**Modern Environmental Science and Engineering (ISSN 2333-2581)**
**August 2020, Volume 6, No. 8, pp. 845-855**
**Doi: 10.15341/mese(2333-2581)/08.06.2020/006**
**Academic Star Publishing Company, 2020**
**www.academicstar.us**

# Environmental Zoning and Management Based on Spatial Analysis and Modelling: Becerra Canyons Case Study, Mexico City

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**Abstract:** The growth of Mexico City in recent decades has had a considerable impact on the Barrancas ecosystem. This is the case of canyons of Alvaro Obregon municipality in the city west, which are currently under strong pressures by population growth derived from the urbanization process. The canyons have been occupied legally and illegally; the occupation is causing changes and degradation to the ravine ecosystem due to deforestation, erosion and sedimentation; this led to transform the site in a disposal of waste, as well as wastewater, which are hotspots of infection and put at risk the quality of life of its inhabitants. Is the aim of this article illustrate how different elements of geospatial information sciences, particularly remote sensing and spatial analysis and modeling, can contribute in a significant way in the design and development of a methodology for environmental zoning and land management, to guide the implementation of environmental management programs in the study area. The environmental zoning, it was based on part in landforms and slope, calculated from a digital elevation model, as sustenance abiotic, and in the land cover and land use, which was generated through the analysis and digital image classification process of photographs, as sustenance biotic. Additionally, the grade of intervention of land cover, as well as the presence of anthropic coverages and its impact level, it was considered in the definition of the environmental areas. For information modeling decision models were used, which were implemented in algorithms as heuristic rules. The result of these was the automated generation of the landforms, zones and environmental units, as well as management zones. In the development and implementation of the methodology mentioned the contribution of the geospatial information sciences was relevant in the generation, processing, analysis and modeling of the required data.

**Key words:** environmental zoning, management, spatial analysis, modelling

## 1. Introduction

In the Mexico City there is an important system of canyons, which have a very rugged topography and a sector of lowlands relatively flat which has allowed the development of the settlements. This system generates valuable environmental services to its population, such as water harvesting for the recharge of aquifers, water balance regulation, retention of polluting particulate and the fixation of carbon dioxide; in addition, is a reservoir and refuge for species of wild flora and fauna. In last decades the growth of Mexico City has caused a considerable impact in these areas; such growth has focused its impact on the change in land use with approach residential, industrial, business or communication channels, which has seriously disrupted the distribution of natural ecosystems. This is the case of the cliffs located in the west of the City, which are currently on strong pressures for the population growth and urbanization, and have being busy legally and illicitly despite the juridical dispositions come from the Environmental Law, ecological zoning and arranging of the territory. The urbanization process has generated changes and environmental degradation to the canyon ecosystem

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due to deforestation, erosion and sedimentation, affecting the species of wild flora and fauna and decreasing the endemic species; becoming a site for the disposal of waste of all kinds, as well as sewage, which are foci of infection and put at risk the quality of life of its inhabitants. These aspects can be corrected through proper planning of the land use and the implementation of management programs, in line with the problem found. A fundamental step for the definition and implementation of such program is the ecological zoning of the territory; through this management zones are defined, units these on which management programs must be implemented.

A basic target of the zoning is to provide information about the specific vocation of use of a territory, for the decision making on the politics of use of this one. It is the objective of this article to illustrate how different elements of the geospatial information sciences, particularly remote sensing and spatial analysis and modeling, can contribute significantly in the design and development of an environmental zoning methodology for environmental zoning for the management through the generation process, analysis and modeling of the required data.

## 2. Environmental Zoning, A Basic Input for the Development and Implementation Management Programs

The environmental zoning (eco-regionalization) consists of defining geographic spaces relatively homogeneous based on the physical and biological environment; the use of this approach as the basis of regionalization enriches the knowledge of the distribution of natural resources, their dynamics in time, the tolerance of the environment to the human intervention [1]. The environmental zoning will evaluate the suitability of the productive territory and assess the potential conflicts between aptitude and current land use. In this regard, zoning in management environmental units constitutes the physical sustenance natural for the definition and implementation of management programs.

According to Verstappen and Van Zuidam (1991) [2] a core aspect of the eco-regionalization is to provide information about the specific vocation of each region, since that decision-making in environmental matters is carried out on the basis of knowledge of the nature and suitability of territories that that host specific natural resources. In this regard, geomorphological cartography alone offers a partial view of the state of the territory and its aptitude.

