Chapter 5

Results

SEPRA: application and validation

5. Introduction

This chapter contains the application and validation of the spatial analysis model SEPRA as introduced in Chapter 4. In the Figure 5.1 an overview of the phases that conforms the proposed model is presented. In general it is the same flowchart as shown in Figure 4.2 expanded and completed by the analysis criteria of all the environmental features involved in the analysis. Also, first and final results to be obtained have been included. Therefore, this graphical version of the spatial analysis has been structured according to the following five spatially differentiated information levels:

1. Map of geostructural stability
2. Map of hydrogeomorphological stability – instability
3. Map of erosion susceptibility
4. Map of fragility of the vegetation cover
5. Map land-use intensity

The subsequent combining of these results are the basis for the following final maps:

1. Physiographic restrictions
2. Landscape sensitivity
3. Landscape suitability

Consequently, by means of the analysis of these maps a zonation of land uses is derived. It is at the same time the basis for the final result: Proposal of the land use-plan.

The chapter is divided into the following three sections 1) Methodological framework, 2) Rivas Dávila case; 2) Quíbor valley case.

5.1 Methodological framework (Outputs)

This section explains the results reached through application of the proposed spatial analysis. The outputs of the model, the applied methods of analysis and the subsequent results are shown. All processes are organized according to the above indicated five information levels. Afterwards, the combination of these data produces a subsequent and integral category of information which is the basis for the proposal of the land-use plan.

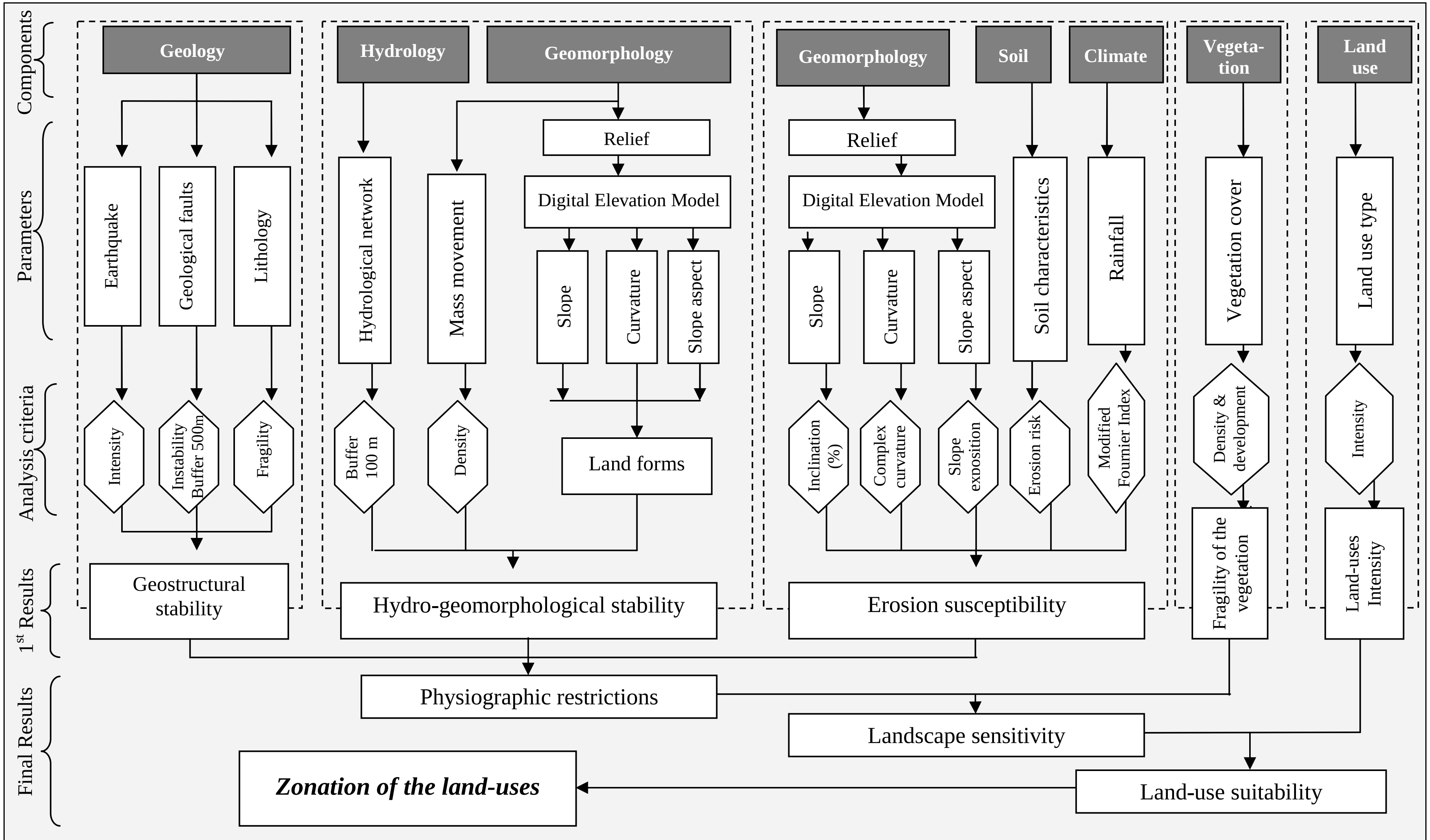


Figure 5.1: Model of spatial analysis SEPRA.

5.1.1 Geostructural stability

The first part of SEPRA includes the evaluation of the geological characteristics of the study area in order to identify the basic conditions of geostructural stability-instability (Figure 5.2).

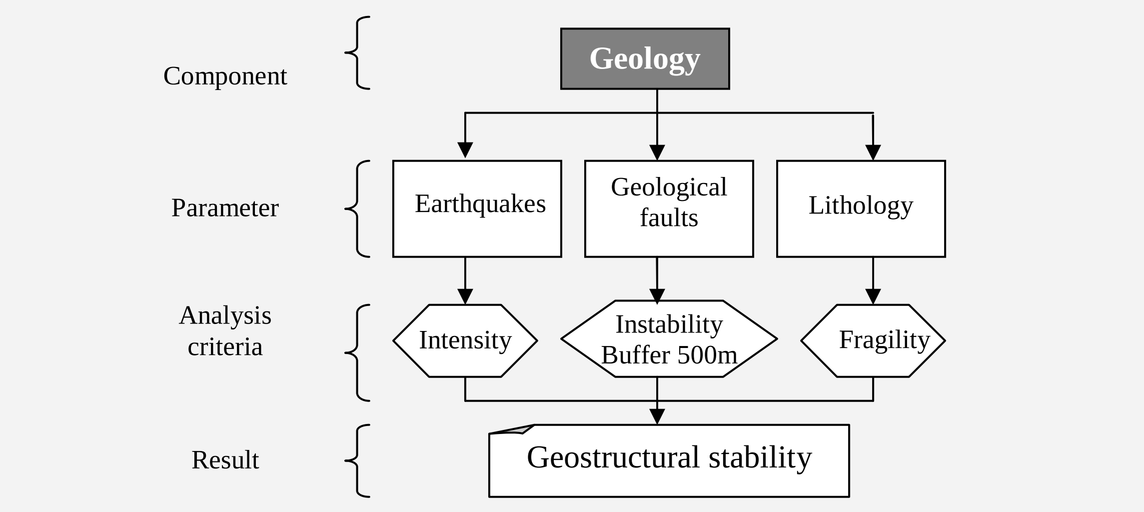


Figure 5.2: Analysis of basic conditions of geostructural stability-instability.

