Generating information for land evaluation in Tocuyo River basin (Venezuela) by means of GIS and Remote Sensing: environmental parameters, land cover, and erosion hazard

Dissertation
zur Erlangung des Doktorgrades
der Mathematisch-Naturwissenschaftlichen Fakultäten
der Georg-August Universität zu Göttingen

vorgelegt von

Onelia del Carmen Andrade Benitez

aus Palmas Reales, Venezuela

Göttingen, 2007

D7:

Referent: Prof. Dr. Martin Kappas
Korreferent: Prof. Dr. Karl-Heinz Pörtge
Tag der mündlichen Prüfung: 10.07.2007

ABSTRACT

Tocuyo River basin is located in Center-Western region of Venezuela, and it comprises many different ecosystem because of Tocuyo River headwaters are located at 3000 m.a.s.l. and it flows into Caribbean Sea, therefore many types of vegetation, climate, and physiography are found in this basin. The first Spanish settlements during the colonization were located along the river, therefore natural resources in the basin have been exploited for hundred of years. Nowadays basin deterioration is evident. State and public Venezuelan institutions are developing the project “Sustainable Development of Tocuyo River Basin”, in which land evaluation plays a central role. Land evaluation, to be reliable, requires much information as input. The objective of the present study was to compile, generate, and finally mapping in digital format the information needed for land evaluation in Torres Municipality, the biggest in Tocuyo River basin, by means of geographical information system and remote sensing. This information is concerning to environmental parameters, vegetal cover, and erosion hazard. Environmental information in Torres Municipality did not exist in digital format. Maps of soil, geology, hydrology, main roads, settlements, borders, and airports were updated either by using bibliographic information or a satellite image. Phyisiography maps were generated using a digital elevation model. Climate information was generated from data of 20 years (1985-2005) from 33 meteorological stations distributed within the study area. This information was intepolated to generate climatic maps. Combined use of remote sensing and digital elevation model, resulted in obtaining a map of land use/land cover of Torres Municipality. Thirteen classes were differentiated based on reflectivity, vegetation index, and elevation, in a resolution of 15m x 15m. Revision Universal Soil Loss Equation model was used to estimate erosion in the basin. Obtaining and mapping of the five parameters of this model was done. Several methodologies exist to calculate rain-runoff erosivity factor, but present study enhance the necessity to generate locally equations to estimate this factor, being the most accurate an equation generated with data obtained nearly to Torres Municipality. Use of digital elevation model was successful in improving the accuracy of precipitation data based on interpolation of data obtained from meteorological stations. In average, rainfall on Torres Municipality resulted with low potential to cause erosion. Calculations based on data from soil map of the municipality resulted in map of soil erodability; resulting that erodability of Torres Municipality soils range from moderately low to high, enlarging the erodability in the agricultural zone. Calculation of LS factor are normally done without consideration of the spatial distribution of the slope length, however, present study demonstrates that there is a high risk of overestimating the values of *LS,* and consequently of the erosion. The values of

the factor *LS* in the municipality resulted relatively low (96.8 % of the study area was smaller than 3.31), since most of the area is a depression. Factors crop and management and conservation practices were obtained from the land use/land cover map. Multiplication cell-by-cell of the maps of rainfall-runoff erosivity, soil erodability and topographic factors resulted in the map of potential erosion for Torres Municipality. Similar procedure, adding the factors crop and management, and conservation practices was used to estimate actual erosion of the municipality. The use, cover, and conservation practices influence decisively in the control of the erosive processes. The smallest erosion values of soil losses were registered in zones of forest and where agricultural practices are carried out. Actual erosion had a range from 0 to 2558 t ha^{-1} y^{-1}, but more than 72 % of the area is under very low water erosion hazard and highly suitable to rainfed agriculture. Areas susceptible to erosion with a soil loss more than 12 t ha^{-1} y^{-1} are found primarily in the higher basin or where there is non-dense cover. Percent of high sustainability for agricultural purpose was 100 % in the agricultural area. In accordance to this, the zone can be used continuously with annual mechanized cultivations without practice of conservation. The results of this study support that the use of RUSLE under GIS environment, helped by digital elevation model are powerful tools for both qualitative and quantitative assessment of soil erosion in a basin.

Use of geographical information system, digital elevation model and remote sensing have facilitated collection, manipulation, and obtaining of data to generate 24 new maps of Torres Municipality in digital format: isohyets, seasonal patterns, isotherms, dry period, evapotranspiration, precipitation concentration, humidity provinces, climatic aggressiveness, soil, geology, physiography, hydrology, main roads, settlement, airports, land utilization type, land use/land cover, RUSLE rainfall-runoff factor, RUSLE soil erodability factor, RUSLE topographic factors, RUSLE crop and management factor, RUSLE conservation practices factors, actual erosion, and potential erosion. The main proposed objective in this research has been reached, and the needed information for land evaluation for rainfed agriculture based on FAO model is now available in digital format. All these information will be the basement to decide the most appropriate land use in a specific land unit within Torres Municipality.

ZUSAMMENFASSUNG

Das Tocuyo Flusseinzugsgebiet liegt in der Mitte von West Venezuela. Es umfasst viele verschiede Ökosysteme da das Quellgebiet des Tocuyo in 3000 m ü.NN liegt und der Fluss dann in das Karibische Meer mündet. Im Flusseinzugsgebiet sind auf Grund dieses Flussverlaufes viele verschiedene Vegetationesformen, Klimate und Morphologien der Erdoberfläche zu finden. Die ersten spanischen Siedlungen wurden entlang des Flussufers errichtet, daher wurden die natürlichen Ressourcen des Flusseinzugsgebietes schon seit Hunderten von Jahren ausgebeutet. Heutzutage ist eine Schädigung des Flusseinzugsgebietes offensichtlich. Der Venezuelanische Staat und öffentliche Einrichtungen haben das Projekt „Nachhaltige Entwicklung des Tocuyo Flussbeckens" ins Leben gerufen, in welchem die Landbewertung eine zentrale Rolle spielt. Eine Landbewertung benötigt viele Informationen als Grundlage. Das Ziel dieses Projektes war die Zusammenstellung und Erstellung von Daten die dann in einer Kartierung in digitaler Form für die Landnutzungsevaluierung zur Verfügung stehen. Diese Informationen, eingebettet in ein geografisches Informationssystem und Fernerkundungsdaten, waren nötig für die Landbewertung der Gemeinde Torres, welche die größte Stadt im Tocuyo Flusseinzugsgebiet darstellt. Die Informationen beinhalten Umweltparameter, Vegetationsdaten sowie das Erosionsrisiko. In der Gemeinde Torres haben Umweltinformationen in digitaler Form bis zu dieser Studie nicht existiert. Vorhandene Karten von Böden, Hydrologie, Geologie, Straßen, Siedlungen, Grenzen und Flughäfen wurden durch bibliographische Informationen oder Satellitenbilder aktualisiert. Mit Hilfe eines digitalen Höhenmodells wurden morphologische Karten erarbeitet. Die Klimainformationen stammen aus Daten der letzten 20 Jahren (1985-2005) von 33 meteorologischen Luftkurorten, die innerhalb des Untersuchungsgebiets verteilt sind. Diese Informationen wurden interpoliert um klimatische Karten zu erzeugen. Die Kombination von Fernerkundung und digitalem Höhenmodell führte zur Erstellung einer Landnutzungs- /Landdeckungs- Karte für die Gemeinde Torres. Dreizehn Klassen wurden basierend auf Reflektionsfähigkeit, Vegetationsindex, und Höhenlage, in einer Auflösung von 15m x 15m unterschieden. Für die Abschätzung der Erosion im Flusseinzugsgebiet wurde das Revision Universal Soil Loss Equation' (RUSLE) Modell verwendet. Die fünf Parameter für dieses Modell wurden erarbeitet und kartiert. Zur die Bestimmung der Erosivität der Niederschläge gibt es verschiedene Methoden. Diese Studie führt vor Augen, dass es nötig ist lokale Gleichungen durchzuführen um diesen Faktor bestmöglich abzuschätzen, in diesem Falle am exaktesten mit Daten die aus der Gemeinde Torres stammen. Das digitale Höhenmodell wurde erfolgreich bei der Verbesserung der Niederschlagsdaten, welche auf der Interpolation

der Daten von den meteorologischen Messstationen beruhen, eingesetzt. Im Durchschnitt hat der Niederschlag auf die Gemeinde Torres ein niedriges Potential Erosion zu verursachen. Durch Berechnungen, die auf Bodenkarten der Gemeinde basieren, wurde eine Bodenerosionskarte erstellt. Das Erosionspotential der Böden in der Gemeinde Torres variiert von moderat niedrig bis hoch, wobei es in den landwirtschaftlichen Zonen ansteigt. Die Berechnung des LS Faktors wird normalerweise ohne Berücksichtigung der räumlichen Verteilung der Hanglänge durchgeführt. Diese Studie zeigte jedoch, dass ein hohes Risiko der Überschätzung des LS und daraus resultierend der Erosion besteht. Die Werte des LS Faktors in der Gemeinde sind verhältnismäßig niedrig (96,8% des Arbeitsgebietgebiets war kleiner als 3,31), da der größte Teil des Gebietes eine Depression ist. Die Faktoren Ertrag, Betriebsführung und Naturschutz wurden der Landnutzungs- /Landbedeckungs- Karte entnommen. Durch die räumliche Verschneidung der Karten über Erosivität der Niederschläge, Bodenerodierbarkeit sowie topographischen Faktoren auf Rasterbasis wurde eine Karte über die potentielle Erosion der Gemeinde Torres erstellt. Mit derselben Methode unter Hinzufügung der Faktoren Bedeckungs- und Bearbeitungsfaktor und Erosionsschutzfaktor wurde die aktuelle Erosion in der Gemeinde bestimmt. Nutzung, Vegetationsdecke und Erosionsschutzmaßnahmen beeinflussen entscheidend die erosiven Prozesse. Die kleinsten Erosionswerte in Bezug auf Bodenverluste wurden in bewaldeten Zonen registriert und dort wo Landwirtschaft betrieben wird. Die aktuelle Erosion liegt in einen Bereich von 0 bis 2558 t $ha^{-1}a^{-1}$, aber in mehr als 72 % des Gebietes ist die Erosionsgefahr durch Wasser sehr viel niedriger. Diese Gebiete sind durch Regenfeldbau geprägt. Gebiete die anfällig für Erosion sind, mit einem Bodenverlust von mehr als 12 t $ha^{-1}a^{-1}$, liegen hauptsächlich im höheren Becken oder in Gegenden mit einer sehr dünnen Vegetationsdecke. Der Prozentsatz für Nachhaltigkeit für landwirtschaftliche Zwecke war 100% in den landwirtschaftlichen Gebieten, deshalb konnten diese Gebiete jährlich, kontinuierlich mit mechanischer Kultivierung ohne Naturschutz genutzt werden. Die Ergebnisse dieser Studie zeigen, dass RUSLE mit GIS und mit Hilfe eines digitalen Höhenmodells ein gutes Werkzeug für die qualitative und quantitative Abschätzung von Bodenerosion in Becken darstellt.

Die Nutzung von Geographischen Informations Systemen (GIS), digitalem Höhenmodell und Fernerkundung hat die Zusammenstellung und Handhabung der Daten so vereinfacht, dass 24 neue digitale Karten der Gemeinde Torres erstellt werden konnten. Diese Karten beinhalten im Einzelnen folgendes: Isohyeten, jahreszeitliche Muster, Isotherme, Trockenzeiten, Evapotranspiration, Niederschlagskonzentration, Feuchtigkeitsprovinzen, klimatische

Aggressivität, Böden, Geologie, Hydrologie, Morphologie, Hauptstraßen, Siedlungen, Flughäfen, Landnutzungsart, Bodennutzung- /Bodenbedeckung, RUSLE Regen ‚runoff' Faktoren, RUSLE Bodenerosivitäts Faktoren, RUSLE topographischer Faktoren, RUSLE Ertrag und Betriebsführungs Faktoren, RUSLE Naturschutz Faktoren, aktuelle Erosion und potentielle Erosion. Das Hauptziel dieser Studie wurde erreicht und die benötigten Informationen für eine Landbewertung auf Basis des Regenfeldbaus basierend auf dem FAO Modell sind nun in digitaler Form vorhanden. Diese Informationen sind die Basis, um über die passende Landnutzung in einer spezifischen Landeinheit innerhalb der Gemeinde von Torres zu entscheiden.

Table of contents

List of figures

Chapter 1. General introduction

Chapter 2. Generating and mapping information of environmental parameters in Torres municipality

Chapter 3. Land use / land cover classification in Torres municipality

Chapter 4. Assessment of erosion hazard in Torres municipality based on GIS

List of tables

Chapter 1. General introduction

I. Justification of the project

Tocuyo River Basin is the most important hydrographical ecosystem in the Center-Western region of Venezuela. The area of the basin is about 1.721.000 has (in three states and 15 municipalities) which represents 57.7 % of the Caribbean Sea Basin of Venezuela. El Tocuyo is the principal river in the basin.

Tocuyo's basin has been inhabited and cultivated for hundreds of years; therefore natural resources of the basin (including particularly water) have been exploited also for hundreds of year, causing negative environmental impact. For instance, slopes have been degraded, vegetal cover has been removed, and soils have been cultivated in an irrational manner. All these factors promote continued erosion, loss of soil fertility, and decrease in the capacity of the river-bed for drainage because of the high production and accumulation of sediment due to erosion. Frequent flood in low lands are evidence of basin deterioration. Lack of comprehensive inventory on the resources avoids a current knowledge about degradation of natural resources (Ferrer, 2003). Due to this situation, Venezuelan public and private institutions decided to carry out a comprehensive study of the status of natural resources in Tocuyo's basin. Main objective is to collect, generate, analyze and interpret information concerning natural resources for proposing an integral management of this basin. These efforts are joined in the project “Sustainable Development of Tocuyo River Basin”.

The most important aspects of this project are the identification and evaluation of non-correct land use, and deterioration of the natural resources in the basin. Both aspects are important issues in land evaluation, especially in FAO model, which assess the land as resource and its suitability for specific use. Because of the quite enormous amount of needed information for aiming this project, the present study is considered an important contribution. This study aims for obtaining and generating information necessary for land evaluation (FAO model) in Torres Municipality, which is the biggest in Tocuyo River Basin. This study will be model for the other municipalities located in the basin.

Because of the different objectives and techniques applied in this study, this thesis has been split in 5 chapter to explain every step of the research in a detailed manner. Present chapter (chapter 1) justifies the project, introduces the study area, states the general objectives, presents a literature review of the main term used in this thesis, emphasizing in land evaluation to justify the importance of this research, and the general methods common to all the phases of the thesis. Chapter 2, 3 and 4 have the same structure i.e. introduction dealing with literature review and background, material and methods, results, discussion and conclusion. Chapter 2 deals with the obtaining of thematic maps of environmental conditions in Torres Municipality based in environmental records (e.g. rainfall, evaporation, temperature, etc.), edaphic reports and analogical information. Chapter 3 deals with the obtaining of a land cover map based on the use of remote sensing helped by digital elevation model. Chapter 4 deals with determination of erosion in the municipality by means of application of Revision Universal Soil Loss Equation (RUSLE) using geographical information system. Finally, chapter 5 is an overview of the obtained results.

II. Characterization of the study area

Torres municipality is located inside Tocuyo River Basin in west of Lara state, Venezuela, within latitudes 9°40' N to 10°34' N and longitudes 69°36' W to 70°52' W, covering an area of about 6954 sq. kilometres (Figure 1). Landscape is very irregular, most of the region is characterized by rugged relief and steep slopes interspersed with undulating depressions at different elevations and expositions. Elevations range from 400 to 3000 meters above sea level. The climate is seasonal continental with accentuated irregularity of the rain regime and with negative hydro balance (P/ETP)[9] in the year. Contrasting relief generates two types of landscape with humidity province very differentiated: a dry or semi-arid with xerophilous vegetation and other sub-humid links to larger elevations. The first is characterized by average annual precipitation ranging around 420 - 700mm, temperature of 27 °C and ETP that varies between 1535 and 1650mm. The second with average annual precipitation ranging around 700 and 1200mm, temperatures within 18 to 25 °C and ETP between 1000 and 1400mm. In general, the vegetal cover of the area is little dense with load species low. The soils are not much permeable, favouring erosive processes. Land uses are mainly agricultural, dominate by breeding of bovine, ovine and caprine, horticulture, sugar cane (*Sacharum officinarum*), grape (*Vitis vinifera*) and subsistence agriculture (Ferrer, 2004).

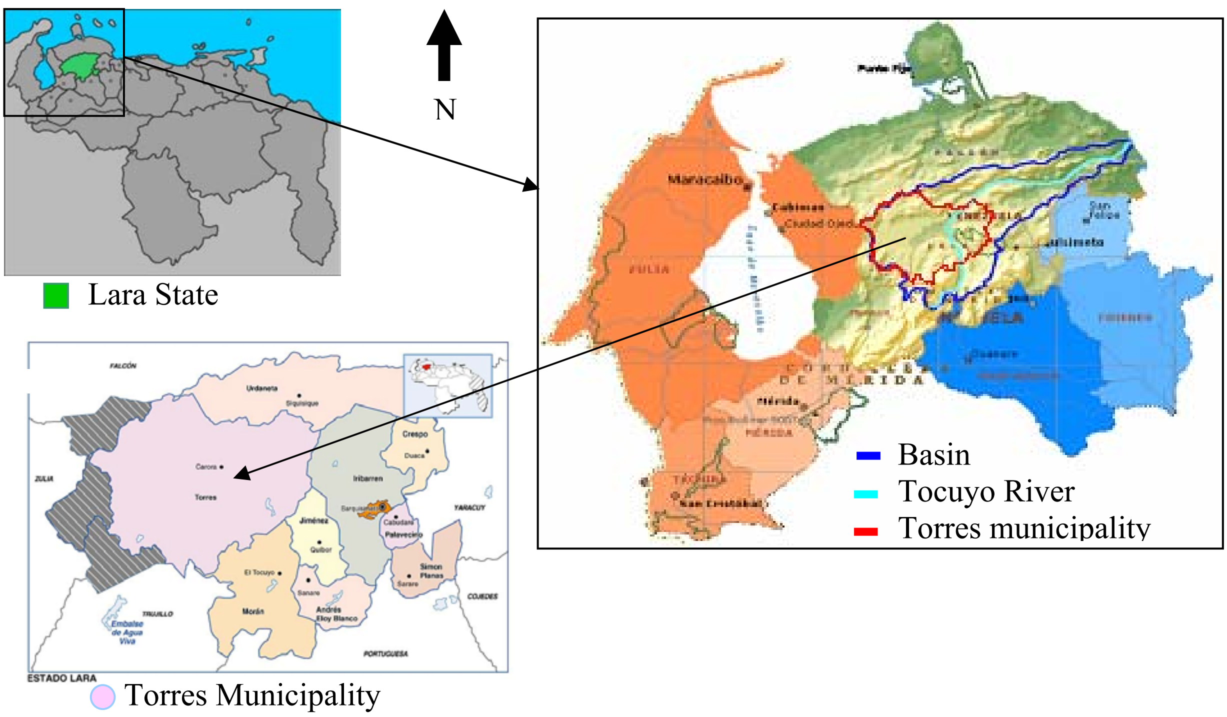


Figure 1. Location of Tocuyo River Basin and Torres Municipality, Lara State, Venezuela

9 quotient that indicates the balance between the entrance of water in rainfall (P) and the loss of water in evaporation (ETP) (Thornthwaite, Ferrer, 2003).

III. OBJECTIVES

1. General objective

To compile and generate the needed information to apply the land evaluation FAO model for rainfed agriculture (FAO,1983) in one of the municipalities that conform Tocuyo River Basin, specifically Torres Municipality, using spatial analysis techniques (GIS and Remote Sensing).

2. Specific objectives.

To generate thematic maps of environmental parameters of the study area

To generate a land use / land cover map for the study area using remote sensing.

To generate erosion hazard maps applying the Revised Universal Soil Loss Equation (RUSLE) erosion model in a Geographical Information System environment.

IV. General concepts

1. Land Evaluation

Population growth and urban expansion have caused land scarcity for agricultural uses, which has incited a revaluation of this resource. This fact increases the agricultural production costs and the level of society conscience about the necessity for environmental preservation, therefore society demands more information about land aptitude for different uses.

Land evaluation is formally defined as "the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation" (FAO, 1976; Rossiter, 1996).

Conceptually, land evaluation requires "matching" of the ecological and management requirements of relevant types of land use with "land qualities" [1], taking local economic and social conditions into account and can be carried out at different scales (e.g. local, national, regional and even global) and with different levels of quantification (i.e. qualitative vs. quantitative) (George, 1983).

The first FAO publication setting out the principles of land evaluation as well as the broad methodological approach for identifying a range of relevant agricultural land-use options for a given area appeared in 1976, "A framework for land evaluation" (FAO, 1976). Subsequent FAO guidelines on land evaluation concerned about detailed application of the 1976 Framework to several specific major land uses, such as rainfed agriculture, irrigate agriculture, livestock and forestry production (FAO, 1983; 1984; 1985; 1991 respectively). It provides practical guidelines on the planning and execution of the various steps in land evaluation, from interpretation of basic data to the final recommendations which form a basis for land use planning and project implementation.

The principles of the 1976 Framework specify that land [2] should be assessed with respect to its suitability for a range of alternate land uses based on several criteria, such as:

- the requirements [3] of specific land uses
- a comparative multi-disciplinary analysis of inputs vs. benefits
- the physical, economic and social context

---

[1] Land quality is an attribute of land which acts in a distinct manner in its influence on the suitability of the land for a specific kind of use (FAO, 1976). Table 1.

[2] Land comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land (FAO, 1976).

[3] Requirements are the specific set of land qualities that determine the production and management conditions of a kind of land use (FAO, 1976).

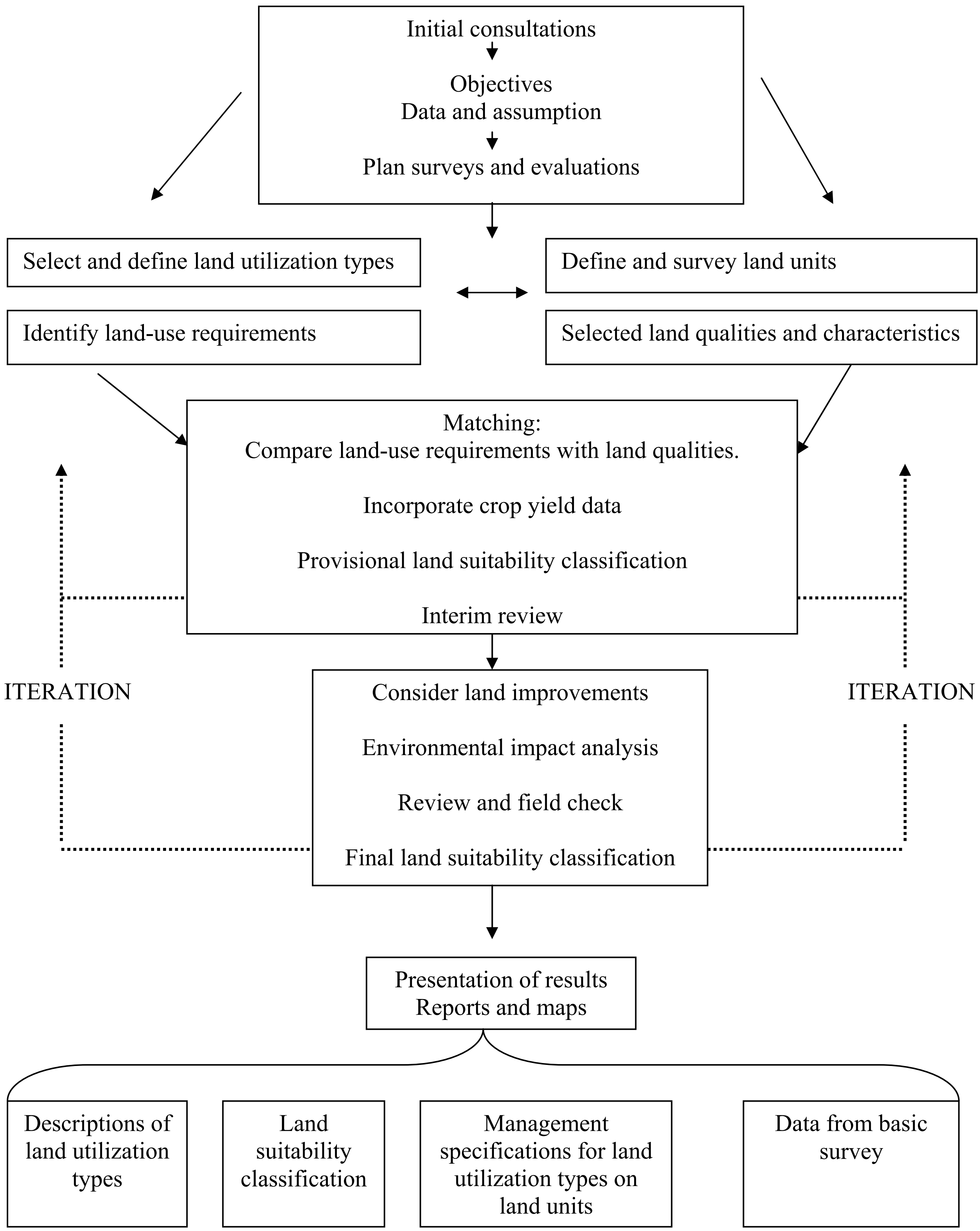


Figure 2. Sequence of operations in land evaluation for rainfed agriculture

- potential environmental impacts and land-suitability.

In the specific case of land evaluation for rainfed agriculture, the procedure outlined in Figure 2 can be applied at different levels of sophistication and detail, according to the objectives and scale of the evaluation and the manpower and finance available (FAO, 1983). The main conceptual steps in land evaluation are:

- Step 1: Initial consultation on the objectives and noting of any assumptions.
- Step 2: Determination of the requirements of relevant land-use options. A land use option is described using the following set of management-related (or input) attributes (reflecting socio-economic setting) that together define a “Land Utilization Type” (LUT)[4],

    - Product, including goods and services
    - Market orientation
    - Capital intensity
    - Power sources
    - Technology
    - Infrastructure
    - Size and configuration of land holdings
    - Income level.

A large number of agricultural LUTs are theoretically possible, as a consequence of the possible combinations of products and/or services, e.g. crops, livestock, and forestry products, under varying management or input (low, intermediate and high) conditions.

The requirements (conditions) that would permit efficient, sustainable functioning of each LUT must be determined. In general, for LUTs focused on rainfed crop production, the major requirements concern crop physiology, technology of management systems, and avoidance of land degradation. A list of criteria, subdivisions, units, methods and diagnostic factors frequently used for assessing requirements in each of these three categories is present in Table 1.

---

4 A use of land defined in terms of a product, or products, inputs and operations required to produce these products, and the socio-economic setting in which production is carried out (FAO, 1996).

Table 1. List of parameters used for assessing the requirements for land use types (LUTs) for rainfed crop production, and land qualities of land mapping unit (FAO, 1985).

N°	**Land quality**	**Subdivision**	**Criteria or diagnostic factor**	**Unit**
1	Radiation regime	Total radiation Day length	Net short wave radiation in growing season Mean daily sunshine in growing season Day length at critical period	mW/m^2 h / d h
2	Temperature regime		Mean temperature in growing season Mean temperature in coldest month of growing season Mean daily maximum of hottest month in growing season	° C ° C ° C
3	Moisture availability	Total moisture Critical periods Drought hazard	Length of growing period Total rainfall in growing period Relative crop yield calculated by moisture balance modelling Relative evapotranspiration, deficit for critical period Probability of significant drought Presence of vegetation indicators	d mm ratio % -
4	Oxygen availability to roots (drainage)		Soil drainage class Periods of saturation of root zone (duration and frequency) Presence of vegetation indicators	class d -
5	Nutrient availability		N, available P, exchangeable K Reaction, ratio $Fe_2 O_3$ Soil parent material Presence of vegetation indicators	%, ppm meq/100gr pH, ratio class -
6	Nutrient retention capacity		Mean for CEC lower horizons Presence of condition modifier Texture class, lower horizons	meq/100gr presence class
7	Rooting conditions		Soil effective depth Root penetration class Stones and gravel Bulk density	cm class % g/cm^3
8	Conditions affecting germination or establishment		Assessment class Present erosion	class class
9	Air humidity as affecting growth		Mean relative humidity of least humid month in growing season	%
10	Conditions for ripening		Successive dry days Sunshine hours Temperature	d h ° C
11	Flood hazard		Periods of inundation in growing season Frequency of damaging floods	d class
12	Climatic hazards	Frost and Storm	Occurrence in growing season	--
13	Excess of salts	Salinity Sodicity	EC of saturation extract (topsoil and lower root zone) Total soluble salts Presence of condition modifier ESP SAR Presence of condition modifier	 mS/cm ppm presence % ratio presence
14	Soil toxicities	Aluminium Calcium Gypsum Others	Al saturation Reaction Presence of condition modifier Depth to carbonate Depth to gypsum	meq/100 pH presence cm cm …
15	Pests and diseases		Pest (known incidence) Disease (known incidence) Climatic indicators Soil indicators	
16	Soil workability		Assessment class Topsoil texture Number of d/y soil in workable condition	class class d
17	Potential for mechanization		Assessment class	class

			Slope	%
18	Land preparation and clearance requirements		Assessment class Landform Vegetation class	class
19	Conditions for storage and processing		Relative humidity in months following harvest Topsoil texture	% class
20	Conditions that affecting timing of production		Day- degrees Date of flowering, harvest	° C x d date
21	Access within the production unit		Terrain class Slope angle exceeded by 33 % of slopes	class %
22	Size of potential management units		Minimum size	ha
23	Location	Existing access Potential access	Distance from tarmac / earth road Index of accessibility	km -
24	Erosion hazard		Model to give soil loss (USLE, FAOSDA, SLEMSA, or local) Slope / soil groups Observed erosion	ton /ha/y % class
25	Soil degradation hazard		Dispersion ratio Index of crusting Soil rest period requirement	ratio - R %

Note: not all parameters listed above are required for every land evaluation study. Those that have a known effect adverse/favourable upon the various kinds of land use under consideration, and those for which practical means of data collection exist.

- Step 3: Mapping land qualities. The spatial unit of analysis for evaluation of suitability is the "land unit" (LU). A land unit (called "a land mapping unit" in the Framework, 1976) is an area of land, usually mapped and serially numbered (e.g. land unit 1, 2, 3, etc), with specified "characteristics" [5] , employed as a basis for land evaluation. The delineation of this unit should, ideally, be based on *land qualities* that have the influence on the land uses under consideration. Depending on the objectives of the evaluation, relevant core data sets may include soils, landform, climate, vegetation, and surface and or groundwater reserves. The units are now commonly referred to as "agro-ecological unit" when the original core data sets that are used in the overlay process consist of climate, soils and land form (terrain) data (FAO, 1983; Rossiter, 1994). In practice, geographic information systems (GIS) are commonly used to overlay relevant data sets in order to derive land mapping units, and it should be defined as function of attributes observable easily in the field (use of remote sensing techniques), relatively stable they should not change easily by management practices actions (FAO, 1985; Chuvieco, 1996). The set of parameters used for assessing land quality of each land mapping or agro-ecological unit are the same as those retained for characterizing the requirements of each land use types (see Table 1).

[5] A land characteristic is an attribute of land which can be measured or estimated and which can be used for distinguishing between LUs or differing suitabilities for use and employed as a means of describing land qualities (e.g. mean annual rainfall, pH, etc.)

- Step 4: Interim matching of land-use requirements with actual land qualities. The requirement of each type of land use (LUR) are compared with the qualities of each mapped land unit and analysed to give and overall "land suitability" [6] class for each relevant land use type (LUT) on each land unit (LU) . The first stage is the initial matching of the land use requirements with the qualities of the land units (see Figure 2) leading a first approximation of land suitability classes.

For non-automated "qualitative" approaches to match, land suitability was described using a hierarchic classification structure (ranging from orders, classes, sub classes to units) that allows the incorporation of fewer or more details on specific land-use limitations (see Table 2). However, in automated approaches, a simplified system based on estimated productivity (% of maximum attainable yield) is often used [7] **.**

- Step 5: Final matching. The interim suitability classifications produced in the preceding step may be re-evaluated taking into consideration a range of additional factors, e.g. potential land improvements, environmental impacts, economic and social analysis.

6 The fitness of a given type of land for a specified kind of land use (FAO, 1976).

7 Very suitable: >80% of potential maximum yields; Suitable: 60-80%; Moderately suitable: 40-60%; Marginally suitable: 20-40%; Very marginally suitable: 5-20%; Not suitable: 0-5% (FAO, 1993).

Table 2. Land suitability classification for rainfed agriculture (FAO, 1983)

<table>
<tr><td colspan="5">Order: Suitable</td></tr>
<tr><td colspan="3">S1 class</td><td>High</td><td>No or non-significant limitations</td></tr>
<tr><td rowspan="3">S2 class</td><td rowspan="3">S2e sub-class</td><td>S2e-1 unit</td><td rowspan="3">Moderate</td><td rowspan="3">Moderately severe limitations which reduce productivity or benefits or increase required inputs</td></tr>
<tr><td>S2e-2 unit</td></tr>
<tr><td>etc.</td></tr>
<tr><td colspan="3">S3 class</td><td>Marginal</td><td>Overall severe limitations; given land use is only marginally justifiable</td></tr>
<tr><td colspan="5">Order: Not Suitable</td></tr>
<tr><td colspan="3">N1 class</td><td>Currently not suitable</td><td>Limitations not currently overcome with existing knowledge within acceptable cost limits</td></tr>
<tr><td colspan="3">N2 class</td><td>Permanently not suitable</td><td>Limitations so severe that they preclude all possibilities of the given use</td></tr>
</table>

Note: sub-classes reflect different kinds of limitations, letters should normally suffice for any subclass (e.g. to erosion hazard: “e”). Different units reflect minor differences in production characteristics or management requirements.

The final step in land evaluation by itself is the presentation of results. The results are presented in the form of one or more maps together with a report, which may be in one or several volumes (FAO, 1983).

Several authors such as Machado et al., (1990), Saballos and Henríquez (1999), Evangelista (1992), Markhdoum (1992), Ferrer and Comerma (1997) have applied the FAO model for land evaluation, selecting the land units based on information of agrological and agroclimatic studies, soil series, agro forestry places and environments.

Comerma and Machado (1991) did an analysis of application of the FAO’s land evaluation systems. They pointed out that this system is applicable and it adapts to Venezuelan conditions, representing in general way, big advantages.

