine the optimal route, we use the algorithm that analyzes costs by distances based on the proposed route, in such a way that it scales the pixel to pixel benefit cost, performing a geospatial analysis of possible sustainable routes. Calculating the most sustainable route and of lower cost is from the digital level or value of each pixel simulating a Euclidean function, so that it does not calculate the exact distance from one point to another, but calculates the optimal distance from its weighted sum or what is the same the accumulated cost.

The units that are used are not the common ones (meters, kilometers ...) but are units of cost or damage greater or lesser to the landscape based on the quantitative cartography of values of the landscape, elaborated for this study. Finally, a map is created that shows the route (Fig. 3) that shows the accumulated cost values.

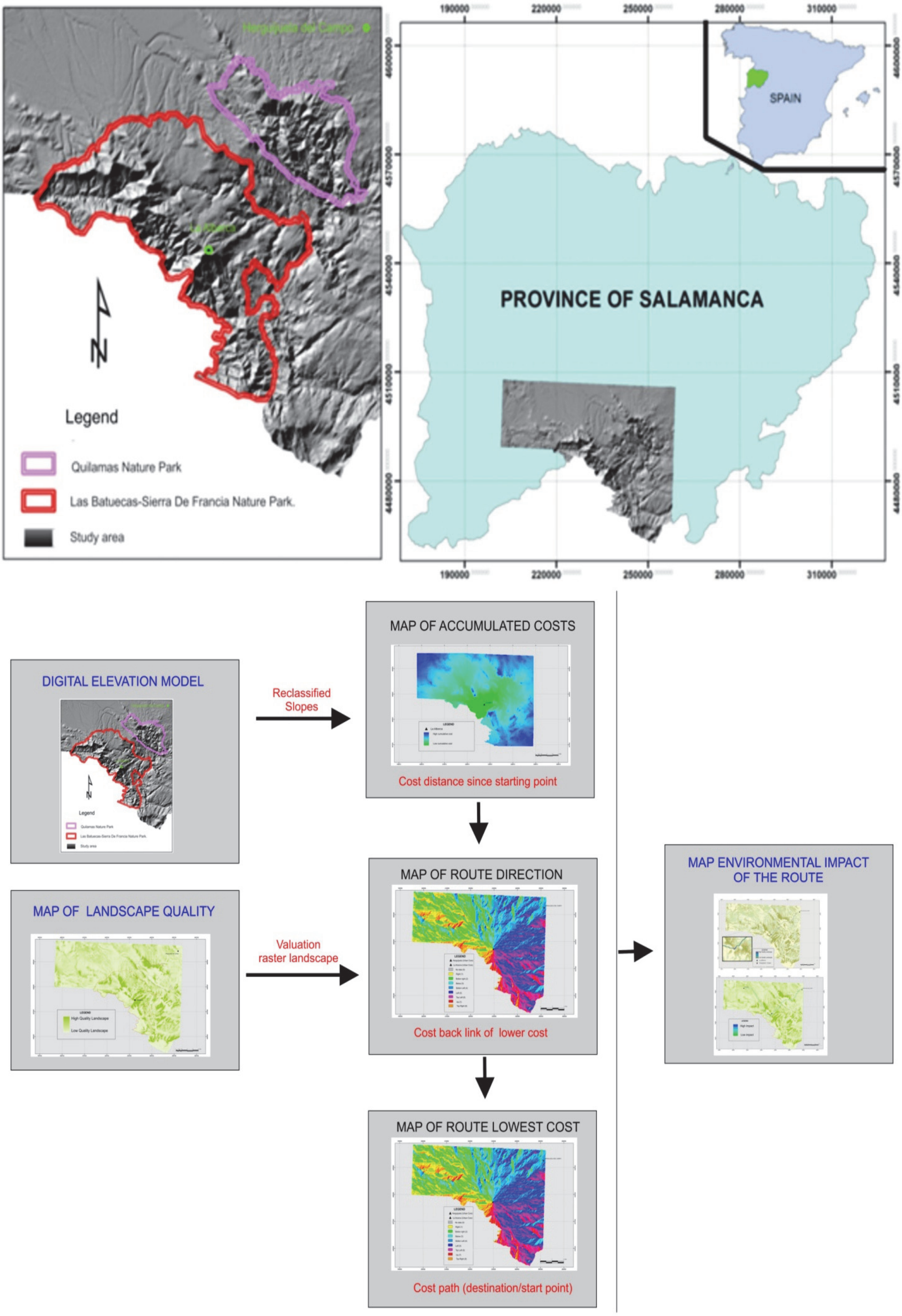

Fig. 1. Map of the study area (up) and methodology flow (down)