Despite the diversity of procedures and techniques used, most of the analyzes of the landscape commonly used attributes of landforms predictors such as key to their models [3].

According to Row (1996) [4] two different approaches exist to conceptualize ecological spatial units, the bio-ecological and geo-ecological one. This author recommends the last one, arguing that “the ecosystem concept does not import how you get there must be that of a volumetric system structural — functionally that occupies a relatively stable space”.

Most of the practices of cartography, traditional and emergent reflect the remarks of Row “the forms of the relief and drainage pattern are two of the features of the terrain that are visible and relatively stable, are also the most important features to understand the ecosystems”. These observations lead to the assumptions widely accepted that “the boundaries between ecosystems can be mapped so that they coincide with changes with the land form, that are known to regulate the reception and retention of energy, water and solids” [5]. Although the topography is just one of the environmental factors that interact in the formation of the landscape, it is assumed that this element is one of the environmental indicators more efficient for the zonation of the landscape [3, 5].

Topography plays an important role in a basin’s hydrological response to precipitation and has a major impact on the hydrological, geomorphological, biological and pedological processes that are active in the landscape [6]. With regard to the environmental zoning, the conceptual framework to follow in the methodology here proposed will be guided, on the one hand by the model proposed by Row (1996) [4] and by the model soil -landscape. The latter is a powerful paradigm that has its origins in the equation of formative factors of landscape originally described by Dokuchaiev (Glinka, 1927) and Hilgard (Jenny, 1961, after Hudson (1992) [7]. This equation identifies the five factors of landscape formation, according to which the landscape is characterized as a function of the lithology, climate, the organisms (vegetal cover), the relief (forms of relief and slope) and time.

## 3. Methods

### *3.1 Study Area*

The study area corresponds to the Barranca River Becerra, which is located in the Alvaro Obregon Delegation, Mexico City (Fig. 1). It consists of three tributaries: Becerra as main arm, Tlalpizahuaya and Jalalpa North; is located approximately between 2300 and 2600 meters above sea level, comprising an area of approximately 146.8 ha.

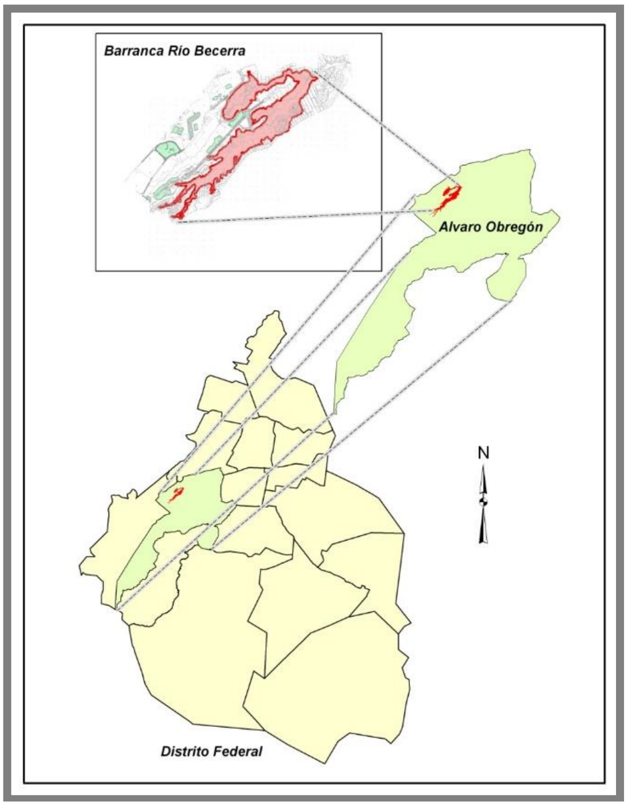


**Fig. 1 Study area: Barranca River Becerra Mexico City.**

The climate of the Barranca is temperate sub-humid with rains in summer, with high humidity content (Cw2), an average annual temperature between 12 and 14°C; rainfall between 800 and 1200 mm per year. La barranca is located in the Mesoamerican Mountain Region, forming part of the floristic province of the southern mountains, to which the Transversal Volcanic Axis are attached.