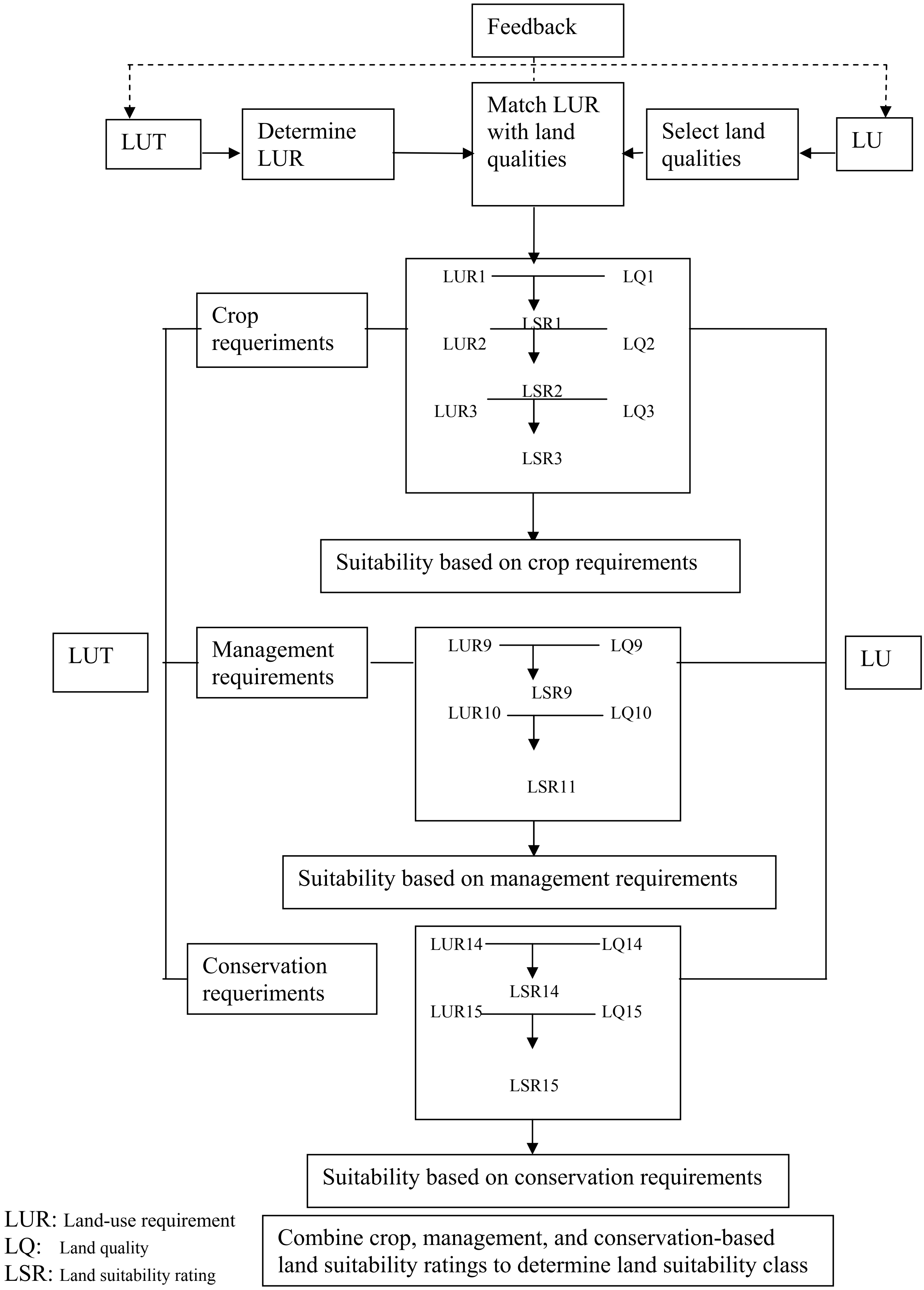


Figure 3. Matching land use requirement (LUR) of the land use types (LUT) with land.

Chapter 2. Generating and mapping information of environmental parameters in Torres municipality

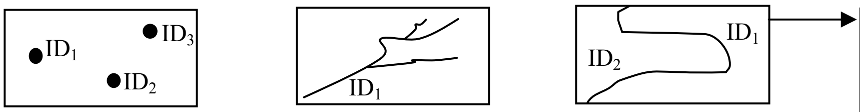
I. Introduction

The strategies of planning a sustainable land management need reliable data of environment parameters, understanding as environment the combination of external physical conditions that affect and influence the growth, development, and survival of organisms; and also the social, economic, and cultural conditions affecting the nature of an individual or community. Important environmental parameters for land evaluation are geology, soils, physiography, climate, vegetation, land use, etc. Assessment of natural resources may be mapped for specific purposes. Combined use of geographical information systems, digital elevation models, and remote sensing may play an important role in a comprehensive analysis of natural resources, for example in its detection (direct or indirect), mapping, extrapolation, interpretation, area calculation, and monitoring.

1. Cartography

Cartography or mapmaking is the study and practice of making maps and charts. A *map* is a set of points, lines, and areas that are defined by their location in space with reference to a coordinate system and by their non-spatial attributes (Burrough, 1986). A map is usually represented in two dimensions but there is no reason to exclude more dimensions except through the difficulty of portraying them on a flat piece of paper. Maps may have two formats: *digital* or *analog* (paper). A paper map is not adapted for being processed by a digital computer (device that represents magnitudes in digits) (Bosque, 1992).

In accordance to the type of information, the map can be *general* (extensive and varied information) or *thematic* (a single subject or theme). The theme may have *qualitative* (as in the case of land-use classes) or *quantitative* (as in the case of the variation of temperature in an area) information. Both information can be expressed in areas of equal value separated by boundaries (soils map) or modelled by a continuous surface, where the variations are shown by isolines or contours (elevation contours on a topographic map). The *map legend* is the key linking the non-spatial attributes to the spatial entities. Non-spatial attributes may be indicated visually by colors, symbols or shading. For geographical information system non-spatial attributes or database need to be coded in a form in which they can be used for data analysis. The code, whose name begins with “ID”, contains a unique name that identifies the attribute, characteristic or variable associated to each entity (polygon, line or point) of the map, for example:



ID	Soils	Texture
1	A1	F
2	A5	FL

Points (Airports) Lines (Hydrology) Polygons (Soils)

The data structure of the digital map in the computer may be represented in two ways: *raster* or *vector.* The simplest raster data structure consists of an array of grid cells (sometimes termed pixels or picture elements). The vector data structure makes use of a set of lines defined by starting and end points and some form of connectivity. There is no single method of entering the spatial data (vector or raster) to a GIS. Rather, there are several, mutually compatible methods that can be used singly or in combination, such as:

- *Manual input to a vector or grid system,* simple, but tedious typing of the data into a file or input to a program.
- *Digitizing,* using a digitizer to encode the X and Y coordinates of the desired points, areas or grid cells. A digitizer is an electronic or electromagnetic device consisting of a tablet upon which the map or document can be placed. The coordinates of a point on the surface of the digitizer are sent to the computer by a hand-held magnetic pen, a simple device called a "mouse" or a "puck".
- *Automated scanning*, these alternatives are found in the pieces known as *scanners*. Scanners can be classified into two types, those that scan the map in a raster mode, and those that can scan lines by following them directly.
- *Spatial data already in digital raster form. A*ll satellite sensors and multispectral sensing devices use scanners to form an electronic image of the terrain. The scanned data are retained in the form of pixels.
- *Interpolated data,* mathematical methods *for* interpolating the values of measured properties at unvisited points from observations taken at discrete locations. The *interpolation* is the procedure of estimating the values of properties at unsampled sites within the area covered by existing point observations. There are several interpolation methods, among them, the Kriging. Kriging is considered an exact interpolator. The average local value can be represented by a continuous surface. The interpolated values can then be converted to a contour map.

Because each cell in a two-dimensional array can only hold one number, different geographical attributes must be represented by separate sets of Cartesian arrays, known as *map overlay*s. The real world is portrayed by series of overlays in each of which one aspect of reality has been recorded (e.g. topography, soil type, roads, rivers, etc). The overlay concept is essentially equivalent to the "picture function" in digital processing, and it is fundamental to most raster image processing. With the maps overlay, new maps can be generated or add spatial and not-spatial attributes to maps previously created (Burrough, 1986).

2. Geographical information systems, digital elevation models and remote sensing for the land evaluation

Often land evaluation presents the results in maps. Location and other spatial characteristics of the evaluation units are important land characteristics in the evaluation (Rossiter, 1996; Boggs et al., 2001). The Geographical Information Systems (GIS)[8] are an indispensable tool for map analysis and presentation of land evaluation (FAO, 1993; Unda, 2001; Davidson, 2002). GIS facilitate the storage and analysis of a wide range of spatial data. Computerized databases and modelling programs are now interfaced with GIS in order to facilitate the computational intensive aspects of land evaluation, for example, the stage of matching potential LUT requirements with land qualities (Bouma, 1989). GIS offer flexibility for multiple interpretations from the same soil data and for the integration of other data (environmental or not) collected in different scales and level of detail (Viloria, 1996; Basher, 1997); and the analysis of alternate scenarios could be output as maps (e.g. showing how would land suitability would change if land improvements were made or if more drought resistance crop varieties were introduced (George, 1983).

Digital Elevation Model (DEM) is an extremely useful product in a GIS for land evaluation. Implementing GIS in erosion assessment provides many advantages, including the ability to provide details of catchments morphology trough of DEMs (Mitas and Mitasova, 1998).A DEM is any digital representations of the variation continues of relief over space (Burrough, 1986). The term digital terrain model (DTM) is also commonly used, but the term DEM is preferred for models containing only elevation data. Rossiter (1994) pointed out that in the land evaluation, the products derived from a DEM, often are:

[8] GIS is an assemblage of computer equipment and an set of computer programs for the entry and editing, storage, query and retrieval, transformation, analysis and display (soft copy) and printing (hard copy) of spatial data (Burrough, 1986).

- Maps of slope or gradient, form (convexity, concavity) and aspect or orientation of the terrain. It affects land qualities such as runoff, erosion hazard, moisture balance, etc. This is important too for determining direction and velocity or surface water flow, isolation and wind.
- Contour maps (isolines) for visualization or to separate land units on the basis of elevation.
- Drainage network and drainage basin delineation; it can follow the terrain to the inter-basin divides, and divide the landscape into watersheds.
- Analytical shading, projective geometry can be used to simulate the illumination of a landscape from a given point. This is used often to create shaded relief maps.

Another important source of information on land characteristics is remotely-sensed data, especially satellite imagery (FAO, 1983; Rossiter, 1994).

Torres municipality, located in the basin of the River Tocuyo, is found in an excellent position to apply technologies of spatial analysis in an integrated context, for example, with the purpose to do an inventory of the natural resources necessary for making a land evaluation, by means of the use of internationally standardized and accepted methodologies.

3. Objectives

3.1 General objective

The main objective of this chapter was to obtain digital thematic maps of environmental parameters in Torres Municipality necessary to make a land evaluation based on FAO model for rainfed agriculture

3.2. Specific objectives

- To update soil and geology maps using available bibliographic information
- To generate and update the maps of hydrology, main roads, settlements, borders, and airports using a Landsat image.
- To generate and mapping information about climatic parameters (isohyets, seasonal patterns, isotherms, dry period, evapotranspiration, precipitation concentration, humidity provinces, climatic aggressiveness), and land utilization type (LUT).
- To generate maps of physiography using a digital elevation model

II. Material and methods

1. Data sources

A Landsat-7ETM+ image (WRS-2, Path 6/ Row 53), acquired on November 11th, 2000, was obtained from the United States Geological Survey (USGS). This scene was chosen because is very clear over the Torres municipality without visible atmospheric effects except for a few small clouds. During imaging the sun elevation was 45°, with an azimuth of 125° (Figure 4). A digital elevation model (DEM) obtained from Seamless Data Server of the USGS (Figure 5) was used too. Additional sources of information were records of meteorological stations, analogue and digital thematic maps of Lara state and field visits.

2. Tools

The software ENVI (Environment for Visualizing Images, USA), version 4.3, ArcGis.9/ArcView.3.2a (Environmental System Research Institute, USA) and MapInfo 5.5 (MapInfo Professional, USA) were used to pre-process, process and transfer (importing/exporting) the data.

3. Generating thematic maps of the study area

3.1 Data pre-processing

The vector map of Torres municipality, on scale 1:100.000 was used as basis map to elaborate the thematic maps. This map has the administrative boundaries of Torres municipality. The map was digitized and georeferenced in Venezuela by Foundation for the Development of the Central-Western Region (FUDECO, 2004) employing a digitizer (tablet). The spatial data was stored in the GIS MapInfo5.5 and its non-spatial attributes were stored and coded (ID) in a database or attribute table. The analogue sheets 6045, 6046, 6047, 6145, 6147, 6245, 6246 and 6247 of Lara state (National Cartography of Venezuela) were scanned and georeferenced according to the map previously digitized. The Landsat image and digital elevation model (DEM) were imported into ENVI file format. In a first step, they were cut according to the coordinates of the study area using the tool “Resize Data”. Data were georeferenced (with a spatial resolution of 30 x 30) to the Universal Transverse Mercator (UTM) projection, Zone 19 North, WGS-84 and corrected geometrically using a set of 20 control points (crossroads and settlements) identified in the map previously digitized.

The spatial data was imported to different GIS system such IDRISI, ArcInfo, ArcView and MapInfo and ENVI. This facilitated the use, analysis and cartography of the spatial entities of Torres municipality.

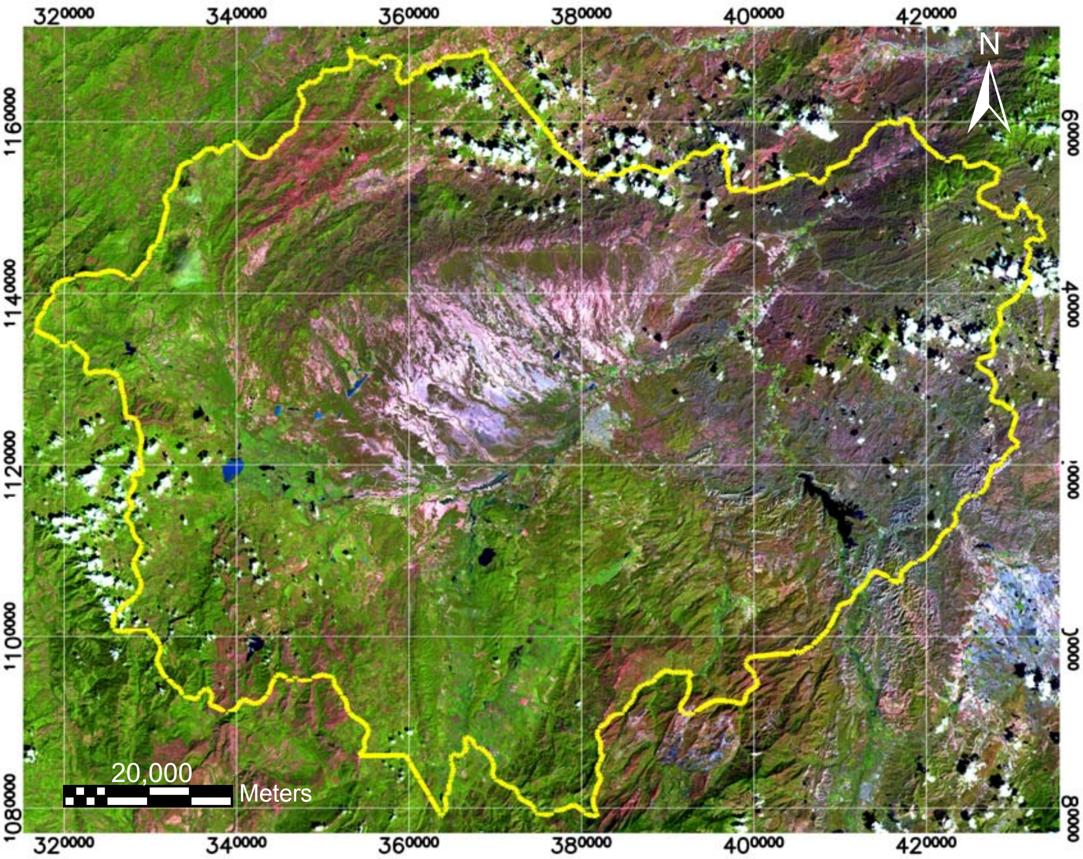


Figure 4. Landsat -7 ETM+ image subset of Torres municipality, Venezuela. RGB 583.

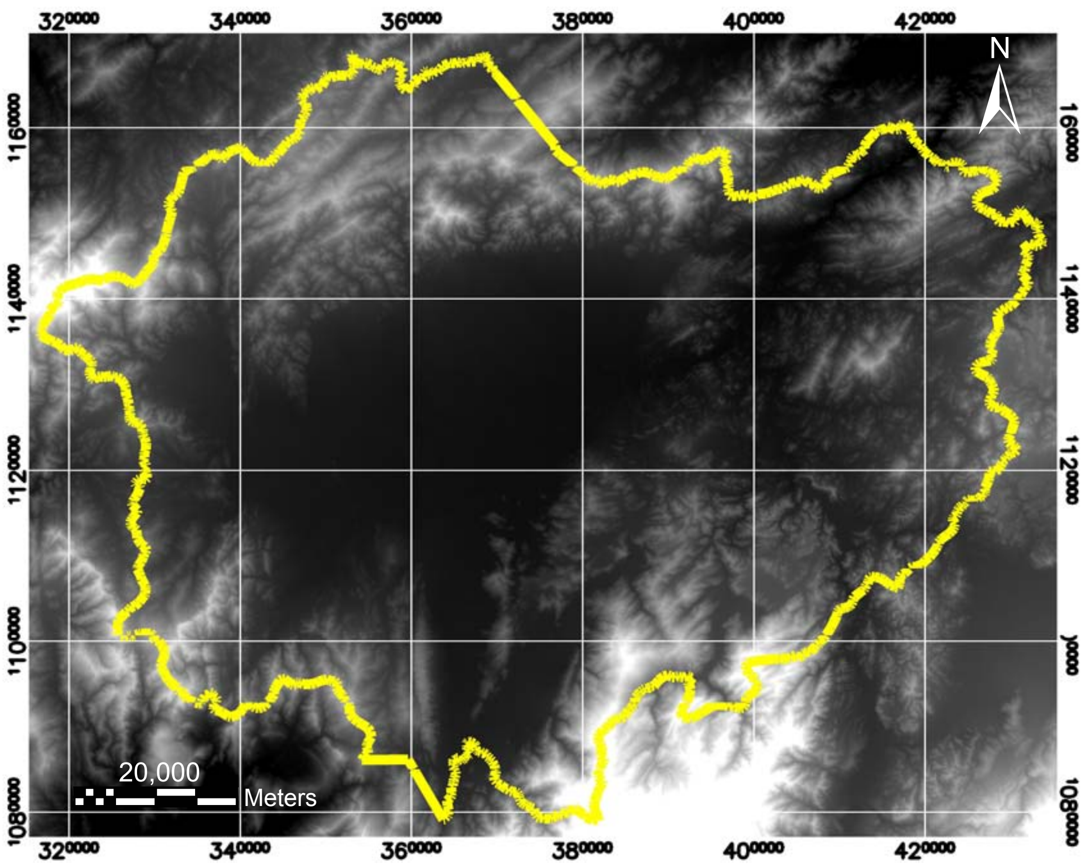


Figure 5. Elevation image of Torres municipality, Venezuela generated from the DEM

3.2 Climate maps

Data of 33 meteorological stations (Table 3) were used in this study. Daily records of precipitation and temperature were collected over years by the local government (MARNR). Data have been recorded for more than 20 years for most of the stations. Used data were within the period 1984-2005. Daily values of each meteorological station were accumulated to obtain monthly and annual precipitation and temperature. Other climatic parameters, as potential evapotranspiration (ET_0), concentration of the precipitation, aggressiveness of the

Table 3. Meteorological stations of Torres Municipality used in this study and annual average records of precipitation and temperature

Meteorological station	Parish	Altitude m.a.s.l.	Longitude	Latitude	Annual total precipitation mm	Annual average temperature °C
La Portería	El Blanco	512.0	-70.624	10.442	1059.7	26.4
El Burro	El Blanco	720.0	-70.516	10.388	1100.8	25.1
Quebrada Arriba	El Blanco	615.0	-70.531	10.244	879.0	25.8
Puricaure	Las Mercedes	520.0	-70.452	10.095	841.5	26.3
El Cuji-Caracaras	Las Mercedes	460.0	-70.383	10.087	903.5	26.7
Prieto-Los López	Las Mercedes	539.0	-70.407	10.018	1024.0	26.2
El Empedrado	Manuel Morillo	844.0	-70.273	9.868	955.0	24.4
Puente Villegas	Manuel Morillo	621.0	-70.241	9.766	1059.5	25.7
Trentino-La pastora	Cecilio Zubillaga	559.0	-70.178	9.812	894.9	26.1
Burere	Las Mercedes	430.0	-70.244	10.106	594.1	26.9
San Francisco	Montes de oca	470.0	-70.304	10.293	636.6	26.6
Altagracia	Montes de oca	479.0	-70.204	10.349	586.8	26.6
Los Pedernales	Montes de oca	645.0	-70.198	10.429	677.5	25.6
El Carrizal	Montes de oca	937.0	-70.226	10.480	813.9	23.8
Carora	Trinidad Samuel	406.0	-70.086	10.186	579.2	27.0
Carora-Granja	Trinidad Samuel	413.0	-70.082	10.163	434.3	27.0
Sabana Grande-T.S.	Trinidad Samuel	523.0	-70.042	10.067	676.2	26.3
Los Arangues	Trinidad Samuel	551.0	-70.052	10.027	702.9	26.1
Sicarigua	Trinidad Samuel	475.0	-70.111	9.951	805.1	26.6
San Pedro	Lara	1440.0	-70.069	9.871	1022.5	20.8
El Jabón	Torres	1499.0	-70.120	9.813	1022.1	20.5
Curarigua	Antonio Díaz	627.0	-69.919	9.999	558.8	25.7
Arenales	E. de los Monteros	428.0	-69.906	10.157	485.0	26.9
Río Tocuyo	Camacaro	388.0	-69.933	10.269	440.5	27.1
Cambural	Siquisique	550.0	-69.625	10.428	495.1	26.2
Torturia-San Pablo	Castañeda	720.0	-69.706	10.143	509.0	25.1
El Culebrero	Castañeda	510.0	-69.813	10.098	480.2	23.8
La Rivera	Las Mercedes	940.0	-70.492	9.958	1172.4	23.8
Palmarito	Montana Verde	600	-70.413	9.573	963.9	25.9
Banco de Baragua	A. F. Alvarado	787	-69.350	10.809	617.1	24.7
Guadalupe	J. B. Rodríguez	582	-69.400	10.229	515.1	26.0
Las Cuatro	Humocaro Bajo	1952	-70.000	9.421	1231.8	17.7
Baragua	Xaguas	383	-69.560	10.353	293.5	27.2

rains, humidity provinces, water balance, seasonal patterns and dry months were calculated from these data.

ETo values were obtained applying the formula of Thornthewaite (1948):

e = 16× (10× tm/I)a (40)   (1)

where:

e: monthly ET_0 in mm (mm/month)

tm: monthly average temperature in ° C

I: index of annual heat

I = ∑ (ij) ; j = 1, ..., 12 (adds of the 12 index of 12 monthly heat)

ij = (tmj/5) 1,514

a: parameter calculated of "I" according to the expression:

a = 0.000000675 × I3 – 0.0000771 × I2 + 0. 01792× I + 0.49239

Humidity provinces values were obtained applying the Climatic Index equation reported by UNEP (1997). This index defines the periods of deficiency and excess of humidity in an area during a specific period of time:

$CI = P/ ET_0$ (4)

Where: P is annual average precipitation and ET_0 is the potential evapotranspiration

The classification of Climatic Index is presented in the Table 4

Table 4. Classification of the humidity provinces considering the Climatic Index (CI) according to UNEP (1997).

Zones or Provinces	**IC**
Hyper arid	< 0.05
Arid	0.05 – 0.20
Semiarid	0.20 – 0.50
Dry Subhumid	0.50 – 0.65
Humid Subhumid	0.65 - 1
Humid	> 1

The value of concentration of precipitation in the year was generated with the Precipitation Concentration Index (PCI) proposed by Oliver (1980):

$ICP = 100 \sum P^2 / P$ (2)

Where: P^2 is monthly precipitation (mm) and P is annual average precipitation (mm)

The classification is presented in the Table 5

Table 5. Classification of the Precipitation Concentration Index (PCI) according to Oliver (1980)

PCI	Class
8.3 - 10	Uniform
10 - 15	Moderately seasonal
15 - 20	Seasonal
20 - 50	Highly seasonal
50 - 100	Irregular

The aggressiveness of the rains was characterized from Modify Fournier Index (MFI) proposed by Arnoldus (1980). This factor determines the capacity or power of the rain to cause erosion.

$MIF= \sum P^2/ P$ (3)

Where: P^2 is monthly precipitation (mm) and P is annual average precipitation (mm)

The classification is presented in the Table 6

Table 6. Classification of the aggressiveness using the Modify Fournier Index (MFI) from Arnoldus (1980)

MFI	Class
0 - 60	Very low
60 - 90	Low
90 - 120	Moderate
120 - 160	High
> 160	Very high

Dry period and seasonal patterns of the rains are defined by means of these criteria proposed by Lobo et al. (2005).

N° dry moths = $P < 0.5\ ET_0$ (4)

N° humid months = $P > ET_0$ (5)

Where: P is monthly average precipitation and ET_0 is the monthly potential evapotranspiration

The data obtained applying these equations were transferred to ArcInfo.9 and a table of attributes was created. For mapping procedure the point theme “Climatologic Stations” was generated. Then, the surface maps of precipitation, temperature, ET_0, humidity provinces, climatic aggressiveness, seasonal patterns, dry months and index of concentration of the rains were made. The surface maps were produced from development point themes using Nearest Neighbor, Kriging interpolation technique, with 12 neighborhoods. The cell size for interpolation was 30 m. With the tool "Contour" of "Spatial Analysis" were derived maps of lines for rain (Isohyets), temperature (Isotherms) and ET_0.

3.3 Physiographic maps

Maps of contour lines (interval of 200 m), slope (in percentage), hill shade (azimuth of 315°, altitude of 45), aspect and landscape were derived directly of the DEM utilizing the extension of “Spatial Analysis” in the GIS ArcInfo.9. The output cell size was 30 m.

3.4 Geological map

A digital geological map of Lara state (MapInfo file format), scale 1:100.000 was obtained from FUDECO (2005). By processes of “Selection” and “Edition” in MapInfo 5.5, a geological map of study area was prepared. The original non-spatial attributes were: era, age, and period. New attributes were added (geomorphology, formation and characteristics of parental material) obtained from studies realized in the region (Ferrer and de Paz, 1985).

3.5 Soil map

A digital soil map of Lara state was obtained from FUDECO (2005) too, under the same conditions. The same procedure was done. The attributes table had the following information: taxonomical classification (Order, Suborder) according to the Soil Taxonomy from USDA (1986), degree of erosion according to Arias and Comerma (19719 and type of landscape. Afterward physical, chemical and biological characteristics of each unit of soil were added. This information was obtained of the soil studies made by MARN in the Lara state. The soil units are the same, but distributed in 3 analogue maps:

1. Soil studies of the mountain region of Matatere and Bobare (MARNR, 1993)
2. Soil studies of the mountain region of Trujillo, Barbacoas and Portuguesa (MARNR, 1993)
3. Soil studies of the mountain region of Baragua and Buena Vista (MARNR, 1993)

3.6 Thematic maps of hydrology, main roads, settlements, borders, airports

The maps were digitized from general maps previously scanned and georeferenced. Landsat image RGB 583 (jpeg file format) provided current details which did not exist in the used analogue maps; therefore these maps were updated by means of the overlay.

3.7 Land Utilization Type (LUT) map

Sixty farmers were interviewed in Torres Municipality. This survey (see Annex 1) contains information on the basic aspects considered to define the Land Utilization Type (LUT). This information was used to create a map of points identifying each agricultural production unit.

Attributes table of this map contains technical, social, and economical information necessary to make the land evaluation.

III. Results

Figure 6 shows the monthly distribution of precipitation, real and potential evapotranspiration, storage of humidity, excess of humidity, deficit of humidity, and temperature of Torres Municipality, based on daily records from 20 years and 33 metrological stations. Climatic demarcation obtained with these parameters is showed in Table 7.

Determination of climatic parameters was achieved by means of calculations (mainly with precipitation data) for each meteorological station. Interpolation of these data resulted in several maps describing the climate in the study area. Maps of climatic parameters defining climate in Torres Municipality are displayed in figure 7, 8, 9, 10, 11, 12, 13 and 14, for isohyets, isotherms, evapotranspiration, humidity provinces, seasonal patterns, distribution of number of months in dry period, precipitation concentration, and climatic aggressiveness respectively. Figures 15, 16, 17, 18 and 19 show the obtained maps of aspect of physiography in Torres Municipality, specifically landscape, contour lines, slope, shaded relief, and aspect; by means of using a digital elevation model.

Updating of geology and soil maps was carried out using bibliographical information, and they are showed in figure 20 and 21. Updating by means of using the Landsat image was achieved for hydrology (figure 22, showing a overlay of rivers and reservoirs), roads and airports (showed as overlay in figure 23), settlements and political division (showed as overlay in figure 24), and land utilization type (LUT) (figure 25).

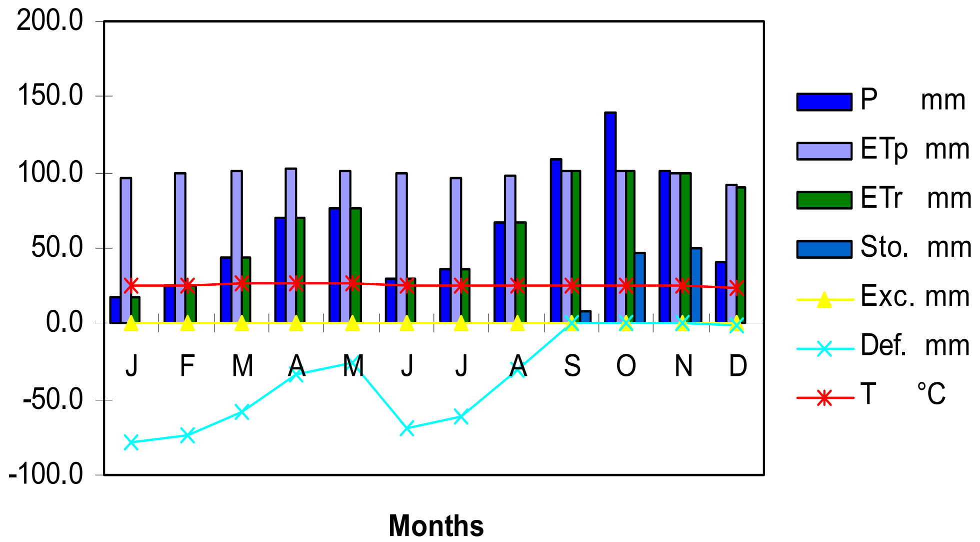


Figure 6. Monthly average value of precipitation, evapotranspiration (potential and real), storage, excess, and deficit (of humidity), and temperature in Torres municipality