The epicenters of the earthquakes recorded in the study areas throughout the last two centuries were plotted, considering their intensity in accordance with the Modified Mercalli Scale (MM). Geological faults were identified by means of previous geological studies of the area. Consequently, buffers around the faulting zones were built in order to identify the more intensively affected areas by the geological faults, e.g. rocks fracturing or landslides. Finally, the fragility of the rocks was deduced from the lithological characteristics described by each geological formation. These layers were processed by means of several ArcGis 9.1 tools such as "*editing*", "*buffer*" and "*identify*".

The geological layers created in vector format, i.e. lines, points and polygons, were converted into raster format using the spatial analysis tool "*feature to raster*". The resulting raster layers were reclassified by means of the "*reclassify*" tool. The reclassification allowed quantitative values to be assigned to the qualitative classes previously obtained. For the favorable environmental conditions, i.e. stable conditions, values of 1 and 2 were assigned. For the unfavorable environmental conditions more high values, 4 or 5, were assigned. In each case the highest assigned value depended on the number of classes determined in the specific analysis.

After this, the *"raster calculator"* tool was utilized in order to generate a combined analysis of the considered geological aspects. In accordance with the established classes and the mathematical operations of the raster calculator, the resulting raster layer summarizes the general behavior of the geological component. In general, the obtained lowest values indicated conditions of lowest instability, while the largest values indicated conditions of highest instability. Thus, the resulting layer shows, for example, that areas affected by high seismic intensity, located within the buffer area of geological faults and with very fragile lithology are classified as highly instable. In the other sense, those sectors of the studied areas with the lowest level of seismic intensity and lithological fragility as well as those located far from a geological faults, are catalogued as geostructurally stable.

5.1.2 Hydro-geomorphological stability

The term hydro-geomorphology designates the study of landforms as caused by the action of water. Water is one of the most important agents in the shaping of land forms (Scheidegger, 1973; Babar, 2006). In accordance with this assumption, in the SEPRA model an integrated evaluation of the geomorphological and hydrological features is performed. The process follows the steps shown in Figure 5.3.

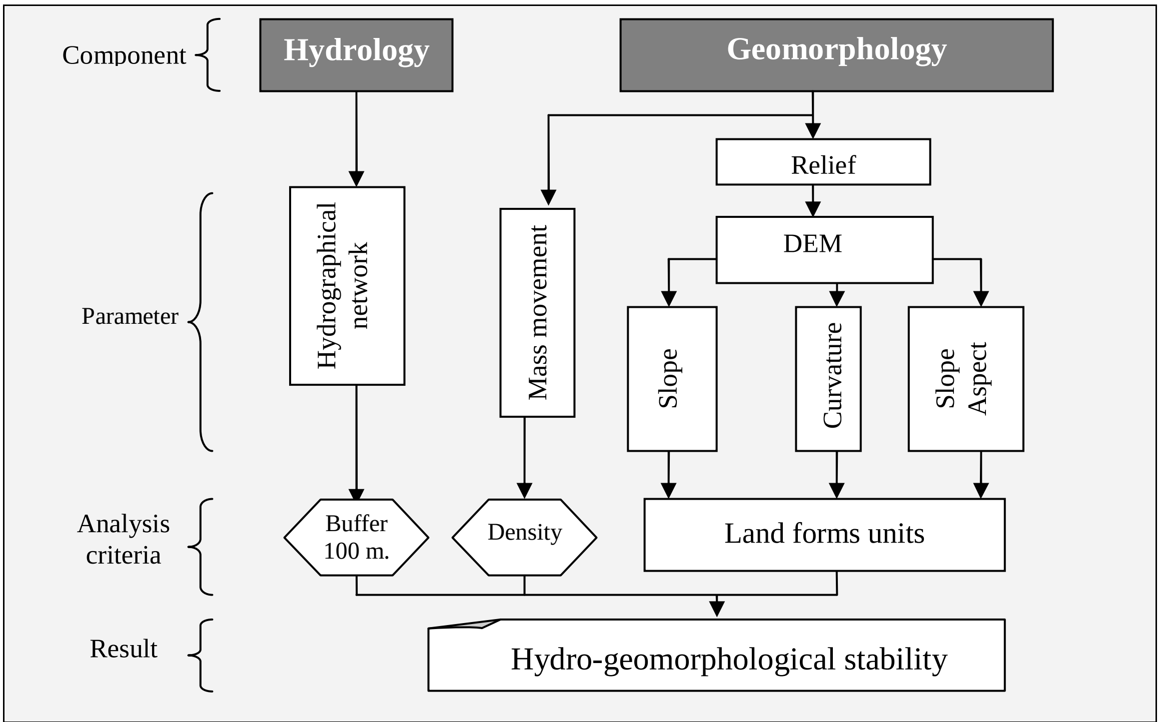


Figure 5.3: Analysis of hydro-geomorphological stability-instability.

The analysis of the hydrographic aspect is based on the stream network, digitalized as part of the base maps of the study areas. Into this spatial analysis it is considered that the dynamic of the stream flow and its relation with the geomorphological processes can generate conditions of instability e.g., regressive and lateral erosion of the channels, landslides and floods. Therefore, it is assumed that the areas located in the nearness of the stream channels are potentially more affected by the dynamic of the stream flow, especially in conditions of overflow. Thus, around of the principal streams are buffer zones established in which those zones more vulnerable to being affected by landslides and floods as a consequence of fluvial dynamics are included. To generate these layers *buffer* and *identify* tools were used.

Geomorphological and relief aspects were also included in this analysis. In one sense, the geomorphological map was analyzed in order to identify the areas where mass movements could occur with higher intensity. Thus, a layer with spatial units characterized by its risks of mass movements was obtained. Next to this, a map of the geomorphological units or land-form units was created based on the analysis of the Quaternary deposits and the several derivatives of the DEM, i.e. slope, slope aspect and relief curvature.

These three layers: buffers of the streams, mass movements risk and land forms units, were converted into raster format and reclassified in order to build a final result which integrates all of these geo-hydrological aspects. In accordance with the selected classification, maps on the hydro-geomorphological stability were obtained.

In general, the areas classified as hydro-geomorphologically stable are those in which the analyzed parameter shows behavior that can be qualified as low risk, i.e., located far from stream channel, less affected by flood process, located in areas of relatively plain relief, but also with low potentiality of mass movements. In this sense, the hydrological and geomorphological risks play a decisive function in the determination of the hydro-geomorphological stability. Consequently the risks of flooding, mass movement are considered as expressions of hydro-geomorphological instability.

5.1.3 Erosion susceptibility

Erosion is a natural process resulting in a relief leveling. As a consequence, erosion of hill slopes is one of the major sources of sediment yield in rivers and downslope sedimentation (colluvial deposits, alluvial deposits, fan deposits). The amount of surface runoff available and the potential energy given, determines the intensity of the erosion processes (Schütt and Thiemann, 2001).

Although erosion is a natural process, its natural rates are altered by a variety of human activities that disturb the land surface (Toy and Foster, 1998). Soil, topography, climate, vegetation cover and human activities are the fundamental factors that intervene in the soil erosion risk (Páez, 1984; Delgado, 1997; Renard et al., 1997), which interact intensively, with a varying load of factors due to the local conditions of the landscape.

In the proposed spatial analysis, an approach refers to the multifactorial causes of the erosion process is the basis, for the erosion susceptibility assessment. The various steps that compound the proposed model are showed in Figure 5.4.

