

Soil Survey Relevant Information for Land Suitability Zoning and Territorial Planning. Case Study Usumacinta Watershed Mexico

Daniel M. Lopez Lopez

Centro de investigación en Ciencias de Información Geoespacial,
Ciudad de México

Aristides Saavedra Guerrero

Centro de investigación en Ciencias de Información Geoespacial,
Ciudad de México

ABSTRACT

In Mexico during the last decades, the anthropic pressure exerted on natural ecosystems and land dedicated to productive activities has been increasing, causing intense negative environmental effects on soil, water, flora and fauna resources. These effects can be addressed through adequate land-use planning; an essential step for the definition and application of management programs is the zoning land by suitability. Soils, conceptualized as a natural body constitute a useful approach for the study and analysis of the natural system. Therefore, the objective of this article is to show the importance and the fundamental role of soil information, acquired through soil survey, in land suitability zoning and territorial planning. From database of soils, qualifiers of physical - chemical soil properties were used to define limitation related with effective soil depth, fertility, soil drainage and salinity - sodicity. Then for each one of these limitation factors, individual maps were constructed, which by a decision model were integrated in a final land suitability map. The results, according to this map show, in the lowlands where slope is less than 12%, three general groups of land suitability: Lands of classes I to III, with slight limitations to crop production (23.2%, of the total area), lands with moderate limitations class IV (8.2 %) y and lands of classes IV, V and VI with moderate to severe limitations, very poor drainage and flooding - waterlogging (24.4%). In the highlands, where the slope is higher than 12% have moderate (class IV, 10%) to severe limitations (VI-VII, 31%) and class VIII (3%).

Keywords: Soil survey, land suitability, territorial planning, Usumacinta Watershed

1.INTRODUCTION

Soils, waters, climate, geology/lithology, geomorphology relief, vegetation and fauna are components that together make up the natural system. These components function in an interrelated way; through these functions the natural system provides essential ecosystem services for society in general and specifically for the local population settled in the territory. To conserve and make adequate use of the services provided by the natural system, knowledge of both the natural environment as a whole and of each of its components and the interactions between them and with society is necessary (1).

Soil is one of the fundamental components of the natural system with great influence on the environment, the local, regional and global economy, and on it depend, to a large extent, the survival and well-being of the present population and future generations. Moreover, as its regeneration is very slow, soil must be considered as a non-renewable and increasingly scarce resource, because it is subject to constant degradation and destruction processes of natural or anthropogenic origin (2).

Soils, conceptualized as a natural body resulting from the interaction of climate and living organisms acting on parent materials, with the modifying influence of relief over time, constitute a useful approach for the study and analysis of the natural system. Based on this premise, the objective of this article is to show the importance and the fundamental role of soil information, acquired through soil survey, in land suitability zoning and territorial planning, which in turn are important elements for the design of policies related to the conservation of ecosystem services provided by both the soil and the natural system as a whole.

For the evaluation of land suitability, the land classification system was used according to its use capacity or American system of the 8 classes which was adjusted and adapted by the authors for the present study according to the existing edaphological information, the INEGI soil map.

SOIL SURVEY AND LAND USE PLANNING

Soil survey is grounded in scientific principles that can be describe by the factors of soil formation and by the relationships between landscapes, landforms, and soils. It describes the characteristics of the soils in a given area, classifies the soils according to a standard system of taxonomy, plots the boundaries of the soils on a map, stores soil property information in an organized database, and makes predictions about the suitability and limitations of each soil for multiple uses as well as their likely response to management systems. Soil survey information answers a wide range of soil-related questions, such as which crops will grow where and what are the best locations for infrastructure, recreation, wildlife habitat, construction materials and sites, mass movements, waste disposal, water management, water reservoirs, irrigation, public health (3).

Soil interpretations provide numerical and descriptive information pertaining to a wide range of soil interpretive predictions. This information can be expressed as classes, indexes, or values with different units of measure. Generally, soil interpretations are made for specified uses and are reported in the form of limitations, suitability, or potentials. For limitations, soil properties that limit land use or establish the severity of limitation are typically indicated. For suitability, soil properties that determine a soil's suitable characteristics may be given (3).