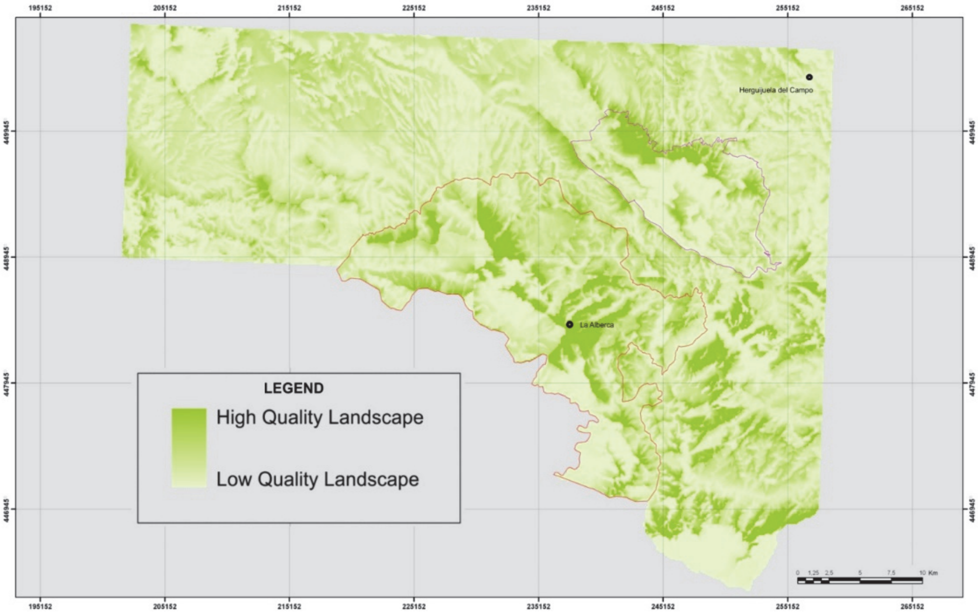

Fig. 2. Map of the landscape assessment for the nature parks Batuecas - S. Francia (red line) and Quilamas (purple line)

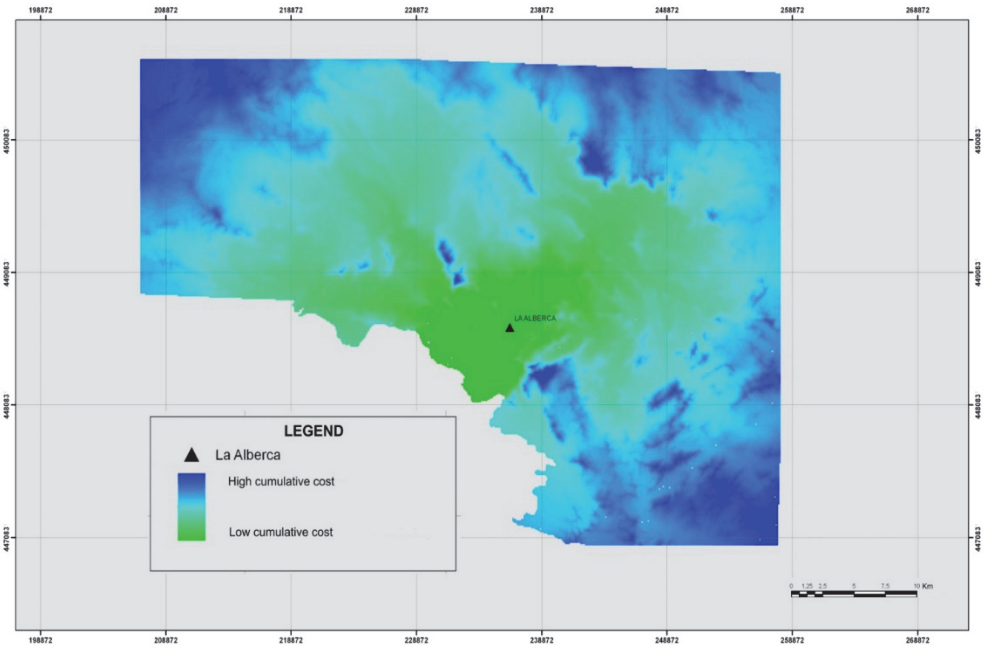

Fig. 3. Map of the accumulated costs

The procedure each pixel is related to the digital values of those around you and the cost of the route is calculated by multiplying the pixel size by the value of each pixel, showing the sustainability of the route based on the cumulative value of environmental cost or impact generated at each point of the route.