### *3.2 Databases*

The data used in this study included:

- Digital elevation model with 1 meter of spatial resolution, generated from contours.
- Map of Land cover and land use, generated by digital classification of digital aerial photographs, spatial resolution 50 cm.
- Terrain slope map, calculated from the digital elevation model

### *3.3 Modeling for Environmental Zoning*

Fig. 2 shows a diagram summarizing the methodological procedure used, comprising two phases: environmental zoning and zoning for management. In this project environmental zoning, was founded on the relief (relief and slope forms) as abiotic sustenance, and on land cover as a biotic sustenance. In addition, was considered in the definition of the environmental zones, the degree of intervention on land cover, as well as the presence of anthropic coverage and its impact level on the environment.

The definition of the landforms was based on calculation of topographical position; which is one of the most common attributes of geoforms, which is used in soil, geology and vegetation studies. It is a variable that tries to characterize local topography in relation to its spatial context. Many physical processes associated with the growth and occurrence of plant species, soil properties and soil types, are correlated with topography position. To calculate this variable an algorithm developed by Zimmermann (2000) [8] was implemented. In this way were obtained the following units: erosional valleys, ridges, foot slopes and slopes. The slopes were classified according to their curvature [9]. By implementing an algorithm developed by these authors, a convergence index was calculated, which defines the channel. Through a decision model the topographic position, curvature and convergence index were combined, resulting in three final relief units, namely: erosional valleys, channel and slopes, the latter characterized according to the curvature in rectilinear, convex and concave.