Soil surveys in agricultural areas identify soil characteristics that determine the suitability and potential of soils for agriculture. Interpretations for agriculture involve placing soils into

management groups (such as the land capability classification system) and identifying important soil properties for crop production, application of conservation practices, and other aspects of agriculture. Other aspects of agriculture include yield potential, susceptibility to erosion, depth of root restricting layers, available water capacity, saturated hydraulic conductivity, annual pattern of soil water states (including soil drainage class, flooding and occurrence of free water), qualities describing tillage, limitations for equipment use (including slope and complexity of slope rock fragments, bedrock outcrops and stickiness), salinity and sodium adsorption ratio, presence of toxic substances, plant nutrient deficiency, ability to retain and release nutrients to plants, ability to retain soluble substances that may cause groundwater contamination, ability to absorb or deactivate pesticides, and pH in relation to plant growth and the need for liming (3).

Zoning by Land Suitability

In Mexico during the last decades, the anthropic pressure exerted on natural ecosystems and land dedicated to productive activities has been increasing, causing intense negative environmental effects on soil, water, flora and fauna resources. These effects can be addressed through adequate land-use planning and the implementation of management programs in accordance with the different problems encountered. An essential step for the definition and application of management programs is the zoning by suitability, on the resulting units the land use and management programs will operate. The basic objective of zoning by suitability is to provide information on the vocation of the land, which is indispensable in making decisions on aspects of land use and management. Zoning consists of delimiting relatively homogeneous geographic spaces based on the physical and biological environment. The use of this approach as a basis for 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 to appreciate the potential conflicts between aptitude and current land use (1).

There are several conceptual and methodological approaches to evaluate land suitability, two of the most widely used are the agroecological zoning developed by Food and Agriculture Organization (FAO) and the classification by land use capacity, developed by the United States Soil Conservation Service (USDA). The latter 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 with Roman numerals, starting with class I, which does not represent limitations for agriculture, up to class VIII, which has no agricultural or livestock potential (4). The sub-classes are divisions of the classes and group lands that have the same number and similar degrees of limitations and risks in their use. Most of the limitations are permanent (slope, unfavorable climate); however, some may be temporary and correctable, for example, water-logging that can be eliminated with adaptation practices (drainage). There are five sub-classes: (t) slope, (e) susceptibility to erosion, (h) humidity - drainage conditions, (s) soils and

(c) climate. The classification of land by suitability can be defined as the process of determining the response of a land unit when used for specific purposes. This grouping allows generalizations to be made based on the potentialities of the soils, limitations on their use, and problems due to inadequate management, including conservation procedures. The classification is applicable for agricultural, livestock, agroforestry, forestry and protection-conservation purposes, and brings together various aspects that determine and condition the most suitable use for each soil, as well as some recommended management and conservation practices. It also allows making decisions on how soil use should be distributed in a given area and knowing the relationship between land use capacity and the needs or requirements necessary for the best use (use of fertilizers and manures), as well as knowing the main limitations of soils for a given use and management (1).

The Soil Survey in Mexico a Database with Great Potential and Little Explored

The history of - National Institute of Statistics and Geography - INEGI's soil information dates back to 1968, the year of the creation of the Commission for the Study of the National Territory and Planning (CETENAP), attached to the Secretariat of the Presidency. The different cartographic products of the soil resource elaborated by INEGI have been: Edaphological Chart scale 1:1 000 000 (1979-1981), the national continua, scale 1: 250 000, Series I (1980-1998) and Series II (2002-2007) and 762 sheets, scale 1:50 000 (1969-1980); the integration of series III is in process (INEGI, 2017). The database referred to in this article corresponds to Series II. The National Soil Vectorial Data Set Scale 1: 250 000 - Series II, is the version elaborated during the period 2002 to 2007 (5), through visual interpretation of satellite images or spatial maps, field verification and laboratory analysis. This product has been conceived to meet the demand for geographically referenced information on soil resources: morphological characteristics, physical and chemical properties, and the most severe limitations to use and management, such as: depth, stoniness, salinity, texture of the surface 30 cm, etc. For soil classification, the international system World Reference Base of Soil Resources published in 1999 by the International Society of Soil Sciences, International Soil Reference and Information Center (ISRIC) and the Food and Agriculture Organization of the United Nations (FAO/UNESCO), adapted by INEGI in 2000, was used (6). The Soil Unit is an area that represents an association of up to 3 soil groups, exceptionally only one is present, the first type is dominant and so on, the less dominant ones cover a minimum area of 20%.