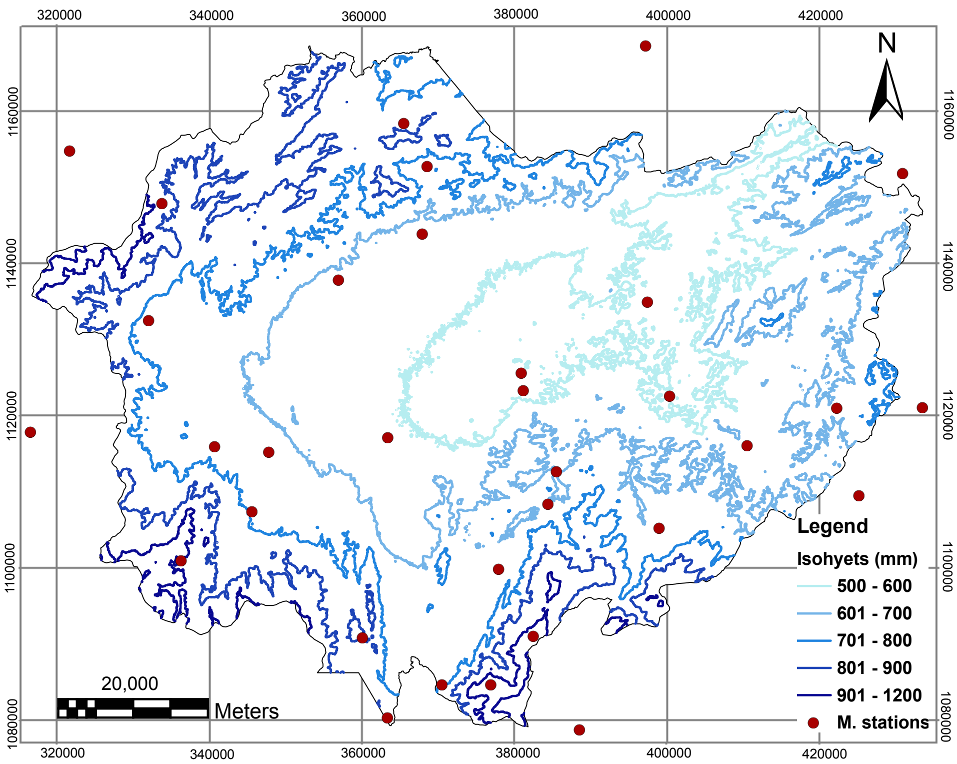


Figure 7 . Map of isohyets in Torres Municipality, Venezuela

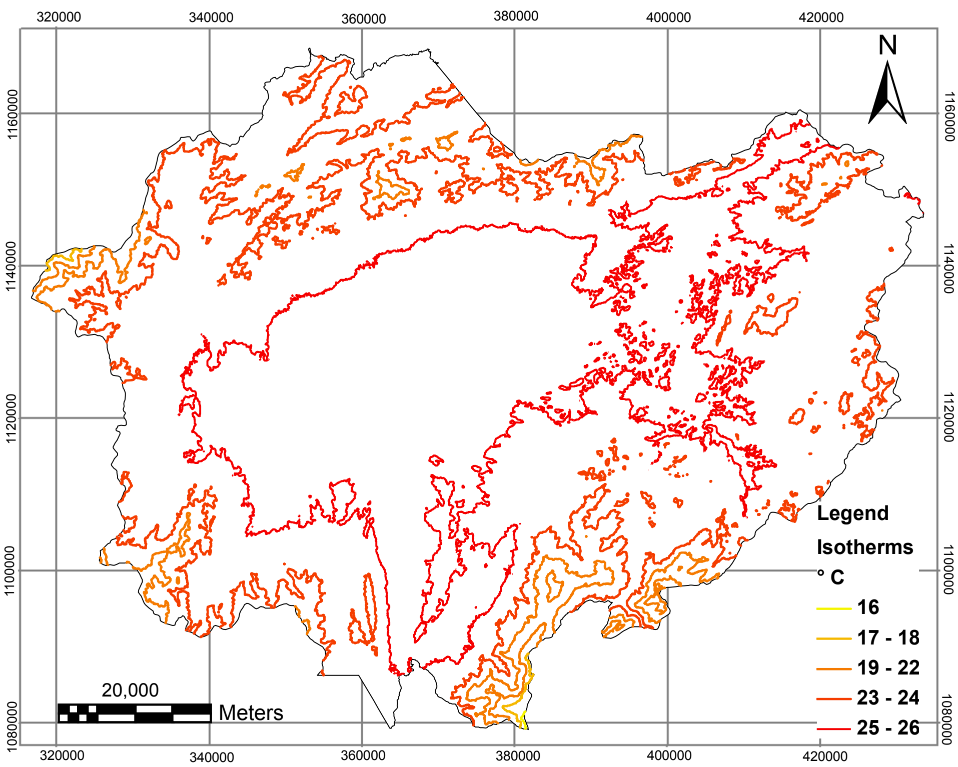


Figure 8. Map of isotherms in Torres Municipality, Venezuela

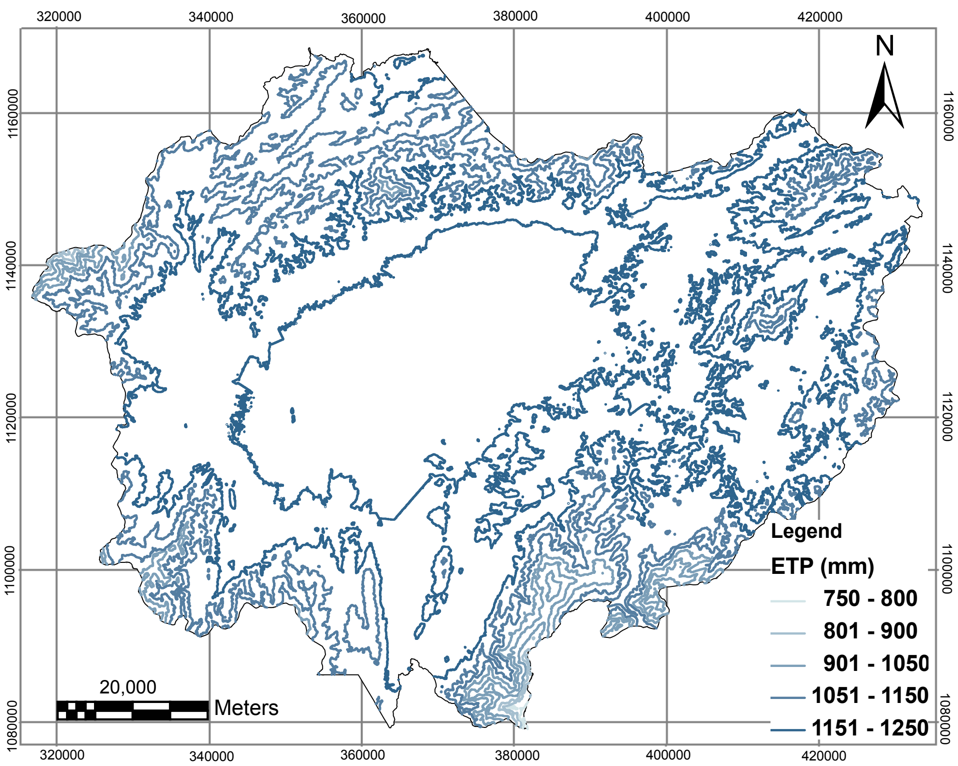


Figure 9. Map of evapotranspiration in Torres Municipality, Venezuela

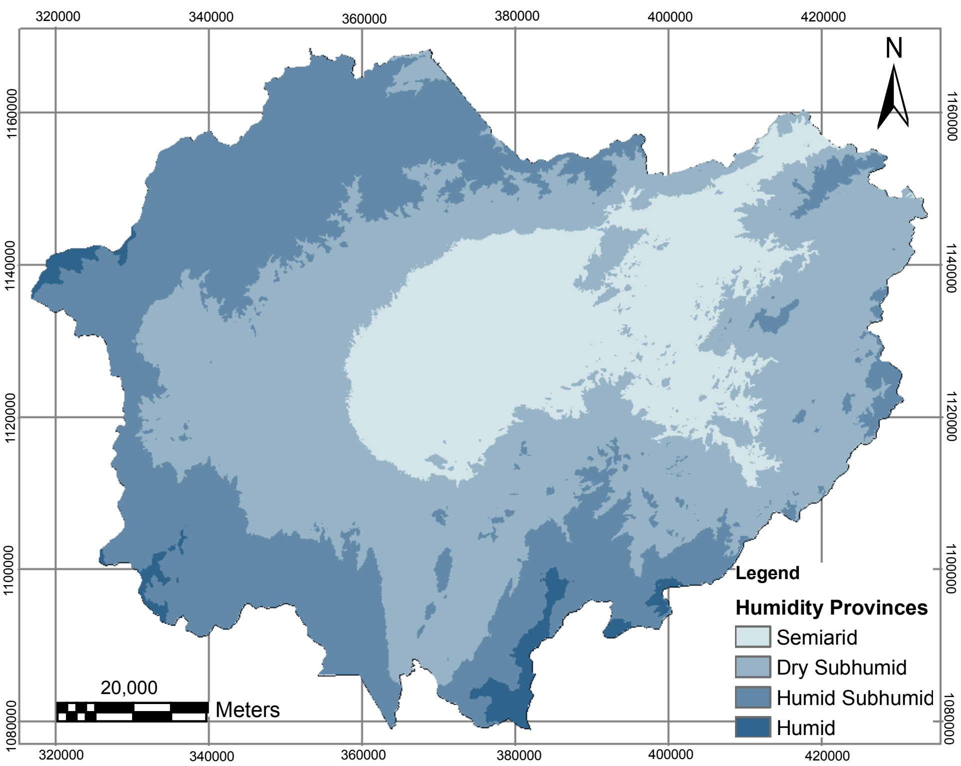


Figure 10. Map of humidity provinces in Torres Municipality, Venezuela

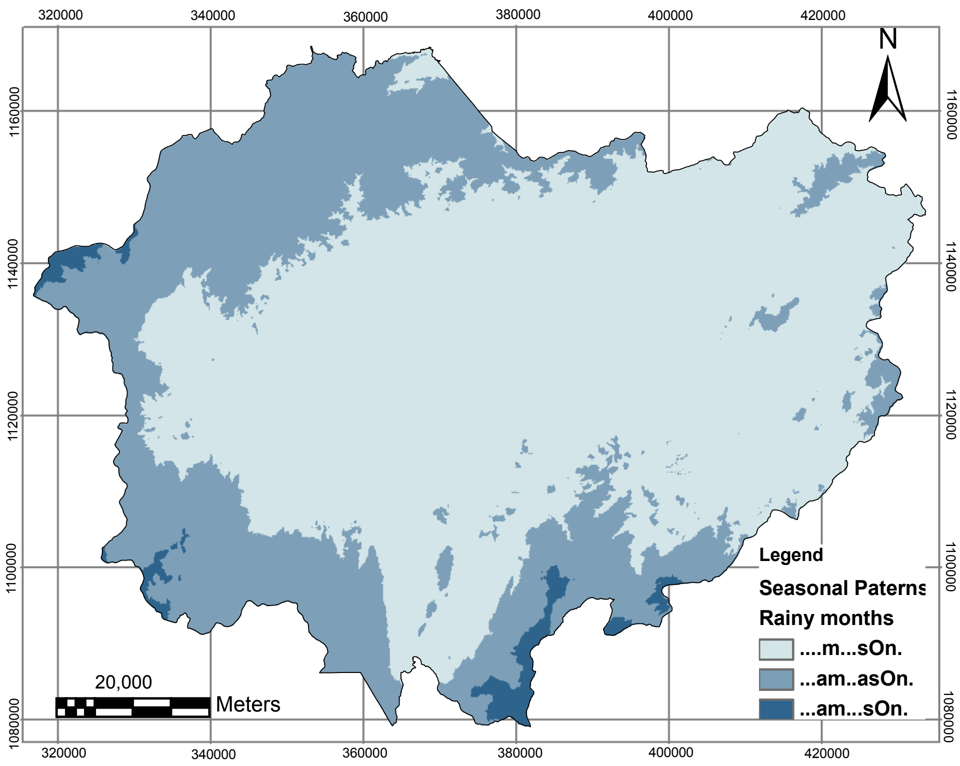
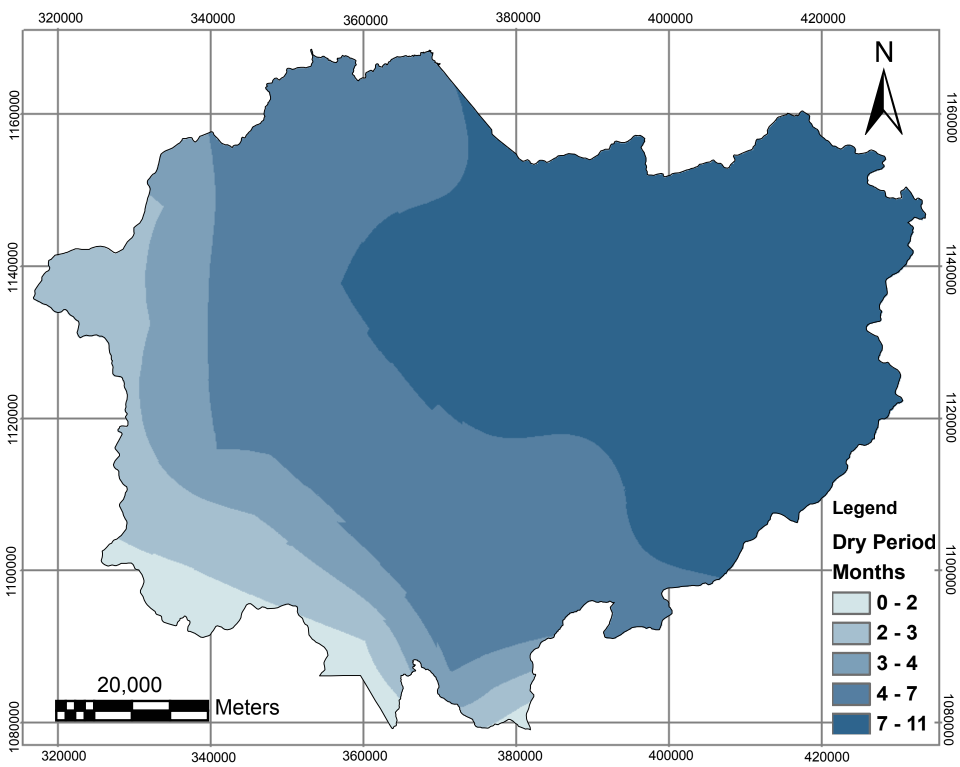


Figure 11. Map of seasonal patterns in Torres Municipality, Venezuela



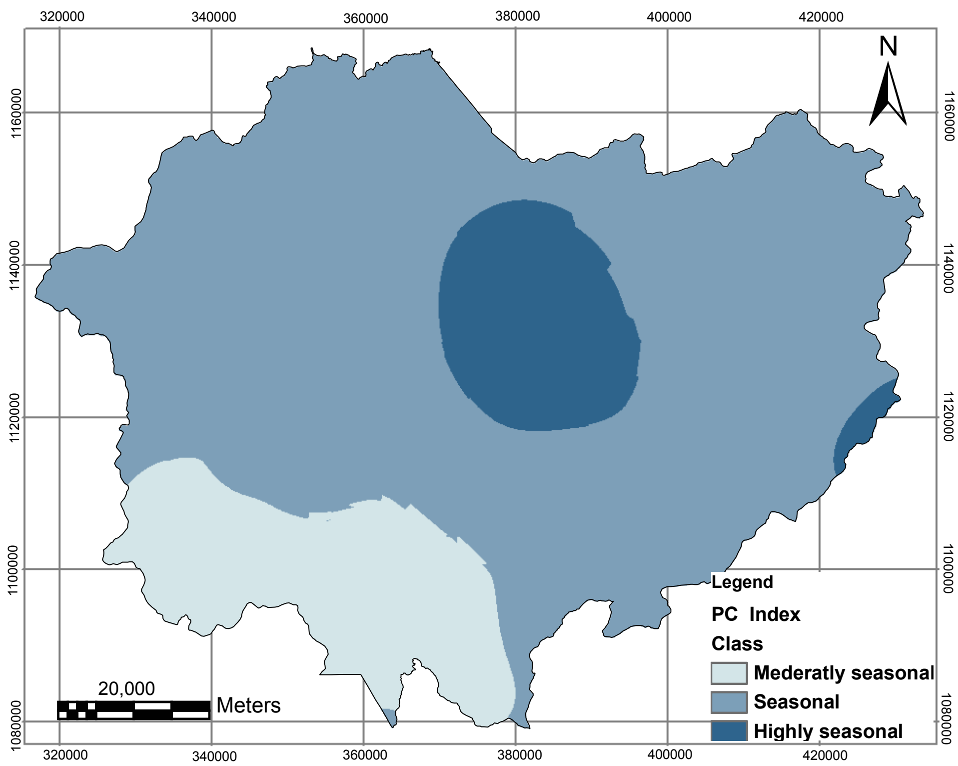


Figure 13. Map of precipitation concentration index in Torres Municipality, Venezuela

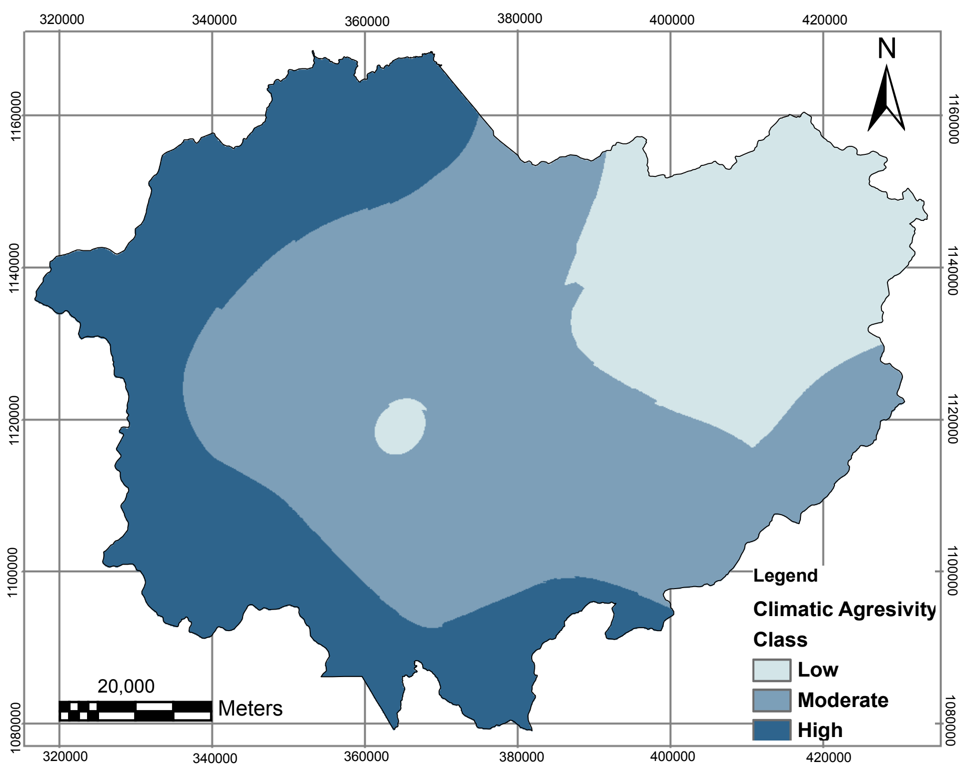


Figure 14. Map of climatic aggressiveness in Torres Municipality, Venezuela

Table 7. Climatic demarcations of the Torres municipality

MCC	S	A	T	ET_0	P	SP	DM	D	AC	CI	HP
Semiarid	MCsa	416-564	27-28	1250-1296	548-564	....m..asOn.	7-11	0-810	Moderate to High	Seasonal to Highly seasonal	Semiarid
Dry Subhumid	MCdsh	511-921	26-28	1186-1274	663-805	….m..asOn.	4-11	0-637	Moderate to High	Highly seasonal	Dry Subhumid
Humid Subhumid	MChsh	725-1524	24-27	725-1521	820-1060	…am..asOn.	2-10	67-433	Moderate to High	Seasonal	Humid Subhumid
Humid	MCh	1398-2324	19-23	870-1060	1017-2324	…am…sOn.	3-7	28-474	High	Seasonal	Humid

MCC: Mixed Continental Climate S: Symbol E: Elevation (m.a.s.l) T: Temperature in °C
ETo: Evapotranspiration (mm) P: Precipitation (mm) SP: Seasonal pattern DM: Dry months D: Deficit in mm AC: Aggressiveness of the rain CI: Concentration of the rains HP: Humidity provinces

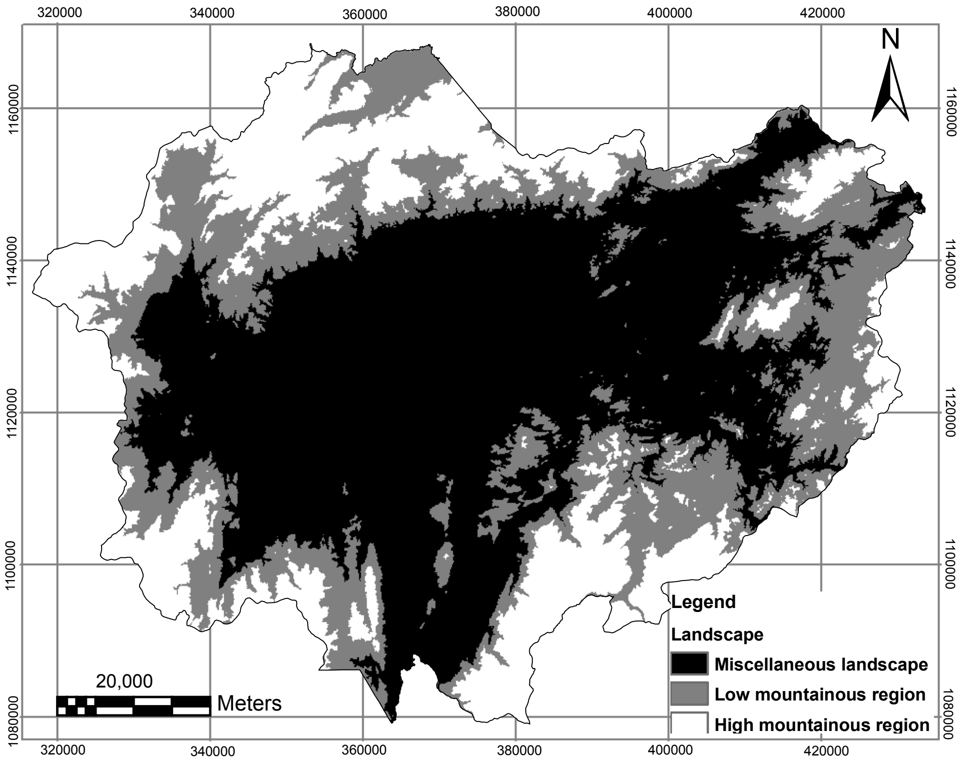


Figure 15. Type of Landscape in Torres municipality, Venezuela

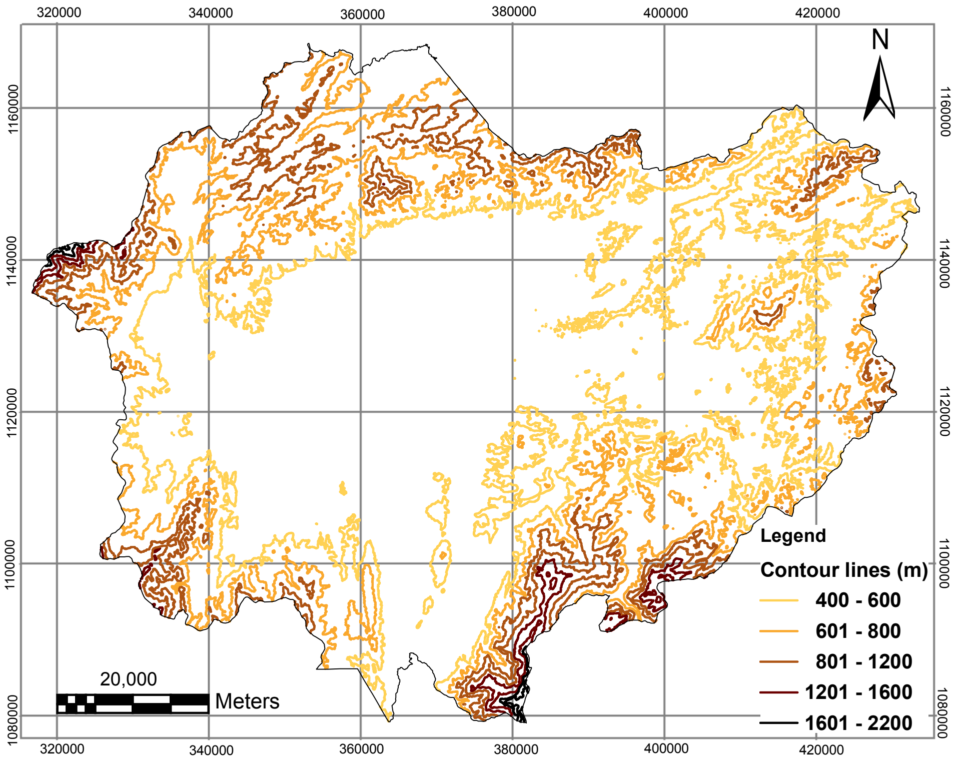


Figure 16. Contour lines in Torres municipality, Venezuela

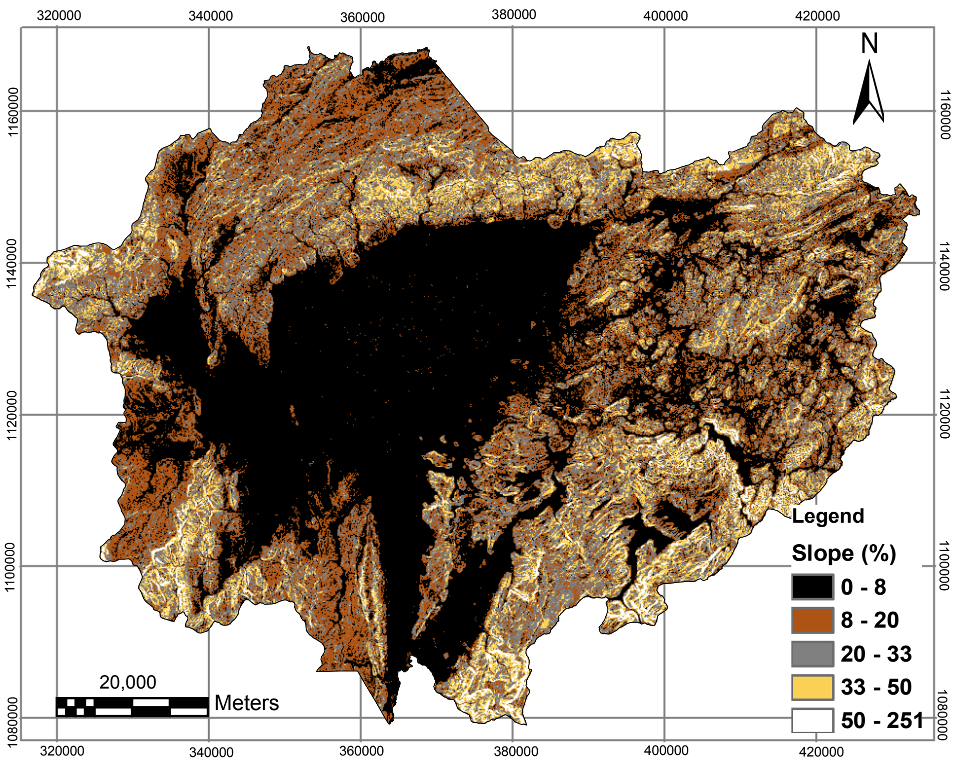


Figure 17. Slope map of Torres municipality, Venezuela

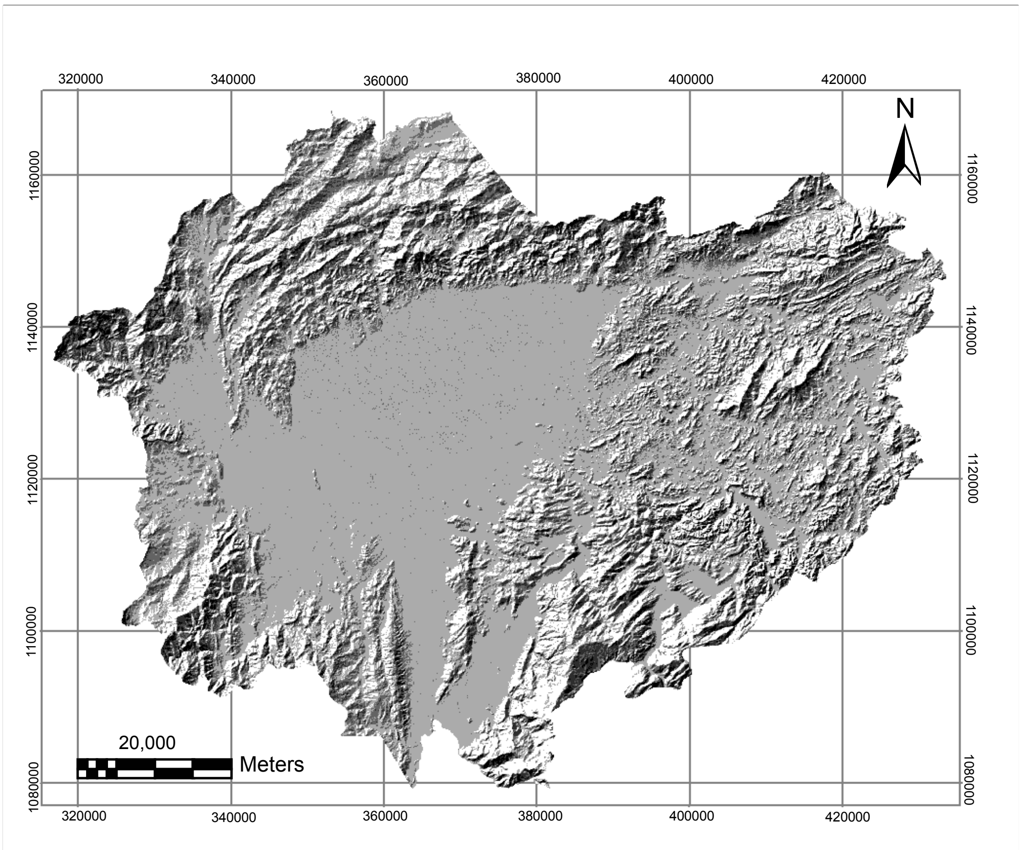


Figure 18. Shaded relief (hillshade) map of Torres municipality, Venezuela

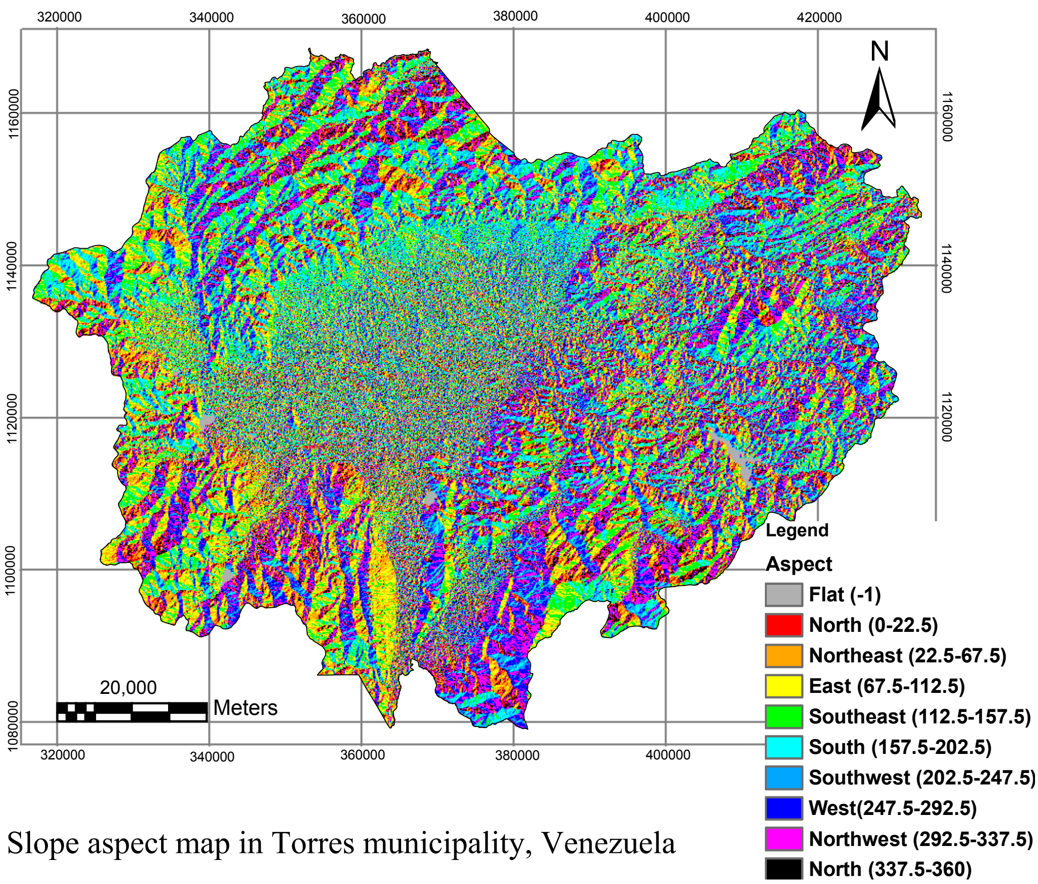


Figure 19. Slope aspect map in Torres municipality, Venezuela

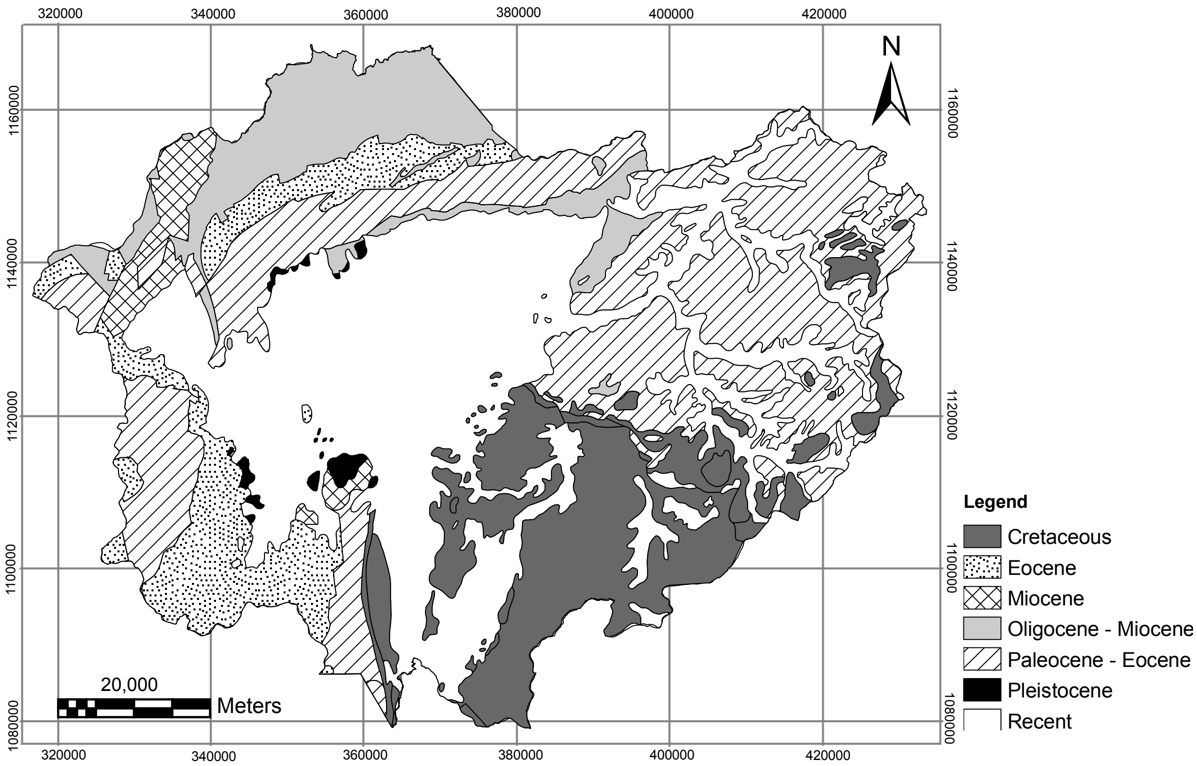


Figure 20. Geological map of Torres municipality, Venezuela

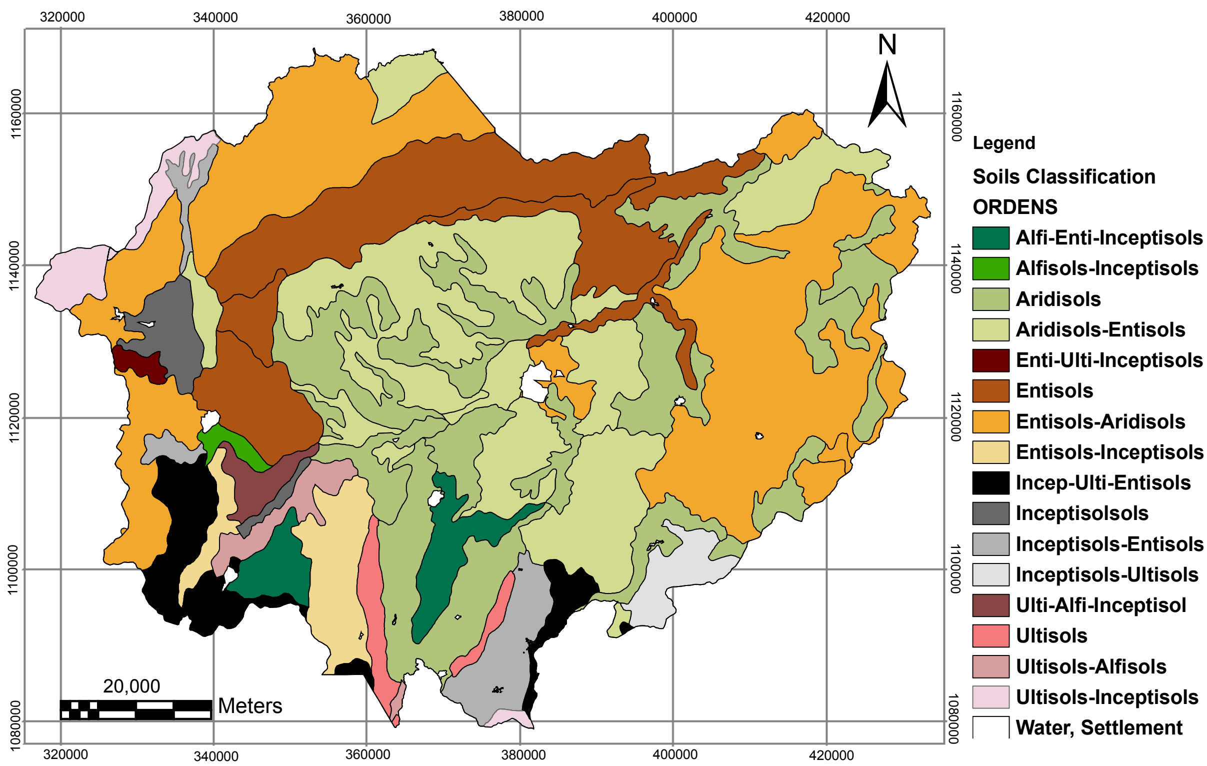


Figure 21. Soils map of Torres municipality, Venezuela

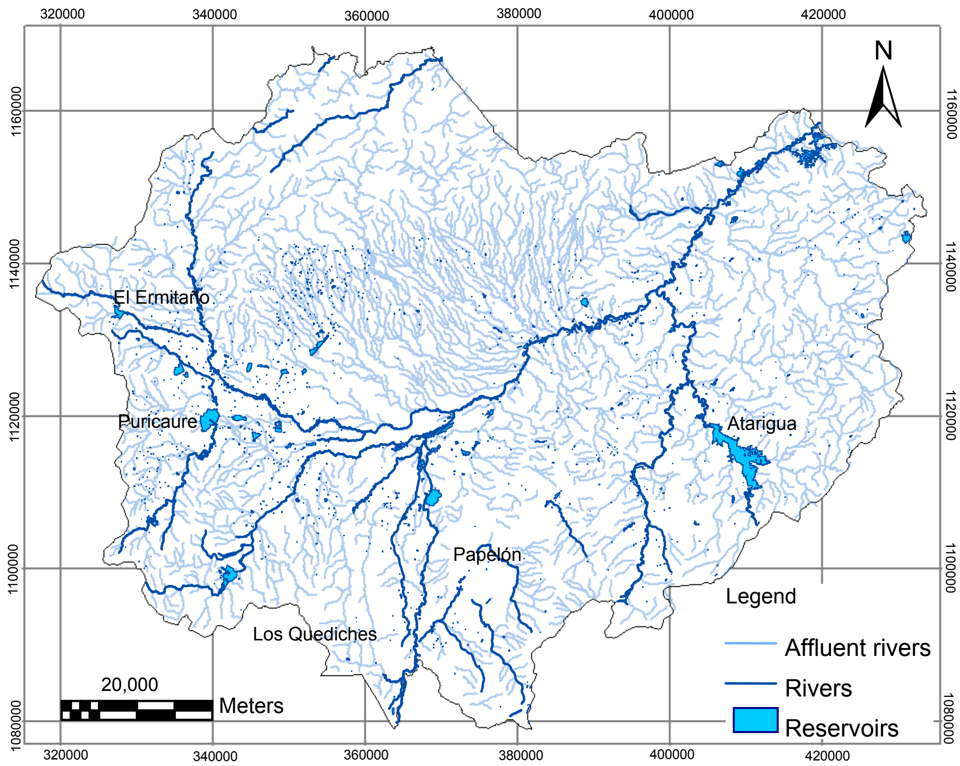


Figure 22. Reservoirs and Rivers in Torres municipality, Venezuela

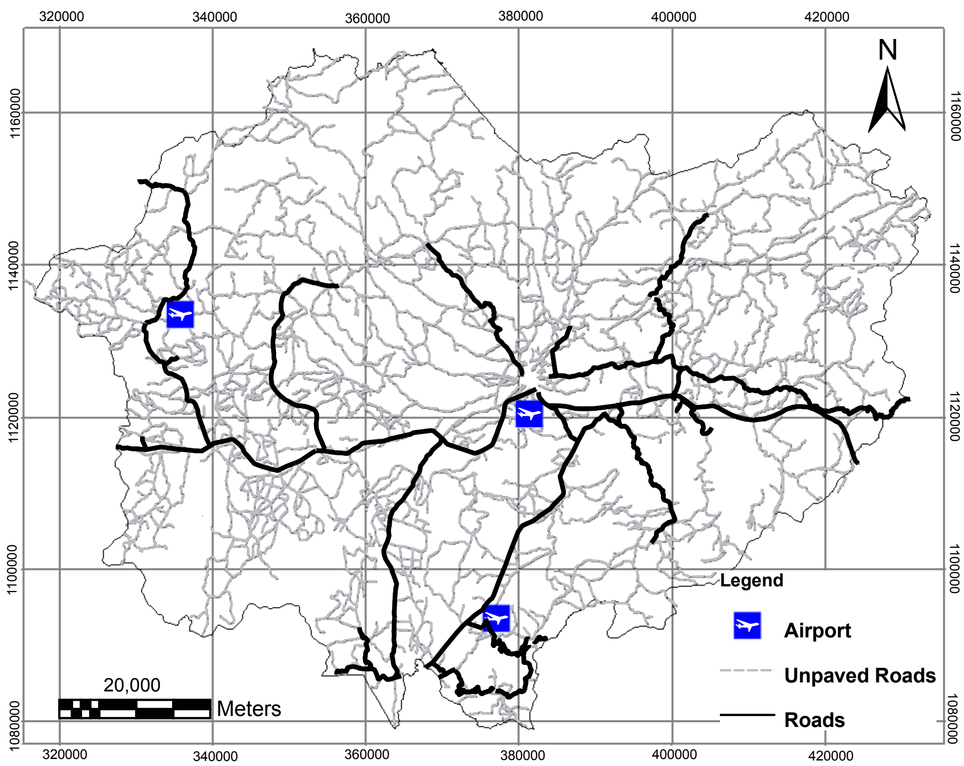


Figure 23. Main roads and Airports in Torres municipality, Venezuela

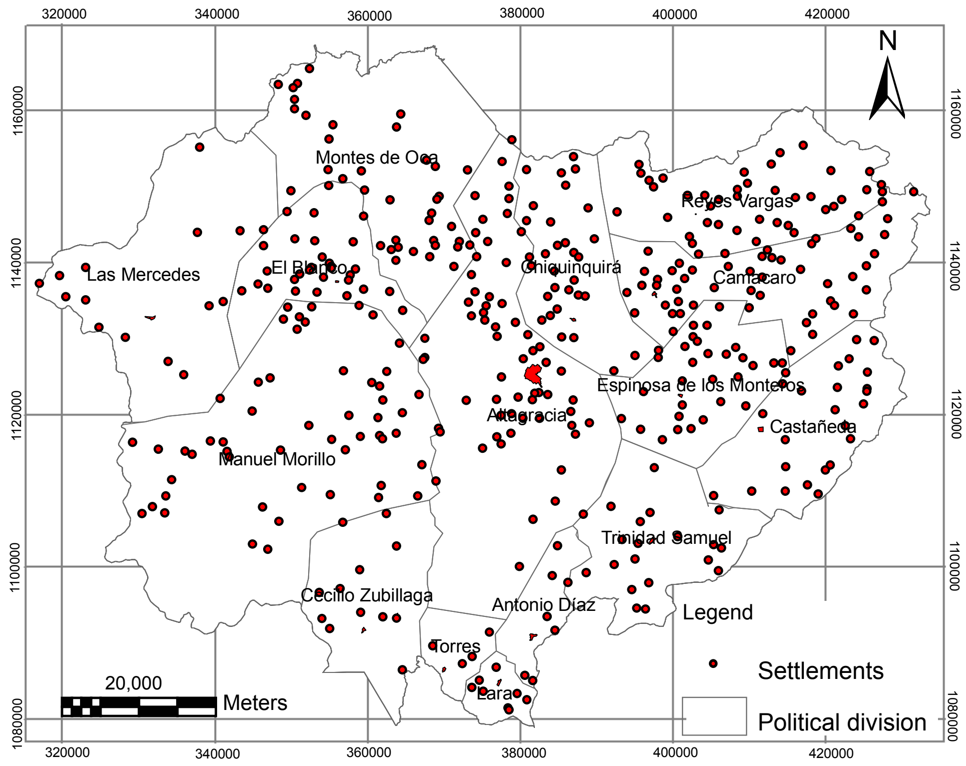


Figure 24. Settlements and political- administrative division of Torres municipality, Venezuela