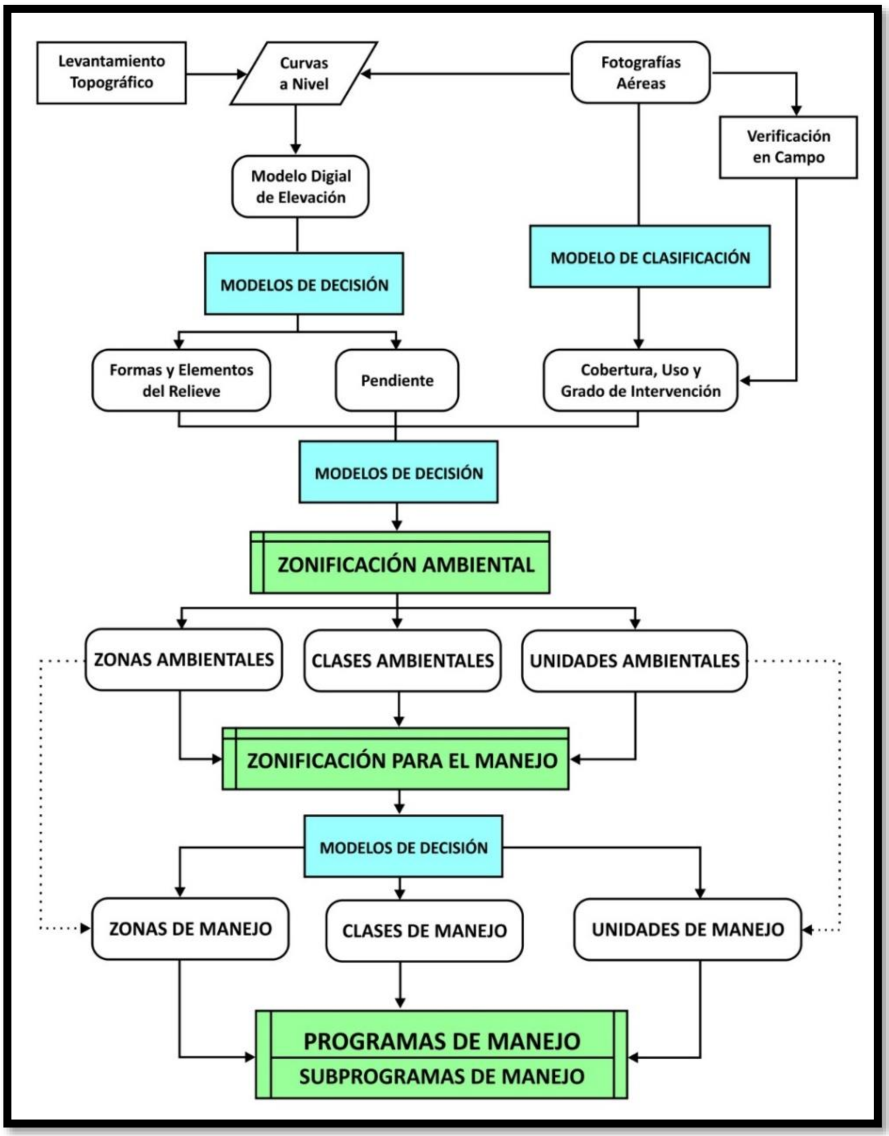


**Fig. 2 Zoning for management, methodological scheme.**

The second element used for environmental zoning was the slope or terrain gradient. The gradient or the angle of inclination has always been an important and widely used topographic attribute. Many classification systems of land suitability use gradient as the primary element to describe classes, along with other factors such as soil depth, drainage, and soil fertility. According to van Zuidam (1986) [10], maps of morpho-conservation make emphasis on the classification of the slope (example inclination and stability). According to this author, the steepness of the slope is often used as important attribute for the type and rate of erosion and mass movements. To calculate the slope a digital model with a spatial resolution of 1 meter was used; to subdivide slope values, the classification proposed by Van Zuidam (1986) [10] was used; it has the advantage this classification that the ranges used are related to geomorphological processes. By the conditions of the study area, it was determined that when the size of the resulting units (as is the case of the convex ridges and slopes) was very small, some slopes were grouped, so that the delimited units had greater spatial continuity.

Finally, the land cover was used as the third element to define the environmental zones. For it aerial photography's were used, which, by a classification process and fieldwork the existing classes of land cover were defined and mapped. In the definition of the land cover and land use classes the following criteria were considered:

1) Vegetation structure: According to this criterion, arboreal, shrub and herbaceous vegetation were defined.
2) Degree of intervention: In this criterion arboreal and shrub vegetation it was considered as a natural vegetation. Therefore, the presence of herbaceous vegetation and uncovered soils was considered as a sign of intervention. Very steep areas were, that have herbaceous vegetation and/or rocky outcrops, were excluded from this criterion.
3) The presence of anthropic cover, such as areas with human settlements (regular and irregular), recreation areas (parks and football fields) and areas occupied by waste from construction and garbage. Irregular settlements and areas with waste were considered as elements that generate a severe environmental impact
4) Finally, it was taken into account that the drainage network (particularly the main channels) to which household waste water is discharged, had a high degree of pollution, which also generate a severe environmental impact.

The three elements of the landscape, the landforms, the slope and the land cover and land use were combined in two models of classification based on a set of heuristic rules and arranged in a structure of decision tree. As a result of the first model was obtained a map of environmental classes, and from the second model, a map of environmental units was obtained.

### *3.4 Modeling for the Zoning of Areas for the Management*

The zoning for the management of the ravine will be the objective image that will guide the actions to be performed in the Ravine, which will be integrated into the different management sub-programs. Current uses, present problems, the potentiality of natural resources, project objectives and the feasibility of carrying out the proposed changes were considered to develop the zoning for management. On this basis the following areas were defined: conservation and protection, environmental restoration, recovery and environmental restoration.

## 4. Results and Discussion

Environmental zoning. Below are first the results of the analysis and modeling of the basic data for environmental zoning, here used are presented: slope, landforms and land cover and land use. The slopes present in the ravine are mostly steep; about half of the area shows slopes greater than 50%, a quarter between 16 and 50%, and the rest slopes less than 16%. These latter correspond to the area's perimeter urbanized and small portions at the bottom of the valley.

From a geomorphological point of view the Barranca River Becerra is located in the Piedmont. Lugo et al. (1984), refers to this unit like transitional slope; it is a sedimentary deposit that constitutes an area of transition between the surfaces almost flat of the basin and the high systems of mountains that limit it; in contrast to the almost flat parts, the slope presents a high degree of dissection.

The result of the modeling of the local relief (Barranca) is shown in Fig. 3, in which it is appreciated that in the Barranca the following land forms are distinguished: The Channel or drainage network, erosional Valley, ridges, escarpments, foot slope and slopes. These latest are characterized by their curvature in rectilinear convex, concave.