METHODS

Land Suitability Classification

For the evaluation of land suitability, the land classification system was used according to its use capacity or American system of the 8 classes developed by the Soil Conservation Service of the United States - USDA, 1965, with adaptations made by the Geographic Institute "Agustín Codazzi" IGAC (7); which was adjusted and adapted by the authors for the present study according to the existing edaphological information, the edaphological vector data set scale 1:250,000. Series II, 2008 (5). Table 1 lists the soil qualifiers used to define the degree of

limitation in relation to: effective soil depth, fertility, soil drainage condition, and soil salinity/sodicity. It should also be noted that at the level of soil Groups, some of them that directly qualify innate soil properties (drainage, fertility, salinity-sodicity), are included, such as GLEYSOLS, SOLONCHAKS, SOLONETZ, LEPTOSOLS, VERTISOLS, ARENOSOLS, PHAEZEMS.

Tabla 1. Qualifiers of soil properties used to define limitation related with effective depth, fertility, soil drainage and salinity/sodicity (6).

QUALIFIERS	DEFINITIONS	Property
Abruptic	having an abrupt textural change	Soil depth
Endoleptic	having continuous hard rock between 50 and 100 cm from the soil surface	
Epileptic	having continuous hard rock between 25 and 50 cm from the soil surface	
Lithic	having, within 10 cm from the soil surface, continuous hard rock.	
Endoskeletal	having, between 50 and 100 cm from the soil surface, between 40 and 90 percent (by weight) gravel or other coarse fragments	
Episkeletic	having, between 20 and 50 cm from the soil surface, between 40 and 90 percent (by weight) gravel or other coarse fragments.	
Eutric	having, at least between 20 and 100 cm from the soil surface, a base saturation of 50 percent or more.	Fertility
Mollic	having a mollic horizon	
Dystric	having, in at least some part between 20 and 100 cm from the soil surface, a base saturation of less than 50 percent	
Epidystric	Dystric, having a base saturation (in 1 M NH ₄ OAc at pH 7.0) of less than 50 percent at least between 20 and 50 cm from the soil surface.	
Hyperdystric	Dystric, having a base saturation (in 1 M NH ₄ OAc at pH 7.0) of less than 50 percent in all parts between 20 and 100 cm from the soil surface, and less than 20 percent in some part within 100 cm from the soil surface.	
Orthidystric	Dystric, having a base saturation (in 1 M NH ₄ OAc at pH 7.0) of less than 50 percent in all parts between 20 and 100 cm from the soil surface.	
Episalic	having a salic horizon between 25 and 50 cm from the soil surface.	Salinity Sodicity
Endosalic	having a salic horizon between 50 and 100 cm from the soil surface.	
Hyposalic	having, in at least some sub-horizon within 100 cm from the soil surface, an ECe-value (electric conductivity of the saturation extract) greater than 4 dS m ⁻¹ at 25o C.	
Hypersalic	having, in at least some sub-horizon within 100 cm from the soil surface, an ECe-value (electric conductivity of the saturation extract) greater than 30 dS m ⁻¹ at 25 o C.	
Endosodic	having, between 50 and 100 cm from the soil surface, more than 15 percent exchangeable sodium or more than 50 percent exchangeable sodium plus magnesium.	

Hyposodic	having, within 100 cm from the soil surface, more than 6 percent exchangeable sodium in at least some sub-horizon more than 20 cm thick	Drainage
Endogleyic	having gleyic properties between 50 and 100 cm from the soil surface.	
Epigleyic	having gleyic properties within 50 cm from the soil surface	
Arenic	having, throughout the upper 50 cm soil layer, a texture of loamy fine sand	
Vertic	Is a subsurface horizon clay which, as a result of expansion and contraction, presents slickensides (faces with smooth ridges or channels) and wedge-shaped aggregates It presents cracks that open and close due to the expansion-retraction of the clay minerals.	

The criteria for defining the degree of limitation for classes and subclasses are listed in tables 2 to 4. The qualifiers used are according to table 1.