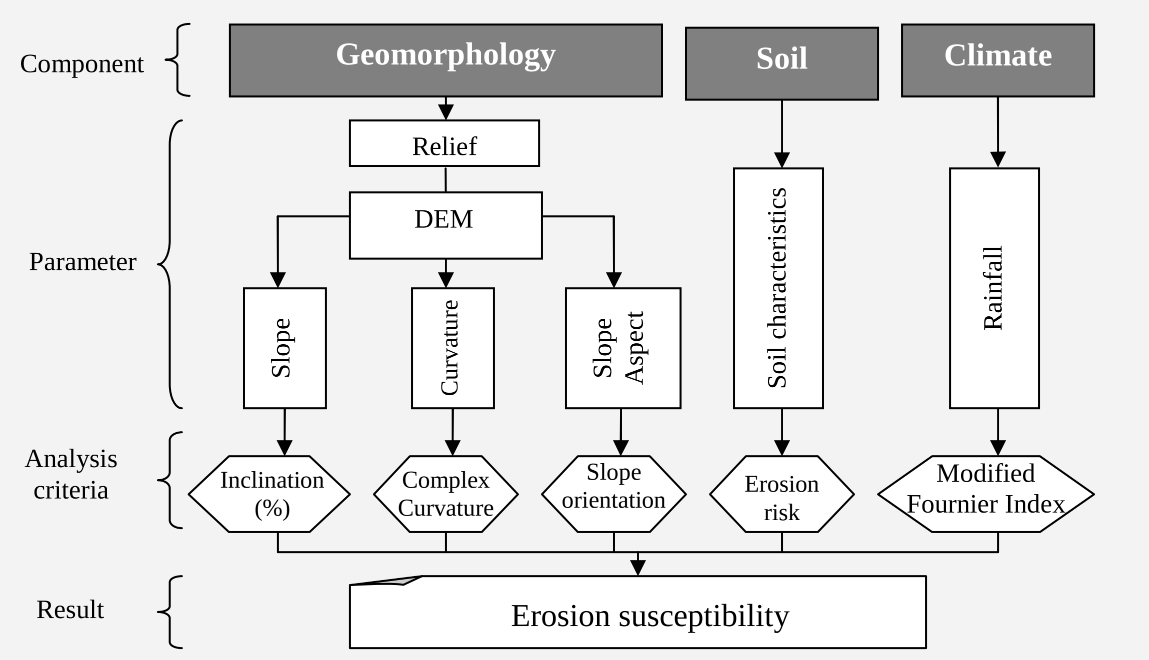


Figure 5.4: Analysis of erosion susceptibility.

Three physical factors that intervene in the erosion process have been considered in the analysis of erosion susceptibility i.e., geomorphology, soil and climate. For each of them, different parameters and criteria of analysis were established according to several approaches explained more widely in the Chapter 4.

There derivatives of the DEM are considered in the analysis of the relief: slope, slope aspect and relief curvature. The slope analysis was based on the premise that the more-inclined terrain units have a higher erosion risk. On the contrary, those lands with lower inclination offer more possibilities of anthropogenic interventions and better conditions of geomorphological stability as well as lower erosion risk. In accordance with the local conditions of the relief of each study area, suitable and different classes were established for this parameter.

The aspect estimates the exposition of the slopes. It was considered in order to determine the slopes with orientations to the east and to the west. East-exposed slope, in tropical zones receives the highest daily radiation (sunny slopes). Unless local factors dictate otherwise, a sunny slope will be frequently warmer, dryer, covers by scarcer vegetation than a sheltered shady slope. Instead, a shady slope will be potentially fresh, humid, and covered by denser vegetation. Due to its favorable conditions for erosional processes it is expected that sunny slopes will be more affected by soil erosion than shady slopes (Zamora, 2002; Ayala et al., 2007; Martínez, 2008).

With respect to the curvature of the slopes, the analysis considered the references which indicate that convex forms are subjected more to erosional processes, while concaves forms are more subjected to accumulation. Linear or straight slopes curvatures present high runoff levels as well as a moderate and high erosion process (Di Stefano et al., 2000; Siepel et al., 2002; Reike and Zapp, 2005).

In order to obtain the indicated layers the corresponding tools of the 3D analyst extension (ArcGis 9.1) were used. The resulting raster layers were reclassified in accordance with suitable classes for each study area.

Soil conditions of the area were analyzed in accordance to elaborated soil maps. Taking into account bibliographic references about the physical characteristics of the described soil units, maps about the natural erosion risk of soils were created for the two study areas. These vector layers were then converted to raster and reclassified as explained before.

Rainfall conditions were also involved in this analysis. In accordance with the available precipitation data, the Modified Fournier Index from Arnold (1980) cited in Pascual et al. (2002) and Andrade (2007) is chosen as the method of analysis. This method allows the aggressiveness of the rainfall to be determined by means of the monthly average precipitation and the annual average precipitation. The values were plotted in a vector layer in accordance with the localization of the meteorological stations. In order to estimate the values for the whole area, the vector layer was processed by means of the

Kriging interpolation technique, with twelve neighborhoods, which is available on the *Spatial Analyst* extension of ArcGis 9.1.

Finally, the five raster layers obtained in this analysis, slope, aspect, curvature, erosion risk and MFI, were combined by means of *raster calculator* in order to obtain a final map which summarized, in accordance with the established thresholds, the soil erosion susceptibility of the study areas.

5.1.4 Fragility of ecological units

As already indicated, vegetation cover builds an important indicator of general environmental conditions, because it is the product of ecological characteristics and anthropogenic interventions. Vegetation can be considered as an indicator of ecological units because it integrates several environmental aspects like climate, relief or soils (Atarrof and Sarmiento et al., 2004). In this work the conditions of the natural vegetation have been identified as ecological units in the case of Rivas Dávila Municipality or vegetal formations in the case of Quíbor Valley. Figure 5.5 contains the steps of this analysis.

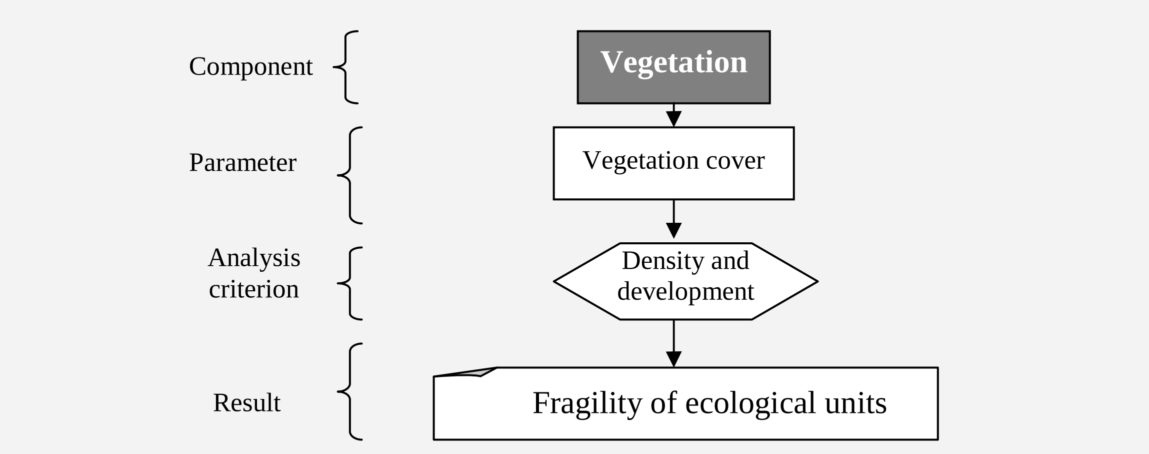


Figure 5.5: Analysis of fragility of ecological units.

