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Spatial Analysis to Mapping Homogeneous Units for Environmental Planning. Study Case Conservation Land Area, Mexico City, Mexico

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ABSTRACT

In Mexico City, the territorial unit known as "conservation land" is of vital importance for the city since it provides essential environmental services for the quality of life of its inhabitants. In recent decades, the growth of the urban sprawl of Mexico City and its suburban area, as well as the advance and expansion of the agricultural frontier, have become the main threats to the proper functioning of the natural system, and therefore affect the environmental services they provide to the city. To provide elements for the territorial planning process, a project was carried out with the objective of evaluating the land suitability of the conservation land, as a basic input for a territorial management proposal, as a strategy for land use planning at regional level. The suitability evaluation was based on the Land Use Capability Classification system developed by the United States Soil Conservation Service, adapted by the authors for the conditions of the study area. The basic input for the management proposal is the evaluation of suitability, which is modeled and analyzed in conjunction with other databases, through structured queries in SQML language; the result is a management proposal in two levels, zones, and subzones. It is concluded that the biophysical land use planning proposed here is an option to address and solve the environmental problems in the study area, and that it can be used at different levels of government where land use policies are designed at different spatial scales. Geospatial modeling and analysis were key elements in the analysis and integration of the information.

Keywords: Spatial analysis, mapping, environmental planning, territorial planning, land suitability.

INTRODUCTION

The "conservation land - SC", the study area considered here, consists of a condition established in the urban legislation and represents the areas where strong restrictions on land use are established, especially from the point of view of planning the growth of the city, since the

natural characteristics that are still preserved, constitute important ecosystems that are vital for the subsistence not only of Mexico City, but for the entire Metropolitan Zone of the Valley of Mexico -ZMVM [10].

The territory considered SC, represents a space of enormous importance not only to the population of Mexico City and as a whole for the endorheic basin of Mexico, but also to the different municipalities of the ZMVM, since it provides environmental services such as water production, oxygen, carbon sequestration (in soils and biomass), climate regulation, biodiversity, soil retention, flood control, agricultural production, forestry and landscape beauty, among others, all of which are indispensable and valuable for sustaining the quality of life of those who live in its area of influence.

However, this zone has been experiencing excessive growth in the last decades, not only due to the significant increase in urban sprawl (regular and irregular settlements, infrastructure) in Mexico City and the surrounding area, but also due to the advance and expansion of the agricultural frontier, a situation that is manifested in the significant changes in land cover and land use, because of the various transformations of large areas of natural ecosystems into agriculture. Thus, population growth and the effects of urban expansion on deforestation, pollution and changes in land use and management are the main threats to biodiversity due to the deterioration, transformation, and substitution of natural ecosystems.

Despite its essential value for the city's livelihood, the ecosystems and its natural resources are also considerably affected and degraded due to the deliberate and irrational extraction of land (soils), burning, exploitation of flora (mosses, lichens), timber products (clandestine exploitation) and non-timber products. All these factors are transforming, pressuring, and threatening the preservation of this invaluable natural space daily.

Based on the above, the objective of this study is to evaluate the land suitability of the SC, as a basic input for a land use planning proposal as a strategy for land use planning at the regional level, for the territorial authorities (municipalities), in such a way that allows them to guide the different productive activities and their most convenient location, as well as the management and protection of natural resources, conservation of protected areas, and implementation of sustainable productive systems and policies oriented to land recovery.

Land Suitability Zoning as a Basic Element for Territorial Planning

Zoning by land suitability consists of delimiting relatively homogeneous geographic spaces based on the physical and biological environment. The use of this approach as a basis for management and regionalization enriches knowledge about the distribution of natural resources, their dynamics over time and the tolerance of the environment to human intervention. Zoning will make it possible to evaluate the productive aptitude of the territory and potential conflicts between aptitude and current land use. In this sense, for this study, zoning in land units will constitute the natural physical support for the definition and application of planning and management programs within the territorial and environmental management units [21].