Table.2. Fertilidad Criterio (f)

Limiting factor Fertility	Criterium - soils types and properties (qualifiers)	Class and sub-class codices
Extremely low	Litics - litics	VIf
Very low	Plintosols, Acrisols, Alisols, Litic Leptosols	IVf
Low	Arenosols, Leptosols, Lixisols, sodic- salinic Solonchack, Dystric- hyperdystic Umbrisols; Other soils: Hyposódics , endosódics	IIIf
Medium	Eutric arenosols, Luvisols, Cambisols, Umbrisols, Gleysols, dystic and umbrihumics Fluvisols, umbrihúmicos, eutric leptols, epileptics Pheozem and vertisols; other soils: dístrics, hiposodics	IIIf
High	Pheozem, vertisols, eutric Regosol -fluvisol, molic livisols - gleysol; other soils molic, humic and vertic	I

Table.3. Soil depth Criterio (p)

Limiting factor Soil depth	Criterium - soils types and properties (qualifiers)	Class and sub-class codices
Extremely shallow (<10 cm)	Litics - litics	VIIIs
Very shallow (< 25 cm)	Litic Leptosol- Other, Litic Leptosol- Leptosol, Leptosol- Leptosol, gravel or stone Leptosol, Other soil - litic Leptosol	VIp-VIIpes
Shallow (< 50 cm)	Epiléptic, stone, eskelel	IVp
Moderately Deep (50-100 cm)	Endoléptic , abruptic	IImodp
Deep/very deep (100 - 150 cm)	Other soils	I

Table.4. Soil drainage Criterio (h)

Limiting factor Soil drainage	Criterium - soils types and properties (qualifiers)	Class and sub-class codices
Swampy – drained Very poor	Gleysol - Gleysols	Vh
Poor	Gleysol- gleyic vertisol, Other - gleysol, Gleysol - epiglyc,	IVh
Drained Excessive	Arenols, arenics	VIhe
Imperfect drained	Endogleyic, Gleyico-other, Endogleyico-other	IIIh
Moderately well drained	Vertisol, vertic	II
well drained	Other soils	I

In the elaboration of the criteria used to form the limiting factors, the two dominant soils (Group 1 and Group 2) in the cartographic unit were considered, taking into account in the analysis their main and secondary characteristics referred to in the INEGI database - Series II, 2008. Based on the criteria defined in tables 4 to 6, fertility, drainage and effective depth maps were calculated in raster format. The land slope map completes the database for the definition and delimitation of land suitability classes and sub-classes. The latter was calculated from a digital elevation model, with a spatial resolution of 15 meters (8); Table 7 shows the ranges used to define the slope classes. Based on these variables and the criteria that define the limiting factors for each suitability class and subclass (Table 2), the land suitability subclass map is calculated. The calculation is done through the design of a conditional algorithm implemented through the ERDAS Imagine program, version 10.0. The maps of land suitability classes and sub-classes were generated by grouping by means of a heuristic decision model; finally a 24-hectare filter was applied, the minimum mapping units mapped in the land sub-classes by land use capacity were delimited and conformed.