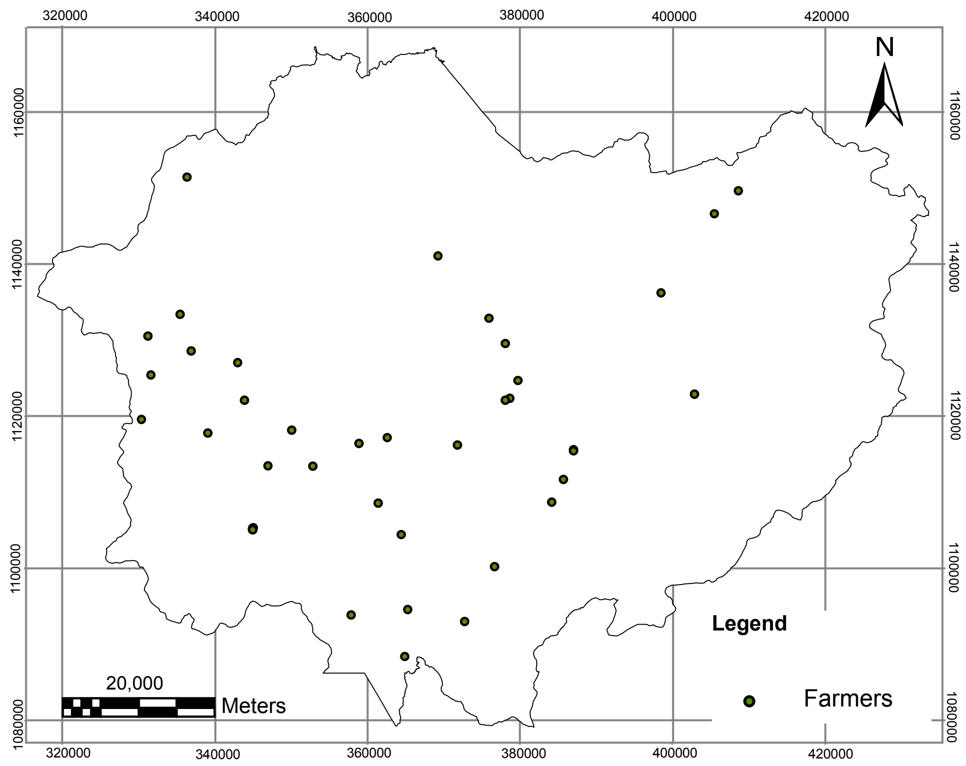


Figure 25. Location of the farmers who were interviewed in Torres municipality

IV. Discussion

1. Climate

Municipality Torres climate can be defined as mixed continental with accentuated irregularity of the rain regime and with negative water balance (P/ETo)[9] through the year. The climate is warm, except for the mountains. It shows a seasonal pattern of bimodal rain, with a short rainy season from April to May and another longer from August to November with peak in October. Dry season occurs between both rainy seasons. This period varies according to humidity province and it is known as "veranito of San Juan". Water balance ($P/ET_{0)}$ establishes certain changes in the humidity regime, which give rise to four humidity provinces or climatic demarcations: semiarid, dry subhumid, humid subhumid, and humid. The average annual precipitation ranges around 548 and 2334 mm, temperatures of 19 to 28 °C and ETo that varies between 725 and 1250mm. During the day, the radiation of the sun generates a thermal energy of 1.94 cal/cm^2/seg.

2. Physiography

The physiography is the study of physical features of the earth surface. It can be delimited in areas, known as landscapes, differentiated by geographical characteristics as location, relief, topography, and physiographic position. Three classes of landscapes can be distinguished in Torres Municipality: high lands (above 800 m.a.s.l), intermediate-elevation lands, and low lands (below 130 m.a.s.l.) (Ferrer and de Paz, 1985). In the Torres municipality, the high lands are represented by the high mountains region of the Andes (South) and low mountains region of Matatere and Bobare. Tocuyo, Guarico, Portugesa and Cojedes rivers rise in Los Andes. The relief is rugged in elevation higher than 1000 m.a.s.l., occasionally flat in valleys and terraces. The percentage of slope can be higher than 20 %. In the small mountains region, the relief does not exceed the 1000 meters and the topography is also rugged (slope of 8 to 20 %). Most of the hydrology is linked to Tocuyo river basin. The intermediate-elevation lands are represented by grounds of alluvial origin. They are “miscellaneous landscapes” because flat, undulating or rough lands may be found together, therefore it is not possible to generalize its distribution. These types of landscape are known as hill foot and depressions.

[9] quotient that indicates the balance between the entrance of water in rainfall (P) and the loss of water in evaporation (ET_0) (Thornthwaite, Ferrer, 2003).

3. Geology

The geological, litologic and geomorphologic aspects constitute a facet of the environmental analysis, to deduce the origin and forms of the landscape, the formative process of the soils, drainage networks design, etc. Three geological eras are present in Torres Municipality, Secondary (superior and inferior Cretaceous periods), Tertiary (Eocene, Palaeocene, Oligocene and Miocene periods) and Quaternary (Pleistocene and Recent periods). Recent (Qr) is localized in the depressions (geomorphologic position). Gravel, sand, clay and alluvial silt are the fundamental components. Toward the mountainous zones or terraces are located the other geological periods. Pleistocene (Qp) can be from clays, silts and/or sands to gravel mixed or badly chosen, whereas in Eocene/Palaeocene dominate the sandstones, lutites, crystalline limestone (dolomite occasionally), calcareous sandstone or quartz and conglomerates. Miocene/Oligocene ((Tmo) predominates in mountainous fronts and uphill. Its mineral composition is characterized by sandstone, lutites, clays, loams, etc. Zones formed during the Cretaceous (Ks and Ki) are characterized by stratified and laminated ferric calcareous lutites, limestones, lutites, etc.

4. Soils

The formative factors of the soil in the municipality are variables. Climate, parental material, vegetation, topography and time have influenced in their variability.

-Semiarid region

The soils in the mountainous areas are not deep; possess large content of stones and rocky outcroppings. There is a predominance of soils with low pedogenetic development of the Order Entisol, Suborder Torriorthens (< 90 days consecutives with humidity, aridic humidity regimen), the Order Inceptisol and Order Aridisol (soil of arid and semiarid), Suborder Orthids (low mineral alteration and can be cambic, calcic, gipsic, petrocalcic or salic horizons). In the Inceptisols and Aridisols, the soils are deeper. The majority of these soils are present in the mountain region of Matatere and Baragua (North of the municipality). In the flat area or depressions, the most prominent soils formative process is the movement of carbonates, gypsum and other salts. A cambic "B" horizon is generally formed.This causes soils from Great Group Camborthids and in smaller grade Calciorthids (calcic horizont) or Salorthids (salic horizont).

- Subhumid and humid region

Geology, climate and topography area the most determinant factors in the soil evolution. The soil profile has a large pedogenetic development. The soils in the mountainous areas are similar to the semiarid region, but the movement of clays from A horizon to B is greater. There is predominance of Alfisol (argilic horizon and moderate to high contents of bases as calcium, magnesium, sodium and potassium) and Ultisols (Ustalfs, Udalfs Ustults and Udults Suborders). In the sectors where predominate limestone may be detected a molic (high contains of bases) on cambic horizon (Tropepts and/or Ustolls Suborders). In the areas with young soils located in the depressions, valleys or banks of rivers dominate Inceptisoles (Ustropets, >90 days consecutives with humidity) and Entisoles (Fluvents Suborder, soils on alluvial deposits).

5. Hydrology

Tocuyo River is the biggest hydrologic system in the municipality. Water from Tocuyo river or from some tributary are conducted to form the reservoirs Atarigua, El Hermitano, Los Quediches, Puricaure, El Papelón and small pounds. The municipality counts also with 7 small systems of irrigation that imply around 600 hectares under irrigation. These are potential options for the growth of the agricultural surface.

6 Roads and airport

In the area of studies there are 3 airports inside the agricultural zone. The municipality also has a good net of highways and roads. Access into the agricultural units does not suppose to be a problem.

7. Settlements and political boundaries

Torres municipality has 425 little settlements. The population density is 23.59 people /km^2 and limits with the following municipalities: by the North with Buchivacoa and Dabajuro (Falcón state), by the South with Morán (Lara state) and Carache (Trujillo state), by the East with Iribarren and Jiménez (Lara state) and by the West with Valmore Rodríguez and Baralt (Zulia state). The municipality is divided into 16 parishes; Trinidad Samuel, Antonio Díaz, Camacaro, Castañeda, Cecilio Zubillaga, Chiquinquirá, El Blanco, Espiniza de los Monteros, Lara, Las Mercedes, Manuel Morillo, Montaña Verde, Montes de Oca, Torres, Reyes vargas and Altagracia.

8. Land utilization type

Sugar cane (*Sacharum sp.*) is the main crop in the municipality, accounting with 52% of the agricultural surface. The farmers are Venezuelans, they work in family, have a good level of instruction and they are organized in associations or cooperative. The farmers are owners of the land and the size of the unit of production varies among 1.5 to 20.000 has. Farmers work with crop rotation and utilize seedbeds for sugarcane and vegetables. The sowing is manual, occasionally mechanized. Land preparation is mechanized. Farmers in mountainous areas deforest and burn the natural vegetation. The control of plagues, diseases and weeds is biological, chemical and manual (weeds). The crops are fertilized with organic or chemical manure, but very few producers carry out soil analysis. Almost all the farmers utilize irrigation. The used water comes from rains, rivers, gaps, deep wells and reservoirs. The method of irrigation used is by gravity or furrow. The water of irrigation contains large content of Ca, Mg, Na, carbonates, etc. The agricultural products are oriented toward the national market.

V. Conclusions

Combined use of spatial technologies (GIS, DEM and Remote Sensing), analogue and digital maps, meteorological data, and field visit, turned out to be successful in generating information and mapping of environmental parameters and socioeconomics. All this information is necessary to achieve a land evaluation based on FAO model for rainfed agriculture in Torres municipality.

Climatic data from 33 meteorological stations, equation calculations, and Kriging interpolation technique were used for mapping several parameters which define the climate of the study area. Eight thematic maps were obtained: isohyets, isotherms, evapotranspiration, concentration of the precipitation, aggressiveness of the rains, humidity provinces, seasonal patterns, and number of dry months. The climate has four climatic demarcations: semiarid, dry subhumid, humid subhumid and humid. Five physiographic maps were derived from digital elevation model: landscape, contour lines, slope, aspect and shade of relief. Three types of landscape were differenced, high and low mountains region (above 800 m.a.s.l. and rugged relief), and “miscellaneous” landscape formed by depressions and hill food. Non-spatial attributes to the spatial entities in the geological and soils map were enlarged through bibliographical information. In the study area seven geologic ages are present: Superior and inferior Cretaceous, Eocene, Miocene, Pliocene, Oligocene, Pleistocene and Recent. The soils vary from low (Entisols) to high pedogenetic development (Ultisols). The first ones are generally in depressions, valleys, river banks; the second ones in mountains and hills. Thematic maps of hydrology (river and reservoirs), roads, airport, settlements and political boundaries were generated through digitization of analogue maps and brought up to date with an image Landsat (maps overlay). For mapping procedure (Edition) the point theme “Land Use Type” was obtained from a survey applied to 60 farmers. Attributes table of this map contains technical, social, and economical information necessary to make the land evaluation.

Chapter 3. Land use / land cover classification in Torres municipality

I. Introduction

1. Vegetation in Torres municipality

The basic criterion for a vegetation classification is related to the class of cover that represents each type of physiognomy (Ferrer and de Paz, 1985).

Map of Vegetation of the Western Central Region (Ferrer and de Paz, 1985) indicates the different classes of physiognomy of the natural vegetal cover in Torres municipality are: forest, bushes or "matorral", and pricking (prickly xerophilous vegetation). Description of every class is the following:

Dense forests: plant communities whose canopy covers more than the 75% of the soil, occasionally can show clear zones which interrupt the continuity of the cover. These clear zones have better conditions for species in the forest undergrowth because of sun lighting.

*Open forest: c*ommunities in which the top of the trees form a not much compact canopy. Forest undergrowth is frequently much denser than the forest. Plants in forest undergrowth possess thin and small trunks. Open forests are characteristic in landscapes with a favorable balance of humidity for 3-6 months in the year. Seventy-five percent of Torres municipality should have this biome because of environmental conditions. Nevertheless, 65% of this kind of forest has been eliminated (Ferrer and de Paz, 1985). The forests that still remain exist because either are located in protected areas, or are located in inaccessible places (either by effect of topography or due to absence of roads). Areas formerly occupied by these forests have been destined to grassland or to the agriculture.

Bushes or thickets: natural communities composed by small and large bushes. These bushes have ligneous consistency, without a predominant trunk, and ramified from the base. Bushes cover all the surface of the soil in a variable density. They are characteristic in lands with severe climatic limitations, especially where humidity deficiency takes place for more than 9 months in the year. The thickets are characteristic in the province of humidity called Semiarid. The small bushes (average height <2 m) are located in the dry hills of the municipality, where rocky and waterproof soils, or very permeable sandy soils are predominating. Therefore, distribution of small thickets is considered to be related not only to climatic limitations, but also to soil constraints. Tall bushes are either "always green" or deciduous. Bushes and the prickly vegetation form an extensive band, where species of both are present. Abundant presence of species possessing thorns offers an appearance of a different type of bushes, therefore it is sometime called "thorny bushes", but, indeed it is not a different type of bush. Threats on this class of physiognomy are free grazing from goats, and burning for establishing pasture lands and cultivations. This management destroys the thicket and gives rise to rapid erosive processes that destroy the possibility of regeneration of the bushy cover, because of little humidity and abrupt or wavy topography.

Prickly xerophilous vegetation: communities conformed by individuals possessing thorns. They are characteristic of the dry zones (semiarid and dry climate), they do not cover all the soil, neither their tops form a continuum canopy. The plants can be arborescent, bushy or herbaceous, and of ligneous or succulent consistency. The prickly xerophilous vegetation is poor in diversity; however density and biomass change radically in the rainy season. In this vegetation can be distinguished two types of plant forms: tall prickly xerophilous vegetation or small prickly xerophilous vegetation. In the tall prickly vegetation predominates species with a height >2 m, arborescent or bushy, and located where the topography is slightly flat or smoothly wavy and the soils are deep. Columnar cactus and legumes with thorns are the most characteristic plants in this category, and cover about 50% of the soil. Small prickly vegetation is composed by herbaceous and bushy plants. It is presented in areas characterized by broken topography, or in the margins of the area occupied by tall prickly xerophilous vegetation.

These natural vegetal cover occupy less than the 50% of the regional surface. The remainder is covered by different types of communities that show a various range of density and forms of distribution, under the denomination of pasture or grassland, cultivations, stubble and land in disuse, dispersed vegetation (ephemeral), bare lands, and urbanized sectors.

Vegetation studies are important for planning strategies in land sustainable management. To aim this objective, determination and monitoring of vegetal cover are necessary.

2. Remote sensing

2.1. Concepts, definitions and generalities

Remote sensing is the technique that permits to obtain information on a object, area, or phenomenon through of analysis of acquired data by an instrument that is not in contact with the object, area o phenomenon under investigation; *remoter sensors* are devices which can collect information about an object from a distance, without touching it, except perhaps with energy emitted from the sensor; *satellite* is spatial station that contains the sensor, which has been placed into orbit to collect information (Chuvieco, 1996). A *remotely sensed image* is an abstraction of the real word (scene) and the objects which constitute the scene (Ferro and Warner, 2002). Remote sensing include numerous applications such as exhaustive and global cover of the terrestrial surface, pan perspective of large spaces (millions of km^2), observation multi-scale (1 m^2 to millions of km^2), information on not visible regions of the spectrum (infrared medium and thermal or micro-waves), repetitive cover, transmission immediate and digital format (Scott, 1997).

2.2 Physical principles

The three main elements of the remote sensing are: the *sensor*, the *observed object* (terrestrial cover) and the *energy flow* that relates them and permits to detect the object. The three forms of acquiring information from a remote sensor are: by *reflection*, *emission, and emission - reflection*. In any of these cases, the energy flow among the cover and the sensor constitutes a form of *electromagnetic radiation.* Electromagnetic radiation is organized in bands of *wavelengths* or *frequency* of similar behavior. The organization of these bands is called *electromagnetic spectrum.* In remote sensing, denomination and amplitude of the bands vary according to different authors, nevertheless the terminology and bands more used are: *visible*, with three elementary bands, called *Blue* (*B, 0.4- 0.5* µm), *Green (G, 0.5-0.6* µm) and *Red (R, 0.6-0.7* µm); *Near-infrared (IR, 0.7-1.3* µm); m*edium- infrared*, with two bands, the first between *1.3* and *2.5* µm called *Shortwave Infrared (SWIR*), the second understood among 3.7 µm, acquaintance exactly as M*edium Infrared* (MIR), *Thermal Infrared* (*TRI, 8-14* µm) and *micro-waves (M, above 1 mm).* The proportion of the flow incidence that is reflected, absorbed, and transmitted depends on the characteristics of the surface that is observed, on the wavelength to which is observed, and on the atmosphere. Therefore, to characterize a specific cover is useful to know its reflective behavior in diverse wavelengths since that will facilitate the discrimination against similar spectral covers (Robin, 1998).

2.3 Resolution, Sensors and Satellites

The *resolution of a system sensor* is defined as the ability to discriminate information of detail (Estes and Simmonett, 1975). *Discrimination* refers to the ability of distinguishing an object of another (Robin, 1998). The *information of detail* refers not only to spatial detail that provides the sensor, but also to number and width of the bands in the spectrum, to its temporary cadence, and to its capacity to distinguish variations in the energy that detects (Campbell, 1996). On the whole, the concept of resolution implies several concepts. The most frequently found in the specialized literature have been:

- *Spatial resolution* appoints smaller object than can be distinguished on an image. The size of the minimum unit of information included in the image is called *pixel (picture element)* and is expressed in meters. A pixel is each one of squares that form an image (Atkinson and Aplin, 2004). The gray or color level that appears in each pixel (as viewed in the computer monitor) is defined as the *numerical value* or *digital number* (DN*),* which corresponds to the codification of radiance detected by the sensor when acquires the image. The spatial resolution is related to the work scale and to the reliability of the interpretation: the smaller is the pixel size, the smaller is the probability to have two or more covers in one pixel (Chuvieco, 1996).
- *Spectral resolution* indicates the number and width of the spectral bands that the sensor can discriminate.
- *Radiometric resolution*, it is related to the sensibility of the sensor, to its capacity to detect variations in the spectral radiance that receives. Commonly this resolution is the number of *bits* that need each element of the image for being stored (8 bits, 2^8 = 256 levels of codification or levels of gray by pixel).
-*Temporal resolution*, this concept is related to the frequency of cover that provides the sensor.
- *Angular resolution*, it is a recent term and refers to the capacity of a sensor to observe the same zone from different angles.

In relation to procedure to receive the energy originating in different covers, the remote sensors can be *passive* (receive the energy from an exterior focus) and *active (*capable of emitting their own energy, as the radar). According to the procedure to record the received energy, the passive can be *photographic* (cameras), *optic-electronic,* and *of antenna* (radiometers of micro-wave). The optic-electronic can explore with *scanners* (a mobile mirror, which oscillates perpendicularly to the direction of the path, permits to explore a stripe of land to both sides of the plan of the satellite) or *pushbroom* (chain of detectors that covers all the field of vision of the sensor).

The satellite in function of its orbit can be *geosynchronous or stationery* and *heliosynchronous*s or *mobile.* The first is placed in very far away orbits of the land (36000 km on the Equator) and observe always the same zone. The second is placed in lower orbits to observe systematically different zones of the planet.

At the end of the sixties the American spatial agency designed the satellites family called Landsat. It was the first project dedicated exclusively to the observation of the natural resources. Good resolution of their sensors, global character, reports of the observations and suitable commercialization, explain their use in various knowledge field worldwide. A new sensor (type scanner, called Enhanced Thematic Mapper plus or ETM +) was incorporated to the last Landsat (7) launched in April 1999. This sensor records information on the seven bands previously used in the other Landsat (visible, near-infrared, infrared, thermal spectrum) and additionally was added the possibility of recording other type of information which is received in the so-called panchromatic band. This band possesses a resolution of 15m and furthermore enlarges the resolution of the thermal band to 60 m (Table 8).The inclusion of the panchromatic channel has great utility to obtain cartographic products of high quality, applying data fusion techniques. The satellite has a heliosynchronous orbit with a 98.2 degree inclination and an altitude of 705 km. It has a swath width of 183 km and repeats coverage interval in 16 days.

Table 8. Characteristics of the sensor ETM+

Band Number	Spectral range (μm)	Ground resolution (m)
1	0.45 – 0.52	30
2	0.52 – 0.60	30
3	0.63 – 0.69	30
4	0.76 – 0.90	30
5	1.55 – 1.75	30
6	10.4 – 12.5	60
7	2.08 – 2.35	30
Pan (8)	0.52 – 0.90	15

2.4 Interpretation of the data

Images can be interpreted *digitally* or *visually*. The *digital* processing is based, almost exclusively, on the radiometric intensity of each pixel for the used bands in the interpretation. The *visual* processing incorporates other elements to the interpretation of the image such as *shine* (intensity of energy received by the sensor for a determined band of the spectrum);

color (selective reflectivity of the objects for different wavelengths); *texture* (spatial heterogeneousness of a determined cover), *spatial context* (location of the studied cover as compared to the location of neighbor elements in the image), *spatial patterns (*peculiar organization of the objects that form a determined cover), *stereoscopic vision (*three dimensional vision of the space observed), *shadows*, *form* and *size*.

2 .5 Digital analysis of images

2.5.1 Correction, enhancement, and visual improvement of the image

Visual enhancement and *improvement* improve the quality of the image. Several techniques are included in this process, such as *adjustment of the contrast* (adaptation of the radiometric resolution of the image to the capacity of the monitor of viewing), *compositions in color* (to visualize information of different regions of the spectrum simultaneously, facilitating visual delimitation of covers), *use of the pseudo-color* (creation of a color look up table associating level of gray to different components of red, green and blue), and *filtering* (to isolate components of interest). The *corrections* of the image include those procedures that tend to eliminate any anomaly detected in the image, either in their location or in the radiometry of the pixels that compose it. This procedure is necessary whether the results suppose to have cartographic validity or they will be connected to other (Chuvieco, 2002). *A geometric correction* tends to reconstruct the radiance detected by the sensor from the digital levels (levels of codification or levels of gray) of the image. This type of correction includes: *restoration of lost lines or pixels*, *elimination of bands in the image, calculation of reflectivity* (atmospheric corrections, topographical shadow, etc.), *calculation of temperature* and *detection of clouds*. A *geometric correction* of the image includes any change in the position (coordinates) that occupies the pixels that form it. The correction can be done from orbital models, from points of control, and with digital models of elevation (Emery et al., 1989).

2.5.2 Extraction of thematic information

Several techniques exist for extracting thematic information from the images such as *quotients,* also called *vegetation indexes* (VI). For obtaining a quotient, digital levels of different bands in every pixel are considered. The use of the quotients to discriminate vegetable masses is derived of the peculiar radiometric behavior of the vegetation. Reflectivity of healthy vegetation displays a contrast between bands of visible spectrum (especially the red band) and near-infrared. Leaf pigments absorb most of the energy coming from visible spectrum, whereas it does not occur for near-infrared spectrum. Therefore a notable spectral contrast results from the low reflectivity of the red band as compared to the high reflectivity of the near-infrared band. The higher is the difference in reflectivity between these two bands, the higher is the vigor of the cover. This phenomenon permits to separate easily the healthy vegetation from other covers. Low contrast indicates either sick vegetation, or senescent vegetation, or non-dense vegetation, or soils, or water because of similar reflectivity for both bands R and IR. Lower contrasts can be recorded for water and clouds (Chuvieco, 2002). Most of the vegetation indexes are supported in this principle. The most employed are the simple quotient (C) among the bands R and IR and the called *Normalized Difference Vegetation Index* (NDVI):

$C = P_{i.IRC} / P_{i.R}$ (1)

$NDVI = P_{i.IRC} - P_{i.R} / P_{i.IRC} + P_{i.R}$ (2)

Where $P_{i.IRC}$ and $P_{i.R}$ indicate the reflectivity of pixel *i* in the band of IR and of R, respectively.

The values of index range from -1 to 1. The common range for the green vegetation is 0.2 to 0.8 (Chuvieco, 2002). These indexes are obtained from the reflectivity, for example, of the bands 7 and 5, for the case of the sensor MSS (Multispectral Scanner); and the bands 4 and 3 for the sensors TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper plus) in Landsat satellite.

Generally, when these indices are used, the atmospheric and geometric correction of the image is not considered, employing the digital number (DN) of the image (Sánchez and Chuvieco, 2002). NDVI is not really a complete land cover classification, but if the type of vegetation is the primary concern, these are very useful and often sufficient (Eastman and Fulk, 1993).

2.5.3 Digital classification and phases of assignment

In this process, the multi-band image is transformed into another image of the same size and characteristics of the original, but the pixel does not have reference with the radiance detected by the sensor, but with the category assigned to that pixel (Campbell, 1996). The methods of classification have been divided traditionally into two groups: *supervised* and *unsupervised*. For supervised classification, a prior knowledge of the land is necessary and requires that the user selects *training field* or *training areas* (samples of pixels from an image, which represent adequately the categories of interest) for using as the basis of classification. Several comparison methods are used to determine whether a specific pixel qualifies as a class member, such as *Parallelepiped, Maximum Likelihood, Minimum Distance, Mahalanobis Distance, Binary Encoding, and Spectral Angel Mapper*. The unsupervised method is an automatic search for groups of homogeneous values (*clusters*) inside the image. It uses statistical techniques to group n-dimensional data into their natural spectral classes. The methods used in this classification are *K-Means* and *Isodata*. Isodata calculates class means evenly distributed in the data space and the iteratively clusters the remaining pixels using minimum distance techniques (Chuvieco, 2002).

In the phase of assignment, each pixel is assigned to one of the classes previously selected. Maximum Likelihood is the criterion most used in the digital classification of images and in the assignment phase. This classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class (Chuvieco, 2002). Their limitations of calculation and demand in the normal distributions of the data has done that alternative criteria less sensitive to these requirements be sought. One of the simplest, but also more efficient methods of alternative classification is the so-called *Decision Tree Classifier*.

Decision Tree Classifier is a no-parametric method that uses a series of binary decisions to place pixels into classes. Each decision divides the pixels of the image into two classes based on the answer "Yes" or "No" to the expression of a variable. Each new class can be divided into two more classes based on another expression. As many decision nodes as necessary can be defined. Different data types (e.g. spectral values spectral, textural or temporary variables of the image or map of soils, DEM, etc.) already geo-referenced (it is not the matter neither from which projection come the data nor the pixel size) can be used all together to make a single decision tree classifier (Hansen et al., 1996). The decision can be "pruned" and edited interactively. The results of the decisions are classes. The trees can be saved and applied to other data sets. The following figure (Figure 26) shows an example of decision tree in ENVI 4.3 (Environment for Visualizing Images, USA).

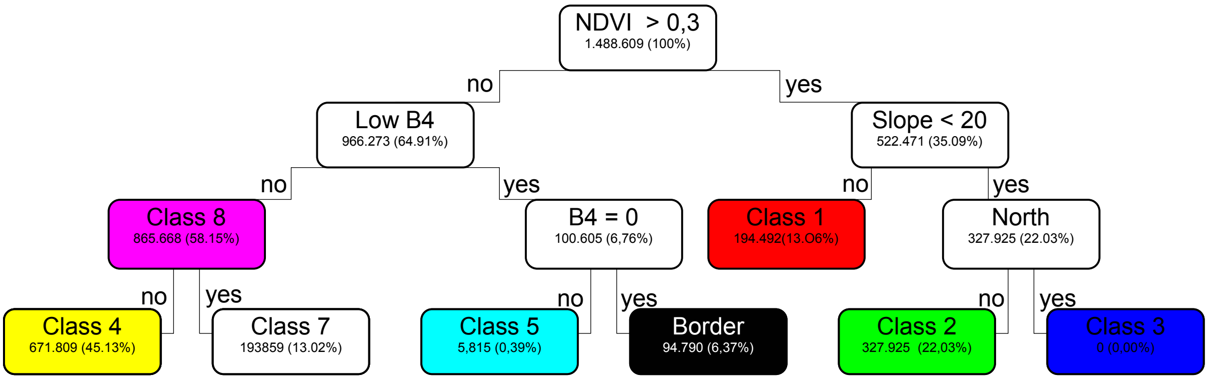


Figure 26. An example of decision tree classifier in software ENVI 4.3.

Decision tree classifier can be considered as a simple example of expert system, very extended in recent years in the techniques of artificial intelligence (Skidmore, 1989). An expert system is formed by an assembly of rules that permits the algorithm to take a series of decisions in function of the values that observes in the image and/or in auxiliary information of the same zone (Chuvieco, 2002). Decision tree classifier has been utilized in recent years successfully in the cartography of vegetal species (Saura and San Miguel, 2001), and cover of the soil (Friedl et al., 1999; Pérez and Noguéz, 2001). A comparative study carried out by Friedl and Brodley (1997) determined the classification accuracies produced by decision tree algorithms and maximum likelihood classification. Results from this analysis showed that the decision tree algorithms consistently outperform the maximum likelihood in regard to classification accuracy.

2.5.4 Post classification processing.

Classified image require post-processing to evaluate classification accuracy, and to reduce the number of classes. Results of this procedure can be exported as image-maps to vector GIS (Anderson et al., 1976). Some software as ENVI (Environment for Visualizing Images, USA), provides a series of tools to satisfy these requirements. For example, *Class Statistics* (to extract statistics from the image used to produce the classification), *Confusion Matrix* (comparison of two images), *Clump and Sieve* (Sieve, to remove the isolated pixels based on a size threshold; and Clump, to add spatial coherency to existing classes), *Combine Classes (*similar classes can be combined to form one or more generalized classes), *Edit Class Color* (to change the color associated with a specific class), *Classes a Vector Layer* (to convert the classified image to vector layer). After any of these procedures, the classified image is a thematic map similar to a conventional map, it means, adjusted to a system of coordinates, with a legend of color that identifies the categories, and a graphic scale.

3. Multi-source data integration and GIS in digital classification

Most of the users of remote sensing have as last objective of their work to integrate the resultant information to other geographical variables. For this purpose GIS, DEM or cartographic variables can play an important role, enriching notably the digital analysis of the image for classification of vegetation (Chuvieco, 1996). This not-spectral information can be incorporated to processing of the image in various phases:

Before the classification: incorporation of a DEM will refine the geometric and radiometric correction of the image, to stratify the image in more homogeneous sectors (bioclimatic or physiographic) (Strahler, 1981).

During the classification: in this phase, additional variables can be helpful to delimit training field (Supervised Classification) and thematic recognition of spectral groups (clusters, in Unsupervised Classification). They can also be incorporated as new bands for the classification, for example a DEM (Franklin et al., 1986).

After the classification: through the GIS can be verified the results. Additional variables can serve to reassign categories, in the event that they have been discriminated only from spectral information (Hutchinson, 1982).

Viewing of results: integration of remote sensing and GIS expands notably the graphic possibilities of the conventional cartography of vegetation. For example, the execution of perspectives in three dimensions of simulated flights from an original or classified image or from a DEM.