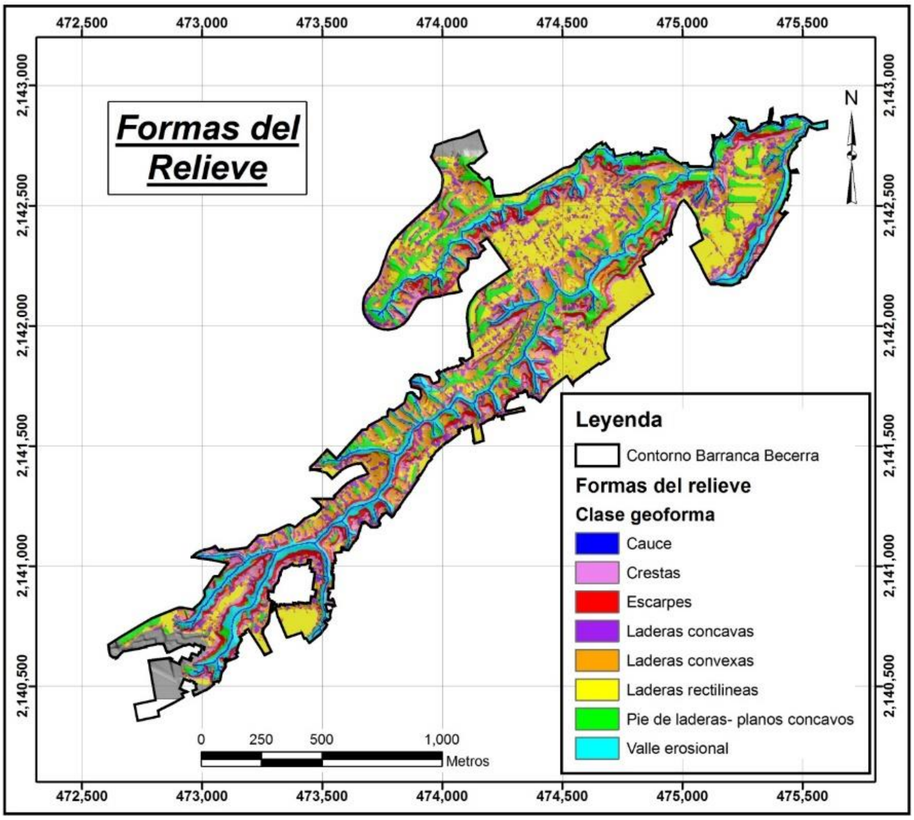


**Fig. 3 Map of landforms, Barranca Rio Becerra.**

Of the information presented so far it is possible to mention that the digital elevation models (MDE) have enormous but underutilized potential for generating useful information for the evaluation of the natural resources, as well as for the modeling of environmental problems. In this aspect the importance and roll of the sciences of geospatial information can be analyzed from two points of view, like generator of information and like provider of the tools necessary for the analysis and modeling of the data required.

Although there exists already information of elevation data provided directly through remote sensors, for this study were not available such data, as the existing ones for the study area had no spatial resolution required, for that reason elevation data from land survey were used (contours lines).

The analysis and spatial modeling had a fundamental role, on one hand in the algorithms contribution for the generation of an automated way, of essential information for environmental modeling such as the slope, convergence index, the curvature and the topography position in the landscape; and on the other hand in the modeling as a whole of this information to generate in an automated way the landforms.

Fig. 4 shows the land cover and land use map, resulting from the digital image processing and classification of aerial photographs; as a result of this process, it can be seen that in most of the study area the use is for conservation and protection, which corresponds to the area covered with natural vegetation and introduced (forests, shrublands and herbaceous). In some areas there are recreational uses, constituted by the parks and soccer fields.

Another important land use in the study area is the urban residential and commercial, complemented with some infrastructures. Complete the land use in the Barranca some small areas dedicated to deposits irregular not controlled of garbage’s and waste of Construction (clandestine dumps). This last use is taking a strong and negative environmental impact in the area of study.

The modeling results for environmental zoning are shown in Figs. 5 and 6 that correspond to the environmental classes and units respectively, the legends are shown in Tables 1 and 2. Environmental zoning for management is a complex process that requires spatial data of different kinds, as well as tools that facilitate both the acquisition and capture of such data, its processing and analysis.