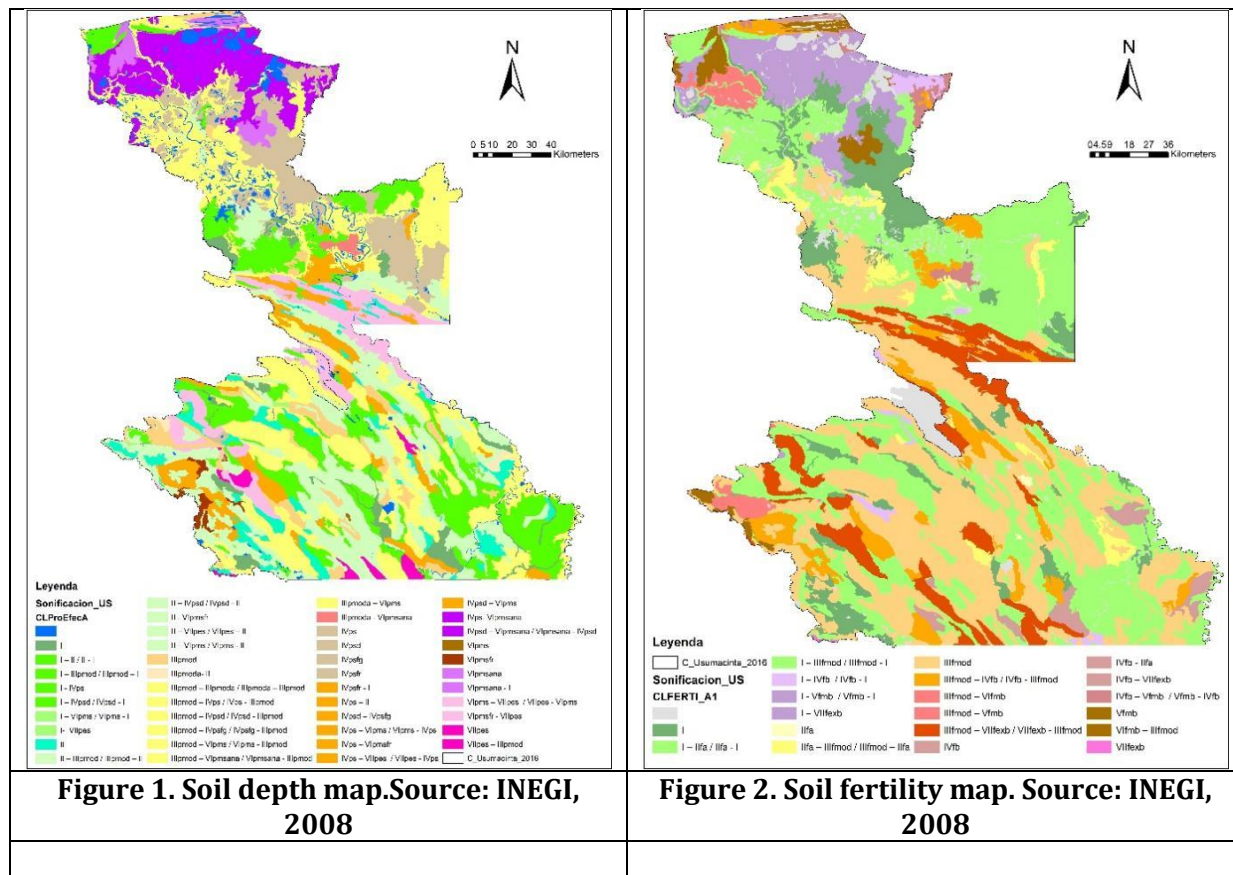
The Study Area

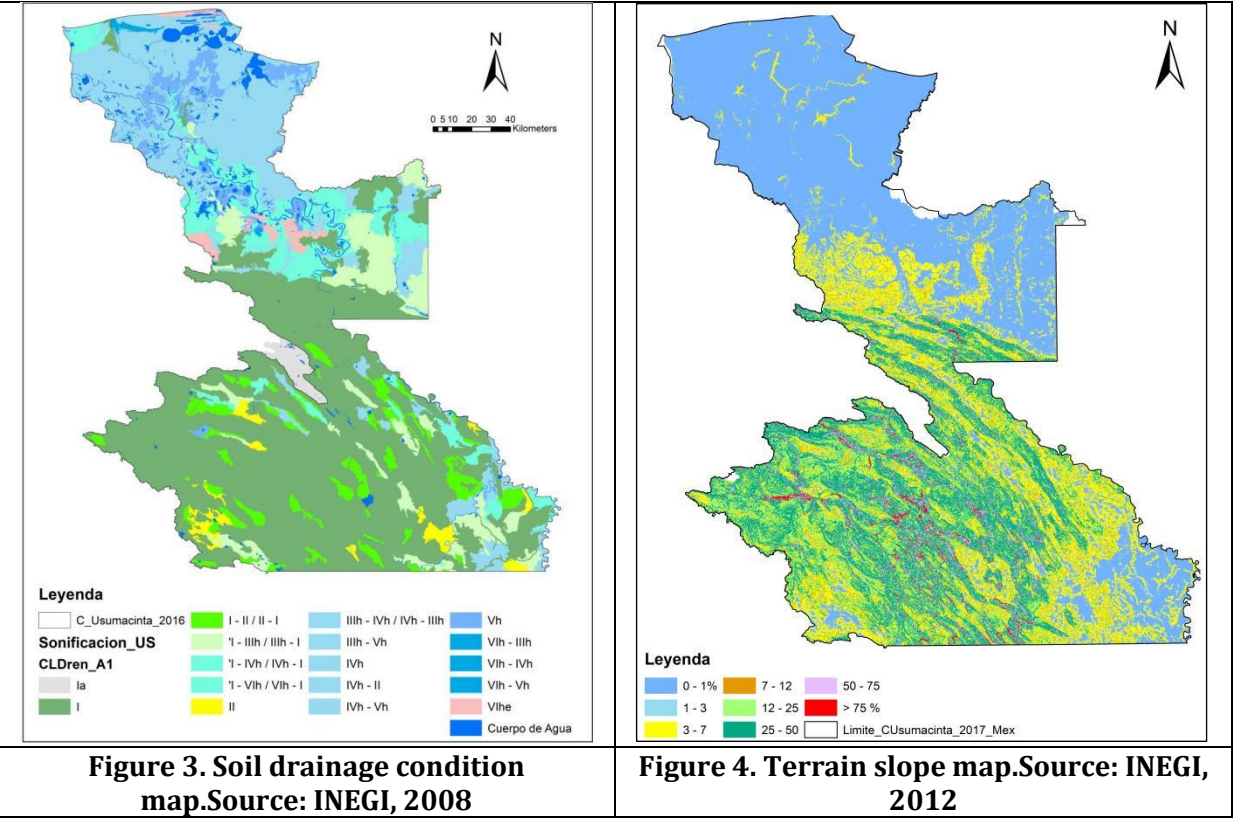
The Usumacinta Basin is a trans-boundary basin shared by Mexico, Guatemala, and Belize (a small portion). It is one of the ecosystems of great natural wealth with a diversity of habitats and species, many of them unique to this area and with extraordinary archaeological remains that are the heritage of millenarian cultures; it is one of the most important freshwater reserves in the region and in the country. The Usumacinta basin has a surface area of 77,436 km², of which 34,237.4 km² (44.21%) are located in Mexico (corresponding to the study area considered here), 43,198.6 km² (55.75%) are located in Guatemala, and the smallest fraction 31.79 km² (0.04%) is located in Belize. The Usumacinta Basin in Mexico, considered the wettest region in Mexico, is part of one of the widest carbonate continental shelves of the Mexican seas and coastal plains, contains one of the most extensive lagoon systems with mangrove areas; it also includes important forest reserves that harbor high biological diversity. It has a mean annual precipitation of 2,068 mm, the minimum annual mean is 875 mm, and the maximum annual mean is in the order of 4,343 mm.

RESULTS AND ANALYSIS

The results are shown in Figures 1 to 5; the figures 1 to 4, show individual map of classes and sub-classes of land suitability, according to each of the limiting factors considered: effective soil depth, fertility, drainage condition and slope. The map in Figure 5 shows the integration of these maps, together with the flood susceptibility map, which forms the land suitability map and its respective legend, showing the spatial distribution of the different classes and sub-classes of land suitability delimited in the Usumacinta river basin. In the resulting final map for each soil unit, the class and subclass is defined by the most limiting factor.

In general, in the lowlands (slope less than 12%) the main limiting factors are the drainage condition (figure 5), susceptibility to flooding and the presence of salts and/or sodium. In the middle and upper part of the basin (slopes > 12%), the most limiting factors for crops production are the steep slopes and the presence of shallow soils. Other limiting factors are moderate to low fertility and the presence of very fine textured soils.





As can be seen in the figure 5, there is a predominance of units with class and subclass as associations (two o more classes of land suitability).