The route is generated when moving from pixel to pixel, so the cost between a pixel 1 and the pixel 2 that is next, and the value of the calculation of the route (D1) is based on a formula (Eq. 1). If the route decides to turn its layout in some diagonal zone (Eq. 2).

$$D1= (cost1 + cost2) /2 \quad (1)$$

$$D1= 1.414214 (cost1 + cost2) / 2 \quad (2)$$

The cumulative cost (AC) for the displacement between pixels (Eq. 3) is calculated so that the value of the displacement between 3 consecutive pixels (cost1, cost2 and cost3) is the sum of "D1" (Eq. 1) and "D2 "(Eq. 4) and so on consecutively until "Dn "

$$AC= D1 + D2+.... + Dn, \quad (3)$$

$$D2=cost2 + cost3 /2 \quad (4)$$

2.3. Calculation of the route direction

To determine the route direction, the direction script in ArcGIS is used. The direction script's operation depends on the spatial orientation of travel between the origin point and the end point. The direction of the route (Fig. 4) is calculated by selecting the optimal value of each pixel and its location, proceeding to vary or rotate based on the digital value of each pixel. This selection of the displacement is based on searching for the pixel or point of lowest accumulated cost. The procedure is to give a value "0" to the arrival and departure points and to the values of the pixels that are in their radius of inflrmation values from 1 to 8. The value is quantified following a dextrous direction, so that the pixel located to the right of the output pixel or "0" presents value 1 (yellow colour), bottom right value 2 (green colour), bottom value 3 (pale blue colour), bottom left value 4 (dark blue colour), to the left value 5 (very dark blue colour), top left value 6 (pink colour), top (7-red colour) and top right value 8 (orange colour).

2.4. Calculation of the route

Starting from the values at each point of the route based on the accumulated costs and their address, the most sustainable or least cost route is calculated from the town of La Alberca (exit) to Herguijula del Campo (arrival), so that The final route is constructed by joining the points of least cost or value of the least impact generated by the plot based on the landscape map, automatically looking for these values among all the digital levels of the pixels of the sector (Fig. 5).