The classification of soils according to their capacity for use "is a systematic arrangement of a practical and interpretative nature, based on the natural aptitude of the soil to produce constantly under continuous treatment and specific uses" [17]. This management provides basic information and exposes the difficulties that soils present in terms of use limitations, needs and management practices required, and provides key and essential elements for the formulation and programming of comprehensive agricultural development plans.

Land evaluation can be defined as the process of measuring the response of a unit of land when used for specific purposes. In this sense, evaluation attempts to predict the behavior of each unit of land, for each current or proposed use; it is a method to support rural development and land planning. The classification of land by its use capacity contemplates an analysis of the different elements and characteristics of the physical environment and the behavior of each land unit according to its characteristics and in accordance with the different limiting factors that intervene in its adequate use and management [20].

The classification by land use capacity is interpretive in nature and is based on the combined effects of environmental climate and permanent soil characteristics on the risks of deterioration, limitations in use, production capacity, and soil management requirements [11]. Lands classified in the same capacity class are similar only in the degree of limitations on use for agricultural purposes and the risk of deterioration when used. A land capability class may include several soil populations, which require different management practices; thus, valid generalizations regarding specific crops and management practices cannot be made at the class level. Thus, the classification by capacity of use is not a classification for specific crops, but for groups of crops; therefore, it is not made according to the most profitable use that can be made of the land.

The use of the land suitability zoning approach allows the delimitation of relatively homogeneous geographic spaces and represents the basis for regionalization since it enriches knowledge on the distribution of natural resources, their dynamics over time and the tolerance of the environment to human intervention. Zoning will make it possible to assess the productive aptitude of the territory and evaluate potential conflicts between aptitude and current land use.

The classification system groups soils into three categories: class, subclass, and management group. The classes by capacity of use group soils with similar degree of limitations or risks that can affect soils and crops. There are eight classes, and they are designated by Roman numerals [16]. The limitations of use are progressively greater from class I to class VIII; thus, class I has all the characteristics and conditions of optimal land for any agricultural exploitation, with high crop yields and the lowest risk of land deterioration. Class II has less favorable qualities and its productivity is lower, increasing operating costs. In classes III and IV, productivity is reduced, and risks and costs increase, to such an extent that in class IV, cash crops can become a risky activity. Class V has severe limitations that restrict its use to certain times of the year or can be used through costly adaptation practices. Classes VI and VII have severe and very severe limitations, the lands are suitable for native plants or site-specific trees and crops that require intensive conservation practices and operating costs are very high. Class VIII groups lands with

very severe to extremely severe limitations, they are not suitable for crops and should only be used for wildlife conservation, research, recreation, and natural resource conservation [21].

Qui Subclasses are divisions of classes and bring together lands that have an equal number and similar degree of limitations and risks in their use. There are five subclasses: (t) slope, (e) erosion susceptibility, (h) moisture (s) soils, and (c) climate; they are designated by adding a lower-case letter after the class and may occur alone or in combination. Most of the constraints are permanent (slope, unfavorable climate); however, some may be temporary and correctable (e.g., waterlogging) that can be eliminated with adaptation practices such as drainage [21].

Territorial Planning

The most used definition of territorial planning (TO) is that given in the 1983 European Charter [6]: "The spatial expression of the economic, social, cultural and ecological policies of any society. It is at once a scientific discipline, an administrative technique and a policy conceived as an interdisciplinary and global approach whose objective is a balanced development of regions and the physical organization of space according to a guiding concept". TO is an important tool for territorial planning and management, and a means to advance and achieve sustainable development from an integral perspective [22] .

Environmental Land Use Planning (ETO) can be defined as an environmental policy tool that aims at the spatial organization of activities in each area, and that takes the environment in a broad conception -including social, natural, and cultural assets- and considers it as the substrate that makes life possible in its various forms [9].

"Ecologically sustainable forest management encourages the development of forests according to the principles of maintaining ecological processes, maintaining biological diversity and optimizing community benefits from all forest uses within ecological limits [3]. The aim is to obtain a balanced return to the community from all forest uses within a regional planning framework that combines environmental, commercial, social and cultural objectives in a manner that, as far as possible, ensures the sustainability of all forest values" [7].