Once the types of vegetation cover of each territorial unit are identified, a reclassification was performed taking into account the characteristics of density, evolution and development of each unit. Thus, for example, those vegetation types located in areas of climatic stress (very cold or very dry), e.g. paramos or semi-arid ecosystems, are considered as highly fragile. In general, these vegetation formations are the product of complicated and very long processes of evolution. They, after interventions, alterations or destructions, will have a practically null recuperation, due to the restrictive ecological conditions. Due to the same reasons, the vegetation units highly developed in either density, size and ecological complexity are cataloged as highly fragile.

5.1.5 Intensity of land-use

The intensity level of the land-use is established as an indicator of the human impacts of on the ecological conditions. It is recognized that land-use constitutes the main human trigger of alteration of ecological conditions. Thus, by means of identifying the affectation levels that represent each land-use type, negatives or positives impacts on the environmental stability can be assessed (Figure 5.6).

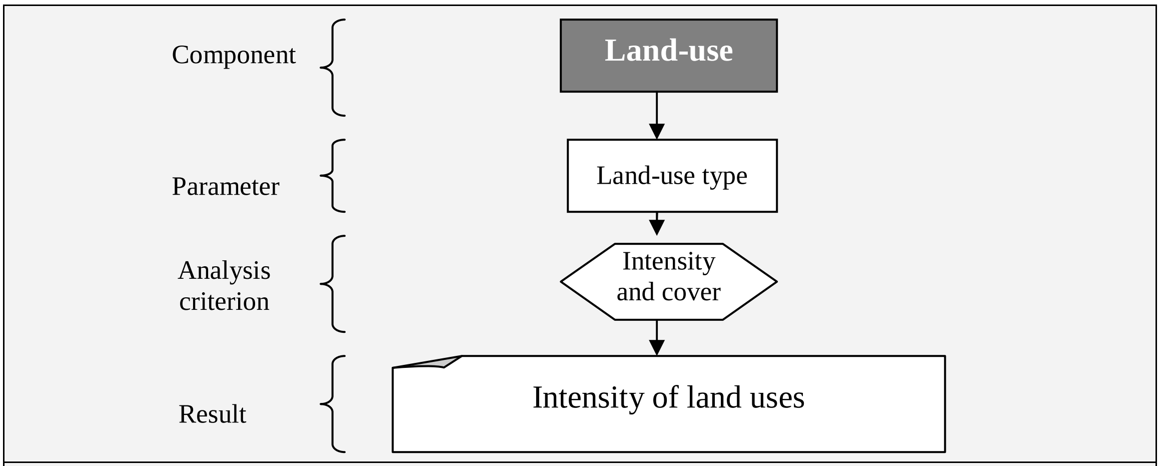


Figure 5.6: Analysis of intensity of land uses.

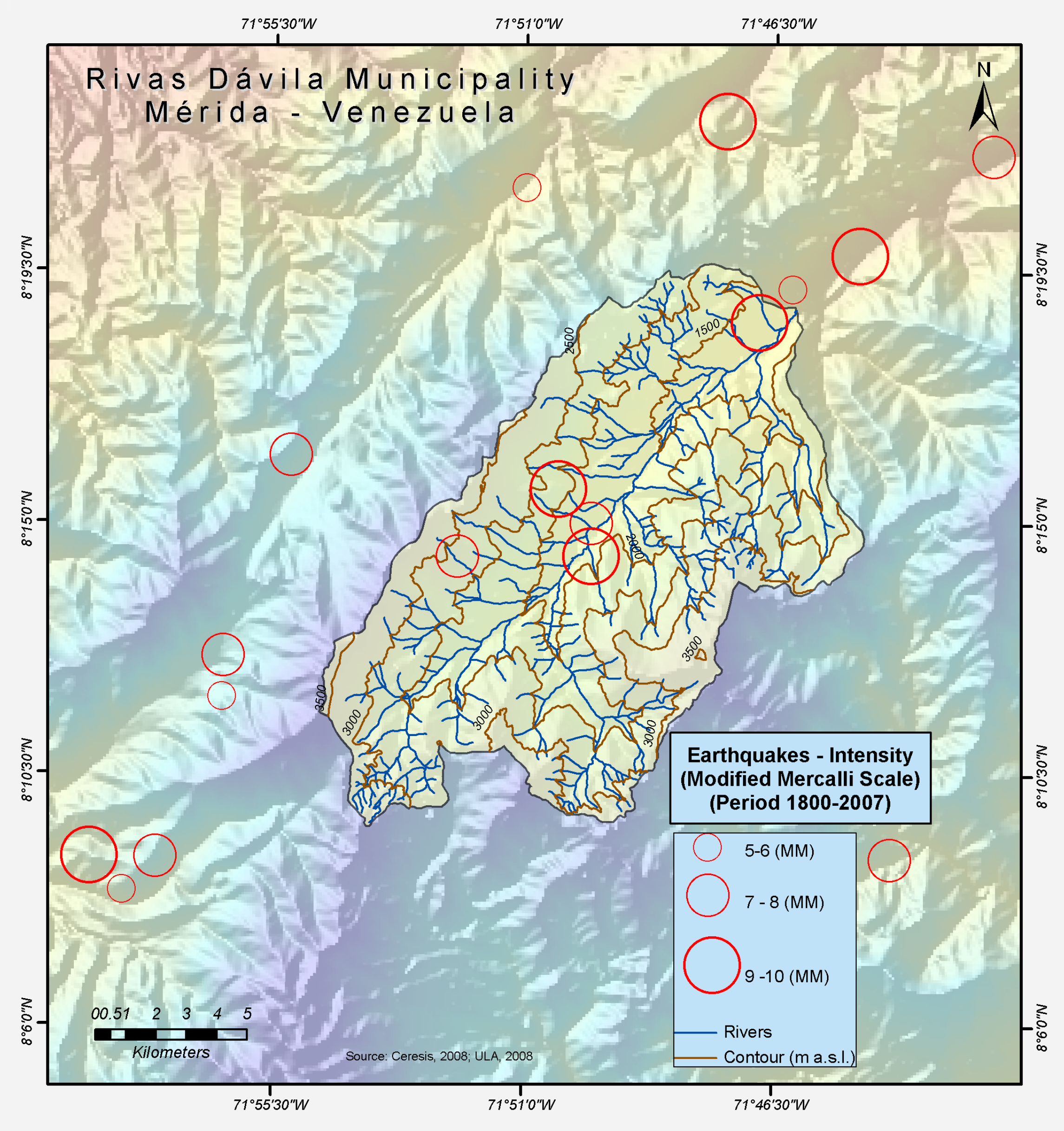
Those land uses that implicate an intensive use of natural resources, with high transformations of environmental conditions, are classified as highly intensive. This is the case, for example, of intensive agriculture or urban settlements. Other activities such as natural conservation or some types of traditional farming of low intensity integrate the group of activities of low intensity.