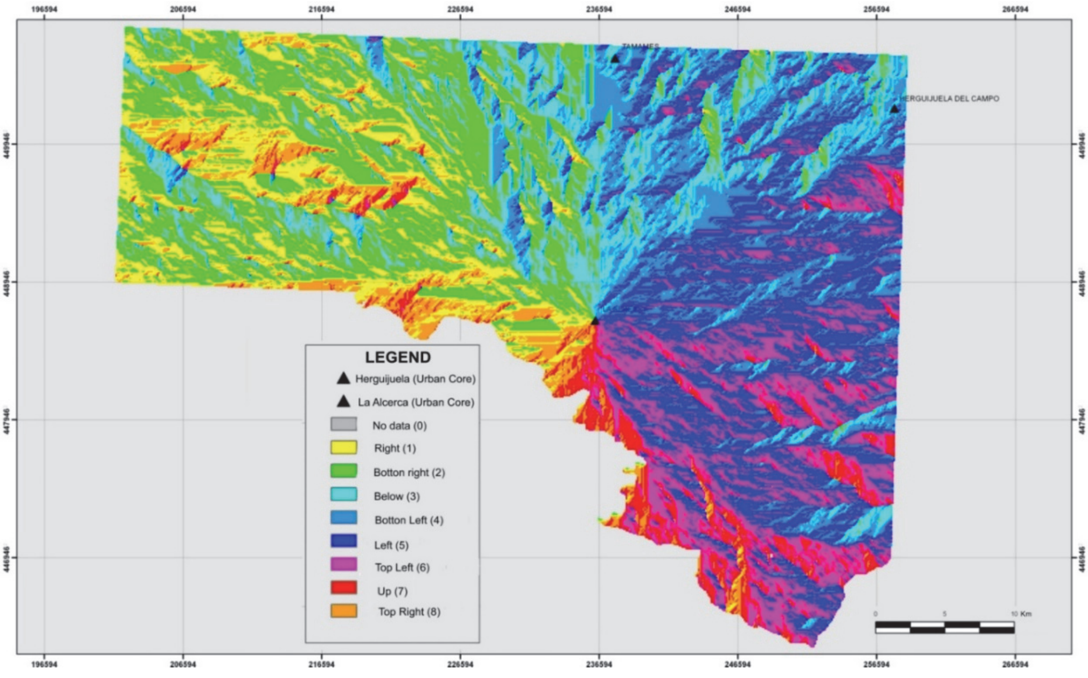

Fig. 4. Map calculation of route direction

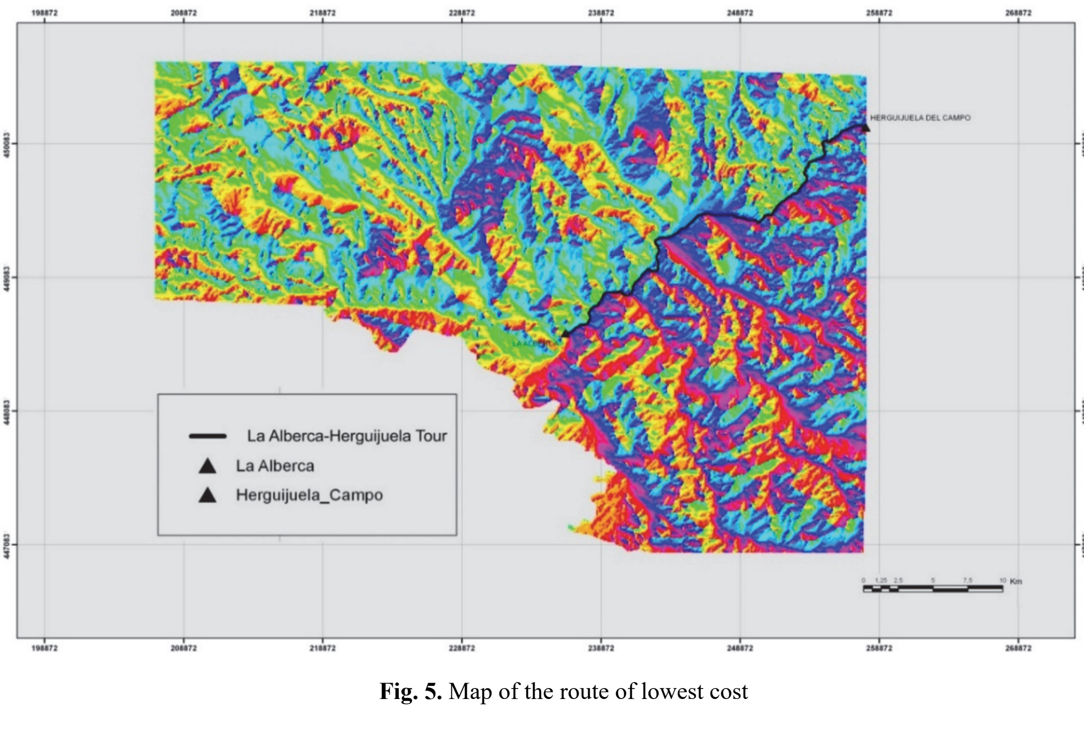

Fig. 5. Map of the route of lowest cost

3. Results and discussions

The analysis of the layout of roads (e.g., roads, farm roads, fire lanes, etc.) and utility infrastructure (e.g., power lines, water supply and drainage pipelines, wind farms, etc.) plays a vital role in protecting natural areas and in strategic planning to minimise environmental impact. Using landscape assessment (i.e., assessing the quality and visual fragility) one can select the path of least environmental impact from any starting point.

In addition, the methodology provides a set of value-weighted pixels of quantified scenic impacts that can be reshuffled by colour to highlight the pixels or regions with greater or lesser impacts on the environment. By extracting the values for each pixel, we can identify the areas with the most significant environmental impact and respond by making changes to these regional routes to choose the more sustainable route. Fig. 6 presents the refined route through the nature parks Batuecas-Sierra de Francia and Quilamas, at a pixel resolution of 20 x 20 meters, in which the blue-colour pixels indicate areas of greater environmental impact and the bright green colour pixels indicate areas of lower landscape quality. In Batuecas-Sierra de Francia, the values are highest in the vicinity of La Alberca and at the beginning of the countryside, while areas of higher aesthetic value occur in Quilamas. The route superimposed on the environmental assessment map shows strong green colours in areas of higher environmental quality and lighter green colours in areas of lower environmental quality. This colour contrast allows simple and efficient analysis of alternative routes in the regions with the most significant visual impact on the route (indicated by the colour blue route) (Fig. 6).