Management with emphasis on forest and agroforestry systems is considered in this study as an important technical planning tool for agroforestry and conservation programs and policies, which is based on the analysis, classification and spatialization of non-forest and preferably forest lands by biological functions and sub-functions of conservation-protection, regulation, production and restoration, with the objective of promoting and encouraging better management of soil and water resources, and contributing to sustainable forest and agroforestry development, as well as their preservation and protection [21].

The Study Area

The city of Mexico, for territorial planning purposes, considers two territorial units [10] the urban development area, commonly called urban land, comprises 41% of the surface and the ecological conservation area, usually known as conservation land (SC), which represents approximately 59% of the extension, being this last unit the one considered as study area in the present publication. This division generally represents the basis for local government agencies for the development and implementation of planning policies and development activities from

the perspective of the conservation of natural resources, biodiversity, and rural and urban development.

MATERIAL AND METHODS

The The methodological procedure used in this study included two main stages, in the first one a zoning by land suitability was made using the Land Classification System by its Use Capacity developed by the United States Soil Conservation Service - USDA, 1965, adapted from IGAC, 2001 [11], which was adapted for the present study according to the existing edaphological information, where the soil classification is referred to the FAO classification system, 1998 [17].

For the definition of land suitability, the following data were used: a) the soil map [14]; from its database the primary and secondary characteristics of the two main soil groups (Group 1 and Group 2) were considered, which represents the base input for the definition of limiting factors (effective depth, drainage condition, salinity/sodicity, and fertility) in the classification of land suitability and b) a digital elevation model, resolution 15m [13], from which a slope map was generated, a factor that complements the group of limiting factors that define land suitability.

In the second stage, a management territorial proposal for agroforestry, forestry and conservation aptitude is made, which integrates several management elements and databases, namely: (a) The agreement integrating and organizing forest zoning, of the National Forestry Commission of Mexico [1], which has been adapted and complemented by the authors for the purposes of this analysis; (b) The zoning by land use capacity, in suitability classes and subclasses developed in stage one; (c) The natural protected areas [4]; d) The regionalization of green areas [22] as well as the contexts and scenarios of the different conditions and benefits of natural ecosystems (ecosystem services) of great relevance provided in the biodiversity regionalization of Mexico City [5]; e) the Cartography of current land cover and use (year 2020) developed by the authors.

The structure of the decision model considered, in addition to the criteria set forth in the CONAFOR agreement, the following premises:

a) If there is secondary vegetation or agriculture in natural protected areas, it is recommended as far as possible to restore the original vegetation, or in the case of agriculture, to make restricted use of these areas with intense conservation practices and crop diversification in agroforestry systems
b) Areas with natural cover (forests, scrublands, grasslands, water) inside and outside NPAs are considered a priority for the conservation of natural vegetation and bodies of water
c) High mountain pastures, due to their fundamental role in the infiltration of runoff and aquifer recharge, are considered important for water sustainability, regulation of runoff and recharge of aquifers
d) Areas on slopes greater than 12% in the forest region, restoration of natural vegetation is recommended
e) Agricultural areas on slopes greater than 12% in the transition zone are recommended for restoration of vegetation cover or conversion to agroforestry crops with intensive conservation practices

f) Agricultural areas on slopes less than 12% in the forest zone are recommended for special use with crop diversification in agroforestry systems, with intensive use and management practices, conservation, prevention, erosion control and rescue of native species, and conservation of natural vegetation
g) Agricultural areas on slopes less than 12% in the forest zone are recommended for special use with crop diversification in agroforestry systems, with intensive use and management practices, conservation, prevention, erosion control and rescue of native species and conservation of natural vegetation
h) Agricultural areas on slopes less than 12% in the transition zone are recommended for agroforestry production in diversified systems and sustainable agroecological activities with intensive prevention and control practices for soil and water conservation
i) Wetland areas and bodies of water (halophilic and hydrophilic vegetation) should be restored, conserved, protected, and monitored to ensure their biodiversity and ecological and hydrological integrity (hydrological regulation). The databases and rules described above were combined, following the criteria defined in the CONAFOR agreement, in a decision model which was implemented through structured queries with SQML.