5.2. Rivas Dávila Municipality

The application of the model of spatial analysis is tackled in this section. The processing is according to the sequential phases established in the flowchart of the model (Figure 5.1)

5.2.1. Geostructural analysis

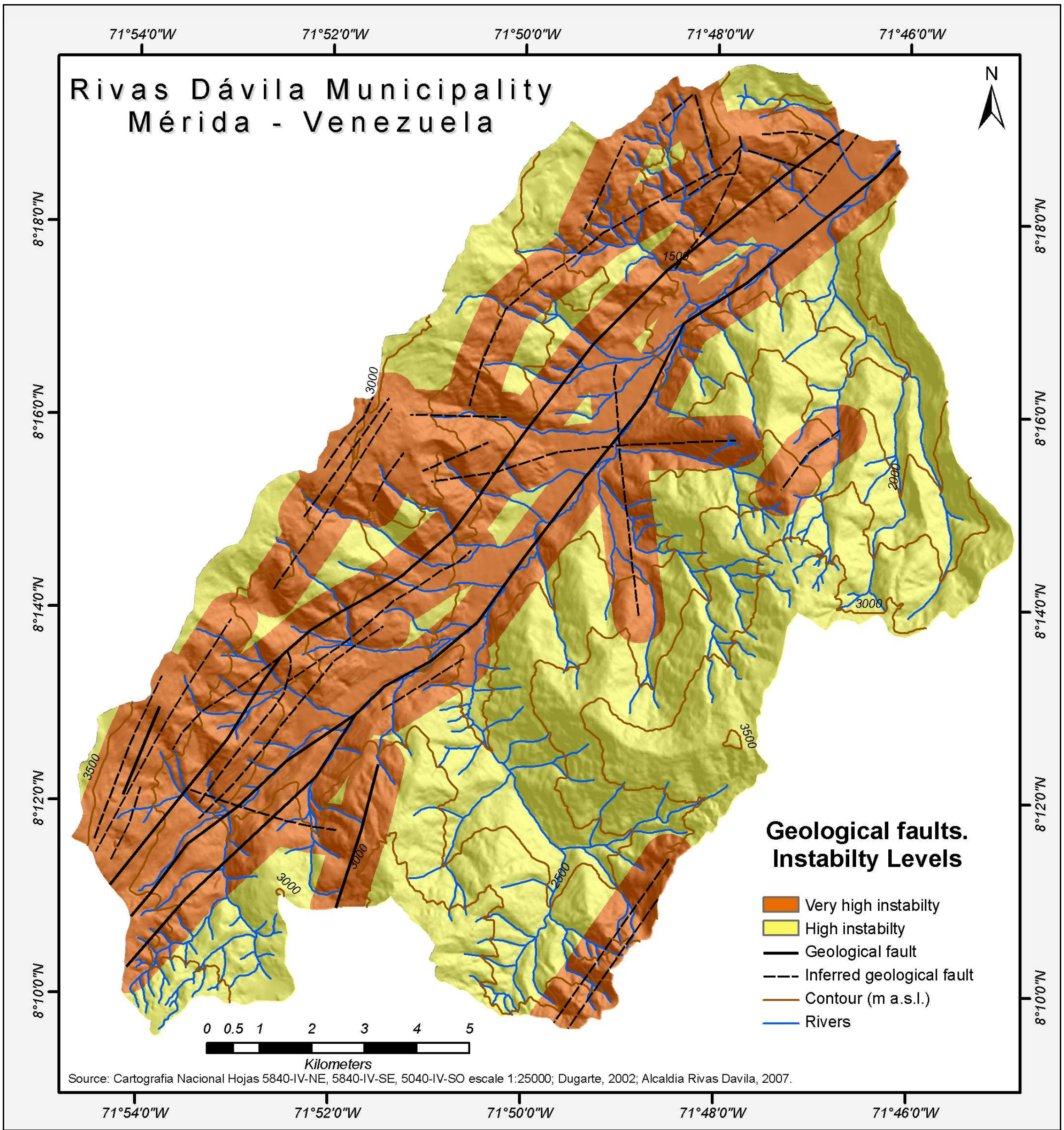
In order to create a seismicity map, the earthquakes registered during the last two centuries with intensities larger than 4 MM, were plotted (Map 5.1). The map shows the high seismicity risk of the region, because six of the sixteen considered earthquakes had intensities larger than 9 MM.



Map 5.1. Intensity of the recorded earthquakes, period 1800-2007.

Additionally, seven earthquakes had intensity levels between 7 and 9 MM. This means that more than 75% of the considered earthquakes were qualified as very strong, destructive, ruinous or disastrous (see Table 4.3). Taking into account this high seimicity and the relatively small area of Rivas Dávila, it was decided that the whole area is subject to a high seismicity risk. Consequently, it did not seem appropriate to establish a zonation in accordance with this parameter. In this sense, seismicity was only considered as a basic reference for the analysis, but was not included as a spatial layer in the analysis, as had been originally formulated.

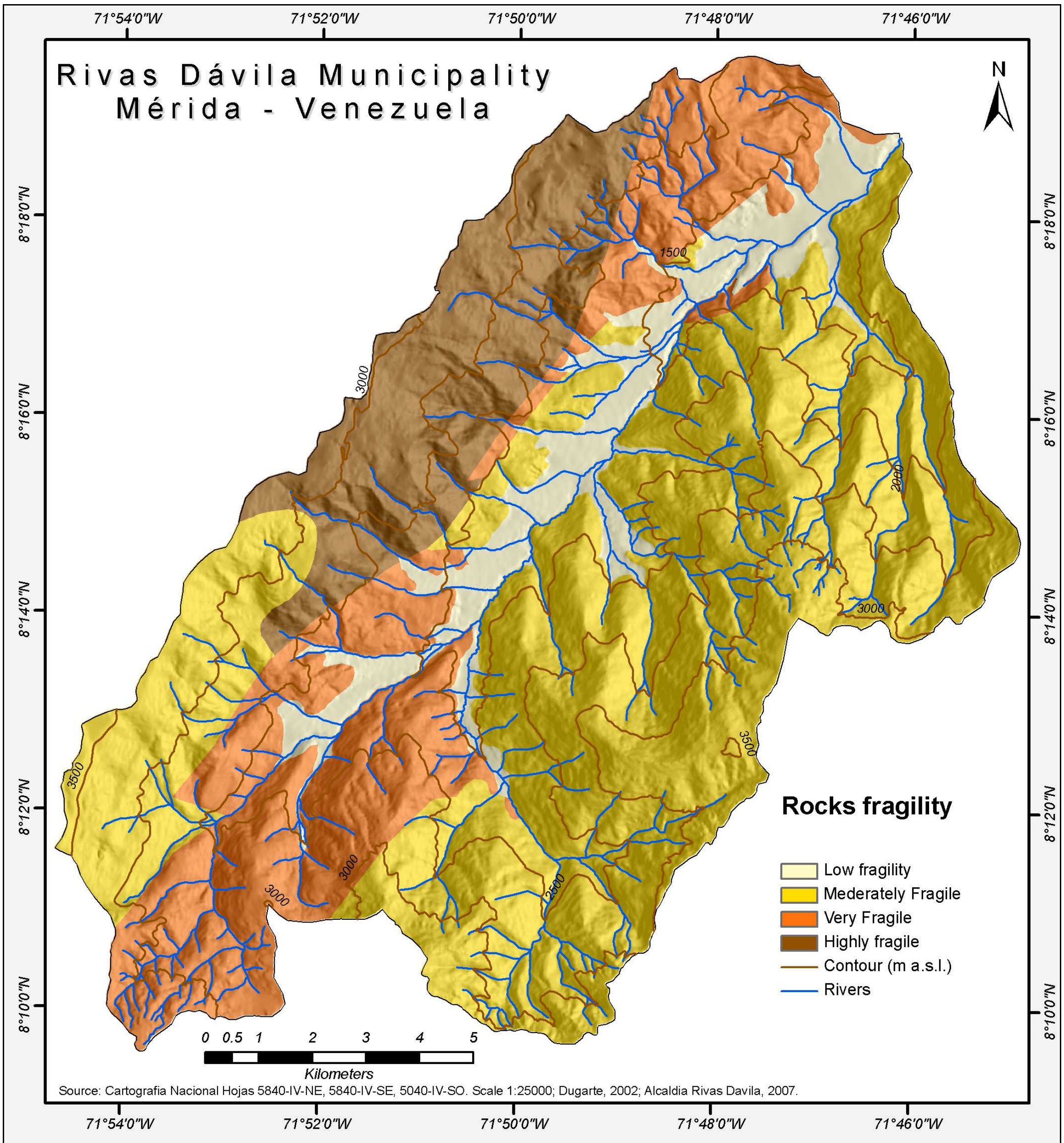
The buffer zones along geological faults (Map 5.2.) were built with a distance of 500 m around the faults as defined by Gokceoglu et al. (2007). By means of this map marked spatial differences can be pointed out. Thus, the left slope is predominantly affected by faults and, consequently, a more geomorpho-structural dynamic can be expected there, e.g., rocks fracturing, landslides or even erosion. In accordance with this layer, a classification of the stability level, due to geological faults, is determined.