We compared the aesthetically more sustainable alternatives for a power line route between two starting points (Herguijuela del Campo and Tenebrón) to a common end point (Town of La Alberca) with each route encompassing the same distance (26 km). Performing the methodology outlined in this essay, we obtained the two routes' quantitative assessments by using the geostatistical GIS operation to calculate the average environmental value of all the pixels through which the routes passed. The Herguijuela del Campo-La Alberca route indicated a significant impact with an environmental quality loss of 40,365 units, while the Tenebrón-La Alberca route indicated a less significant impact with a loss of environmental quality loss of only 34255 units. Thus, the Tenebrón-La Alberca route is believed to be the less cost effective one because it creates less environmental impact and, as such, would be considered the more environmentally sustainable alterative (Fig. 7).

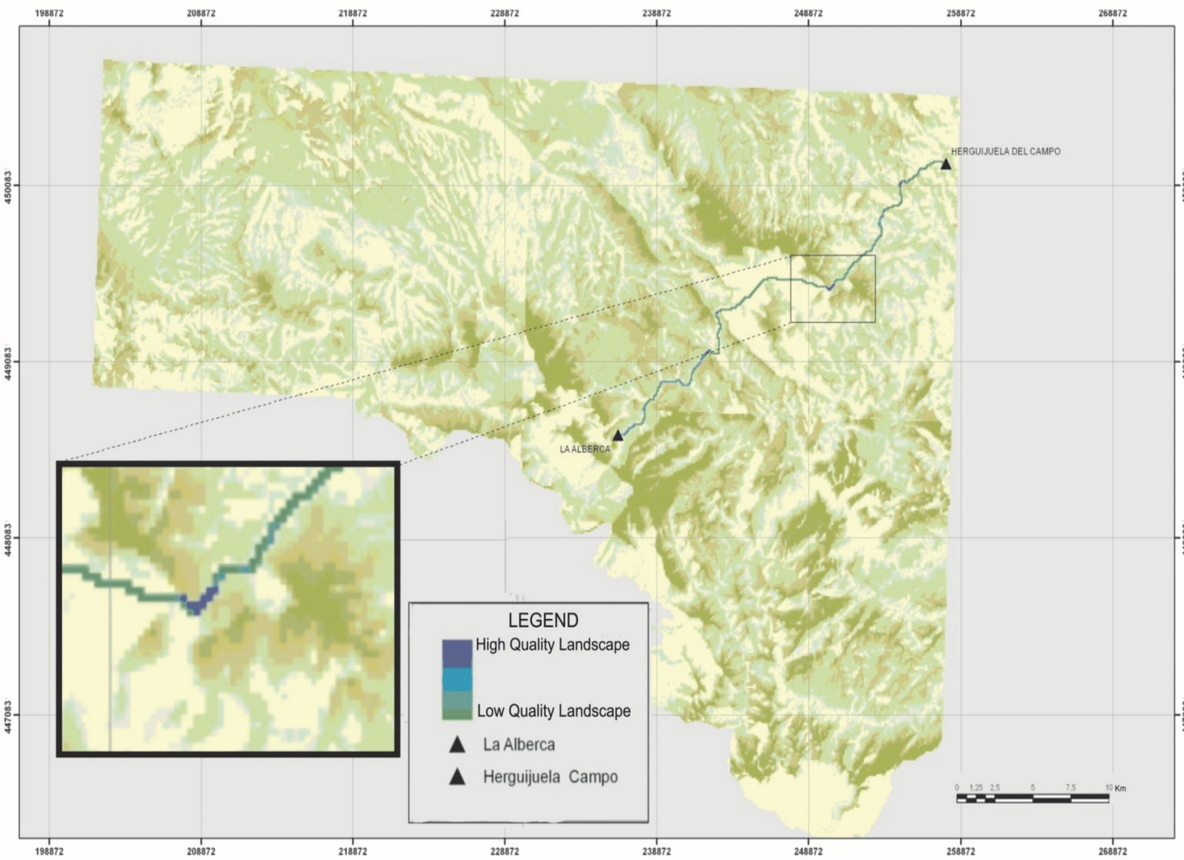

Fig. 6. Map of the proposed route between Herguijuela del Campo and La Alberca (The colours in the legend refer only to route)