4. Application of remote sensing

Remote sensing is an important source of information on land on land characteristics (FAO, 1983; Rossiter,1994) and has several applications, e.g. crop monitoring, natural resources survey and monitoring, planning, energetic projections, highway engineering, archaeology, environment, making and updating of maps (Barrett and Curtis, 1992; Possada, 2000; Chikaoui et al, 2005,). With respect to land evaluation, the most common application of remotely-sensed images is a *land cover classification*, also called a *land use map*. Moreover, there are a several additional applications: to identify land mapping units such as geomorphic forms and ecological zones, update base maps without full field survey (new roads, canals, field patterns, settlements, etc.), to locate specific points of interest to the evaluation (e.g. settlements), to provide *time series* for temporary or seasonal phenomena. The basic idea in land cover classification is that the spectral characteristic in a multi-band image can separate different land uses. That is important in land evaluation because many land uses depend on the presence or absence of certain land cover. Present land cover can be by itself diagnostic for land suitability. Predictive models for land evaluation may require land cover information. A classic example is represented by C factor in the erosion predictive models so-called USLE (Universal Soil Loss Equation) (Wischmeier and Smith, 1978) or RUSLE (Revised USLE) (Anderson et al., 1976).

In several tropical countries, there is a lack of very basic vegetation information which would be needed for effective forest protection and management (Gleitsmann, 2006). Tropical vegetation is typically studied over large areas using medium and low resolution satellite data, most commonly of the Landsat sensors MSS, TM and ETM+ (Ichii et al., 2003, Paradella et al. 1994; Peralta and Matter (2002); Sanchez-Azofeifa et al. 2002). Classifications based on Landsat or similar medium-resolution satellite data can give a first overview over the spatial distribution of the major vegetation units.

5. Objective

The objective was to determine land cover and land use in Torres Municipality, Venezuela, based on information provided by satellite data (sensor ETM +) and a digital elevation model (DEM) in order to generate a thematic map of these parameters necessary for land evaluation

II.Material and methods

1. Data sources

A Landsat-7ETM+ image (WRS-2, Path 6/ Row 53), acquired on 11 November 2000, was obtained from the United States Geological Survey (USGS). This scene was chosen because is very clear over the Torres municipality with not visible atmospheric effects except for a few small clouds. At the time of imaging, the sun elevation was 45°, with an azimuth of 125°. The digital elevation model (DEM) was obtained from Seamless Data Server of the USGS. Additionally, thematic maps previously digitalized (Chapter 1) on 1:100.000 scale of Lara state were available as sources of spatial information and to compare the results.

2. Tools

The software ENVI (Environment for Visualizing Images, USA), version 4.3 was used for the vast majority of image processing and classification in this study. ArcGis.9/ArcView.3.2a (Environmental System Research Institute, USA) and MapInfo 5.5 (MapInfo Professional, USA) were used for the handling and transfer (importing/exporting) of some of the data in vector format.

3. Data pre-processing.

The Landsat image and the DEM were imported into ENVI. In a first step, they were cut according to the coordinates of the study area using the tool "Resize Data". Bands 1 to 7 were resampled to obtain the same spatial resolution as compared to the panchromatic band. This procedure was followed to combine all Landsat channels in one file with a common spatial resolution, and to enable a more accurate geometric correction. This procedure was done using "Nearest-neighbor Resampling". The 8 bands were georeferenced to the Universal Transverse Mercator (UTM) projection, Zone 19 North, WGS84 and corrected geometrically using a set of control points (20) which were identified on a base map of known quality (topographical map of Lara state made by the service of National Cartography of Venezuela) by means of overlay. Topographic effects on the image were not corrected because they were relatively small due to satellite angle. On the whole, the image used appears very clear, without any conspicuous unevenness of atmospheric contamination across the scene, except the clouds (Figure 4, Chapter 2) .No atmospheric correction was conducted. The DEM was imported into the ENVI 4.3. A subset was obtained according to the Landsat image with the same spatial resolution and geographic coordinates (Figure 5, Chapter 2).

4. Classification, phases of assignment and post- classification

The types of land cover present in Torres municipality consisting in dense forest, open forest, brushes ("matorral"), grassland (pasture), pricking (prickly xerophilous vegetation), dense crops, non-dense crops, soils with ephemera vegetation, bare lands and rocks, and settlements were used as basis for the classification. Additional informational classes (land cover types not include in the list of map of vegetation of Torres municipality, but obviously present in the image) were: water, clouds and shadows. Through image enhancement techniques the image visual quality was improved. By means of this improvement, drainages, borders, roads, and settlements were better identified, and additionally improvement of the previously used digital maps was achieved.

These procedures were implemented systematically in several steps of the work, involving: interpretation of bands, for example, band 4 (vegetation, drainage, delimitation water/soil), bands 1, 2 and 3 (water, bare soil, roads etc); coloured compositions in red, green and blue (321; 432; 453; 743 and 543) and method of indexes of vegetation (NDVI) to identify regions without vegetation.

The first classification was achieved by means of Isodata unsupervised classification to obtain an improved set of spectral classes which will be used in the classification. This analysis was carried out on all bands, except the thermal one. The chosen parameters were: 5 and 10 classes, maximal interaction equal to 1, change threshold equal to 5%, minimal number pixel in class and maximal class standard deviation equal to 1, and 5 as minimum class distance. The result of this approach was used to perform the method of classification Decision Tree Classifiers using a series of binary decisions to place the pixels into classes. Data from vegetation index (NDVI), spectral values of the image, and DEM-derived topographic data were used as criteria to achieve the classification. Post-classification techniques Clump and Sieve, Combine Classes and Edit Class Color were applied in ENVI 4. 3, to improve the result of the decision tree classifier. Clump and Sieve functions were used to agglutinate adjacent pixels similarly classified (Clump), and to remove isolated pixels (Sieve) in the image. The applied filter was the filter of median with a 7 x 7 uniform raster. Combine Classes was used to combine similar classes. Finally, the mapped classes were transformed from raster format (with a spatial resolution of 30 meters) to the vector format using Classes to Vector Layers function. Afterward the mapped classed in vector format were exported to ArcGis.9. In this software were made the last adjustments and improvement (i.e. delimitation of some zones and settlements) for the obtaining the land use / land cover map of Torres municipality.

III. Results

The Figure 27 shows the image obtained with the Isodata unsupervised classification. With this method, 7 classes were generated. The Figure 28 shows the image obtained for vegetation index (NDVI). The values of NDVI ranged from -0.69 to 0.65. The best classification by means of Decision Tree Classifiers used the variables NDVI, slope, and the bands 4 (IR), 5(SWIR) and 1 (B). The series of binary decisions (in form of dichotomic decision-maker) that were used as well as the percentage of pixels assigned for each class is s shown in the following page.

Twenty four classes were obtained. The classes were reduced to 13 by the combination of the classes (with Combine Classes Parameter function in ENVI) to obtain the categories displayed in Table 9.

Table 9. Classes and categories of cover obtained with the method of classification Decision Tree Classifier in the Landsat ETM+ image of Torres municipality.

Classes		Categories
Class 7 = Class 18 = Class 30	(23.95%)	Prickly xerophilous vegetation
Class 8 = Class 13	(7%)	Dense forest
Class 9	(1.47%)	Bare soil (Dry)
Class 10 = Class 29	(3.24%)	Bare soil and rocks
Class 11 = Class 25	(1.69%)	Clouds
Class 12	(7.70%)	Grassland
Class 14 = Class 22	(12.85%)	Open forest
Class 15 = Class 24 = Class 27	(16.26%)	Brushes
Class 16 = Class 21	(16.24%)	Bare soil with ephemeral vegetation
Class 17	(0.28%)	Water
Class 19 = Class 20	(3.37%)	Shadow
Class 23 = Class 28	(3.31%)	Dense cultivations
Class 26	(2.57%)	Little cultivations

The category of "Settlement" was added after the classification by means of processes of digitization in ArcInfo.9, because was not at all spectrally separable in the Landsat image.

Finally, the figure 5 displays land cover/ land use of the Torres municipality obtained from the image of Landsat ETM+ by decision tree classifier.

1.a. NDVI value higher than 0.10	(Yes)	………………..	2	
	(No)	………………..	14	
2.a. Slope higher than 3 %	(Yes)	………………..	3	
	(No)	………………..	7	
3.a. NDVI value higher than 0.20	(Yes)	………………..	4	
	(No)	………………..	Class 30	(9.98%)
4.a. NDVI value higher than 0.34	(Yes)	………………..	5	
	(No)	………………..	Class 15	(13.94%)
5.a. NDVI value higher than 0.41	(Yes)	………………..	6	
	(No)	………………..	Class 12	(7.70%)
6.a. NDVI value higher than 0.49	(Yes)	………………..	Class 13	(6.46%)
	(No)	………………..	Class 14	(10.85%
7.a. NDVI value higher than 0.2	(Yes)	………………..	8	
	(No)	………………..	Class 7	(3.27%)
8.a. NDVI value higher than 0.34	(Yes)	………………..	9	
	(No)	………………..	13	
9.a. NDVI value higher than 0.42	(Yes)	………………..	10	
	(No)	………………..	12	
10.a. Band 4 value lower than 110	(Yes)	………………..	11	
	(No)	………………..	Class 23	(0.70%)
11.a. NDVI value higher than 0.49	(Yes)	………………..	Class 8	(0.54%)
	(No)	………………..	Class 22	(2%)
12.a. Band 4 value lower than 80	(Yes)	………………..	Class 27	(0.23%)
	(No)	………………..	Class 28	(2.61%)
13.a. Band 4 value lower than 80	(Yes)	………………..	Class 24	(2.09%)
	(No)	………………..	Class 26	(2.57%)
14.a. Band 4 value lower than 100	(Yes)	………………..	15	
	(No)	………………..	22	
15.a. Band 5 value lower than 71	(Yes)	………………..	16	
	(No)	………………..	19	
16.a. Band 5 value lower than 45	(Yes)	………………..	17	
	(No)	………………..	18	
17.a. NDVI value lower than -0.35	(Yes)	………………..	Class 17	(0.28%)
	(No)	………………..	Class 19	(1.51%)
18.a. Band 5 value lower than 65	(Yes)	………………..	Class 20	(1.86%)
	(No)	………………..	Class 21	(1.24%)
19.a. NDVI value lower -0.28	(Yes)	………………..	Class 9	(1.47%)
	(No)	………………..	20	
20.a. NDVI value lower -0.20	(Yes)	………………..	Class 29	(3.21%)
	(No)	………………..	21	
21.a. NDVI value lower 0	(Yes)	………………..	Class 16	(15%)
	(No)	………………..	Class 18	(10.70%)
22.a. Elevation higher than 500 m	(Yes)	………………..	23	
	(No)	………………..	Class 25	(1.66%)
23.a. Band 1 value lower than 120	(Yes)	………………	Class 10	(0.03%)
	(No)	………………..	Class 11	(0.08%)

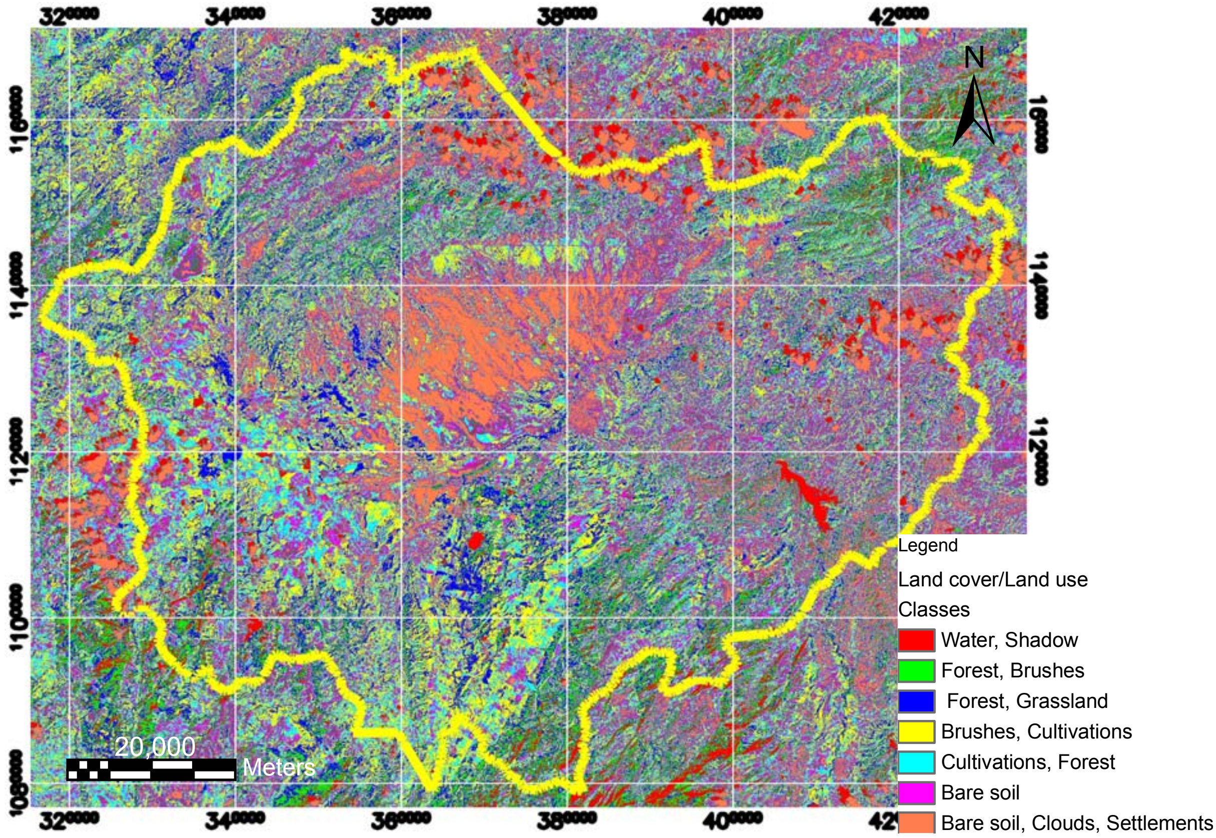


Figure 27. Isodata unsupervised classification image of Torres municipality, Venezuela.

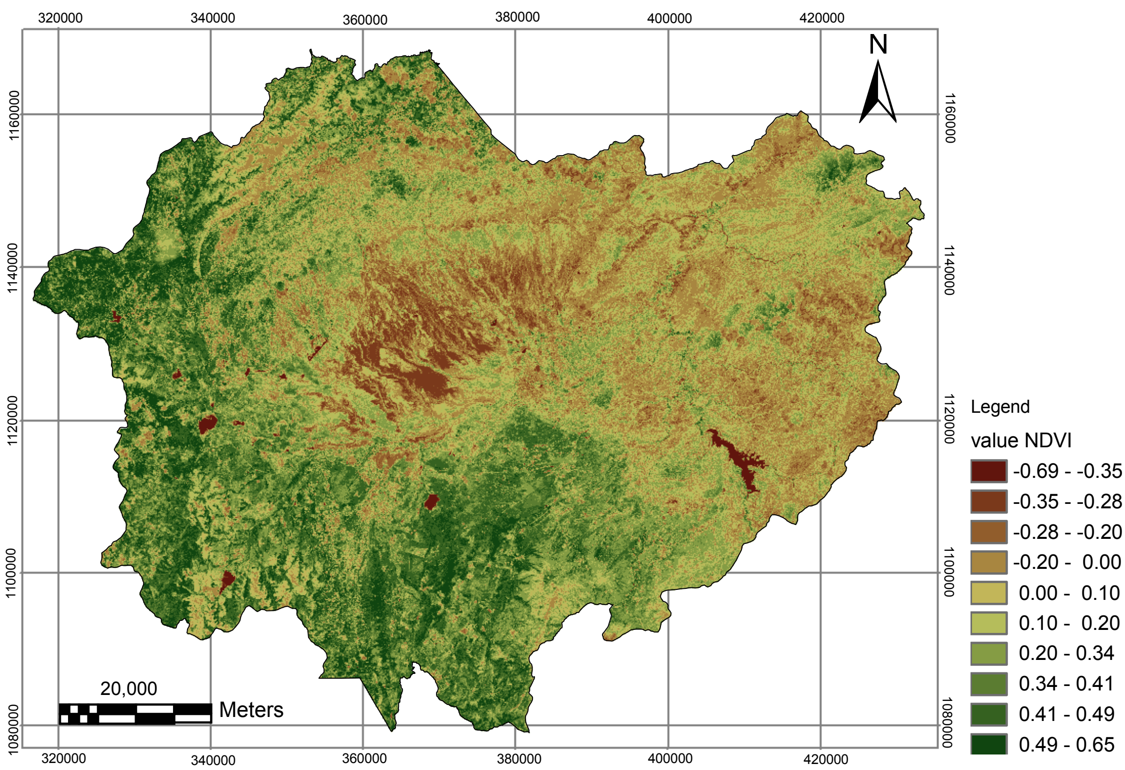


Figure 28. NDVI values image of Torres municipality, Venezuela

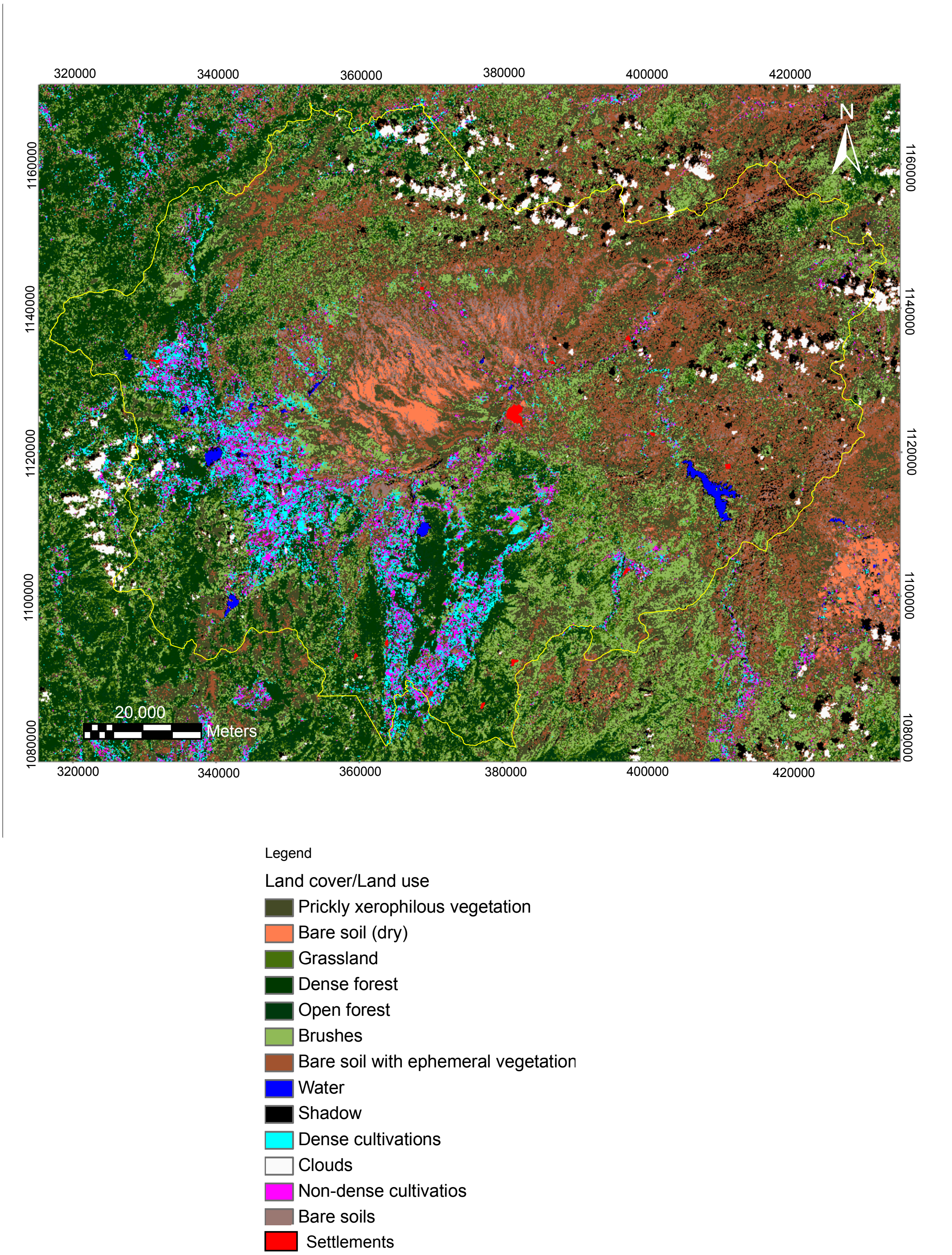


Figure 29. Land cover/Land use in Torres municipality, Venezuela by Decision Tree Classifier

IV. Discussion

1. Isodata unsupervised classification

The algorithm of Isodata unsupervised classification seemed quite adequate to delimit homogeneous values inside the image in this study, supporting the report of Mather (1998). Nevertheless, a spectral mixture of the informational classes (e.g. “water” with “shadows”; “settlement” with “bare soil” and “clouds”, etc) can be seen in the image, and they were not spectrally separable. Perhaps the control parameters were not well defined. The number of spectral groups in the image is not known at the beginning of the classification, neither the ideal value of internal dispersion nor of distance among group. Therefore this analysis became an exploratory process that help to define the spectral values of some pixels for the final classification.

2. Variables and expressions

Lower values than 0.1 for NDVI represented areas with clouds, shadows, water, bare soils, ephemeral vegetation, and settlement because they have a very low contrast when R and IR bands are compared (Chuvieco, 2002). Values higher than 0.41 were obtained in areas covered by forests. The area of “dense forest” reached values higher than 0.49, because the content of chlorophyll in the leaf is directly related to this index, since the absorption of the band R is influenced strongly by chlorophyll content (Azure-Roof et al., 2001). Holben (1980) indicates that the vegetal covers have a NDVI value around 0.1 and the dense vegetation between 0.5 and 0.7. This report support the use of NDVI value of 0.1 as critical threshold for separating vegetal covers from other covers in the Decision Tree Classifier method. Values of reflectivity higher than 80 in the band IR and percentage of slope smaller to 3% permitted the discrimination of irrigated cultivations. Agricultural area of Torres municipality is located on flat topography (Ferrer and de Paz, 1985). In relation to the soil, Curran et al. (1990) state that the content of humidity influences in inverse form the reflectivity of the visible and infrared spectra, with higher intensity in the band of water absorption (blue band) They also report that soil colour is influenced by humus content and parental material. High reflectivity of IR band result when soil is calcareous or sandy, low reflectivity of this band is consequence of high content of humus. These values of reflectivity and NDVI separated the Classes 9, 10 or 29 and 16 or 21, “bare soil (dry)”, “bare soil and rocks”, and “soil with ephemeral vegetation” respectively. The high reflectivity of the water is produced in the blue band becoming gradually lower toward to IR (Band 4) and SWIR (Band5), where it practically does not exist. Therefore the border land-water is very clear in these bands (Ji et al., 1992). This served as base to separate the Class 17 (water) of the remainder given categories, especially from the category "shadows" (Classes 19 and 20). Values of reflectivity higher than 120 in the Blue band, and 500 meters of elevation separated clearly the class "clouds" from the bare soils.

3. Classification

According to this Landsat ETM+ classification, the total forest cover 20 % of the area, located in mountainous areas where the conditions of humidity are favorable. The bushes or thickets are located where the province of humidity is semiarid and occupy a 15 % in the municipality. The prickly xerophilous vegetation is present in extensive continuous surfaces where topography is flat or smoothly wavy. This surface cover 19.47 % of the area. Bare soils or with dispersed vegetation (ephemeral) occurs on areas of flat topography (depression), where the main limitation is the humidity (semiarid). These categories occupy around 26% of the area. The agricultural zones are located in areas with flat topography and generally where springs exist. Distribution of covers in Torres municipality is related to the conditions of the soil, climate, and topography (Ferrer and de Paz, 1985; COPLANART, 1994) and the present study support this statement.

V. Conclusion

Use of data provided by satellite data (sensor ETM +) and by a digital elevation model, and use of Decision Tree Classifier as classification model resulted in a successful combination for generating a detailed map of land use/land cover of Torres municipality, differentiating 13 categories. Reflectivity data of 8 different bands of the remote sensor on points of 15m x 15m in the field gave a suitable approach of the land use in this big area, allowing a detailed classification. Digital elevation model was helpful to differentiate some categories with similar reflectivity for most of the bands of the remote sensor. Decision tree classifier demonstrated to be relatively simple due to an intuitive classification structure. Furthermore, decision tree algorithms make no assumptions regarding the distribution of input data because it is a non-parametric procedure. Remote sensing combined to other tools as digital elevation model seem to have an enormous potential for investigating the land cover/land use of the whole Tocuyo River Basin and for extension for other basins in Venezuela. Monitoring of vegetation can also be achieved in these areas by means of these tools.

Chapter 4. Assessment of erosion hazard in Torres municipality based on GIS

I. Introduction

Torres municipality is one of the most important regions for agricultural production in Tocuyo River Basin. Problems associated to agricultural activities such as intensive cultivation and socioeconomic pressure to incorporate more land to agriculture have accelerated the rate of water erosion in this area. Accelerated soil erosion is detrimental both in terms of reduced agricultural productivity, and environmental impacts such as non-point source pollution (Ferrer, 2003). For planning soil conservation strategies in the basin, an important aspect to consider is identification of specific high-priority areas for the implementation of management practices. Thus, the evaluation and mapping of regional erosion hazards is increasingly needed by national and local agencies related to agricultural activities and environmental protection.

1. Erosion hazard in the land evaluation

1.1 Definition and basic concepts.

Defined by ASCE Task Committee (1970) as the loosening or dissolving and removal of earthy or rock materials from any part of the earth's surface, erosion is a process of detachment and transportation of soil materials by erosive agents (Foster and Meyer, 1972). Erosion can be caused by wind (wind erosion), by rainfall (rainfall erosion), or by runoff (runoff erosion). Runoff erosion can happen in unconcentrated flow (sheet erosion), in rills (rill erosion), or gullies (gully erosion). Rills are such small concentrations of running water that they can be completely removed by normal cultivation methods, whereas gullies cannot be. Erosion in the channel is called channel erosion (Aksoy and Kavvas, 2005).

Soil eroded from a given area is defined in terms of rate of erosion. Total sediment outflow from a watershed per unit time is called sediment yield. It is obtained by multiplying the sediment loss by a delivery ratio (Novotny and Chesters, 1989).

Factors affecting water erosion are climate, topography, soil, vegetation and anthropogenic activities such as tillage systems and soil conservation measures (Kuznetsov et al., 1998). In humid areas, approximately above an annual rainfall of 700 mm in the tropics, consideration of wind erosion may not be necessary, nevertheless water erosion hazard can be severe in the semi-arid zone (FAO, 1993).

1.2 Evaluation of the erosion

All land evaluations should take into account erosion hazard (Lane et al., 1992; Páez 1994). Erosion hazard is defined as the potentially serious effects of soil erosion by water and wind (FAO, 1985). In case of land evaluation for rainfed agriculture, erosion is an important factor to consider in the land unit (LU) and involves both:

a) The susceptibility of land to erosion and,
b) The resulting loss in productivity of the land affected.

The most satisfactory methods of erosion hazard assessment such as, the Universal Soil Loss Equation (USLE), the FAO Soil Degradation Assessment (FAOSDA), the Soil Loss Estimator for Southern Africa (SLEMSA), etc., are based on predicted soil losses by modelling the determinants of climate, soil, erodability, slope and vegetation factors (FAO, 1985). Erosion models are very useful in soil conservation and non-point source assessments as they allow predicting the soil erosion of various land use and management practices before they are implemented (Lane et al., 1992). Linking erosion simulation models with geographic information systems, digital elevation models, and remote sensing provides a powerful tool for land assessment and management (De Roo, 1998; Mitas and Mitasova, 1998).

2. Soil erosion models: USLE, RUSLE

Process-based methodologies for soil erosion prediction, such as the Water Erosion Prediction Project, WEPP (Nearing et al., 1990, Laflen et al., 1991), the European Soil Erosion Model, EUROSEM (Morgan et al., 1998), and GUEST (Ciesiolka et al., 1995; Rose et al., 1997) have been developed and continuously refined. Nowadays the most commonly used method of predicting the average soil loss rate from agricultural lands is the USLE (Shi et al., 2002; Irvem *et al*., 2006). Estimation of erosion by using USLE result from the effect of several factors such as rain, soil, topography, cover and conservation practices; estimated erosion is supposed to be for specific conditions. USLE has been reported as the methodolgy most related to soil properties as compared to WEPP and 137Cs technique (Bacchi et al., 2003).

Renard *et al*. (1997) have modified the USLE into a Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors. RUSLE is an erosion empiric model designed to predict the longtime average annual soil loss (A) carried by runoff for specific field slopes in specified cropping and management systems as well as from rangeland. Widespread use has substantiated the usefulness and validity of RUSLE for this purpose. It is also applicable for nonagricultural conditions such as construction sites (Renard *et al*., 1996).

The RUSLE is written as:

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where A is the soil loss in $t\ ha^{-1}\ y^{-1}$ over a period selected for R, usually a yearly basis; R is the rainfall-runoff erosivity factor expressed in $MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$; K is the soil erodability factor expressed in $t\ h\ MJ^{1}\ mm^{-1}$; L is the slope length factor; S is the slope steepness factor; C is the cover and management factor; and P is the conservation practices factor. L, S, C and P are dimensionless.

In land evaluation terms, the factors, *C* and *P* are derived from the specification of the land use type (LUT), whereas the factors *R, K, L* and *S* are land characteristics derived from the land unit (LU). The USLE/RUSLE is designed for predicting soil loss from a given field, as a basis for the selection of conservation practices for specific sites; it is not intended for predicting soil loss from watersheds or other large areas (FAO, 1985).

3. Determining RUSLE factor values

3.1. Rainfall-runoff erosivity (R) factor

The energy of a given storm is the decisive factor that effects the intensity at which rain occurres and the amount of precipitation that is associated with each particular intensity value. Rainfall-runoff erosivity is estimated using the EI_{30} measured: the total storm energy (E) times the maximum 30-min intensity (I_{30}), number of storms in an N year period (Renard *et al*., 1997).

$$EI_{30} = [\sum (E \times I_{30}])/ N \quad (2)$$

These values are generally obtained from rain gauge graph analysis (Wischmeier *et al*., 1978). Only rainfall events higher than 12.5 mm are considered in the analysis of the bands, because minors events than these have low erosivity (Renard *et al.,* 1997). Normally there is lack of continuous data from pluviographs; therefore, to overcome this problem, it is possible to resort the regression equation (called monthly erosivity equation). The general expression of the equation is linear ($R = b + a\ L$) or quadratic ($R = a + b\ (L) + c\ (L^2)$), where R is the monthly average erosivity, L is monthly average of rainfall (mm) and *a, b, c* are the coefficients of the regression line obtained locally (Silva, 2005). The following equations are generally used worldwide:

Wischmeier and Smith (1978): $$R = \sum_{i=1}^{12} 1.735 \times 10^{[1.5 log (p_i^2)/P - 0.8188]} \quad (3)$$

Roose (1997): $R = 1.73 \times 0.5 \times P$ (4)

Foster (1977): $R = 0.276\, P \times I_{30}/100$ (5)

Morgan (1997): $R = I_{30}\,(9.28P - 8.383)/1000$ (6)

Arnoldus (1977): $R = a\,(F)^b, \quad F = [\sum_{i=1}^{12} pi^2]/P$ (7)

Where: *pi* is the monthly precipitation (mm); *P* is annual precipitation (mm); I_{30}=75 mm/h; *a*=2.64; b=1.5

The regression equations are easily applied and only require monthly and annual precipitation data because the other equation terms have been assumed. The regression equations obtained for several authors in Venezuela (Páez, 1992; Ojeda, 1994; Andrade and Rodríguez, 2002) do not cover the whole country. Moreover, the variations in the local precipitation pattern inside regions cause diverse relations between the sheet of rain, its intensity, its occurrence in time and its erosivity. Therefore, the equation of erosivity in a locality may be inadequate in other regions or even within the same geographic region (Silva, 2005). Another way to obtain approximations of the erosivity is employing the model of simulation EPIC (Erosion Productivity Impact Calculator/Environmental Policies Integral Climatic, Williams et al., 1984, USDA-ARS-BRS, 1997). EPIC is based on empirical equations that calculate duration and intensity of the rain according to daily precipitation. The basic equation of erosivity (EI) for EPIC (obtained in MJ x mm/ha x h) is:

$EI = [R\,[12.1 + 8.9(\log r_p - 0.434)]\,(r_{.5})]/100$ (8)

Where: *R* is the daily sheet of rain (mm); r_p is the peak intensity of rain (mm/h) and $r_{.5}$ is the maximum intensity (mm/h) in 30 min

EPIC simulated daily erosivity values were evaluated by comparison to rain gauge graph analysis in a single peak rainy season in some agricultural zones of Venezuela. The author (Paredes and Silva, 2004 and Siva, 2005) concludes that EPIC may be a suitable substitute rain graph for estimating cumulated erosivity values, but recommends to evaluate the model in localities with other rain pattern. The following regression equation was generated by Silva (2005) in the proximity of Torres Municipality:

$$EI = 0.016(P)^2 + 1.2433(P) + 17.283 \quad (9)$$

Where: P is the monthly precipitation (mm).

3.2. Soil erodability (K) factor

Soil erodability is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the soil-erodability factor (K). In RUSLE, it accounts for the influence of soil properties on soil loss during storm events on upland areas. To estimate the K values, the most widely used and frequently cited relationship is the soil-erodability nomograph (Wischmeier *et a*l., 1971). The nomograph comprises five parameters: percent of modified silt (0.002-0.100 mm); percent of modified sand (0.1-2.0 mm), percent of organic matter (OM), and classes for structure (s) and permeability (p). A useful algebraic approximation (Wischmeier and Smith 1978) of the nomograph for those cases where the silt fraction does not exceed 70% is:

$$K= [2.1 \times 10^4(12 - OM)\, M^{1.14} + 3.25\,(s\text{-}2) + 2.5\,(p\text{-}3)] / 100 \quad (10)$$

Where: M is the product of the primary particle size fractions: (percent of modified silt or the 0.002-0.100 mm size fraction) x (percent of silt + percent of sand).

The following relationships are very useful for predicting K values of soils for which data are limited (for instance, no information about the very-fine-sand fraction or organic-matter content), the textural composition is given in a different classification system, and when there are no data about structure and permeability.

$$K = 7.594 \left\{0.0034 + 0.0405\, exp\, [-1/2 \times (log\,(Dg) + 1.659/0.7101)^2\,]\right\} \quad (11)$$

$$K = 7.594 \left\{0.0017 + 0.049\, exp\, [-1/2 \times (log\,(Dg) + 1.675/0.6986)^2\,]\right\} \quad (12)$$

$$K = 0.0035 + 0.0388\, exp\, [-1/2 \times (log\,(Dg) + 1.519/0.758)^2\,]\} \quad (13)$$

Where:

Dg (mm) = $exp\,(0.01\sum f_i\, ln\, m_i)$ (14)

and Dg = geometric mean particle diameter; f_i is the primary particle size fraction in percent, and m_i is the arithmetic mean of the particle size limits of that size (Wischmeier and Smith 1978, Shirazi and Boersma 1984; Römkens et al., 1987; Poesen, 1992).

3.3. Topographic factors (L and S)

The effect of topography on erosion in RUSLE is accounted for by the LS factor. Erosion increases as slope length increases, and it is considered as the slope length factor (*L*). Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier and Smith, 1978). Surface runoff will usually concentrate in less than 400 ft (122 m), which is a practical slope-length limit in many situations, although longer slope lengths of up to 1000 ft (305 m) are occasionally found.

The slope steepness factor (*S*) reflects the influence of slope gradient on erosion. Soil loss increases more rapidly with slope steepness than it does with slope length.

Both slope length and steepness substantially affect sheet and rill erosion estimated by RUSLE.

The following calculations were examined and adopted in the calculation of the *L* and *S* factors.

3.3.1. The L factor calculation

Plot data used to derive the slope length factor (*L*) have shown that average erosion for the slope length λ (in m) varies as:

$L = (\lambda /22.13)^m$ (15)

Where 22.13 meter is the unit plot length in meter (Wischmeier and Smith, 1978), λ is the horizontal projection of slope length; m is a variable slope-length exponent. The m is defined by the following equation (Foster et al., 1997):

$m = \beta / (1 + \beta)$ (16)

Where β is the ratio of rill erosion caused by flow to interrill erosion which is principally caused by raindrop impact.