Map 5.2: Instability due to geological faults.

It is defined that the zones inside the buffer (0-500 m) have very high instability, while the remaining areas have high instability, because they are not sufficiently far to be considered unaffected by the faults.

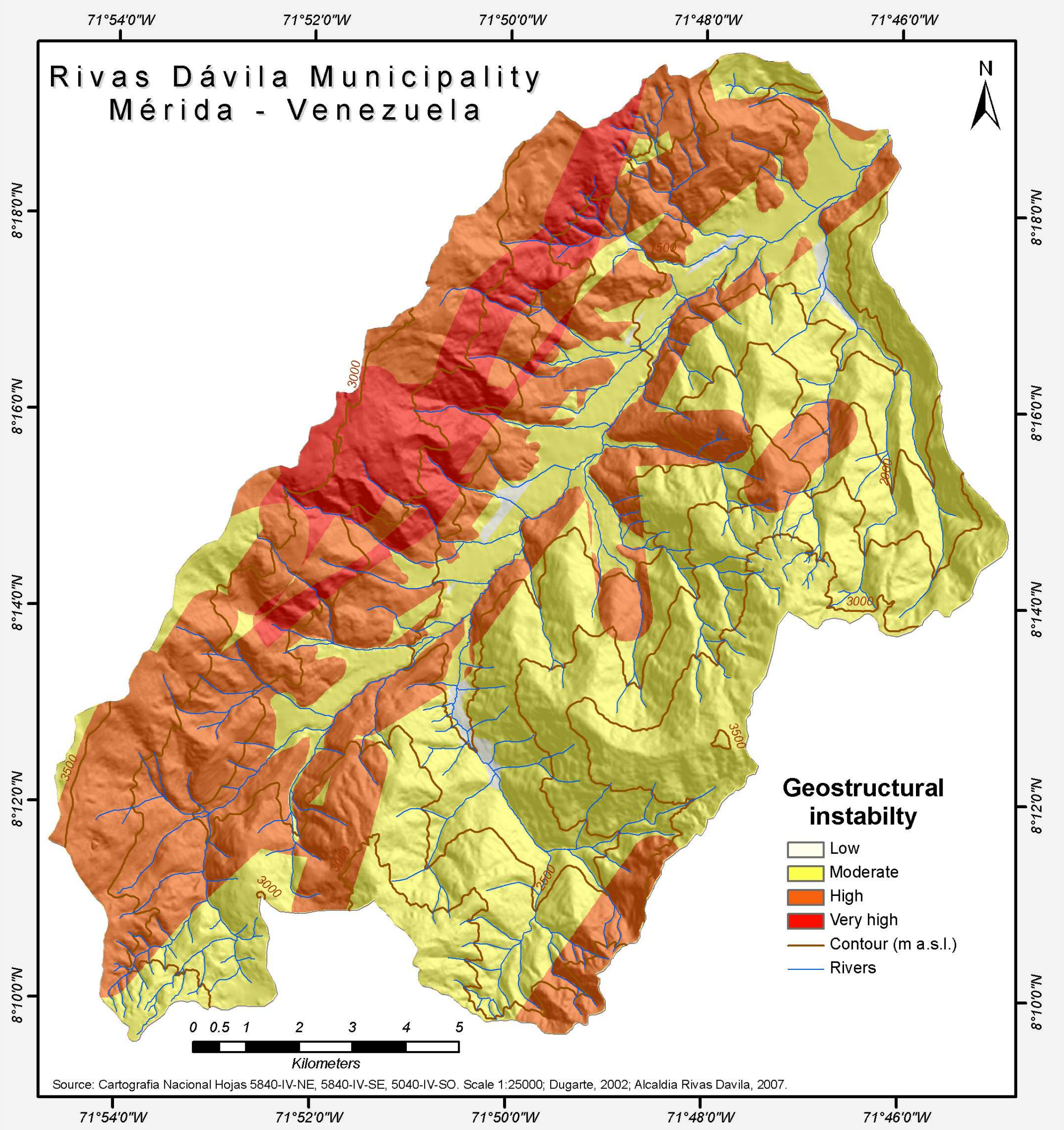
The assessment of the susceptibility or fragility of the bedrocks to the weathering was also included in this analysis. The rocks of the Quaternaries deposits, located in the valley bottom and conformed by unconsolidated conglomerates of low weathering grade, were considered as low fragility.



Map 5.3: Fragility of the rocks.

The Precambrian rocks of the Sierra Nevada formation, gneisses, schists and granites were classified as having moderate fragility due to their stronger condition than young rocks. Since their most susceptible characteristics, the two Paleozoic formations of the area were evaluated as highly fragile. Therefore, the phyllites, shales and limestone of the Mucuchahí formation were classified as high fragility, while the shales, phyllites and schists of the Tostós formation belong to the very high fragility class.