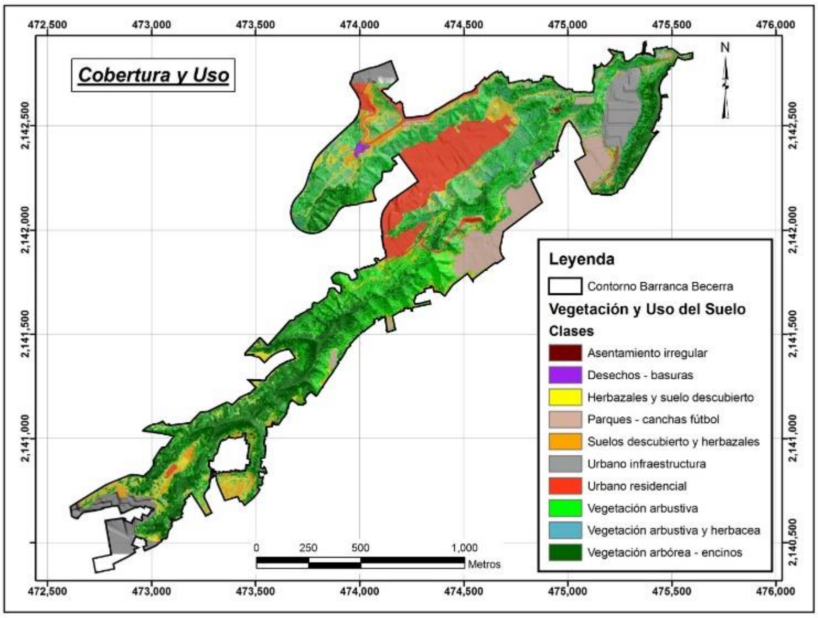


**Fig. 4 Map of vegetation cover and land use.**

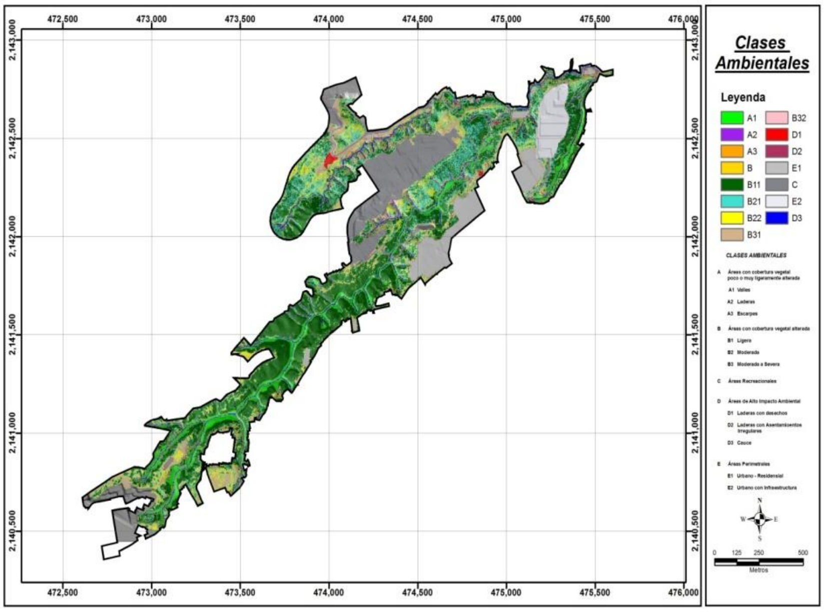


**Fig. 5 Map of environmental classes.**

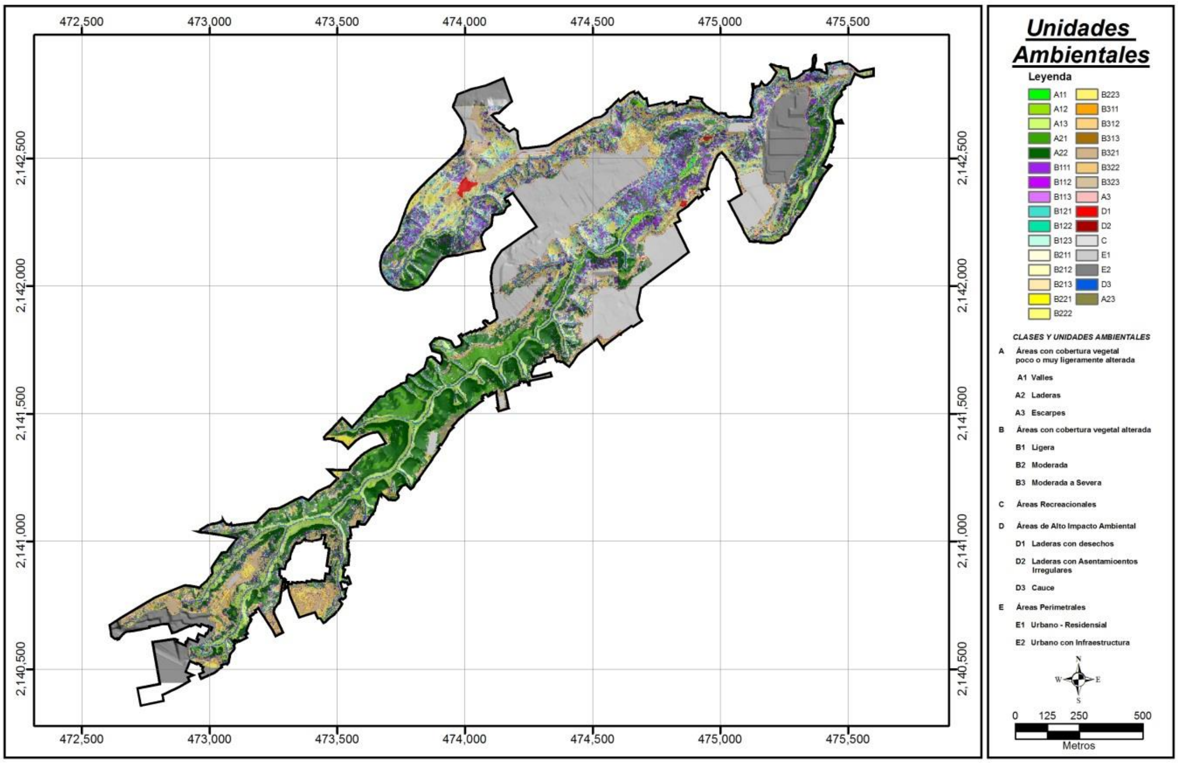


**Fig. 6 Map of environmental units.**

**Table 1 Legend of environmental classes map.**

| Environmental Zones | Environmental Classes | Symbol |
|---|---|---|
| 1. Areas with little or very slightly altered vegetation cover | Erosional valley with tree and shrub cover | A1 |
| | Hillsides with tree and shrub cover | A2 |
| | Scarps with herbaceous vegetation and rocky outcrops | A3 |
| 2. Areas with altered vegetation cover | | B |
| 2.1 Slightly altered | Erosional valley with shrub and herbaceous vegetation | B11 |
| | Hillsides with shrubby and herbaceous vegetation | B12 |
| 2.2 Moderately altered | Erosional valley with herbaceous vegetation and bare soils | B21 |
| | Hillsides with herbaceous vegetation and bare soils | B22 |
| 2.3 Moderately to severe altered | Erosional valley with bare soils and herbaceous vegetation | B31 |
| | Slopes with bare soils and herbaceous vegetation | B32 |
| 3. Recreational areas | Hillsides with parks and soccer fields | C |
| 4. Areas where the vegetation has been replaced and which due to their current use exhibit a severe environmental impact | | D |
| 4.1 Areas with garbage and construction waste | Slopes covered with debris | D1 |
| 4.2 Occupied areas with irregular settlements | Slopes with irrgular settlements | D2 |
| 4.3 Drainage areas contaminated by household wastewater and garbage | Channel | D3 |
| 5. Perimeter areas | | E |
| 5.1 Residential urban areas | Slopes for residential use | E1 |
| 5.2 Urban areas with infrastructure | Hillsides with infrastructure | E2 |

**Table 2 Legend of environmental units map.**

| Environmental Zones | Environmental Units | Slope (%) | Symbol |