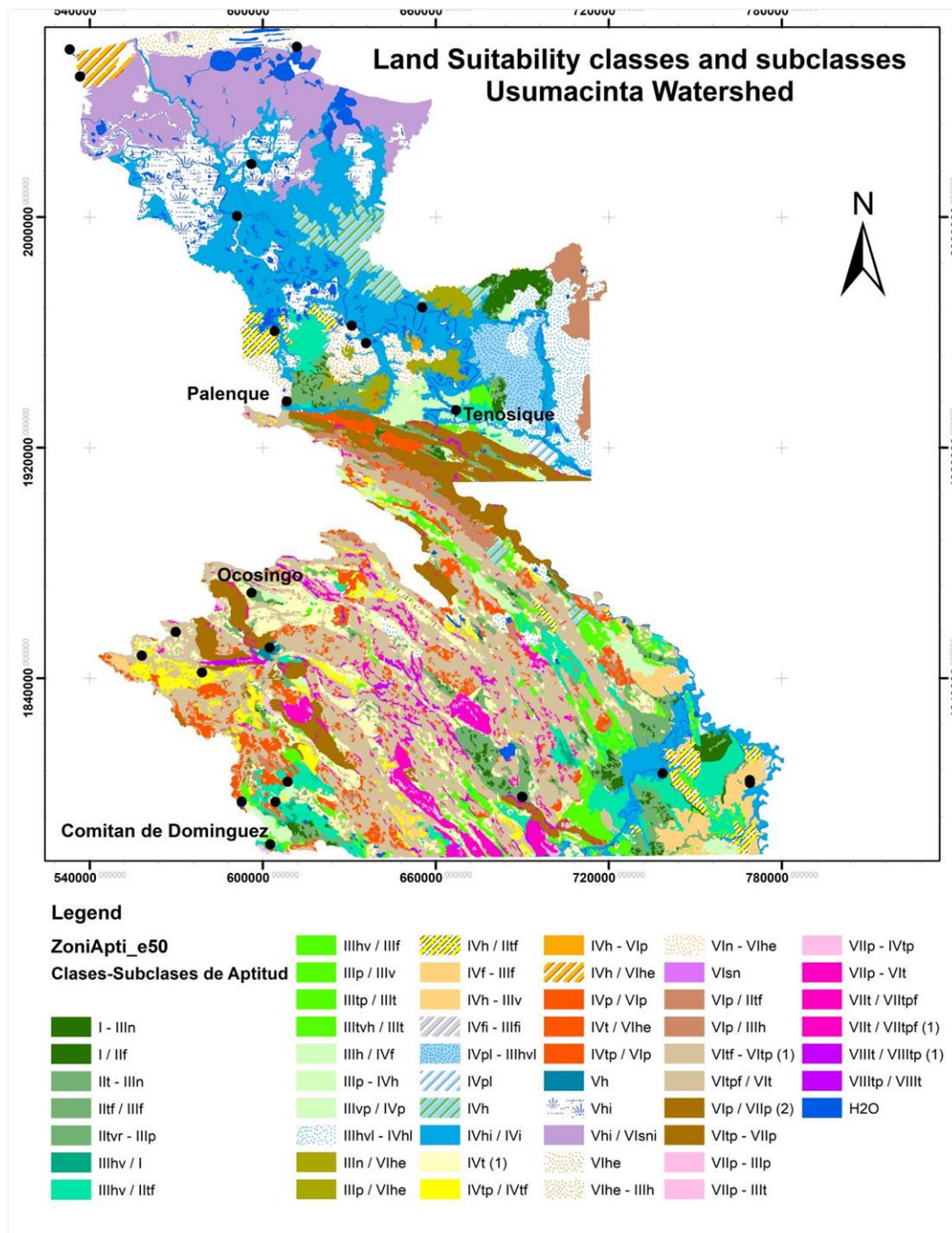


Figure 5. Land suitability map of Usumacinta watershed (own elaboration)¹

To facilitate the analysis of the results, the different classes and sub-classes shown in the map of figure 5 can be grouped into nine groups as is shown in figure 6, for which a brief description is given below.

¹ **Limiting factors:** p: soil depth; f: fertility; h: poor drainage; t:slope; i: flooding; sn: salinity-sodicity; pes: shallow soils; v: very fine texture; l: puddling of water