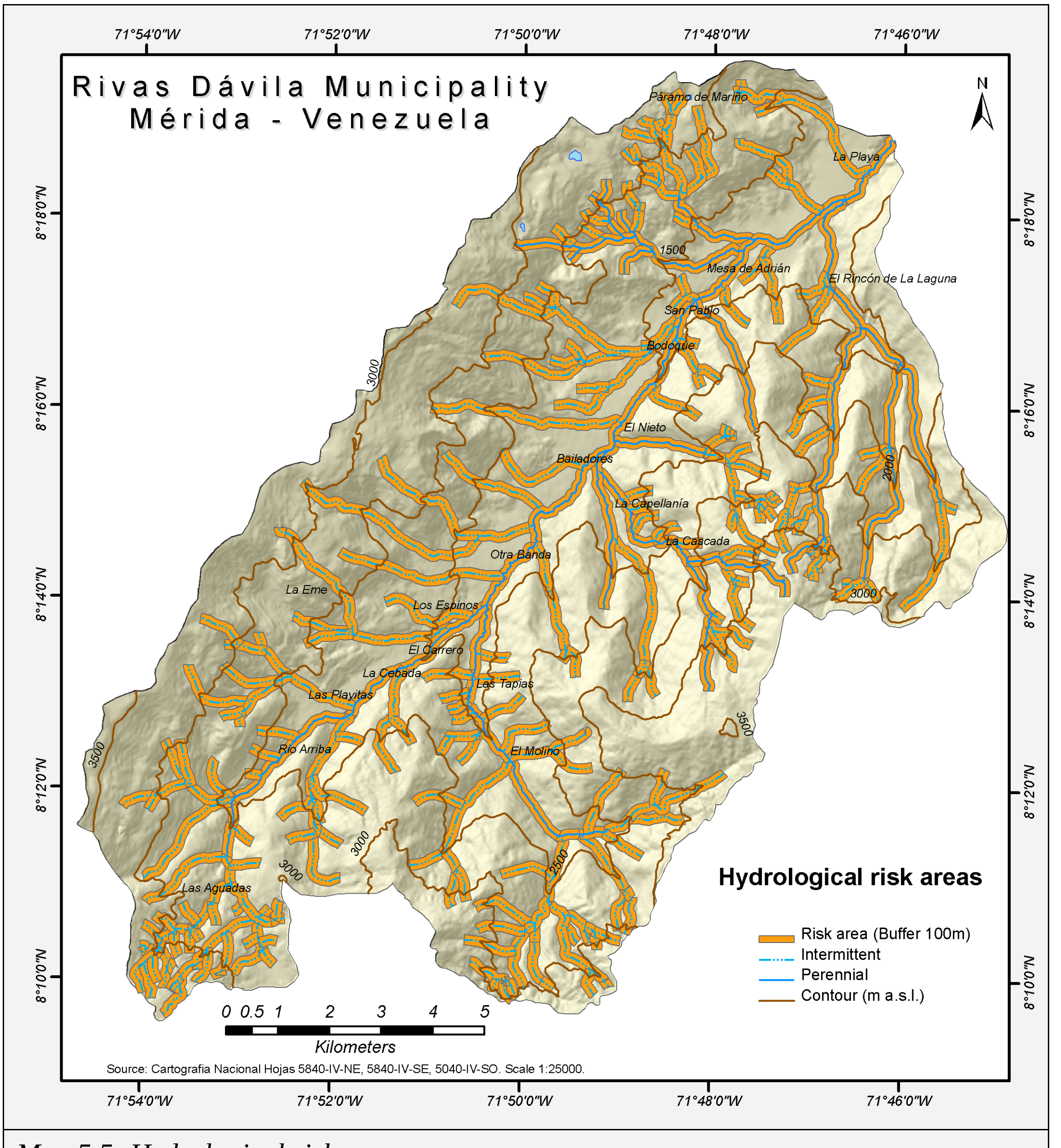
The resulting raster layers where processed by the *raster calculator* to generate the map of geostructural stability. The product (Map 5.4) allows it to be concluded that the west slope of the valley presents the highest geostructural instability in accordance with the predominance of an extended faulting zone and the high fragility of the lithological units.



Map 5.4: Geostructural instability.

5.2.2 Hydro-geomorphological stability

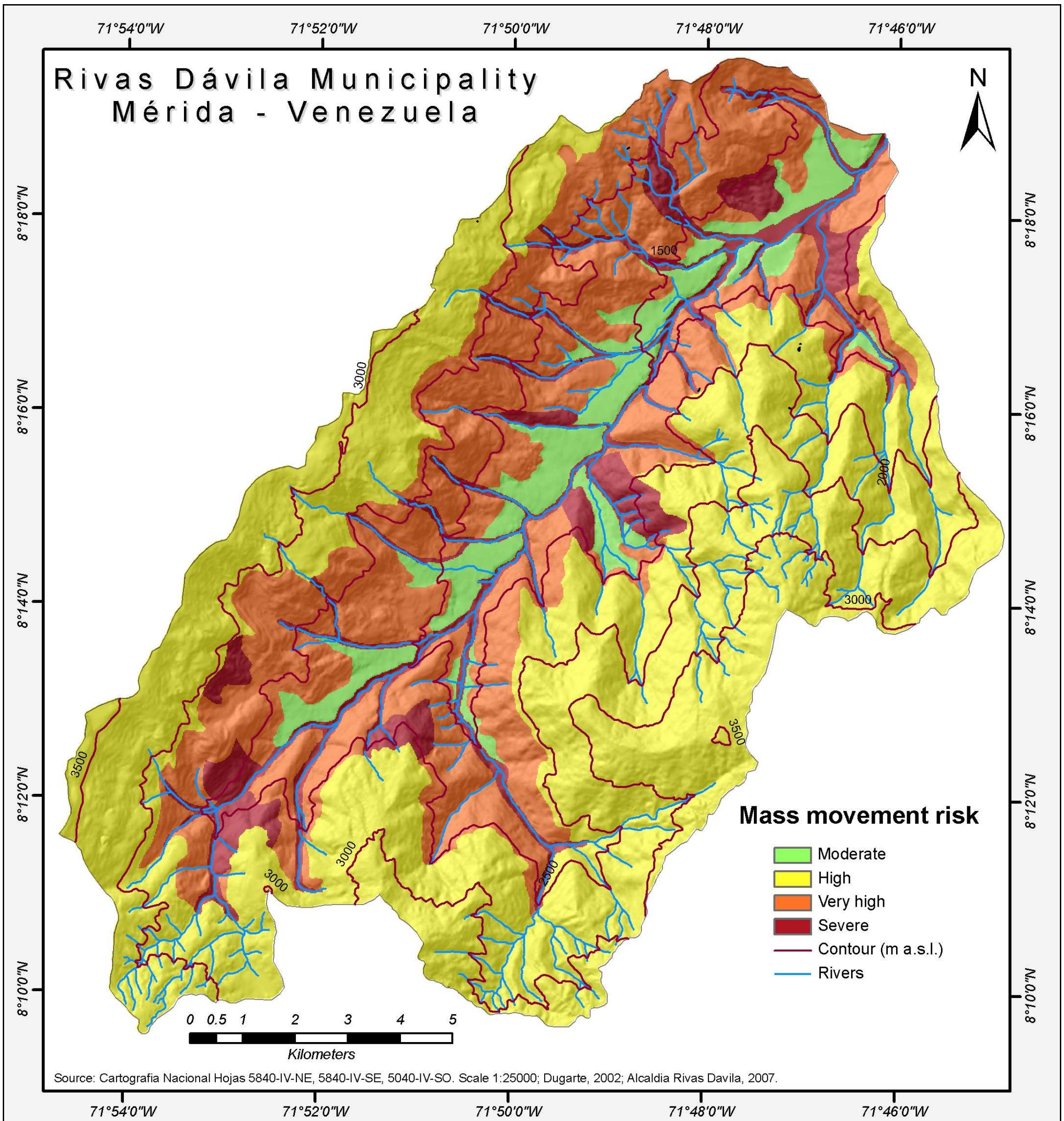
This analysis implicates the identification of the risk areas associated to the hydrological network. It is considered that the nearness of the streams is more subjected to instability as a consequence of the hydrological dynamics, i.e. overflows, floods, undermining or landslides among other processes. In this sense, the hydrological network is processed by means of the *buffer* tool with a distance of 100 m around the streams (Map 5.5).



Map 5.5: Hydrological risk areas.

This vector layer was rasterized and reclassified, assigning values of 4 to the buffer and 1 to the remaining areas. Thus, the instability of the buffer zones is emphasized.