Values for the ratio β of rill to interrill erosion for conditions when the soil is moderately susceptible to both rill and interrill erosion have been computed (McCool et al., 1989):

$$\beta = (\sin \theta / 0.0896) / [3.0(\sin \theta)^{0.8} + 0.56] \quad (17)$$

Where θ = slope angle in degree. Given a value for β, a value for the slope-length exponent m is calculated from equation (16).
Sometime β is at the same time multiplied by coefficient called *r.* Being 0.5 in forestlands or grasslands; 1 in agricultural land and 2 in settlements (Barrios, 2000).
The variable m may also be determined assuming value of 0.5 for slopes exceeding 5 percent, 0.4 for 4 percent slopes and 0.3 for slopes less than 3 percent (Shi et al, 2002), assuming a constant value of 0.5 (McCool et al. 1989, 1993) or applying the following equation proposed by Oñate (2004):

$$m = 0.1342 \times Ln\, \theta + 0.192 \quad (18)$$

Where θ = slope angle in percent

3.3.2. The S factor calculation
The slope steepness factor (S) is evaluated using the following two equations for the two steepness categories (McCool et al., 1987).

$$S = 10.8 \sin \theta + 0.03 \quad \text{when steepness} < 9\% \quad (19)$$

$$S = 16.8 \sin \theta - 0.50 \quad \text{when steepness} \geq 9\% \quad (20)$$

Since the above equations are applicable to slopes greater than 15 feet (4.56 m), the following equation is used to evaluate S when the slope length is shorter than 15 feet:

$$S = 3.0 (\sin \theta)^{0.8} + 0.56 \quad (21)$$

To describe the influence of slope steepness, Nearing (1997) produced a single continuous function for S:

$S = -1.5 + [17/ (1+ exp^{2.3- 6.1 sin\ \theta})]$ (22)

The effects of these factors have been evaluated separately in research using uniform-gradient plots. However, in erosion prediction, the factors *L* and *S* are usually evaluated together, and values can be selected from:

- Tables generated for uniform slopes combining the previous equations (5), (16), (17), (19), (20), and (21) (McCool et al. 1989, 1993).
- Taking into account only the slope gradient (*S*) spatial distribution with constant value of λ, 50 and 100 meters (Barrios, 2002*)*
- Associating a value of *λ* according to slope gradient classes. LS are calculated directly from a digital slope map. The following relation (Edeso *et al*., s/*f*) based in Mintegui (1998) is applied.

% Slope	0-3	3-12	12-18	18-24	24-30	30-60	60-70	70-100	>100
Factor LS	0.3	1.5	3.4	5.6	8.7	14.6	20.2	25.2	28.5

- Calculating the *LS* factor in the USLE or RUSLE from a grid-based DEM, combined with GIS, applying hydrological flow routing algorithm to obtain *λ* (Desmet and Govers, 1996).

3.4. Crop and management (C) factor

The C factor is used within both the USLE and the RUSLE to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation strategies. The C factor indicates how the conservation strategy will affect the average annual soil loss, and how that soil-loss potential will be distributed in time during construction activities, crop rotations, or other management schemes (Renard *et al*., 1997). As with most other factors within RUSLE, the C factor is based on the concept of deviation from a standard, in this case an area under clean-tilled continuous-fallow conditions. The soil loss ratio (SLR) is then an estimate of the ratio of soil loss under actual conditions to losses experienced under the reference conditions. Wischmeier (1975) and Mutchler et al. (1982) indicated that the general impact of cropping and management on soil losses can be divided into a series of subfactors. Each subfactor contains cropping and management variables that affect soil erosion and are expressed as functions of one or more variables, including residue cover, canopy cover, canopy height, surface roughness, below-ground biomass (root mass plus incorporated residue), prior cropping, soil moisture, and time. Based on new descriptions of cropping and management practices and their influence on soil loss (Laflen *et al*. 1985), soil-loss ratios are computed as:

$$SLR = PLU \times CC \times SC \times SR \times SM \quad (23)$$

Where *SLR* is the soil-loss ratio for the given conditions, *PLU* is the prior-land- use sub factor, *CC* is the canopy-cover subfactor, *SC* is the surface-cover subfactor, *SR* is the surface-roughness subfactor, and *SM* is the soil-moisture sub factor.

3.5 Conservation practices (P) factor

By definition, the support practice factor (*P*) in RUSLE is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage. These practices principally affect erosion by modification of the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster, 1983). For cultivated land, the support practices considered include contouring (tillage and planting on or near the contour), strip cropping, terracing, and subsurface drainage. On dry land or rangeland areas, soil-disturbing practices oriented on or near the contour that result in storage of moisture and reduction of runoff are also used as support practices. *P* does not consider improved tillage practices such as no-till and other conservation tillage systems, sod-based crop rotations, fertility treatments, and crop-residue management. Such erosion-control practices are considered in the C factor (Renard *et al*., 1997).

4. Soil erosion and GIS

The coupling of GIS and soil erosion/sediment yield models is an efficient procedure for determining the spatial distribution of soil erosion and sediment yield under a variety of simulation scenarios (Fu et al., 2006). GIS have been used successfully for assessing soil erosion in several basins by means of different erosion models such as USLE/RUSLE (e.g. Molnár and Julien, 1998; Mati et al., 2000; Lufafa et al., 2003; Sivertun and Prange, 2003; Hoyos, 2005; Hoyos et al., 2005; Erdogan et al., 2006; Fu et al., 2006; Irvem et al., 2007; Saroingsong et al., 2007), water erosion prediction project (WEPP) (de Jong van Lier et al., 2005; Raclot and Albergel, 2006), erosion potential method (EPM) (Tangestani, 2006). GIS have been used also for comparing some erosion models (Amore et al., 2004).

The combined use of GIS and USLE/RUSLE has been proved to be an effective approach for estimating the magnitude and spatial distribution of erosion (Mitasova et al., 1996; Molnar and Julien, 1998; Millward and Mersey, 1999; Yitayew et al., 1999; Fernandez et al., 2003). Within a raster-based GIS, the RUSLE model can predict potential erosion on a cell-by-cell basis, which is advantageous when attempting to identify the spatial patterns of soil loss present within a large region (Shi *et al.*, 2002; Diaz, 2005). The GIS can then be used to isolate and query these locations to yield vital information about the role of individual variables in contributing to the observed erosion potential value (Oñate, 2004; Barrios, 2002).

5. Objectives

5.1 General objective

To develop GIS-based soil erosion hazard (actual and potential) map of Torres Municipality, Venezuela, based on the model of RUSLE; and to determine the suitability ratings for soil erosion hazard in a land evaluation according to FAO (1985) and Páez (1994).

5.2. Specific objectives

- To adapt the available data to methodologies used for calculation and mapping of individual factors of RUSLE model, and to GIS environment.
- To compare different methodologies for estimating rainfall-runoff erosivity (R), and topographic factors (L and S) for RUSLE model.
- To determine the suitability ratings for soil erosion hazard to estimates the requirements conservation practices.

II. Material and Methods

The overall methodology involved the use of RUSLE in a GIS environment. Individual GIS layers were built for each factor in RUSLE. Each factor is considered as a thematic layer. These layers were then spatially combined on a per-pixel basis by cell-grid modelling procedures in ArcGIS 9 (Environmental System Research Institute, USA) to predict soil loss in a spatial domain and to produce a final layer of a composite map of erosion hazard intensity in t ha^{-1} yr^{-1}. This intensity map was further classified into different priority classes upon maximum acceptable limits of estimated soil loss (FAO, 1987; Páez, 1994). From these data, simple algorithms were used to classify the area into different hazard zones. The various input layers for geoprocessing comprised mixed types (resolution, scale, units, coordinates) and, in a first step were, transformed to a unique cartographic reference system (UTM Zone) before processing could start.

1. Data sources

The data sources to determine in RUSLE factors were obtained from meteorological stations, soil surveys, Digital Elevation Model (DEM), land user/cover map previously generated (Chapter 3), and results of other relevant studies.

2. Determining RUSLE factors

2.1 Rainfall-runoff erosivity (R) factor

Thirty three meteorological stations were used in this study (Chapter 2). Daily and monthly amounts of precipitation for these stations were collected over years by Ministry for Environment in Venezuela. Majority of these precipitations were derived from 20 years of precipitation data (1985-2005). Daily values of precipitation were accumulated to obtain annual, total, and monthly average of rainfall.

In the area, most of the meteorological stations do not have the information required by the original equation (2). Then, the factor *R* was determined by calculation based on equations (3), (4), (5), (6), (7) and (9). Equations (7) and (9) were also applied to precipitation events higher than 12.5 mm as well. Values of factor R obtained for each equation in each of the 33 meteorological stations were subjected to Pearson's correlation (Statistix 8, Analytical Software, USA) to know the relationship and the consistency among the different approaches. This information gave additional criteria to select the most adequate equation. This equation was used to generate three maps of R factor based on either interpolation of meteorological data, or elevation or combination of both approaches. For the approach based on meteorological data, the data belonging to monthly R based on the best selected equation were transferred to ArcGIS.9 and an attribute tables was created. For mapping procedure, the point theme of *R* was generated. Then, the surface map of R was produced a spatial interpolation technique (Nearest Neighbor, Kriging interpolation) with 12 neighborhoods. The cell size for interpolation was 30 m. For the approach based on elevation, R calculated for each of the 33 meteorological data were regressed on elevation based on a digital elevation model of the study area. The obtained regression equation was used in the "Raster calculator" of ArcGIS.9 to generate the map of R factor based on elevation. The third map, a combination between the two previously explained, was obtained using also "Raster calculator", but the input were the two maps previously generated. The average was weighted, giving double importance to the map based on elevation. For comparing the three methodologies, 40 points were chosen randomly and the values for the three approaches were subjected to Pearson's correlation (Statistix 8, Analytical Software, USA).

2.2 Soil erodability (K) factor

The *K* factor map was prepared from the soil map (Chapter 2) and its attribute data. The *K* values were estimated using the soil-erodability nomograph method and the combination and average of equations (11), (12) as well as equation (13) in case of a lack of very-fine-sand fraction data in two soil units.

2.3 Topographic factors (L and S)

The *LS* factor was calculated and spatially distributed through command "Spatial Analyst" in ArcGIS.9, applying RUSLE in the grid-based DEM of the study area.

The algorithm for computing the *S* factor was obtained from a surface image of slopes derived from DEM using the extension "Spatial Analyst". The equations (19), (20) and (21) were adapted for its determination. The *L* factor was conditioned at the same time by the space distribution from λ and *m* exponent. A combination of the equations (17) and (16) determined the *m* value.

Due to the difficulty to obtain the space distribution of λ (limitation of some GIS) and to decide on the best procedure to determine the RUSLE LS factor in the area, and in the future in the Tocuyo river basin, the determination of *LS* was made applying three methodologies:

- two simple alternative approaches wich take into account only the slope gradient (*S*) spatial distribution: constant value λ (50 and 100 m) and λ as a function of the slope gradient (Mintegui, 1998), and

- λ spatially distributed obtained with the program SAGA.2 GIS (System for Automated Geoscientif Analysis, Goettingen), as ASCII text file, using the command "Slopelength" in the module "Terrain Analysis". "Slopelength" calculates each pixel's slope length within a region and the longest slope length is assigned to that. Before manipulation of this file could be performed, it must be converted to the ArcGIS form. Once imported to ArcGIS, the file was built by the command "ASCII to Raster".

The relation from Mintegui (1998) was transformed according to Barrios (2002) to obtain a continuous relation, applicable to each pixel of the raster:

$$LS = 0.0009(p)^2 + 0.0798(p) \text{ to } S \leq 30, \text{ and } LS = 0.2558(p) + 3{,}248(p) \quad \text{to } S > 30.$$

Finally, values of factor *LS* (*LS*_50, *LS*_100, *LS*_ Mintegui and *LS*_SAGA) obtained for each approach in each of the 33 meteorological stations were subjected to Pearson's correlation to know the relationship and the consistency across the different calculations by means of Statistix 8 (Analytical Software, USA).

2.4 Crop and management (C) factor

This factor was extracted of land use / land cover map created previously from Landsat-7 ETM+ (Chapter 3). The land use/cover map includes the classes: water, settlement, dense forest, open forest, brushes or thicket, clouds, shadows, prickly xerophilous vegetation, dense and non-dense cultivations, fallow lands, bare soil with ephemeral vegetation, and bare soil and rocks. Due to lack of information to apply equation (25), the crop and management factor (*C*) corresponding to each crop/vegetation condition were estimated from RUSLE guide tables (Morgan, 1995; Wischmeier and Smith, 1978) and indicated in Table 10. These values were used to re-classify the land/cover map to obtain the *C* factor map of the municipality. A field checking previously made in order to collect ground truth information and the wide knowledge of territory, facilitated the interpreted land use/ cover and assigning of *C* values (clouds and shadows classes). For cultivatios and fallow lands classes, a value of 0.56 was selected due to predominance of sugar cane (*Sacharum spp.*) in the area.

Table 10. C factor value for each land use class (Morgan, 1995; Wischmeier and Smith, 1978)

Land use class	*Average C factor*
Water and settlement	0.000
Dense forest	0.003
Open forest	0.013
Grassland	0.150
Brushes	0.200
Clouds and shadows	0.313
Prickly xerophilous vegetation	0.450
Cultivations and fallow lands	0.560
Bare soil with ephemeral vegetation	0.900
Bare soil and rocks	1.000

2.5. Conservation practices (P) factor

Unfortunately, conservation practices are not considered in the cultivated lands of the zone. However, a *P* factor map was prepared from land use/cover map. The *P* factor values were based in the work by Morgan (1999) developed to USLE. Table 11 lists the *P* values:

Table 11. Conservation practices (*P*) factor according to Morgan (1999)

Land use type	*Slope (°)*	*P Factor*
Agricultural land with level crop	0-1	0.60
	2-5	0.50
	6-7	0.60
	8-9	0.70
	10-11	0.80
	12-14	0.90
Other land	all	1

2.6. Determining soil erosion hazard

Soil erosion hazard was determined by multiplying the respective RUSLE factors interactively with the command “Raster Calculator” in ArcGIS.9 using equation (1). Composite maps of actual and potential erosion hazard were generated. The potential erosion hazard was calculated on the basis of *R, K* and *LS.* With the purpose of comparing the results obtained, a map of erosion (Figure 37) was made in accordance to the description of the erosion in the Torres municipality by MARNR (1993). The description is based on land classification for agricultural use capacity in Venezuela (Arias and Comerma (1971) and presents five degree of present erosion: without or light, light, moderate, hard, very hard and severe. Though the categories of erosion are not described in the map, would be able to be taken the following classifications as example, although the criterion of classification is not the same (Table 12 and 13).

Quantification of the relationship among actual and potential erosion determined in this research, and erosion estimated for Torres Municipality by Arias and Comerma (1971), was carried out by means of calculation of Pearsons' correlation coefficient based on the erosion values at 33 points. To determine how well each RUSLE factor explains each erosion calculation (i.e. actual, potential and based on Arias and Comerma, 1971), also Persons' correlation was determined.

Table 12. Characterization of degrees of erosion (CIREN, 1996)

Degrees of Erosion	Characteristics
Without or light	There are not evident signs of erosion. Only sheet erosion is appreciated in occasional form in those sectors where does not exist vegetable cover.
Light	Small ranges of erosion exist, like changes of color, presence of small channels or rills, presence of rocks superficially.
Moderate	Clear signs of sheet erosion and rill erosion. The previous characteristics are accentuated. Cracks have them various centimeters of wide and depth.
Severe	An active process of sheet erosion, rills and gullies exists. An alone in small area is possible to identify the superficial horizon of the soil.
Very severe	Great part of the surface presents deep gullies. Practically not soil exists, or only patches of this exist. Only the subsoil is presented and in many areas the parental material.

Table 13. Quantification of degrees of erosion (Oñate, 2004; Odura-Afriye, 1996)

Oñate		Odura-Afriye	
Degrees	Level (t ha^{-1} y^{-1})	Degrees	Level (t ha^{-1} y^{-1})
Light	< 10	Without or light	< 5
Moderate	10 - 50	Light	5 - 12
Hard	50 - 200	Moderate	12 - 50
Very hard	> 200	Severe	50 - 100
		Very severe	100 - 200
		Extremely severe	> 200

2.7. Determining suitability ratings for soil erosion hazard

The quantitative output of factors was classified according to a system developed by Páez (1994) for agricultural soils in Venezuela and according to the suitability ratings for soil erosion hazard for rainfed agriculture (FAO, 1985) (Table 21 and 22).

Páez's system uses the *CP*max of the USLE (factors C and P) as criterion. It assess the erosion hazard (sheet erosion and rill erosion) in arable lands, classifies the factors related to the erosion in agreement to the potential that they have to cause it, and estimates the requirements of the following conservation practices: contour and minimum tillage, crop rotation, strip cropping, vegetative barriers, buffer strip and drainage terraces, and its design specifications. Eight classes and their limit values are established according to conservation requirements of the land units due to erosion risk. *CP*max ($CPmax=T/R \times K \times L \times S$) represent the management requirement in the land unit to control erosion, where T is the tolerance of soil loss established by soil depth (D), R, K, L and S are the factors erosivity, erodability and slope, respectively. Conservation practices requirement are increased to the extent that the value of CPmax diminishes.

To evaluate the resultant loss in the productivity of the land affected by water erosion is proposed to utilize the criterion of *CP*max. A map of CPmax was elaborated and is shown in Figure 38. In the Table 21 the degrees of aptitude by risks of erosion in function of this quality are established.

III. Results

Two GIS-based soil erosion hazard (actual and potential) maps of Torres Municipality, Venezuela based on the model of Revised Universal Soil Loss Equation (RUSLE) was obtained (Figure 35 and 36). Lack of data was the main constraint to make the map; however, several alternative methodologies proposed in these cases were useful to overcome the problem. Adaptation of the proposed methodologies to GIS environment was achieved. Results of each proposed objective are presented as follow:

1. RUSLE Factors

All the equations used to estimate values of factor *R* gave results highly correlated ($P<0.01$) (Table 14), indicating a very close relationship among the different approaches.

There was no cause, under statistical view, to discard some of the equations; therefore other criteria were used to select the most adequate equation. Because of lack of adjustment in units of some equations, soil loss due to erosion calculated by RUSLE (keeping constant all the

Table 14. Pearson's correlation among calculation of factor R obtained with different equations

	Equation 3	Equation 4	Equation 5	Equation 6	Equation 9	Equation 9a	Equation 7
Equation 4	0.83**						
Equation 5	0.83**	1.00**					
Equation 6	0.82**	1.00**	1.00**				
Equation 9	0.88**	0.98**	0.98**	0.98**			
Equation 9a	0.88**	0.98**	0.98**	0.98**	1.00**		
Equation 7	0.97**	0.94**	0.93**	0.94**	0.97**	0.97**	
Equation 7a	0.97**	0.94**	0.94**	0.93**	0.97**	0.97**	1.00**

** Significant differences at $P<0.01$ 9a and 7a (rains greater than 12.5 mm)

other factors of the model) are underestimated (e.g. equation 3, 4, 5 and 6 give values averages of erosivity smaller than 1500) as compared to previously estimated erosivity values in the region by Paredes and Silva (2004) and Páez (1994). These equations are discarded for this reason. Remained equations (7 and 9) resulted in similar erosivity ranges to the previous estimated; however, equation (9) is supposed to be the most adequate because it was formulated for Venezuelan conditions, near to Torres municipality. The accumulated values of the erosive energy of rain with inclusion or not of the values of inferior rains than 12.5 mm do not produce great changes in the results; nevertheless the map for *R* factor was elaborated for rains greater than 12.5 mm. The three methodologies used to estimate R factor in the maps were correlated (Table 15). Values obtained by means of the weighted average were highly correlated (P<0.01) to both, the values based on data from meteorological stations and the values based on elevation (Table 15). Data obtained from the weighted average were used as the definitive R factor map.

Table 15. Correlation among three methodologies for calculating factor *R*

	Based on interpolation (Method A)	Based on elevation (using DEM) (Method B)
Based on elevation (using DEM) (Method B)	0.38*	
Weighted average of method A and B	0.79**	0.87**

* Significant at probability of 0.05
** Significant at probability of 0.01

Similarly the procedures used for estimating *LS* factor showed significant correlation (P<0.01) (Table 16).

Like for factor *R*, there was no cause, under statistical view, to discard some of the procedures. Nevertheless, the total losses of soil obtained when applying RUSLE (keeping constant all the other factors of the model) in each one of them differs greatly.

Table 16. Pearson's correlation among three methods for estimating *LS* factor

	*LS*_100	*LS*_50	*LS*_Mintegui
*LS*_100	1.00**		
*LS*_50	0.79**	0.77**	
*LS*_SAGA	0.72**	0.73**	0.41**

** Significant differences at P<0.01

The final values of factor *LS*, according to each method, appear in Table 17.

Table 17. Statistical classification, values of factor *LS* and erosion obtained in each method.

Procedure	Count	Min.	Max.	Sum	Mean	St.deviation	Total Erosion
*LS*_SAGA	7553408	0	34.32	6219083.16	0.86	0.98	2558
*LS*_50	7553408	0	27.9	18612846.65	2.57	2.55	3620
*LS*_100	7553408	0	47.04	28196990.06	3.89	4.18	6058
*LS*_Mintegui	7553408	0	28.83	32245325.78	4.45	4.28	4479

The methodologies are ordered thus, according to data variation (standard variation divided mean) as follows: *LS*_Mintegui < *LS_100* < *LS_50* < *LS*_SAGA. The procedure that takes into account the space distribution from λ obtains the lowest values for *LS* and erosion. A similar result obtained Barrios (2000) when applied such methods to determine values of *LS* in a catchments in Venezuela. The author concludes that exists a high risk of overestimating the values of *LS,* and consequently the erosion, when is not considered the space distribution of the length of the slope. Taking into account the obtained results and considering that 97 % of the length of the slope in study area is smaller to 25 meters, the chosen method to compute factor *LS* for RUSLE was *LS*_SAGA.

Table 18 displays the percent of cover for each specified land use class in the map of C factor and Table 19 shows the percent of cover for each land use type of P factor.

Table 18. C factor value (Morgan, 1995; Wischmeier and Smith, 1978) and percent of cover obtained for each land use class

Land use class	*Average C factor*	*% Cover*
Water and settlement	0.000	1.24
Dense forest	0.003	4.61
Open forest	0.013	20.60
Grassland	0.150	1.24
Brushes	0.200	15.02
Clouds and shadows	0.313	3.95
Prickly xerophilous vegetation	0.450	19.47
Cultivations and fallow lands	0.560	7.90
Bare soil with ephemeral vegetation	0.900	11.4
Bare soil and rocks	1.000	14.56

Table 19. Percent of cover of each land use type of conservation practices (*P*) based on Morgan (1999)

Land use type	*Slope (°)*	*P Factor*	*% Cover*
Agricultural land with level crop	0-1	0.60	7.78
	2-5	0.50	2
	6-7	0.60	-
	8-9	0.70	-
	10-11	0.80	-
	12-14	0.90	-
Other land	all	1	90.22

As summary of RUSLE factors, the values of the erosivity of rain (*R*) oscillated between 1200 and 4166 MJ mm ha^{-1} h^{-1} y^{-1}. The factor of erodability of soil (*K*) had a variation between 0.001 and 0.05 t h MJ^{-1} mm^{-1}. The topographic factors (*LS*) it had a range of variation between 0 and 34.33 (0.09 to 4.51 and 0.03 to 15.09, to *L* and *S*, respectively). The values of C and P oscillated between 0 and 1. Figures 1, 2, 3, 4, 5 and 5 show the maps of each factor, except *L* factor.

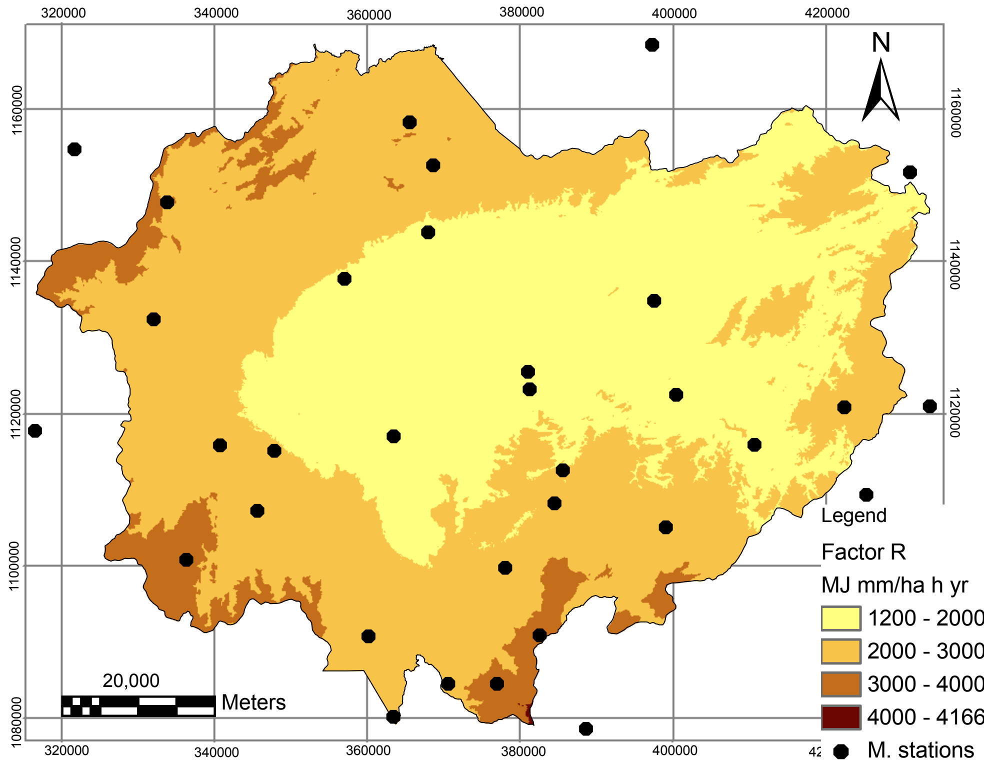


Figure 29. Rainfall-runoff erosivity (*R*) factor distribution in the Torres municipality, Venezuela

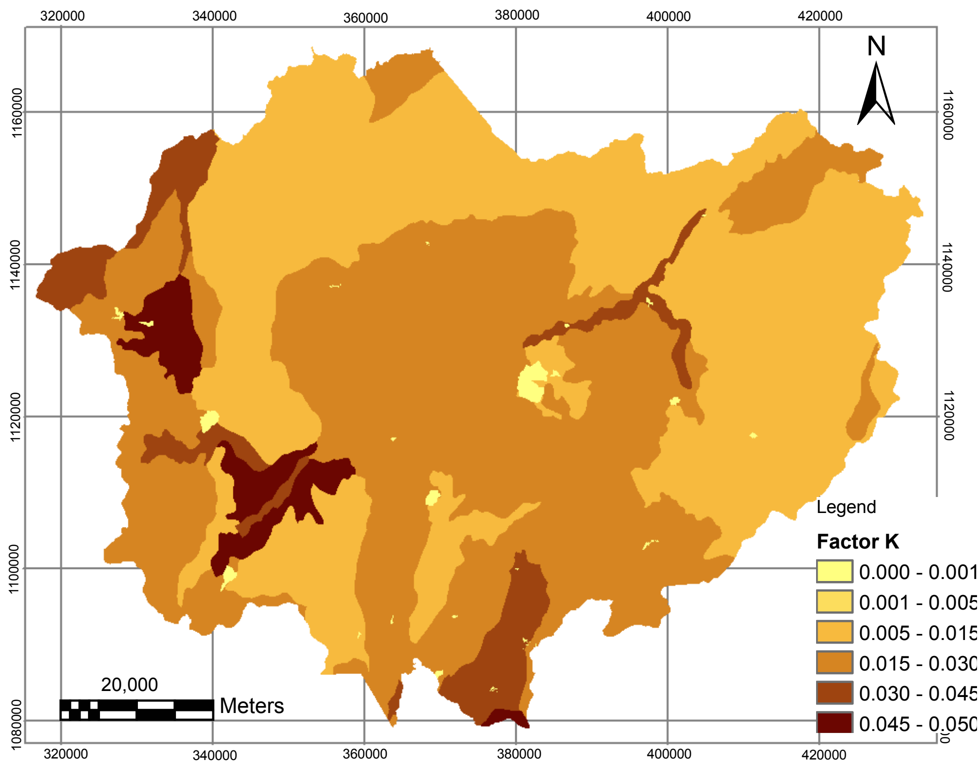


Figure 30. Soil erodability (*K*) factor distribution in the Torres municipality, Venezuela

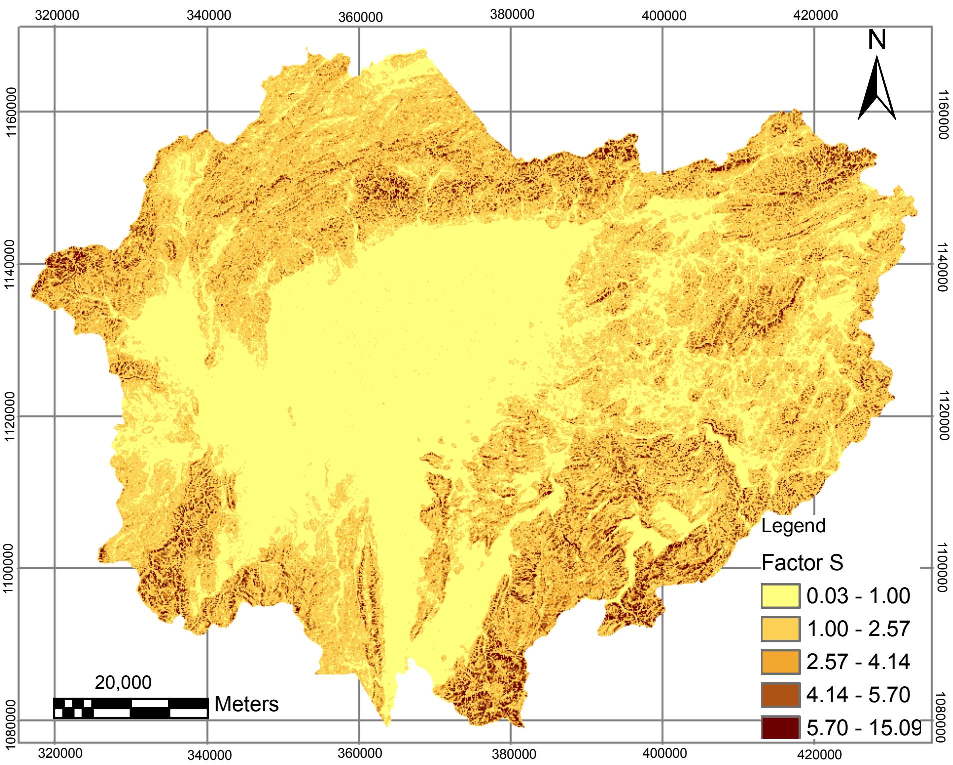


Figure 31. Slope steepness factor (*S*) distribution in the Torres municipality, Venezuela

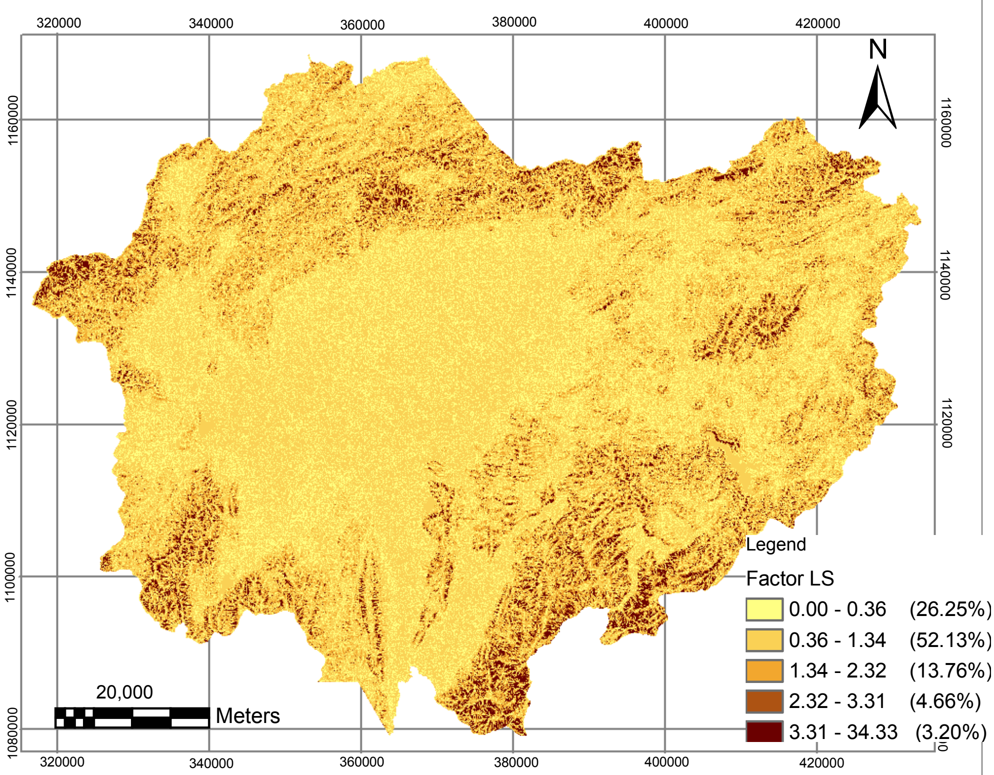


Figure 32. Topographic factors (*L* and *S*) distribution in the Torres municipality, Venezuela

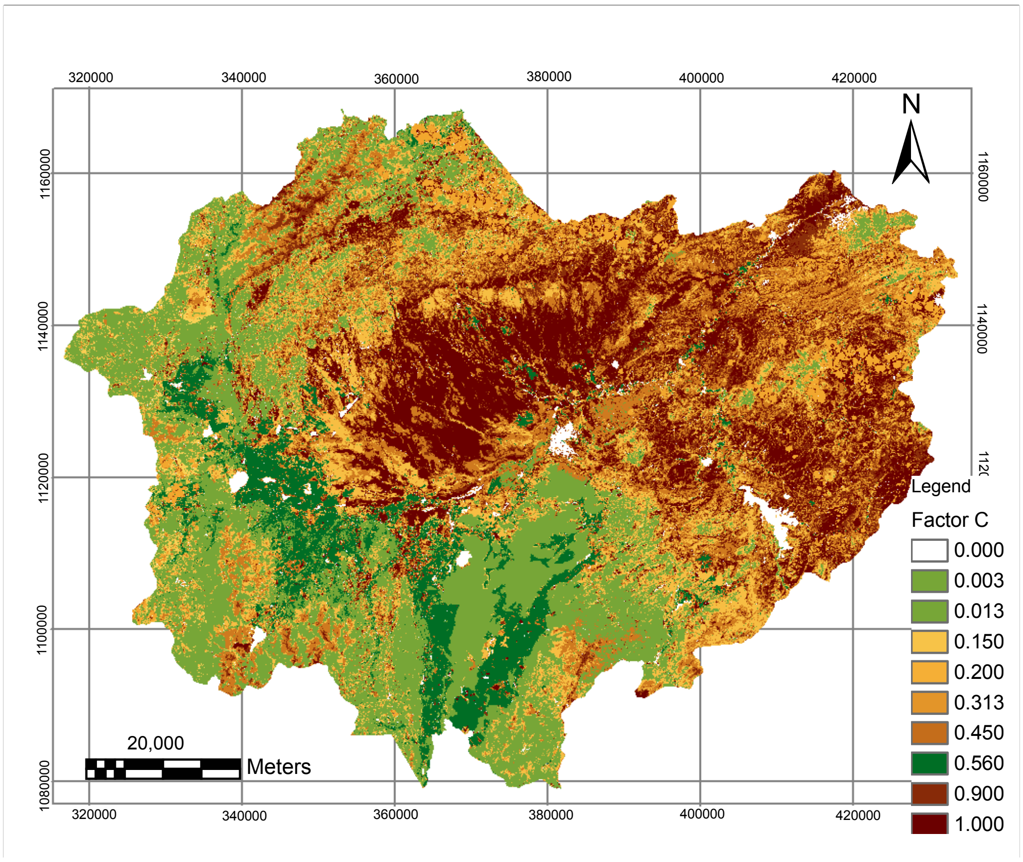


Figure 33. Crop and management (*C*) factor distribution in the Torres Municipality, Venezuela

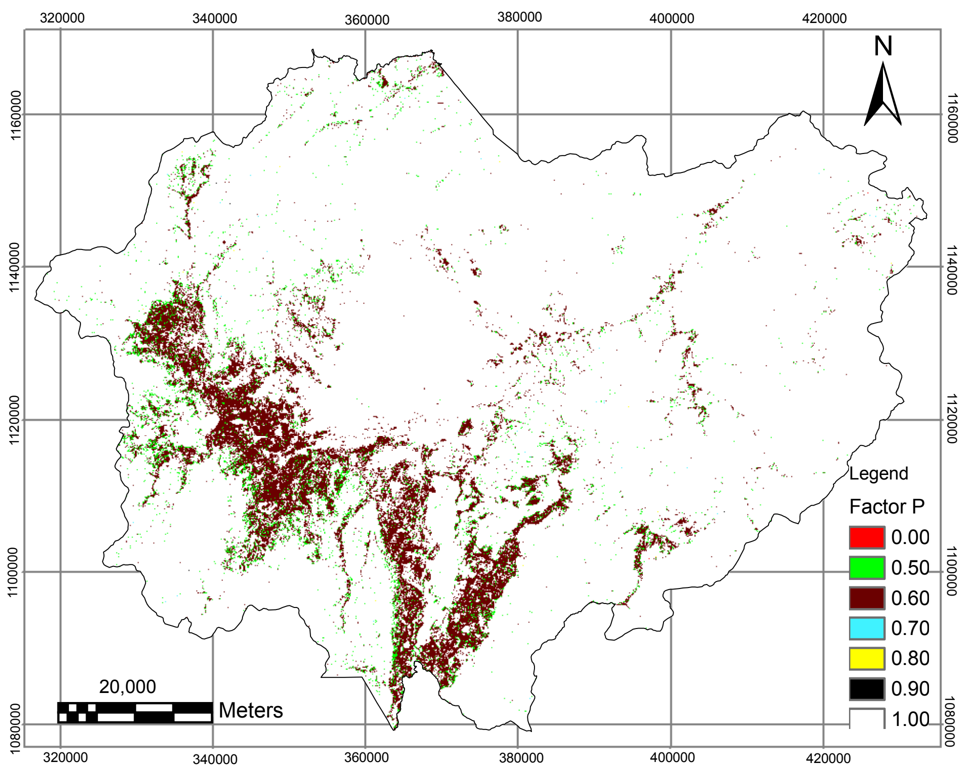


Figure 34. Conservation practices (*P*) factor distribution in the Torres municipality, Venezuela

2. Determining erosion hazard

The potential erosion hazard calculates the soil loss on the basis of climate, soil and topography factors only, i.e. omitting the land use factor. The erosion hazard in t ha^{-1} yr^{-1} has a range of 0 to 2558 for the actual (Figure 35) and 0 to 4223 for the potential (Figure 36). Erosion estimated by Arias and Comerma (1971) was different to actual and potential erosion determined in this research (Table 20). Actual erosion was mainly explained by length of the slope (*L*) and cover factor (*C*), whereas potential erosion is mainly explained by rainfall-runoff erosivity (*R*), soil erodability (*K*) and steepness of the slope (*S*) (Table 20).