RESULTS AND DISCUSSION

The land cover and land use map of study area is shows in Figure 3. Considering that the total area of Mexico City covers an extension of 149,909 ha, Figure 2 shows that there is a predominance of anthropic cover (urban areas, quarries, and agricultural areas) covering an extension of 98,441.7 ha, corresponding to 66.2% of the total area; on the other hand, natural cover (forests, grasslands, shrublands, wetlands and water bodies) covers an extension of 51,466.9 ha, corresponding to 33.8% of the total area.

The largest area of natural cover corresponds to forests, of which the largest area is occupied by pine forests (18,894.8 ha), followed by Oyamel forests (8,474.2 ha), mixed pine-oak forests (6,374.1 ha) and, to a lesser extent, Holm oak forests (1,268.5 ha).

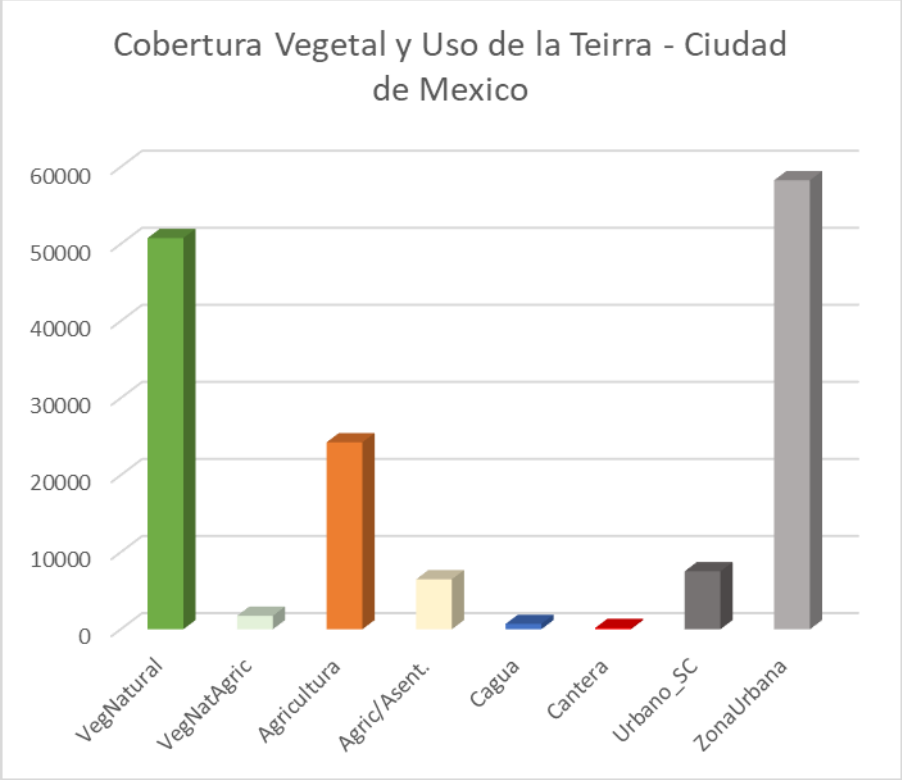


Figure 2. Natural and anthropogenic land cover, area (hectares).

The map in Figure 4 shows the results of the zoning by land suitability capacity, expressed in classes and subclasses. In the area with forest cover, the dominant classes are IV and VI; their main limitations are the presence of shallow soils (<25 cm) and slope (12-25-50%). In some sectors, class III is present, with moderate soil fertility and slope (7-12%), some of these areas are dedicated to agriculture (corn, barley).

In the transition zone, dedicated in part to agriculture (corn, oats, nopal), some of which is interspersed with human settlements, classes IV and VI predominate, with the main limiting factors being shallow and very shallow soils and slopes of 7-12%. In some sectors there is class III, whose limiting factors are moderate fertility and slope (7-12%). In the lower and flatter sectors, class VI is present, in this case its limiting factors are the presence of salts and/or sodium, the slopes are less than 3%.