|---|---|---|---|
| 1. Áreas with little or very slightly altered vegetation cover | Erosional valleys with shrub and tree cover | < 15% | A11 |
| | | 15-50 % | A12 |
| | | 50-100% | A13 |
| | Hillsides with tree and shrub cover | < 15% | A21 |
| | | 15-50 % | A22 |
| | | 50-100% | A23 |
| | Scarps with herbaceous vegetation and rocky outcrops | > 100% | A3 |
| 2. Áreas with altered vegetation cover | | | B |
| 2.1 Slightly altered cover | Erosional valley with shrubby and herbaceous vegetation. | < 15% | B111 |
| | | 15-50% | B112 |
| | | 50-100% | B113 |
| | Hillsides with shrubby and herbaceous vegetation | < 15% | B121 |
| | | 15-50% | B122 |
| | | 50-100% | B123 |
| 2.2 Moderately altered | Erosional valley with herbaceous vegetation and bare soils | < 15% | B211 |
| | | 15-50% | B212 |
| | | 50-100% | B213 |
| | Hillsides with herbaceous vegetation and bare soils | < 15% | B221 |
| | | 15-50% | B222 |
| | | >50 – 100% | B223 |
| 2.3 Moderate to severe | Erosional valley with bare soils and herbaceous vegetation | < 15% | B311 |
| | | 15-50% | B312 |
| | | 50-100% | B313 |
| | Slopes with bare soils and herbaceous vegetation | < 15% | B321 |
| | | 15-50% | B322 |
| | | 50-100% | B323 |
| 2.4 Recreational areas | Hillsides with parks and soccer fields | < 3% | C |
| 4. Areas where the vegetation has been replaced and that due to their current use exhibit severe environmental impact | | | D |
| 4.1 Areas with garbage and construction waste | Slopes covered with waste | < 15% | D1 |
| 4.2 Occupied areas with irregular settlements | Slopes with irregular settlements | < 15% | D2 |
| 4.3 Drainage areas contaminated by sewage | Chanel | | D3 |
| 5. Perimeter areas | | | E |
| 5.1 Urban residential areas | Hillsides with residential use | < 15% | E1 |
| 5.2 Urban areas with infrastructure | Hillsides with urban use of infrastructure | < 15% | E2 |