Table 20. Correlation among actual and potential erosion with RUSLE factors and erosion estimated by Arias and Comerma (1971)

	R	K	L	S	C	P	Actual	Potential
Actual	0.20	0.31	0.48^{**}	0.23	0.46^{**}	0.08		
Potential	0.42^{*}	0.52^{**}	0.16	0.36^{*}	0.12	0.12	0.56^{**}	
Arias and Comerma	0.06	-0.46^{**}	-0.24	0.22	0.31	0.41^{*}	0.10	-0.05

* Correlation at P<0.05

** Correlation at P<0.01

3. Determining of the suitability ratings for soil erosion hazard

Figure 35 shows the actual erosion hazard in the Torres municipality, expressed in four broad classes and ranging from very low hazard areas, where annual soil loss rates average are less 12 t ha^{-1} yr^{-1} (72.19 %) to moderate hazard areas with over 50 t ha^{-1} yr^{-1} (3.01 %). The proportion in percentage (%) tabulated for *R, K, L, S, A (*actual erosion hazard) and CPmax in each category can be seen in the Tables 21 and 22.

Table 21. Proportion (%) tabulated in the area of soil erosion hazard according to suitability ratings for rainfed agriculture (FAO, 1985) and *CPmax* (Páez, 1994). The number in parentheses corresponds to agricultural zone.

		Grades of Suitability			
		Highly suitable (s1)	Moderately suitable (s2)	Marginally Suitable (s3)	Not suitable (n)
A (t/ha/yr	*Range*	*≤ 12*	*12-25*	*25-50*	*>50*
	%	72.19 (54.96)	16.32 (35.16)	8.48 (9.62)	3.01 (0.24)
CPmax	*Range*	*>0.12*	*0.12 - 0.045*	*0.045 -0.012*	*≤ 0.012*
	%	86.54 (100)	9.87	3.34	0.26

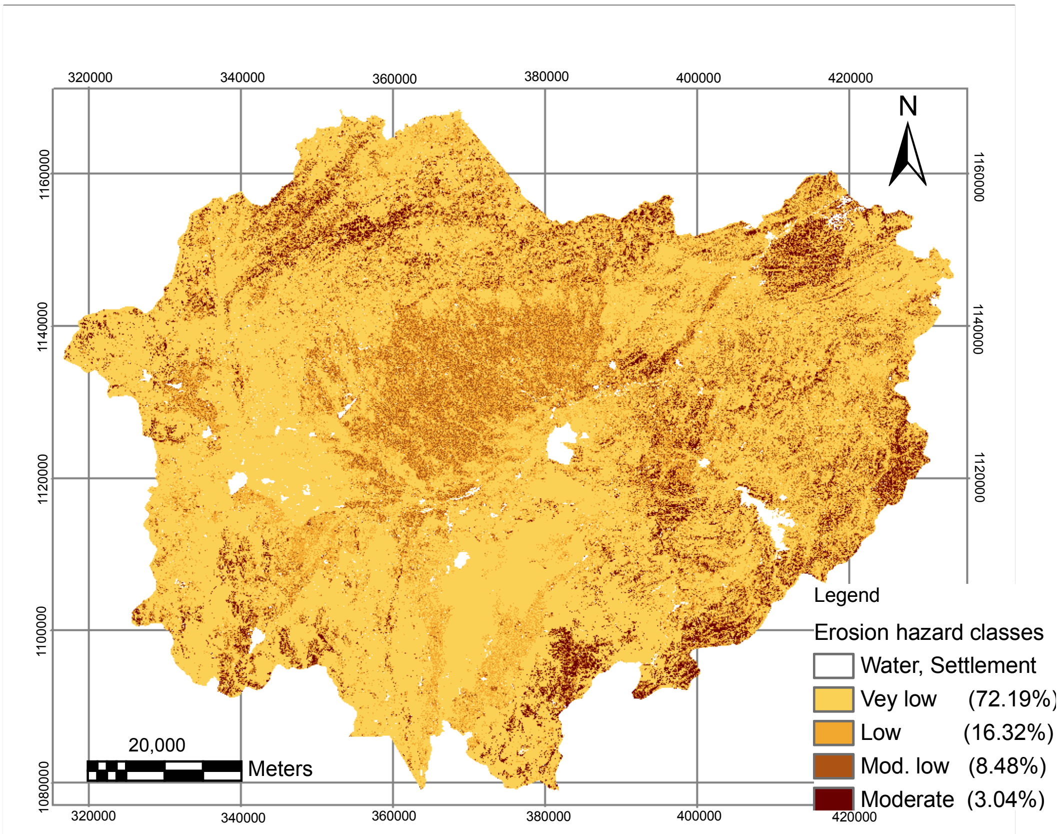


Figure 35. Actual erosion hazard in the Torres municipality, Venezuela

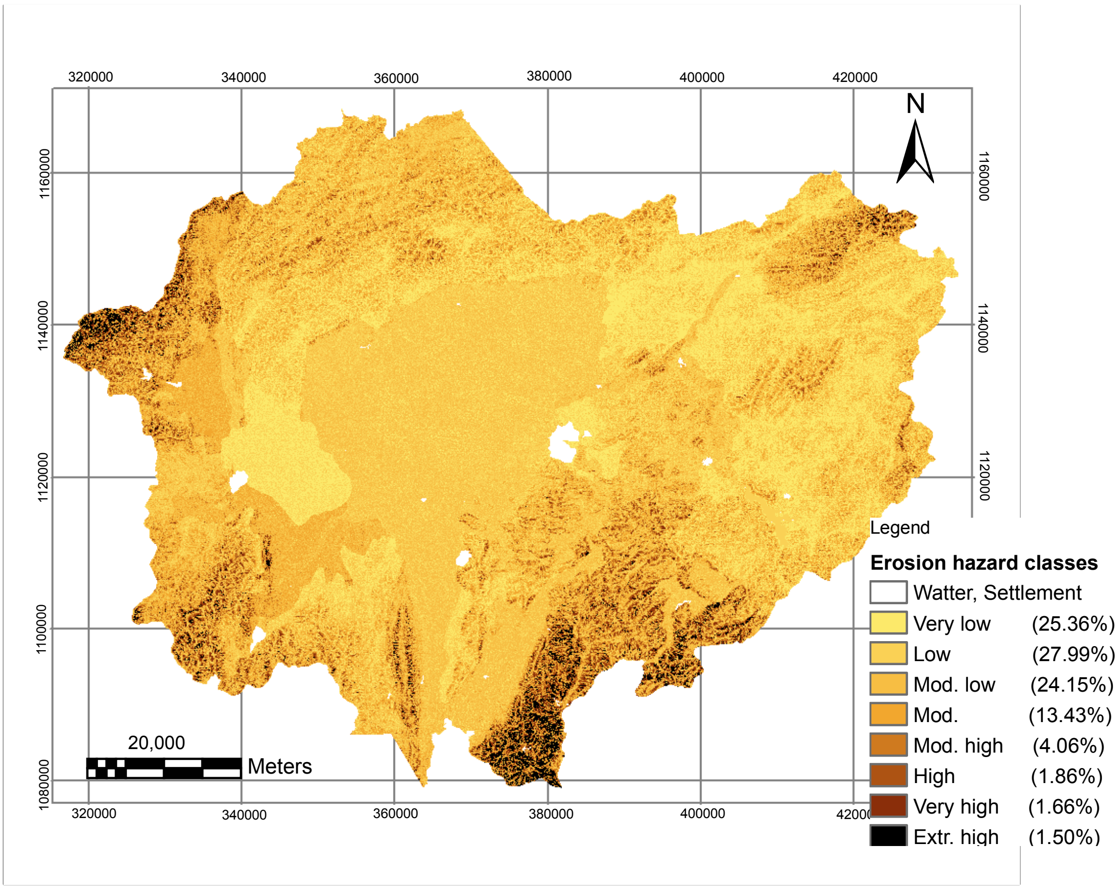


Figure 36. Potential erosion hazard in Torres municipality, Venezuela

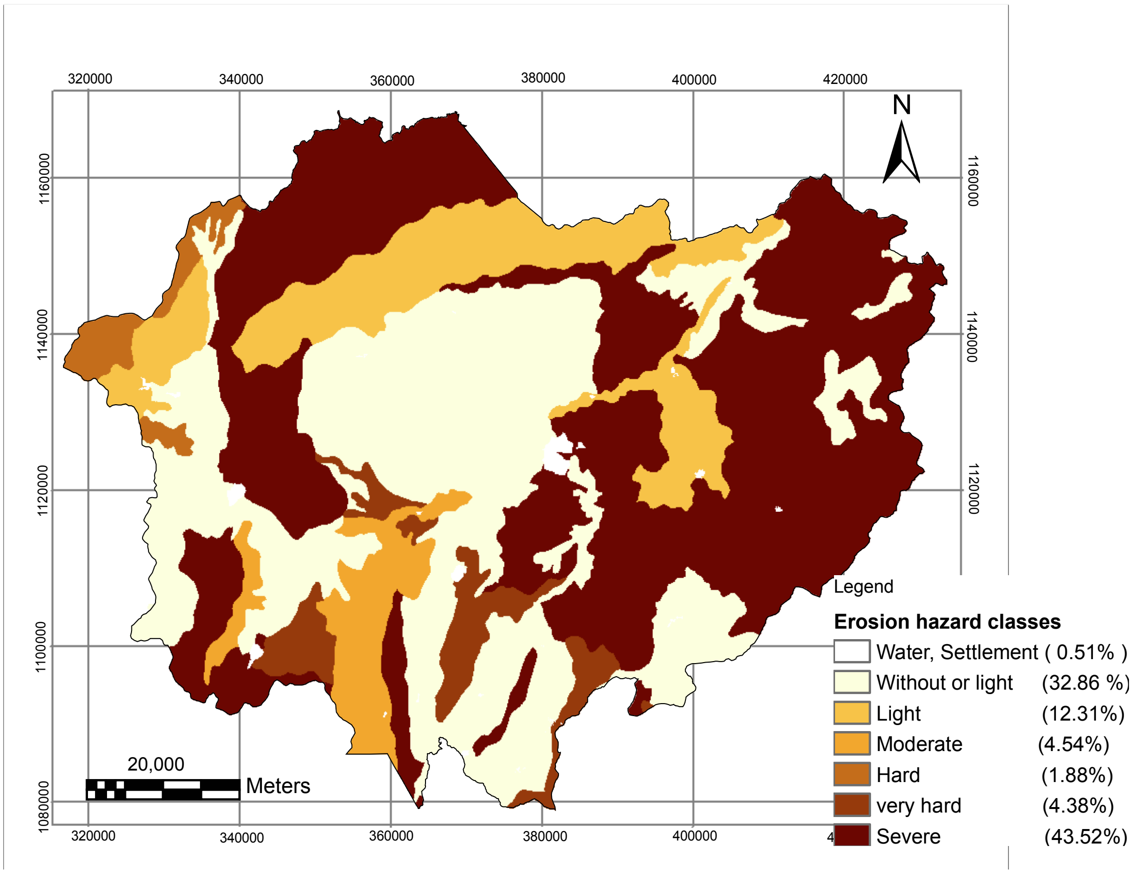


Figure 37.Erosion hazard according to land classification for use capacity (Arias and Comerma, 1971).

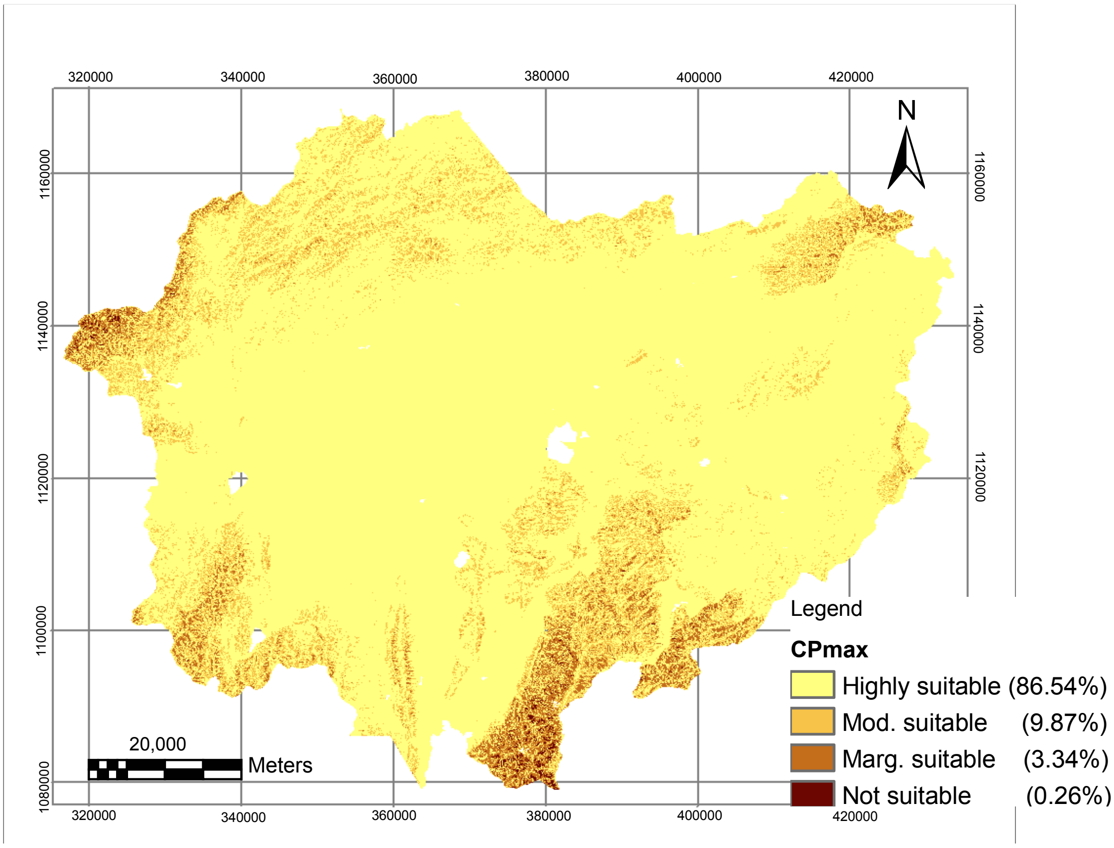


Figure 38. *CPmax* factor distribution in the Torres municipality, Venezuela

Table 22. Proportion (%) tabulated in the area according to classes of risk and vulnerability to the water erosion and qualification of the factors related (Páez, 1994). The number in parentheses corresponds to agricultural zone.

Factor	Grades of vulnerability to erosion							
	Very low (1)	Low (2)	Mod. Low (3)	Mod. (4)	Mod. High (5)	High (6)	Very high (7)	Ext. high (8)
R range	***0 - 2000***	*2000 - 4000*	*4000 - 6000*	*6000 - 8000*	*8000 - 10000*	*10000-12000*	*12000-14000*	*>14000*
%	53.7 (4.2)	45.6 (95.8)	0.72 (0.01)					
K range	*≤ 0.01*	*0.001 - 0.005*	*0.005 - 0.015*	*0.015- 0.030*	*0.030–0.045*	*0.045-0.060*	*0.060-0.075*	*> 0.075*
%			45.3	44.6 (74.6)	6.2 (10.4)	3.5 (15)		
L range	*< 25*	*25 – 50*	*50 – 100*	*100 – 150*	*150 - 200*	*200- 250*	*250 – 300*	*> 300*
%	97.5 (97.6)	2.0 (1.9)	0.4 (0.4)	(0.04)	(0.001)			
S_1 range	*0 - 1*	*1 - 3*	*3 - 5*	*5 -10*	*10 - 15*	*15 - 20*	*20 - 25*	*> 25*
%	27 (98.6)	17.9 (1.2)	9.64 (0.1)	10.55 (0.03)	8.09 (0.02)	7.2	6.1	13.29
S_2 range	*0 - 3*	*3 - 8*	*8 - 12*	*12 -20*	*20 - 30*	*30 - 50*	*50 - 100*	*> 100*
%	77.9	0.8	1.4	11.7	6.7	1.5	0.03	
D range	*≥ 250*	*250 - 200*	*200 -150*	*150 - 100*	*100 - 50*	*50 - 25*	*25 -10*	*< 10*
T	*> 24*	*24 – 20*	*20 - 16*	*16 - 12*	*12 - 8*	*8 - 4*	*4 - 2*	*< 2*
A range	*≤ 12*	*12 – 25*	*25 – 50*	*50 – 100*	*100 – 150*	*150 – 200*	*200 – 300*	*> 300*
%	72.19	16.32	8.48	2.43	0.41	0.10	0.05	0.02
CP_{max}	*≥ 0.5*	*0.5 – 0.12*	*0.12 – 0.08*	*0.08 – 0.045*	*0.045– 0.018*	*0.018– 0.012*	*0.012– 0.001*	*< 0.001*

S_1 (%, low lands) S_2 (%, high lands, over 800 m) D (cm) T (t/ha/year) CPmax = T/R.K.L.S

IV. Discussion

1. RUSLE Factors

Taking into account the wide spatial diversity and limitations in the data, it was found that the RUSLE integrated to geographical information system (GIS) could be used to predict soil loss in the area.

R values ranged between 120l and 4166 MJ mm ha^{-1} h^{-1} y^{-1}, most of them (53.7% of the study area) within the range of 1201- 2000 MJ mm ha^{-1} h^{-1} y^{-1}, therefore rainfall in the area under study has very low potential to cause erosion according to Páez (1994). Ninety six percent of R values in the agricultural area had low erosivity. However, it has been long recognized that the climatic characteristics of this region with topographic factors, soil, poor plant coverage due to semi-arid climate, and land use factors have escalated the water erosion. In arid or semi-arid regions, the runoff cause very high concentrations of sediment resulting in a limitless sediment supply (Aksoy and Kavvas, 2005). Large amounts of precipitation and runoff occurring during rainy epoch could cause high erosion rates if the soil cover is minimal (ASCE Task Committee, 1970). The area of study, although dry most of the year, is subjected to occasional intensive rains which are able to make a heavy erosion (Ferrer, 2003). The calculation of the index of aggressiveness of the rains through the modified Fournier index (Arnoldus, 1980) (determined in Chapter 1) indicated that aggressiveness of the rainfall in the region ranged from moderate to high, and are directly related to the elevation in agreement to Irvem et al. (2007). However the current study, in disagreement to Ferrer (2003) and to Fournier index indicates that R values in the study area have low erosivity. Cause of lack of agreement could be the data used to estimate R: current study used annual and monthly precipitation instead hourly precipitation, therefore current study is not taking into account the hourly-based intensity of the rainfall.

The erodability of the soil (K) ranged from moderate low (45.3% of the study area) to high (3.5% of the study area), enlarging the erodability in the agricultural zone. Susceptibility of the study area soils to erosion can be explained by high content of slime and very-fine-sand fraction (40% and 10% respectively), which contribute to an easy soil disintegration (Mati et al., 2002), although the content of clay reaches the 25%. Additionally the content of organic matter is not higher than 4%. In terms of erosion, soils under these conditions in combination with hilly topography, poor plant coverage and inappropriate agricultural practices are under serious risks (Irvem et al., 2007).

The values of the factor *LS* are relatively low (96.8 % of the study area have values lower than 3.31), since most of the area is a depression. The lengths of slopes are smaller than 25 m (97.6

% of the study area). The slope steepness is lower than 3% in 45% of low lands, 80% of high lands and 97.5% of the agricultural soils. This fact suggests that topography of the municipality mostly favors little erosion. Steeper and longer slopes are combined in only 3.2% of the area to result in higher velocities of the runoff and therefore greater potential for erosion. Areas of convex topography such as ridges, where flow diverges, had low *LS* values. A comparison with the slope gradient map (Figure 31) revealed a clear effect of steepness on the *LS* factor, with areas of greater slopes having high *LS* values and usually corresponding to the back slopes between the summits and drainage lines (Hoyos, 2005).

The half of the study area possesses two extreme conditions for favoring and avoiding erosion: cover with forest, which covers 25% of the area, and bare soil with and without ephemeral vegetation which cover also 25% of the area. This condition explains the significant correlation of C factor to the erosive processes.

With respect to factor *P*, the 90.22% of the area has a value of 1, due to that the agricultural area occupies alone 7.9%. Therefore, the lack of practices in the area has a large influence in the erosion rates. While the C factor dissipates the kinetic energy of the raindrops before impacting soil surface (Erdogan et al, 2006), the conservation practices principally affect erosion by modification the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster, 1983; Lee, 2004).

2. Soil erosion

The analysis of correlation determined that statistically the actual and potential erosion are related, but there is not relation to the estimated by Arias and Comerma (1971). Lack of correlation to the estimated by Arias and Comerma (1971) is explained by the methods of estimation. Estimation of actual and potential erosion in the present research have been based on RUSLE model which quantify erosion, and afterward, classify areas of 30m x 30m in ordinal categories based on the magnitude of erosion. On the contrary, Arias and Comerma (1971) estimated erosion in a qualitative manner. Nevertheless, in spite correlation coefficient was not significant ($P>0.05$), similar patterns (Figure 35, 36 and 37) among the categories and distribution of the erosion are observed, it means, in detailed information these maps do not display any relationship (lack of correlation) but in general view these maps display similar patterns. The spatial distribution of the erosion in the maps of actual and potential erosion is more detailed because of coupling of GIS and soil erosion models result in an efficient procedure for determining the spatial distribution of soil erosion and sediment yield under a variety of simulation scenarios (Guobin et al., 2004).

Large losses of soils are observed in the zones where either the precipitation is higher ($R \geq 2000$), with little cover ($C \geq 0.45$), without conservation practices (P=1), and with convex topography ($LS \geq 3.31$, S ≥ 5.7). Values of the factors are directly related to the losses, the larger are the values, the greater are the losses (Renard et al., 1997). This relation was less evident when the factors of erosion were correlated with the method of Arias and Comerma (1971), even though this system considers the effect combined of the topography, climate and the cover as main factors to determine the risks of erosion. This disparity is explained again for the different ways for estimating erosion, being the erosion estimates calculated in this research more reliable.

The factors most related to the actual erosion were LS and C factors. It is evident the areas with the largest soil losses are associated to large values of *LS* factor (specially the factor S), lack of cover, and erodability of soil. When actual and potential erosion are compared, the effect of factors C and P become more evident. Soil losses are duplicated and degrees of moderate high (4.06%), high (1.86%), very high (1.66%) and extremely high (1.5 %) erosion according to the classification of Páez (1994) are reached. The protective effect of the vegetation is still greater in the agricultural zone. The sediment yield greater than 25 t $ha^{-1}yr^{-1}$ could be increased in 100 % due to the susceptibility to erosion (moderate to high) of those soils.

The lowest erosion values are registered in zones of forest (around the 98% is smaller than 8 t ha^{-1} yr^{-1}) and where are carried agricultural practices (54.96% smaller to 12 tons). This causes notes that the cultivations reduce considerably the erosive processes especially in the semiarid zone (Oñate, 2004). With respect to areas of natural brushes, prickly xerophilous and ephemeral vegetation had the most irreversible soil losses (>50 tons). When their coverage in the area was considered (15.02, 19.47 and 11.40 %, respectively), it appeared that the areas have a serious problem that should be dealt with conservation measures. This was attributed to the fact that these type of cover occurred on the slopes with the range of *K* value between 0.015 and 0.050. In the agricultural land the soil erosion was not as critical as in the land of the natural shrubs and prickly xerophilous vegetation. This was due to, although they had the relatively higher C values (0.56) than those (0.20 and 0.45, respectively), the fact that the land of the agricultural crops was situated in the areas where the range of *LS* was between 0 and 3.36 and deposition occurred.

3. Suitability ratings for soil erosion hazard

Table 21 shows the suitability ratings for soil erosion hazard for rainfed agriculture (FAO, 1985) in all area. According to this, the 72.19% of the area is highly suitable (losses smaller than 12 tons), the 16.32% is moderately suitable (losses between 12 and 25 tons), the 8.8% is marginally suitable (losses among 25 to 50 tons) and only the 3.04% is not suitable (lost greater than 50 tons.). In the agricultural area the factors *R*, *L* and S has very low potential to cause erosion according to Páez (1994), but the *K* factor classify as moderate to high. One hundred percent of the agricultural area falls in the category of suitable because of sediment yield does not surpasses 50 t ha^{-1} y^{-1}; 54.4% of the agricultural area classify as highly suitable- The existence of moderate to marginally suitability will clearly call for some combination of changed land use, special management practices, or major land improvements (FAO, 1985).

Soil removal as consequence of erosion causes decline in agricultural productivity. For example, in Mozambique and Nigeria, a 50% for loss in productivity of maize and cowpeas resulted from removal of 3 mm of topsoil from a forest soil with total depth of 15 cm (Saroisong et al., 2006). Productivity loss due to erosion is most significant in areas where nutrients are concentrated close to the surface, soils with little depth, and areas with high rates of soil loss (FAO, 1985). Considering the tolerance of soil loss established by soil depth (greater than 100 cm), the percent of high sustainability is equal to 100% in the agricultural area, due to *CP*max is higher than 0.12. Based on the conditions reported based in the current study, and based on Páez (1994), the zone can be used continuously with annual cultivations mechanized without practice of conservation. Nevertheless it is desirable the use of conservation practices such as vegetative barriers or buffer strip, crop rotation, the cultivations of cover, green manures, etc.

V. Conclusions

The RUSLE/GIS technology was used to predict soil erosion hazard in the Torres municipality located in the Tocuyo River Basin, Venezuela. Based on the results obtained, the suitability ratings and the requirements conservation practices were determined. Different methodologies for estimating rainfall-runoff erosivity (*R*), and topographic factors (*L* and *S*) for RUSLE were used. *R* factor was determined for rains greater than 12.5 mm, applying the regression equation reported by Paredes and Silva (2004), because it resulted in similar erosivity ranges to the previous estimated for the region. This equation was used to obtain a map of R factor based on the interpolation of the meteorological data. Additionally, in view of the effect of elevation on actual amount of precipitation, *R* values were site-specifically corrected using a DEM. The resultant map for *R* factor was made with weighted average for both methods. Mean annual R factor values ranged from 1200 to 4166 with averaged 2683 $MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$, having climatologically very low potential to cause erosion. *LS* Factor, obtained from a DEM, was made, applying three methodologies: two simple alternatives approaches which take into account only the slope gradient (*S*) spatial distribution, assuming constant values of length (50 and 100 m) and length as a function of the slope gradient; and the third that considers the spatial distribution of the length and slope gradient (LS_SAGA. The criterion used to select one of the proposed methodologies was that exists a high risk of overestimating the values of *LS,* and consequently of the erosion, when it is not considered the space distribution of the length of the slope. Due to this, the chosen method to compute factor *LS* for RUSLE was *LS_SAGA*. The values of the factor *LS* are relatively low (96.8 % of the study area is smaller than 3.31), since most of the area is a depression. There is a clear effect of steepness on the *LS* factor. *K* factor prepared from the soil map has ranges of erodability of the soil from moderate low to high enlarging the erodability in the agricultural zone. Probably, that is due to the high contents of slime and very-fine-sand fraction and the low content of organic matter, this situation contributes to easy soil disintegration. *C* and *P* factors were computed from land use map of Torres municipality. The use, cover, and conservation practices influence decisively in the control of the erosive processes. The smallest erosion values of soil losses are registered in zones of forest and where agricultural practices are carried out. Finally, soil losses or sediment yield in $t\ ha^{-1}\ y^{-1}$ were estimated as a product of *R, K, LS, C* and *P* layers, having a range of 0 to 2558, but more than 72 % of the area is under very low water erosion hazard and highly suitable to rainfed agriculture, under erosion hazard view. Areas susceptible to erosion with a soil loss more than 12 $t\ ha^{-1}\ y^{-1}$ are found primarily in the higher basin or where there is little cover. In this area, priority must be given for protection of forest and reforestation of steep bare lands. Witch respect to assessing of loss in productivity due to erosion in the agricultural area, the percent of high sustainability is equal to 100 % in the agricultural area. In accordance to this, the zone can be used continuously with annual cultivations mechanized without practice of conservation. Nevertheless some measures of conservation are recommended.

It is clear from the results of this study that RUSLE is a powerful model for the qualitative as well as quantitative assessment of soil erosion intensity for the conservation management. However, future works are necessary to validate and confirm the results of RUSLE prediction. GIS has given a very useful environment to undertake the task of data compilation and analysis.

Chapter 5. Concluding summary

Tocuyo River Basin is an important hydrographical ecosystem in Center-Western region of Venezuela. Many types of climates, topography, vegetation, and land uses may be found in the basin, because Tocuyo's headwaters are located at 3000 meters above sea level and flows, after 350 kms, into Caribbean Sea. The first Spanish settlements during the colonization were located along Tocuyo River. Natural resources in the basin have been exploited for hundred of years, without scientific evaluation of the environmental impact, but with evident basin deterioration. A sustainable management of the basin requires a detailed knowledge and inventory of the environmental conditions in the basin, understanding as environment the combination of external physical conditions that affect and influence the growth, development, and survival of organisms; and also the social, economic, and cultural conditions affecting the nature of an individual or community. To aim for this objective, a big project entitled “Sustainable Development of Tocuyo River Basin” has been proposed for Venezuelan state and private institutions to plan long-term strategies for a sustainable use of the basin. To achieve this proposal, the frame of land evaluation based on FAO model is supposed to be adequate due to previous experiences in other tropical basins. This model requires information such as climate, soil, topography, vegetation, erosion process, and socioeconomics, in each point where land evaluation is made. Because of the size of the basin, spatial analysis techniques (geographical information system and remote sensing) are considered very helpful for this purpose. As the first step in this big project, an inventory of most of the information required by the model of land evaluation is necessary. Fifteen municipalities exist within Tocuyo River basin, the biggest is Torres Municipality in which elevation range between 100 and 3000 meters above sea level. Due to the different environmental conditions in Torres Municipality, it was chosen as “pilot region” to get the needed information. Present research is a contribution of this big project, in which information related to environmental parameters, vegetal cover, and erosion in Torres municipality was collected, generated, and analyzed by means of the use of geographical information systems and remote sensing.

Any proposed use for a land unit in the basin will be influenced by environmental factors. Environmental information in Torres Municipality did not exist in digital format. Maps of soil and geology were updated based on bibliographic information. Hydrology, main roads, settlements, borders, and airports were updated by means of remote sensing, using a Landsat image. Phyisiography maps were generated using a digital elevation model. Climate information was generated from data of 20 years (1985-2005) from 33 meteorological stations distributed within the study area. Annual precipitation and temperature was used to generate isohyets and isotherms digital maps, respectively. Use of annual and monthly precipitation in several calculations resulted in determination of seasonal pattern, dry period, evapotranspiration, humidity provinces, and climatic aggressiveness. Maps of all these parameters were also generated. Land utilization type (LUT) in the municipality, a specific parameter of FAO land evaluation, was generated by the results of a survey applied to 60 farmers. Map of LUT was also generated.

Current land use and land cover are also important in definition of the most appropriate land use of the land. Use of Decision Tree Classifier on the combined use of remote sensing and digital elevation model, resulted in obtaining a map of land use/land cover of Torres Municipality. Thirteen classes were differentiated based on reflectivity, vegetation index, and elevation, in a resolution of 15m x 15m. These classes were: dense forest, open forest, bushes, prickly xerophilous vegetation, grassland, dense crops, non-dense crops, bare soil with ephemeral vegetation, bare soil (dry), bare soil and rocks, clouds, water, and shadow.