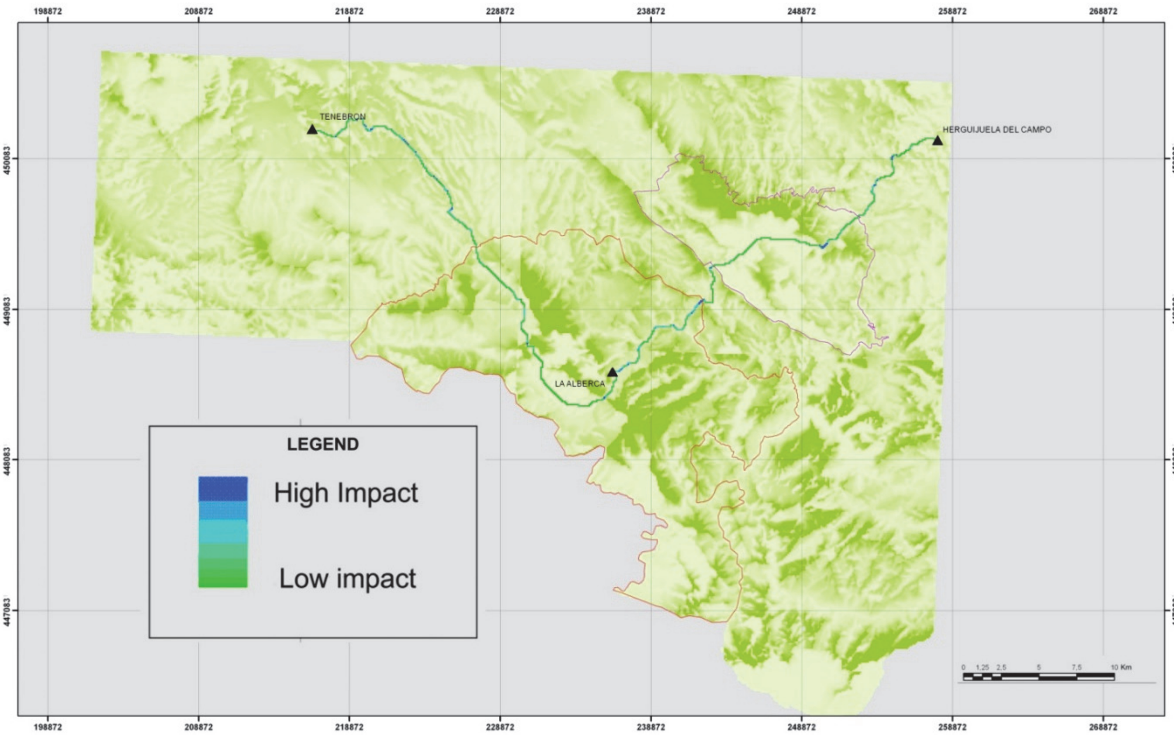

Fig. 7. Map of the environmental impact for routes through Herguijuela del Campo-La Alberca/La Alberca-Tenebrón (The colours in the legend refer only to routes)

4. Conclusions

The methodology of linear infrastructure route determination outlined in this essay is very useful in the early stages of planning. It allows the selection of alternative routes from among multiple routes proposed by the analysis of environmental assessment data. The analysis can be modified to assess the lowest cost impact based on any parameter (in our example, the parameters were landscape quality and visual fragility).

The methodology developed is a simple technology with scripts implemented in GIS, which reduces the chances of possible alternatives for any path between two points anywhere in the world. It also allows quantitatively estimate the environmental cost of each alternative scenic route before they carry out any action in the natural environment. It is a tool of great interest and use as it can prevent and decide preplanning multiple linear infrastructures (roads, pipelines, routes...) to zero environmental cost. Moreover, this methodology provides a complex thematic analysis, which takes into account different variables: topography, vegetation, orientations ... that is defined by a thematic map of landscape quality of the study area, in raster format, where each portion of the territory has a quantitative value. It allows us to quantify environmental parameters such as landscape, difficult to assess and large spatial variability.

The resulting maps allow the creation of a digital database of natural areas that can be used as tools to facilitate and improve spatial analysis and, in turn, allow for rapid multidisciplinary coordination. Thus, sustainable development is the preferred rational and environmentally respectful land use strategy.

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