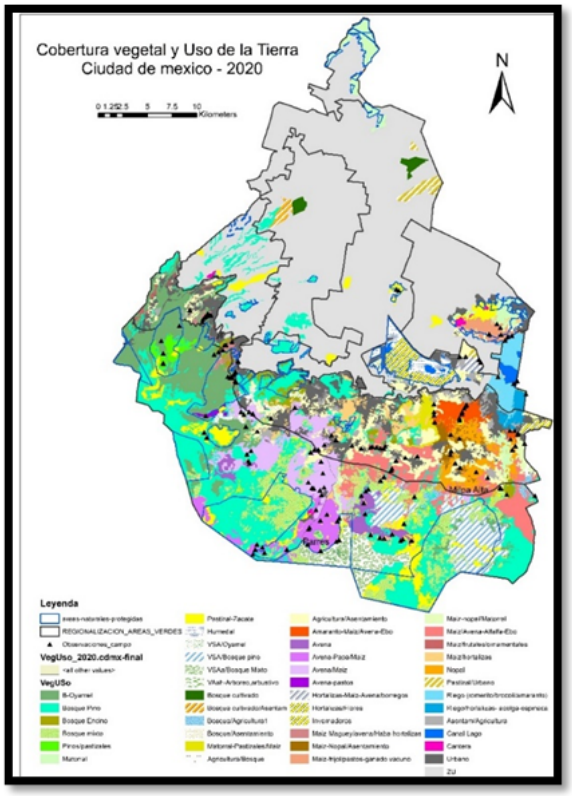


Figure 3. Land cover and land use map

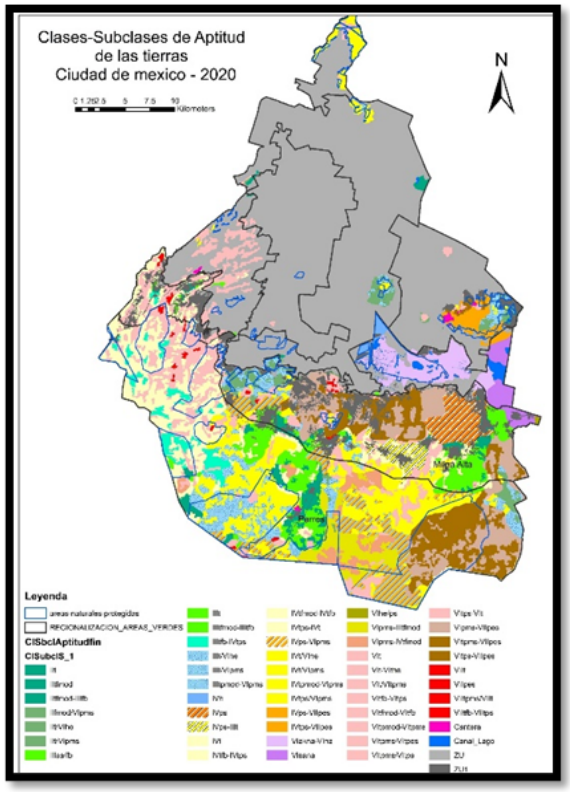


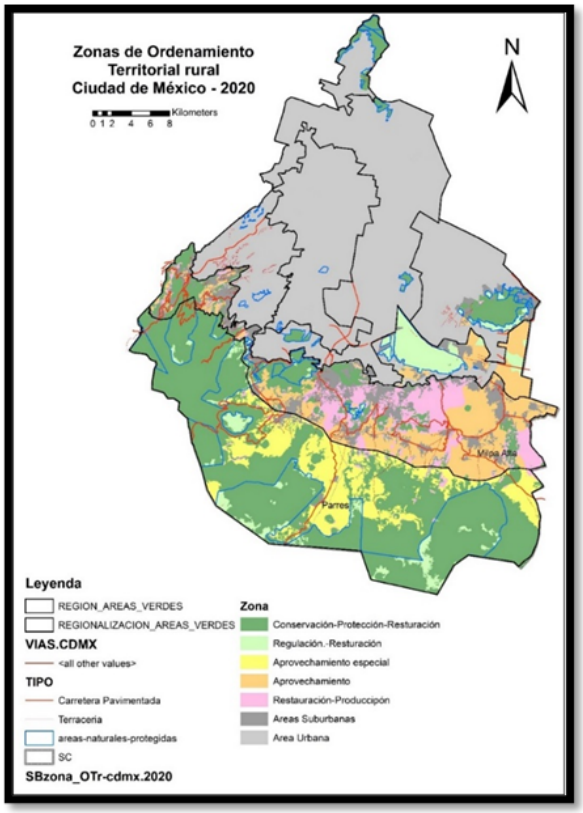
Figure 4. Land suitability classes-subclasses.

In the rural development planning cycle, land evaluation serves as a connector between resource inventories and decision-making on land use planning and management [8]. The land suitability zoning developed constitutes the basis of the land management proposal with emphasis on the biophysical environment, in conservation, forestry, agroforestry and agricultural systems, with some essential practices of prevention, control and management of land and crops. It is considered a basic biophysical proposal, since it establishes an adequate use according to its aptitude and allows the orientation and optimization of the current use of the territory, by conforming units of use and management according to the limitations, qualities, and aptitudes of the territory; while it advises the search for alternatives for the cases in which the current or past forms of management are inadequate.

The land use evaluation presented here was carried out based on some basic criteria for the protection and preservation of the ecological conservation area (SC); on the other hand, the biological diversity, its scenic beauty, and the main challenges facing this natural space are highlighted, with the objective of generating awareness and greater knowledge concern with the importance of territory and its ecosystems conservation**.**