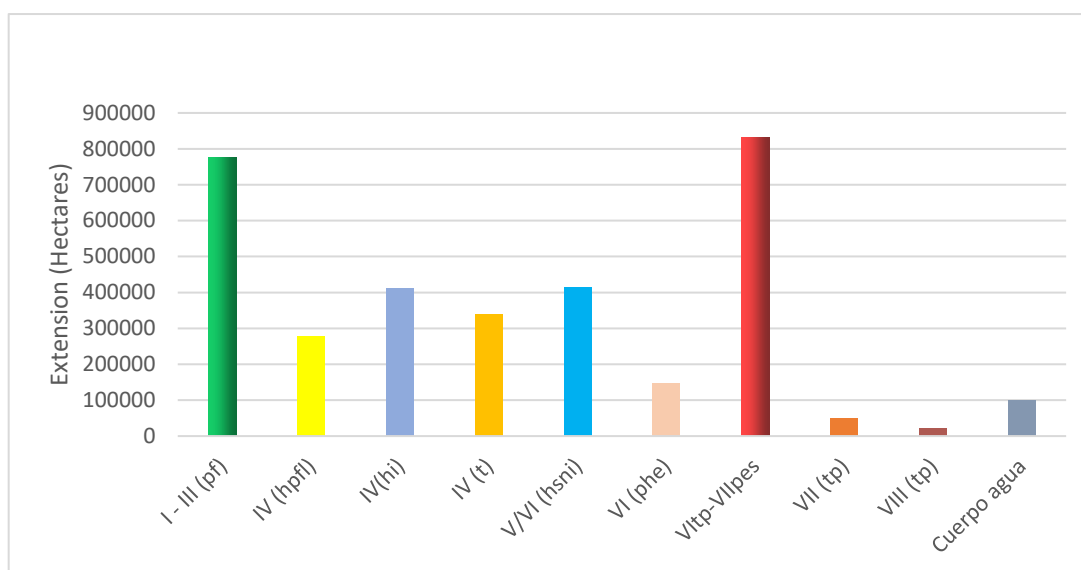


Figure 6. Classes and sub-classes of land suitability and its extension (hectares)²

At the lowlands with a slope less than 12%, there are three groups:

- Arable lands, with an extension of 774,990 hectares (23.2% of total area), with light limitations to crop production, include classes I to III, with slopes less than 7%, some soils have low fertility or moderate depth; they are suitable for a wide range of crops, require light conservation and management practices. Some class III lands are included here in association with class IV and VI, in this case the limiting factor is low fertility or excessive drainage (arenic soils).
- Lands³ of class IV(hpfl), occupy an extension of 277,756 hectares (8.3%) include lands in association with class III, with slopes less than 12%, suitable for a wide range of crops, but some require fertilization (sub-classes IIIf and IVf). Some areas are subject to puddling of water (IVhl). The sub-classes with poor drainage their use is restricted to pastures, or crops with drainage practices. It is included in this group lands with arenic soil, excessive drainage or shallow soils (class VI (phe)
- Classes IV(hi) and classes V/VI(hsni) lands with slopes of less than 3%, occupy an extension of 825,063 hectares (24.4%) with serious limitations for agricultural production, as they are poorly drained soils and subject to flooding(IV-Vhi), others with sever limitations due your content of salinity and sodicity, their use is restricted to conservation of natural vegetation.

In the middle and upper land two groups can be distinguish:

- Lands of land suitability Class IV, with slopes of 12 to 25% (IVt), their suitability is restricted to agroforestry crops and pastures. Occupy an extension of 338,756 hectares (10% of total area)

² Limiting factors: p: soil depth; f: fertility; h: poor drainage; t: slope; l: flooding; sn: salinity-sodicity; pes: shallow soils

³ Small sector of these lands are localized in the upper land

- b) Very steep lands, slopes higher than 25%, include lands of classes VI(tp) in association with class VII(pes) in addition of steeped slope, the soils are shallows a very shallows, occupy a larger extension in upper land (832,740, correspond to 24.7% of total area). Also conform this group lands of class VII(tp), with an extension of 49,308 hectares (1.46%), slope 50-75% and shallow soils; and finally complete this group small sector of very steeped lands (slope >75%).

CONCLUSIONS

- The information contained in the soil databases through processing and analysis can be expressed in individual maps on characteristics relevant to land use suitability, such as effective depth, drainage condition, fertility, salinity-sodicity.
- The digital elevation model is an important source of information for environmental modeling, in this study it served as a basis for the calculation of slope, an important variable in the definition of land suitability.
- -Using decision models, the different land use constraints can be combined and integrated to generate a map showing the suitability of lands for different uses.

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