In this regard the role of the geospatial information sciences in this study was critical, on the one hand, through the remote sensing, with the contribution of data and their processing and on the other hand through the analysis and spatial modeling which it was possible to combine this information with the relief and slope from the digital models, already described in the previous paragraph.

With the zoning of a protected natural area and environmental value as is the case the Barranca Becerra, it seeks to identify and delineate the biophysical characteristics of the land, which condition the human activities, as well as the variables to consider within the requirements of conservation of natural resources to ensure a sustainable use. The environmental zoning resulting (Fig. 5) is the basis for the zoning for management. Thus, from the environmental classes were generated classes for management, and these in turn were subdivided into Management Units.

**Table 3 Legend of environmental management map.**

| Environmental Zones | Environmental Units | Slope (%) | Symbol |
|---|---|---|---|
| 1. Áreas with little or very slightly altered vegetation cover | Erosional valleys with shrub and tree cover | < 15% | A11 |
| | | 15-50% | A12 |
| | | 50-100% | A13 |
| | Hillsides with tree and shrub cover | < 15% | A21 |
| | | 15-50 % | A22 |
| | | 50-100% | A23 |
| | Scarps with herbaceous vegetation and rocky outcrops | > 100% | A3 |
| 2. Áreas with altered vegetation cover | | | B |
| 2.1 Slightly altered cover | Erosional valley with shrubby and herbaceous vegetation. | < 15% | B111 |
| | | 15-50% | B112 |
| | | 50-100% | B113 |
| | Hillsides with shrubby and herbaceous vegetation | < 15% | B121 |
| | | 15-50% | B122 |
| | | 50-100% | B123 |
| 2.2 Moderately altered | Erosional valley with herbaceous vegetation and bare soils | < 15% | B211 |
| | | 15-50% | B212 |
| | | 50-100% | B213 |
| | Hillsides with herbaceous vegetation and bare soils | < 15% | B221 |
| | | 15-50% | B222 |
| | | > 50-100% | B223 |
| 2.3 Moderate to severe | Erosional valley with bare soils and herbaceous vegetation | < 15% | B311 |
| | | 15-50% | B312 |
| | | 50-100% | B313 |
| | Slopes with bare soils and herbaceous vegetation | < 15% | B321 |
| | | 15-50% | B322 |
| | | 50-100% | B323 |
| 2.4 Recreational areas | Hillsides with parks and soccer fields | < 3% | C |
| 4. Areas where the vegetation has been replaced and that due to their current use exhibit severe environmental impact | | | D |
| 4.1 Areas with garbage and construction waste | Slopes covered with waste | < 15% | D1 |
| 4.2 Occupied areas with irregular settlements | Slopes with irregular settlements | < 15% | D2 |
| 4.3 Drainage areas contaminated by sewage | Chanel | | D3 |
| 5. Perimeter areas | | | E |
| 5.1 Urban residential areas | Hillsides with residential use | < 15% | E1 |
| 5.2 Urban areas with infrastructure | Hillsides with urban use of infrastructure | < 15% | E2 |

## 5. Conclusions

The Barranca Becerra still preserves natural vegetation in 50% of its area, 24% of vegetation shows some degree of intervention, in this area restoration measures must be applied, and 24% corresponds to urbanized areas.

The area with the greatest environmental impact corresponds to 5% of the total area and in this area the greatest efforts must be concentrated for its recovery.

Geospatial information sciences were relevant in the generation, analysis, and modeling of the data required for zoning and environmental management proposals in the study area.

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