The results of the territorial management are shown in the maps of Figures 5 and 6, which correspond to two categories, zones, and subzones, respectively. Five units have been delimited in the management zones (Figure 5), namely: Conservation-Protection-Restoration, Regulation-Restoration, Special use, use and Restoration-Production-Conservation.

The management subzones (Figure 6) correspond to subdivisions of the zones; Table 1 shows the delimited subzones and their corresponding zone.



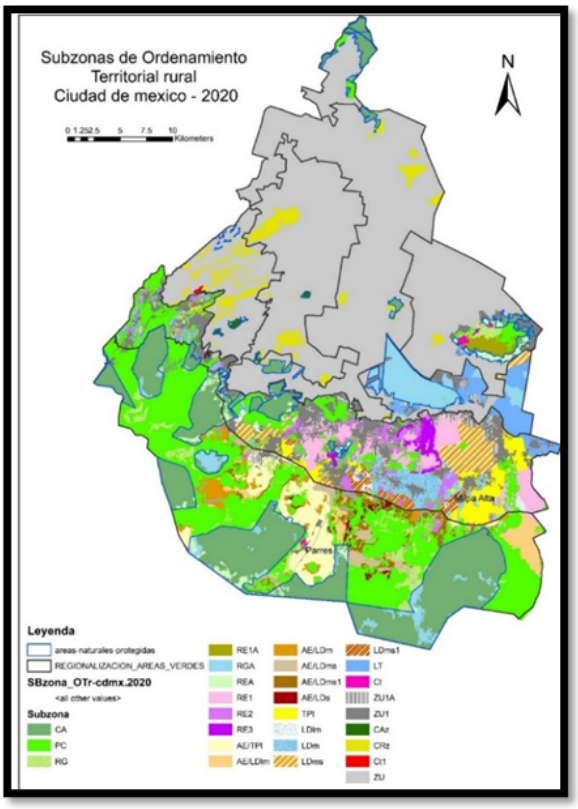


Figure 5. Zones of Territorial Management Figure 6. Subzones of Territorial Management

The basic criteria contemplated in this proposal are designed in such a way that they provide some guidelines to complement and help in the definition of territorial planning policies and strategies concern to adequate use, management and conservation of lands and ecosystems, in order to rationalize the different actions and interventions on the territory based on the suitability of its lands and at the same time, to promote the protection and conservation of the current natural protected areas. They can also serve as a guide to propose the creation of new protected areas due to the extraordinary characteristics and great importance of the natural ecosystems that are not yet protected and that are currently threatened and are losing ground due to constant pressures and anthropic actions described in previous pages.