Accelerated soil erosion is detrimental both in terms of reduced agricultural productivity, and environmental impacts such as non-point source pollution, therefore identification of specific high-priority areas for the implementation of management practices is increasingly necessary. Several models exist to estimate erosion rates; one of the most utilized is Revision Universal Soil Loss Equation. Erosion estimation by this model consists in a linear multiplication of the following factors: rain-runoff erosivity (potential of the rain to cause erosion), soil erodability (susceptibility of the soil to be eroded), topography (the more is the length and the steepness of a slope the more is the potential erosion), crop and management (effect of cropping and management practices on erosion rates), and conservation practices (effect of conservation practices on erosion rates). Obtaining and mapping of these parameters were made. Several methodologies exist to calculate rain-runoff erosivity factor. Present study enhance the necessity to generate locally equations to estimate this factor, being the most accurate an equation generated with data obtained nearly to Torres Municipality. Use of digital elevation model was successful in improving the accuracy of precipitation data based on interpolation of data obtained from meteorological stations. In average, rainfall on Torres Municipality resulted with low potential to cause erosion. Calculations based on data from soil map of the municipality resulted in map of soil erodability; resulting that erodability of Torres Municipality soils range from moderately low to high, enlarging the erodability in the agricultural zone. Calculation of LS factor are normally done without consideration of the spatial distribution of the slope length, however, present study demonstrates that there is a high risk of overestimating the values of *LS,* and consequently of the erosion. The values of the factor *LS* in the municipality resulted relatively low (96.8 % of the study area was smaller than 3.31), since most of the area is a depression. There is a clear effect of steepness on the *LS* factor. Factors crop and management and conservation practices were obtained from the land use/land cover map. Multiplication cell-by-cell of the maps of rainfall-runoff erosivity, soil erodability and topographic factors resulted in the map of potential erosion for Torres Municipality. Similar procedure, adding the factors crop and management, and conservation practices was used to estimate actual erosion of the municipality. The use, cover, and conservation practices influence decisively in the control of the erosive processes. The smallest erosion values of soil losses were registered in zones of forest and where agricultural practices are carried out. Actual erosion had a range from 0 to 2558 t ha^{-1} y^{-1}, but more than 72 % of the area is under very low water erosion hazard and highly suitable to rainfed agriculture. Areas susceptible to erosion with a soil loss more than 12 t ha^{-1} y^{-1} are found primarily in the higher basin or where there is non-dense cover. In this area, priority must be given for protection of forest and reforestation of steep bare lands. With respect to assess productivity losses due to erosion in the agricultural area, the percent of high sustainability is equal to 100 % in the agricultural area. In accordance to this, the zone can be used continuously with annual mechanized cultivations without practice of conservation. The results of this study support that the use of RUSLE under GIS environment, helped by digital elevation model are powerful tools for both qualitative and quantitative assessment of soil erosion in a basin.

Use of geographical information system, digital elevation model and remote sensing have facilitated collection, manipulation, and obtaining of data to generate 24 new maps of Torres Municipality in digital format: isohyets, seasonal patterns, isotherms, dry period, evapotranspiration, precipitation concentration, humidity provinces, climatic aggressiveness, soil, geology, physiography, hydrology, main roads, settlement, airports, land utilization type, land use/land cover, RUSLE rainfall-runoff factor, RUSLE soil erodability factor, RUSLE topographic factors, RUSLE crop and management factor, RUSLE conservation practices factors, actual erosion, and potential erosion. The main proposed objective in this research has been reached, and the needed information for land evaluation for rainfed agriculture based on FAO model is now available in digital format. All these information will be the basement to decide the most appropriate land use in a specific land unit within Torres Municipality.

REFERENCES

AKSOY, H. & M. KAVVAS (2005): A review of hill slope and watershed scale erosion and sediment transport models. - Catena, 64: 247–271.

AMORE, E., C. MODICA, M. NEARING & V. SANTORO (2004): Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. - Journal of Hydrology, 293:100-114.

ANDERSON, J., E. HARDY, J. ROACH & R. WITMER (1976): A land use and land cover classification system for use with remote sensor data. - US Geological Survey Professional Paper 964, Washington, DC: USA.

ANDRADE, O., & O. RODRIGUEZ (2002): Evaluación de la eficiencia de barreras vivas como sistemas de conservación de suelos en ladera. – Bioagro, 14(3):123-132.

ARIAS, L., & J. COMERMA (1971): Un sistema para evaluar la capacidad productiva de los terrenos en Venezuela. - Seminario de clasificación interpretativa con fines agropecuarios. Maracay. Mimeografiado. 10 p.

ARNOLDUS, H. (1977): Metrology used to determine the maximum potential average soil loss due sheet and rill erosion in Morocco. - FAO Soils Bulletin, 34: 39-51

ARNOLDUS, H. (1980): An approximation of the rainfall factor in the Universal Soil Loss Equation. In: De Boodt M. & D. Gabriels (Eds) Assessment of erosion. - John Wiley and Sons, Inc. Chichester, West Sussex, UK. 127 – 132.

ASCE TASK COMMITTEE (1970): Sediment sources and sediment yields. - ASCE, Journal of the Hydraulics Division, 96 (HY6):1283 – 1329.

ATHINSON, P. & P. APLIN (2004): Spatial variation in land cover and choice of spatial resolution for remote sensing. - International Journal of Remote Sensing, 25 (18): 3687-3702.

BACCI, O., K. REICHARDT & G. SPAROVEK (2003): Sediment spatial distribution evaluated by three methods and its relation to some soil properties. - Soil & Tillage Research, 69: 117–125.

BARRETT, E. & L. CURTIS (1992): Introduction to environmental remote sensing. 3rd ed. London: Chapman & Hall. 426 pp.

BARRIOS, A. (2000): Distribución espacial del factor LS (RUSLE) usando procedimientos SIG compatibles con IDRISI aplicación en una microcuenca andina. - Revista Forestal Venezolana, 44 (1): 57-64.

BASHER, L. (1997): Is pedology dead and buried? - Australian Journal Soil Research, 35: 979-994.

BOGGS, G., C. DEVONPORT, K. EVANS & P. PUIG (2001): GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropic of Australia. - Land Degradation Development, 12: 417- 434.

BOSQUE, J. (1992): Sistemas de información geografica. - Editores Rialp, S.A Madrid. 419 p.

BOUMA, J. (1989): Using soil survey data for quantitative land evaluation. - Advances in Soil Science, Vol 9.

BURROUGH, P. (1986): Principles geographical information systems for land resources assessment. Clarendon press. Oxford. 193 p.

BURROUGH, P. & R. MCDONNELL (1998): Principles of Geographical Information Systems. Oxford University Press, New York

CAMPBELL, J. (1981): Spatial correlation effects upon accuracy of supervised classification of land cover. - Photogrammetric Engineering & Remote Sensing 47: 355-363.

CAMPBELL, J.(1996): Introduction to remote sensing. 2nd Edition. Tailor & Francis, London.

CHIKHAONI, M., F. BONN, A. BOKOYE & A. MERZOUK: (2005): A spectral index for land degradation mapping using ASTER data: Application to a semi-arid Mediterranean catchments. - International Journal of Applied Earth Observation and Geoinformation, 7: 140-153.

CIESIOLKA, C., K. COUGGHLAN, Z. ROSE, M. ESCALANCE, G. HASHIM, P. PANINGBATAN & S. SOMBARPNIR (1995): Methodology for a multy-country study of soil erosion management. - Soil Technology, 8: 179–192.

CIREN (1996): Descripciones de suelos, materials y símbolos: estudio agrológico Santiago de Chile. 2 Volúmenes. 479 p.

CHUVIECO, E. (1996): Fundamentos de teledetección espacial. 3ra. Edición. España.565 p.

CHUVIECO, E.(2002): Teledetección ambiental. La observación de la tierra desde el espacio. l. 1ra. Edición. España.584 p.

COMERMA, J. & D. MACHADO (1991): Los sistemas de evaluación de tierras de la FAO. En: Seminario de clasificaciones interpretativas con fines agropecuarios. Torres, S. y D. Lobo (comp.) Palmaven, S. A. P. 15-21

COPLANARH (1975): Inventario Nacional de Tierras, regiones Noroocidental, Centro Occidental y Central. MAC. - Centro Nacional de Investigaciones Agropecuarias. Publicación 43.Vol 1. 493 p.

COPLANARH (1994): Vegetacion actual de la región centroccidental: Facón, Lara, Portuguesa, Yaracuy de Venezuela. Un resumen ecológico de acuerdo a la fotointerpretación. Smith, R. Boletín N° 39-40.

CRISTOBAL, J., X. PONS & M. NINYEROLA (2005): Modelling actual evapotranspiration in Catalonia (Spain) by means of remote sensing and GIS. 1st Göttingen GIS & remote Sensing Days, environmental Studies. 7-8 October, 2004. Göttingen, Germany.

CURRAN, P., G. FOODY, K. KONDRATYEV, W. KOSODEROV & P: FEDCHENKO (1990): Remote sensing of soils and vegetation in the USSR, Londres, Taylor and Francis.

DAVIDSON, D. (2002): The assessment of land resources: achievements and new challenges. Australian Geographical Studies 40(2):109-128

DE JONG VAN LIER, Q., G. SPAROVEK, D. FLANAGAN, E. BLOEM & E. SCHNUG (2005): Runoff mapping using WEPP erosion model and GIS tools. - Computer & Geosciences, 31:1270-1276

DE ROO, P. (1998): Modelling runoff and sediment transporting catchments using GIS. - Hydrology Processes, 12: 905- 922.

DIAZ, O. (1995): Estudio de fragilidad de suelos y aplicación de la USLE en base a SIG para la “Microcuenca el Maqui, sexta region, Chile”. Pontificia Universidad de Chile. 81 p.

EDESO J, P MARAURI Y A MERINO (s/f): Aplicaciones de los sistemas de información geográfica en los estudios geomorfológicos ambientales : el mapa sintético y el mapa de erosión. http://www.arraquis.es/pedromm/articulo.htm.

EASTMAN, J. & M. FULK (1993): Long sequence time series evaluation using standardized principal components. - Photogrammetric Engineering & Remote Sensing, 59(8): 1307-1312.

EMERY, W., J. BROWN & Z. NOWARK (1989): AVHRR image navigation: Summary and review. Photogrammetric Engineering & Remote Sensing, 55: 1175- 1183.

ERDOGAN, E., G. ERPUL & I. BAYRAMIN (2006): Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. - Environmental Monitoring and Assessment, 14: online-first DOI 10.1007/s10661-006-9464-6.

ESTES, J. & D. SIMONETT (1975): Fundamentals of image interpretation. In: R Reeves (ed), Manual of remote sensing, Falls Church. - American Society of Photogrammetry. Pp 869-1076.

EVANGELISTA, P. (1992): Land evaluation for agroforesty in the Philippines. PhD. Thesis College Laguna. Philippines.218 p.

FAO (1976): A framework for land evaluation. Soils Bulletin 32 FAO. Rome, Italy.

FAO (1983):. Guidelines: land evaluation for rainfed agriculture. - Soils Bulletin 52. FAO. Rome, Italy.

FAO (1984): Land evaluation for forestry. - Forestry Paper 48. FAO. Rome, Italy.

FAO (1985): Guidelines: land evaluation for irrigated agriculture. - Soils Bulletin 55. FAO. Rome, Italy.

FAO (1991): Guidelines: land evaluation for extensive grazing. - Soils Bulletin 58. FAO. Rome, Italy.

FAO (1993): Guidelines for land-use planning. - Development Series 1. FAO. Rome, Italy.

FAO (1996): Agro-ecological zoning guidelines. - Soils Bulletin 73. FAO. Rome, Italy.

FERNANDEZ, C., J. WU, D. MCCOOL & C. STOCKLE (2003): Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. - Journal of Soil and Water Conservation, 58:128–136.

FERRER, E. (2003): Analisis estructural preliminar de la Hoya del Rio Tocuyo, 1ra parte. CICHRT. Lara, Venezuela. 12 p.

FERRER, E. (2004): El ecosistema hidrográfico de la Hoya del Río Tocuyo. Universidad Yacambú. 43 p.

FERRER, E. (2003): Análisis Estructural Preliminar de la Hoya del Rio Tocuyo 2003.1er Parte. Serie Carcterización de la Hoya del Rio Tocuyo. N°04-04-12-02. 12 p.

FERRER, E. & H. DE PAZ (1985): Análisis ambiental de la región centroocidental de Venezuela. FUDECO. 257 p.

FERRER, J. & J. COMERMA (1997): Riesgos de erosion hídrica bajo el uso actual de la tierra en las Mesas Orientales de Venezuela. - Revista VENESUELOS, 5:2-8.

FERRO, C. & T. WARNER (2002): Scale and texture in digital image classification. - Photogrametric Engineering and Remote Sensing, 68 (1) :51-63.

FOSTER, G., L. MEYER & C. ONSTAND (1997): A runoff erosivity factor and variable slope length exponents for soil loss estimates. - Transactions of the American Society of Agricultural Engineers, 20:683–687.

FRANKLIN, J., T. LOGAN, C. WOODCOCK & A. STRAHLER (1986): Coniferous forest classification and inventory using Landsat and digital terrain date.- IEEE Transactions on Geosciences and Remote Sensing, 24: 139-149.

FRIEDL, M. & C. BRODLEY (1997): Decision tree classification of land cover from remotely sensed data. - Remote Sensing of Environment, 61 (3): 399- 409.

FRIEDL, M., C. BRODLEY & A. STRAHLER (1999): Maximizing land cover classification accuracies produced by decision trees at continental to global scales. 37 (2): 969-977.

FU, G., S. CHEN & D. MCCOOL (2006): Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS. - Soil & Tillage Research, 85:38-49

GEORGE, H. (1983): An overview of land evaluation and land use planning at FAO. - Land and Plant Nutrition Mangement Service, AGLL; FAO.16 p.

GLEITSMANN, A. (2006): Exploiting the spatial information in high resolution satellite data and utilizing multi-source data for tropical mountain forest and land cover mapping. - Ibidem. Stuttgart. Germany.

GUOBIN, F., S. CHENA & D MCCOO (2006): Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS. - Soil & Tillage Research, 85: 38–49.

HANSEN, M., R. DUBAYAN & R. DEFRIES (1996): Classifications tress: an alternative to traditional land cover classifiers. - International Journal of Remote Sensing, 17: 1075-1081.

HOLBEN, B. (1980): Spectral assessment of soybean leaf area and leaf biomass. Photogrammetric - Engineering and Remote Sensing, 46: 651-656.

HOLDRIDGE, L. (1967): Life zone ecology. Revised ed. San José, Costa Rica: Tropical Science Center. 206 pp.

HOYOS, N. (2005): Spatial modeling of soil erosion potential in a tropical watershed of the Colombian Andes. - CATENA, 63:85-108.

HOYOS, N., P. WAYLEN & A. JARAMILLO (2005): Seasonal and spatial pattern of erosivity in a tropical watershed of the Colombian Andes. Journal of Hydrology, 314:177-191.

HUTCHINSON, C. (1982): Techniques for combining Landsat and ancillary data for digital classification improvement. - Photogrammetric Engineering and Remote Sensing. 48 (1): 123-130.

ICHII, K., M. MARUYAMA & Y. YAMAGUCHI (2003): Multi-temporal analysis of deforestation in Rondonia state in Brazil using Landsat MSS, TM, ETM+ and NOAA AVHRR imagery and its relationship to changes in the local hydrological environment. - International Journal of Remote Sensing, 24 (22): 4467-4479.

IRVEM, A., F. TOPALOGLU & V. UYGUR (2007): Estimating spatial distribution of soil loss over Seyhan River Basin in Turkey. - Journal of Hydrology, 336:30-37.

JI, W., D. CIVCO & W. KENNARD (1992): Satellite remote bathymetry: a new mechanism for modeling. - Photogrammetric Engineering & Remote Sensing, 58: 545-549.

LANE, L., K. RENARD, G. FOSTER & J. LAFLEN (1992): Development and applications of modern soil erosion prediction technology: the USDA experience. - Australian Journal of Soil Research, 30:893-912.

LAFLEN, J., T. FRANTI & D. WATSON (1985): Effect of tillage systems on concentrated flow erosion. Proceedings of the Fourth International Conference on Soil Conservation, Maracay, Venezuela.

LAFLEN, J., L. LANE & G. FOSTER (1991): WEPP: a new generation of erosion prediction technology. - Journal of Soil and Water Conservation, 46: 34–48.

LOBO, D. s.f. Guía metodológica para la elaboración del mapa de zonas áridas, semiáridas y subhúmedas secas de américa latina y al caribe. 58 p

LUFAFA, A., M. TENYWA, M. ISABIRYE, M. MAJALIWA & P. WOOMER (2003): Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. - Agricultural Systems, 76:883-894

MARNR (1993) : Estudios de suelos de las sierras of Matatere y Bobare. Escala 1:250.000. MARNR. 56 p.

MARNR (1993) : Estudios de suelos de las sierras of Trujillo, Barbacoas y Portuguesa. Escala 1:250.000. MARNR. 45 p.

MARNR (1993) : Estudios de suelos de las sierras of Baragua y Buena Vista. Estados Lara y Falcón. Escala 1:250.000. MARNR. 68 p.

MACHADO, D., R. MEDINA & F. NAVARRO (1990): Evaluación del uso de las tierras agrícolas en el área bajo riego de la zona de El Cebollal, Falcón. Trabajo especial de grado. Programa de Agronomía, Universidad Experimental Francisco de Miranda. Coro, Venezuela.

MARKHDOUM, M. (1992): Environmental unit: an arbitrary ecosystem for land evaluation. - Agriculture, Ecosystems and Environment, 41(2):209-214.

MATHER, P. (1998): Computer processing of remotely sensed images. 2nd Edition, Chischester, John Wiley & Sons.

MATI, B., R. MORGAN, F. GICHUK, J. QUINTOR, T. BREWER & H. LINIGER (2000): Assessment of erosion hazard with the USLE and GIS: A case study ofthe Upper Ewaso Ng'iro North basin of Kenya. - International Journal of Applied Earth Observation and Geoinformation, 2:78-86.

MCCOOL, D., L. BROWN, G. FOSTER, C. MUTCHLER & L. MEYER (1987): Revised slope steepness factor for the Universal Soil Loss Equation. - Transactions of the American Society of Agricultural Engineers, 30: 1387–1396.

MCCOOL, D., L. BROWN, G. FOSTER, C. MUTCHLER & L. MEYER (1989): Revised slope length factor for the Universal Soil Loss Equation. - Transactions of the American Society of Agricultural Engineers, 32: 1571–1576.

MCCOOL, D., G. GEORGE, M. FRECKLETON, C. DOUGLAS & R. PAPENDICK (1993): Topographic effect of erosion from crop land in the Northwestern Wheat Region. - Transactions ASAE, 36:771–775.

MILLWARD, A & J. MERSEY (1999): Adapting the RUSLE to model soil erosion potential in a mountainous tropical sub-catchment. - Catena, 38: 109–129.

MINTEGUI, J. (1988): Análisis de la influencia del relieve en la erosión hídrica."Hipótesis de estudio para correlacionar la pendiente con la longitude del declive en un terreno". V Asamblea Nacional de Geodesia y feofísica. pp. 2229-2245. Madrid.

MITAS, L. & H. MITASOVA (1998): Distributed soil erosion simulation for effective erosion prevention. - Water Resources Research, 34: 505-516.

MITASOVA, H., J. HOFIERKA, M. ZLOCHA & L. IVERSON (1996): Modelling topographic potential for erosion and deposition using GIS. - International Journal of Geography and Information Systems, 10:629–641.

MOLNAR, D. & P. JULIEN (1998): Estimation of upland erosion using GIS. - Computer & Geosciences, 24:183-192

MORGAN, R. (1995): Soil Erosion and Conservation. Addison-Wesley Longman, Edinburgh.

MORGAN, R. (1997): Erosión y Conservación del Suelo. Versión Española. Mundi- Prensa. Madrid. España. 343 p.

MORGAN, R., J. QUINTON, R. SMITH, G. GOVERS, J. POESEN, K. AUERSWALD, G. CHISCI, D. TORRI & M. STYCZ (1998): The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from field and small catchments. - Earth Surface Processes and Landforms 23: 527–544.

MORGAN R, QUINTON J, SMITH R, GOVERS G, POESEN J, AUERSWALD K, CHISCI G, TORRI D AND M STYCZEN (1999): Reply to discussion on the european soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. - Earth Surface Processes and Landforms, 24: 567–568.

MUTCHLER, C., C. MURPHREE & K. MCGREGOR (1982): Subfactor method for computing C-factors for continuous cotton. - Transactions ASAE, 25:327- 332.

NEARING, M., L. ASCOUGH & J. LAFLEN (1990): Sensitivity analysis of the WEPP hillslope profile erosion model. - Transactions ASAE, 33: 839–849

NEARING, M. (1997): A single, continuous function for slope steepness influence of soil loss. - Soil Science Society American Journal 61: 917-919.

NOVOTNY, V. & G. CHESTERS (1989): Delivery of sediment and pollutants from nonpoint sources: a water quality perspective. - Journal of Soil and Water Conservation, pp. 568–576.

ODURA-AFRIYE, K. (1996): Rainfall erosivity map for Ghana. Geoderma, vol. 1125. - Elsevier Science BV, New York, p. 6.

OJEDA, R.(1994): Diseño, replanteo y evaluación de prácicas de conservación en un lote representativo, El Pao, estado Cojedes. Trabajo de grado. FAGRO-UCV. 62 p.

OÑATE, F. (2004): Metodología para la evalución del riezgo de erosión en zonas áridas y su aplicación en el manejo y protección de projectos hidráulicos. - Revista electronica de la REDLACH. (1).1 6p.

OLIVER, J. (1980): Monthly precipitation distribution: A comparative index. - Professional Geographer, 32(3) 300 – 309.

PAEZ, M. (1992): La ecuacion universal de pérdidas de suelo. En: Conservacion de suelos y aguas. FAGRO-UCV. p III.1-III.

PAEZ, M. (1994): Clasificación de suelos con fines de planificación agrícola. - Revista de la Facultad de Agronomía (Maracay), 20:83-100.

PARADELLA, W., M. DA SILVA, N. DE LA ROSA & C. KUSHIGBOR (1994): A geobotalical approach to the tropical rain forest enviroment of the Carajás mineral Province (Amazon Region, Brazil), based on digital TM-Landsat and DEM data. - International Journal of Remote Sensing, 15(8): 1633-1648.

PAREDES, J. & O. SILVA (2004): Evaluación del componente de la erosividad de las lluvias del modelo EPIC en algunas localidades de Venezuela. XVI Congreso Latinoamericano de la Ciencia del Suelo. 26 Sep-1 Oct. 2004. cartagena de Indias, Colombia.

PEBESMA, E.J. (1991-1998): Gstat, GNU Software Foundation.

PEBESMA, E.J. & C.G. WESSELING (1998): 'Gstat: a program for geostatistical modelling, prediction and simulation.' - Computers & Geosciences, 24 (1): 17-31.

PERALTA, P. & P. MATHER (2002): An analysis of deforestation patterns in the extractive reserves of Acre, Amazonia from satellite imagery: a landscape ecological approach. - International Journal of Remote Sensing, 21:2555-2570.

PEREZ, F. & D. NOGUEZ (2001): Los paisajes erosivos en la cuenca media del río Cidacos (La Rioja, España). Una aproximación cartográfica mediante la utilización de datos de satélite y MDT. Zubía monográfico, 13 : 157-176.

PETTA, R., T. OHARA & C. MEDEIROS (2005): Enviromental GIS database for desertification studies in the brazilian northeastern areas. 1st Göttingen GIS & remote Sensing Days, environmental Studies. 7-8 October, 2004. Göttingen, Germany.

POESEN, J (1992): Mechanisms of overland flow generation and sediment production on loamy and sandy soils with and without rock fragments. In: Parsons, A.J., Abrahams, A.D. (Eds.), Overland Flow Hydraulics and Erosion Mechanics. UCL Press, London, UK, pp. 275–305.

POSSADA, E. (2000): Principios de percepción remota. Notas de clase, versión preliminar. CIIDIG. CIA. Santa Fe de Bogotá, Colombia.

RACLOT, D. & J. ALBERGEL (2006): Runoff and water erosion modelling using WEPP on a Mediterranean cultivated cachment.- Physics and Chemistry of the Earth, 31:1038-1047.

RENARD, K. & G. FOSTER (1983) Soil conservation: principles of erosion by water. In: Dregne, H.E.,Willis,W.O. (Eds.), Dryland Agriculture. Agronomy Monograph No. 23. - American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison,Wisconsin, pp. 155–176.

RENARD, K., G. FOSTER, G. WEESIES, D. MCCOOL & D. YODER (1996): Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). - Agriculture Handbook Number 703, Agricultural Research Service, United States Department of Agriculture, Tucson, AZ, USA, pp. 101–142.

RENARD, K., G. FOSTER, G. WEESIES, D. MCCOOL & D. YODER (1997): Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agric. Handb. No.703. USDA, Washington, DC.

ROBIN, M. (1998) La Télédétection, París, Nathan.

RÖMKENS, M., S. PRASAD & J. POESEN (1987): Soil erodibility and properties. Transactions of the 13th Congress of the International Society of Soil Science, 5: 492–504.

ROOSE E. (1977): Erosion and runoff in West Africa from 20 years of records for small experimental plots. Works and Documents of OSTROM No. 78. Paris.

ROSE, C., K. COUGHLAN, C. CIESIOLKA & B. FENTIE (1997): A new conservation methodology and application to cropping systems in tropical steeplands. In: Coughlan, K.J., Rose, C.W. (Eds.), Program GUEST (Griffith University Erosion System Template), Canberra, Australian Centre for International Agricultural Research. ACIAR Technical Report No. 40.

ROSSITER, D. (1994): Lecture Notes: "Land Evaluation". Cornell University College of Agriculture & Life Sciences. Department of Soil, Crop, & Atmospheric Sciences. Semester August 1994.

ROSSITER, D.(1996): Evaluación de tierras: éxitos y fracasos. XIII Congreso Latinoamericano de la Ciencia del Suelo. Sao Paulo, Brasil. 2-8 Agosto. 8 p.

SABALLOS, A. & M. HENRIQUEZ (1999): Evaluación de la aptitud de uso de las tierras de la Estación Experimental Miguel Luna Lugo para la asociación mandarina (*Citrus reticulata*)-patillla (Citrullos vulgaris) en condiciones de secano. VII Congreso Colombiano de la Ciencia del Suelo. Bogotá, Colombia.

SANCHEZ–AZOFEIFA, G., B. RIVARD, J. CALVO & I. MOORTHY (2001): Dynamics of tropical deforestation around national parks: remote sensing of forest change on the osa penísula of Costa Rica. - Montain research and Development 22(4): 352-358.

SÁNCHEZ, M. & E. CHUVIECO (2002): Estimación de la evapotranspiración del cultivo de referencia, Eto, a partir de imágenes NOAA-AVHRR. - Revista Española de Teledetección, 14: 11-21.

SAROINGSONG, F., K. HARASHINA, H. ARIFIN, K. GANDASASMITA & K. SAKAMOTO (2007): Practical application of a land resources information system for agricultural landscapes planning. - Landscape and Urban Planning, 79:38-52.

SAURA, S. & J. SAN MIGUEL (2001): Cartogrfía de zonas forestales en España mediante imágenes IRS-WIFS y árboles de clasificación. In :Rossell J and J Martínez-Casasnovas (eds). Teledectección, medioambiente y cambio global. Lleida. Universidad de Lleida y editorial Milenio. Pp: 151-154.

SCOTT, J. (1997): Report on earth observation, hazard analysis and communications technology for early warning. Geneva, IDNDR Secretariat.

SHI, Z., C. CAI, S. DING, Z. LI, T. WANG AND Z. SUN (2002): Assessment of Erosion Risk with the RUSLE and GIS in the Middle and Lower Reaches of Hanjiang River. In: 12th ISCO Conference, Beijing 2002. 73-78.

SHIRAZI, M. & L. BOERSMA (1984): A unifying quantitative analysis of soil texture. - Soil Sciece . Society American Journal. 48:142-147.

SILVA, O. (2005): Evaluación de la erosividad de la lluvia diaria simulada con EPIC en una localidad de montañas bajas en Venezuela. -Venesuelos, 2(2): 81-85.

SIVERTUN A AND L PRANGE (2003): Non-point souce critical area analysis in the Gisselö watershed using GIS. - Environmental Modeling & Software, 10:887-898.

SKIMORE, A. (1989): An expert system classifiers eucalypt forest types using thematic mapper data and digital terrain model. - Photogrammetric Engineering & Remote Sensing, 55: 1149-1464.

STRAHLER, A. (1981): Stratification of natural vegetation for forest and rangeland inventory using Landsat digital imagery and collateral data. -International Journal of Remote Sensing, 2: 15-41.

TANGESTANI, M. (2006): Comparison of EPM and PSIAC models in GIS for erosion and sediment yield assessment in a semi-arid environment: Afzar Catchments, Fars Province, Iran. - Journal of Asian Earth Sciences, 27:585-597

THORNTHWAITE, C. (1948): An approach toward a rational classification of climate. - Geographical Review, 38:55-94

UNDA, J. (2001): Estrategias para la generación de información faltante de suelos en zonas montañosas con fines de evaluación de tierras. Caso: Microcuenca de la Quebrada El Parchal, Edo. Lara. Tesis de Maestría. Postgrado en Ciencia del Suelo. Facultad de Agronomía. Universidad Central de Venezuela. Maracay, Venezuela.

UNEP (1997): World Atlas of Desertification. Second Edition. Middleton N. and Thomas D. (Eds). 182p.

USDA-ARS-BRS (1997): EPIC. Software.http://www.brc.tamus.edu/epic

VILORIA, J. (1996): Un Nuevo enfoque de inventario de suelos con base a sistemas de información geográfica. Seminario pstgrado en Ciencia del Suelo. Universidad Central de Venezuela.

WILLIAMS, J., C. JONES & P. DYKE (1984) A model approach to determining the relation between erosion and productivity. -Trans. ASAE, 27(1): 129-144.

WISCHMEIER, W. (1975): Estimating the soil loss equations cover and management factor for undisturbed lands. In: Present and Prospective Technology for Predicting Sediment Yields and Sources, pp. 118-125. US. Dep. Agric., Agric. Res. Serv., ARS-S-40.

WISCHMEIER, W., C. JOHNSON & B. CROSS (1971): A soil erodibility nomograph for farmland and construction sites. -Journal of Soil and Water Conservation 26: 189- 193.

WISCHMEIER, W. & D. SMITH (1978): Predicting rainfall erosion losses: A guide to conservation planning. USDA Agric. Manual 537.

YITAYEW, M., S. POKRZYWKA & K. RENARD (1999): Using GIS for facilitating erosion estimation. Applications Eng. Agric. 15: 295–301.

G E OG R A P H I S C H E S   I N S T I T U T

DER GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

ABTEILUNG KARTOGRAPHIE, GIS & FERNERKUNDUNG

ASPECTOS BASICOS A CONSIDERAR PARA DEFINIR EL TIPO DE USO DE LA TIERRA

I: ASPECTOS SOCIALES

1. Nombre:____
2. Ubicación Geográfica:
3. Latitud Norte_________________________Longitud Oeste:___________________________
4. Domicilio:
   Finca_________________Caserío:_____________Ciudad:___________________
5. Nacionalidad: Venezolano:______________Extranjero (País) :_________________________
6. Edad:__________
7. Nivel de Instrucción:
   Analfabeta_____Primaria______Media______Superior___________
8. Número de personas que conforman el núcleo familiar:________
9. Tenencia de la tierra:
   Propia____Arrendada____Medianera____Estado___Ejido____Baldío____otro________
10. Participa en alguna asociación de productores:
   Si____No:_________Cúal?:____

II. ASPECTOS TECNICOS-ECONOMICOS

11. Tamaño de la unidad de explotación:_____________(Ha)

12. Cultivo

Cultivo	Area	Epoca de siembra	Cultivar

13. Rotación de cultivo,
   Cuáles?____

14. Utiliza semilleros?: Si_____ No:_______

15. Semilleros:

Cultivo	Desinfección		Fertlización		Area	Costo
	Producto	Cantidad	Producto	Cantidad		

16. Preparación de tierras:

Cultivo	Arado		Rastra	Nivelación		Subsolado	
	Profundidad	N° Pases	N° Pases	Si	No	Si	No

17. Siembra:

Cultivo	Tipo de Siembra		Distancia de siembra	Densidad	Calidad de la Semilla
	Manual	Mecánica			

18. Control de plagas:

Cultivo	Plaga	Epoca	Producto	Dosis	Frecuencia

19. Control de enfermedades:

Cultivo	Enfermedad	Epoca	Producto	Dosis	Frecuencia

20. Control de malezas:

Cultivo	Maleza	Tipo de control		N° de controles		Producto	Dosis
		Químico	Manual	Químico	Manual		

21. Fertilización:

Cultivo	Orgánico		Forma simple		Forma compuesta		N° de aplicaciones	Forma de aplicación 1, 2, 3 ó 4*
	Tipo	Cantidad	Tipo	Cantidad	Tipo	Cantidad		

* 1= incorporado 2= surco 3= agua 4= foliar

22. Realiza análisis de suelo?: Si________No_________Fecha_________Tipo______________
Por qu é?____

ANALISIS DE LABORATORIO (cuándo se tengan, valores promedios de los 1eros 60 cm)

Prof. cm	% Arenas					% Arena	% Limo	% Arcilla	Textura
	amg	ag	am	af	amf				

pH	% MO	% N	% C	P *	K *	Ca *	Mg *	Na *	Al *	Mn *	% CaCO3	% CaSO4	CE *	CIC *	PSI o RAS *	PSB *

* unidades o método de determinación

23. Aporque:

Cultivo	N° de aporques	Manual	Mecanizado

24. Utiliza riego?: Si________No________Fuente?:____________________________________

ANALISIS DE LABORATORIO (cuándo se tengan)

pH	CE *	Turbiedad *	RAS *	Sales Totales *									Dureza *		
				Ca	Mg	Na	K	CO3	Cl	SO4	F	Otros	Cálcica	Magnésica	Total

* unidades

25. Riego:

Cultivo	Método	Frecuencia	Tiempo	Calidad del agua

26. Rendimiento:

Cultivo	Rendimiento	Cómo considera el rendimiento?		
		Bueno	Regular	Malo

27. Asistencia técnica: Si_____ No_______Quién?_______________________________________

28. Asistencia crediticia: Si______No______Institución __________________________________

29. Experiencias en las actividades agrícolas: ____________(Años).

30. Facultad en el manejo de las actividades agrícolas: Buena______ Regular_____Mala______

31. Dispuesto a asumir cambios sugeridos?: Si____ No_____

III. ASPECTOS ECONOMICOS

32. Comercializa directamente la producción? : Si______ No_____

33. Compra a otros productores?: Si______ No_____

34. Vende el producto a puerta de finca?: Si______ No______

35. Destino de la producción:

Mercados locales: Si____ No_____Cuál?___________________ Cantidad______(Kg)

Mercados nacionales: Si____ No_____ Cuál?____________________Cantidad______(Kg)

Exportación: Si____ No_____ Cuál?___________________ Cantidad______(Kg)

36. Mano de obra familiar: Cantidad _____ Salario _________(Bs)

37. Mano de obra fija: Cantidad _____ Salario _________(Bs)

Muchas gracias por su colaboración!!!

Ing. Onelia Andrade , Prof. Dr. Martín Kappas

Curriculum vitae

Personal

Name:	Onelia del Carmen Andrade Benitez
Sex:	Female
Date of Birth:	06.04.1967
Place of Birth:	Palmas Reales, Venezuela
Nationality:	Venezuelan
Marital Status:	Married
Current Address:	Albrecht Thaer Weg 24a/12, 37075 Göttingen
E-Mail:	oneliaandrade@yahoo.es

Education

1975-1980	Elementary School, Las Llanadas, Trujillo state, Venezuela
1980-1984	Secondary School, Monay, Trujillo state, Venezuela
1985-1994	Universitary degree as Agronomist, Universidad Centrooccidental Lisandro Alvarado,Barquisimeto, Lara state, Venezuela
1996-1999	Master in Science of Soil, Universidad Central de Venezuela, Maracay, Aragua state, Venezuela
2005-2007	Ph.D. Student, Georg-August University, Göttingen, Germany

Professional career

1999 – to date:	Lecturer, Enviromental Studies Faculty, Yacambú University, Cabudare, Lara State, Venezuela

ACKNOWLEDGEMENTS

I would like to acknowledge all the people of Venezuela and Germany which, directly or indirectly, have been important to accomplish this assignment.

I give thanks to Professor Dr. Martin Kappas for supporting me during the work on this thesis, his scientific knowledge. Also, my gratitude for Prof. Dr. Karl-Heinz Pörtge for their suggestions and comments.

My sincere gratitude to Dr. Stefan Erasmi for his valuable help, suggestions and interest during all the stages of this research.

Special thanks are offered to my colleagues at the at the University of Göttingen, Institute of Geography, Department of Cartography, Remote Sensing, and GIS, for their friendly attitude and technical support.

No words are needed to thank my friends for their support and affection.

To my family, to dear husband Hernán and my children María Virginia and Hernán José, my life and my source of happiness, I want to say thanks a lot.

And finally, thanks to God and the life because all I have lived in this process.

.