The proposed biophysical land use planning, in zones and subzones, is presented as an option to address and solve in some extent the above-mentioned problems and has the purpose of reorienting the productive activities of the communities to benefit their inhabitants and through experiences and new processes of social participation to improve and generate sustainable development alternatives that allow for the conservation of their NPAs and the sustainability of ecosystems.

Zoning into zones and subzones facilitates its use at the different levels of government where land use policies are designed, where Zones being the most suitable units for small-scale planning (regional or state level), and subzones at a lower level, municipality-basins [15].

ZONES	SUBZONES	MAP SYMBOL
CONSERVATION PROTECTION RESTORATION REGULATION RESTORATION PRODUCTIVE RECONVERSION SPECIAL USE IN FOREST REGION USE AT THE TRANSITIONAL URBAN - RURAL REGION	Conservation-protection inside Natural Protected Areas (NPAs)	CA
	Conservation-protection outside of NPAs	PC
	Conservation - regulation in high mountain areas	RG
	Agricultural areas for restoration and regulation	RE1A
	Regulation and restricted use inside NPAs	RGA
	Restoration and restricted use inside NPAs	REA
	Restoration - Reconversion – production, slope < 12%	RE1
	Restoration - reconversion – production, slope 12-25%	RE2
	Restoration, in forest región, slope 12-25%	RE2A
	Restauración – conservación, slope 25 - 50%	RE3
	Special use on arable land with slight limitations	AE/TPl
	Special use on arable land with moderate to severe limitations	AE/LDlm
	Special use on arable land with moderate limitations	AE/LDm
	Special use on arable land with moderate to severe limitations	AE/LDms
	Use on arable land with slight limitations	TPl
	Use on arable land with moderate to severe restrictions	LDlm
	Use on arable land with moderate restrictions	LDm
	Use on land with moderate to severe moderate limitations	LDms
	Use - Regulation on flat land with moderate to severe limitations	LT
	Quarry	Ct
SUBURBAN/ URBAN	Settlement /Agriculture	ZU1a
	Suburban /Urban	ZU1

Table 1. Zones and subzones of territorial planning at the conservation land area of Mexico City. Zoning into zones and subzones facilitates its use at the different levels of government where land use policies are designed, where Zones being the most suitable units for small-scale planning (regional or state level), and subzones at a lower level, municipality-basins [15].

On the other hand, from the point of view of the functions of each institution, the proposed territorial management can be used by different institutions in a specific way, namely: a) In the design and prioritization of policies for the adequate use and management of the territory; b) establishment of programs and projects for Environmental Restoration in the study area, in order to reduce the impacts of extreme weather events; c) In the design, prioritization and implementation of policies for the restoration of vegetation cover, in order to decrease runoff and increase infiltration and retention of rainwater through sustainable soil management actions; d) design of policies, plans, programs and projects with the purpose of restoring and/or conserving natural resources in the NPAs; e) design of policies with the purpose of restoring

and/or conserving, particularly in lowland areas (wetland areas) that are indispensable in the regulation and buffering of runoff, in order to reduce the impacts of extreme hydrometeorological events; and finally for private enterprise interested in the identification and location of areas suitable for forest plantations [15].

CONCLUSIONS

- The proposed biophysical land use planning, in zones and subzones, is presented as an option to address and solve some of the environmental problems in the study area and has the purpose of reorienting productive activities to be sustainable, as well as to conserve and protect the forest resources of the area.
- The proposed management in zones and subzones facilitates its use at different levels of government where land use policies are designed, at different spatial scales.
- Geospatial modeling and analysis are key elements when it is necessary to analyze and integrate information in this case focused on zoning and land use planning.

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