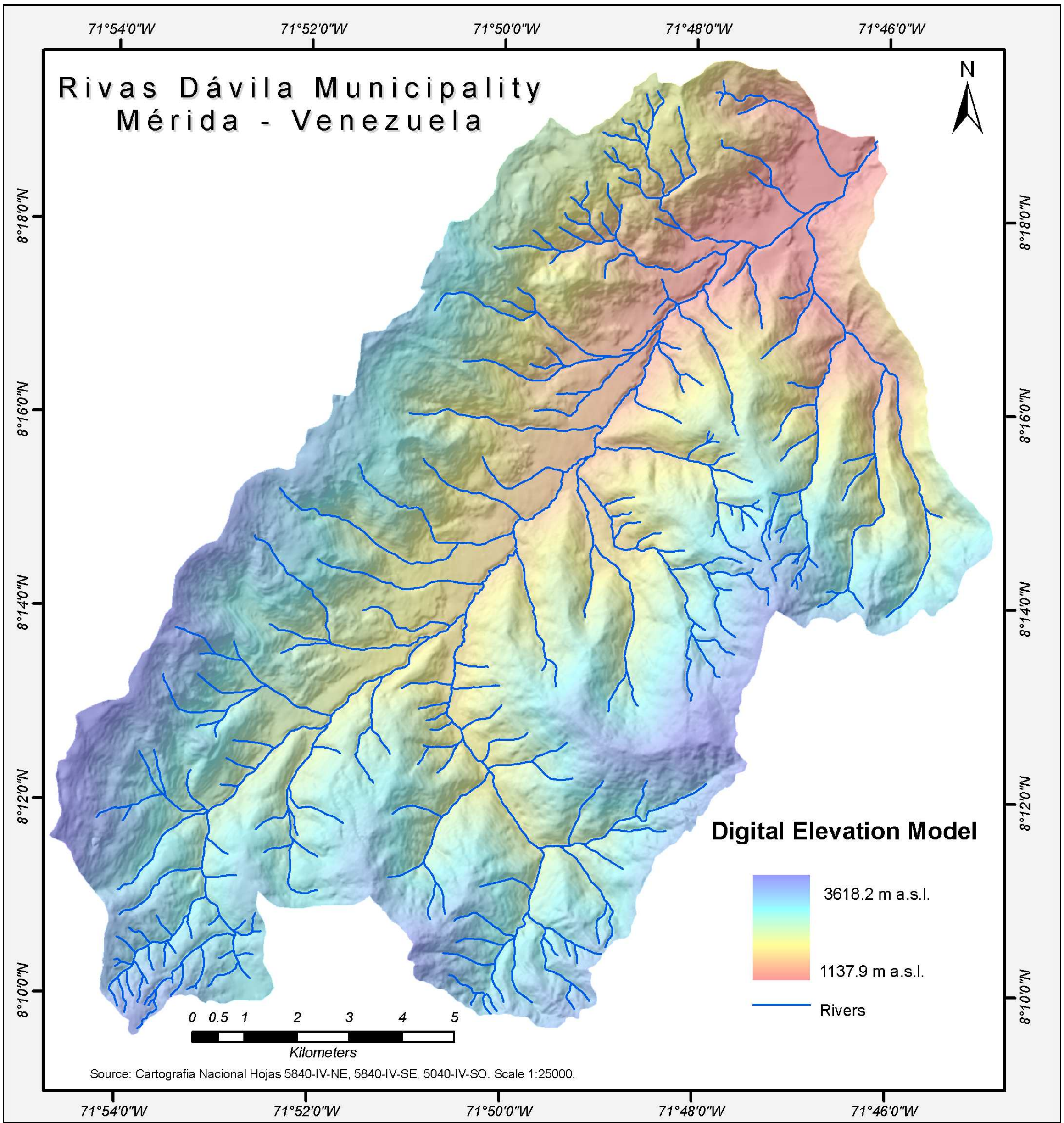
Geomorphological analysis is carried out focusing processes and forms. For the geomorphological processes the identified landslides on the different land units allowed a zonation about the mass movement risk to be established. Thus, the zones with the most quantity of landslides were defined as the highest risk and vice versa (Map 5.6).



Map 5.6: Mass movement risk.

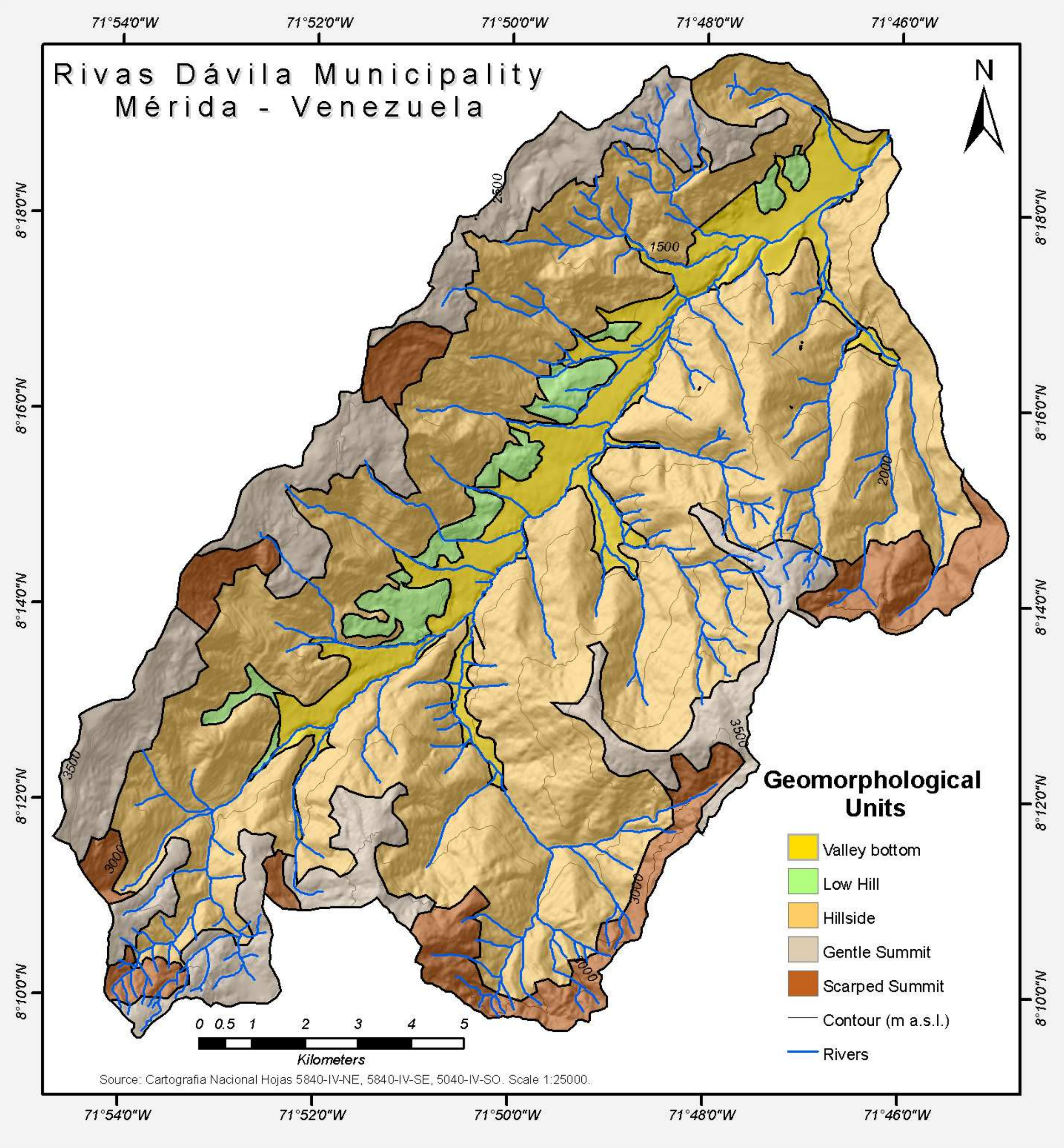
This map indicates that the valley bottom presents moderate risks to mass movement, caused by its low inclination. Some specific slopes are not only dominated by landslides, but also by a high risk of gully erosion. The largest parts of the study area, integrated by summits and hill slopes, were identified as high risk and very high risk areas, respectively.

Additionally, geomorphological analysis is referred to the landscapes forms. In this sense, from the topographic map (1:25,000) with interval contours of 20 m, a DEM digital elevation model was constructed. For this the respective tools of the 3D Analyst extension of the ArcGis 9.1 were used (Map 5.7).



Map 5.7: Digital elevation model.

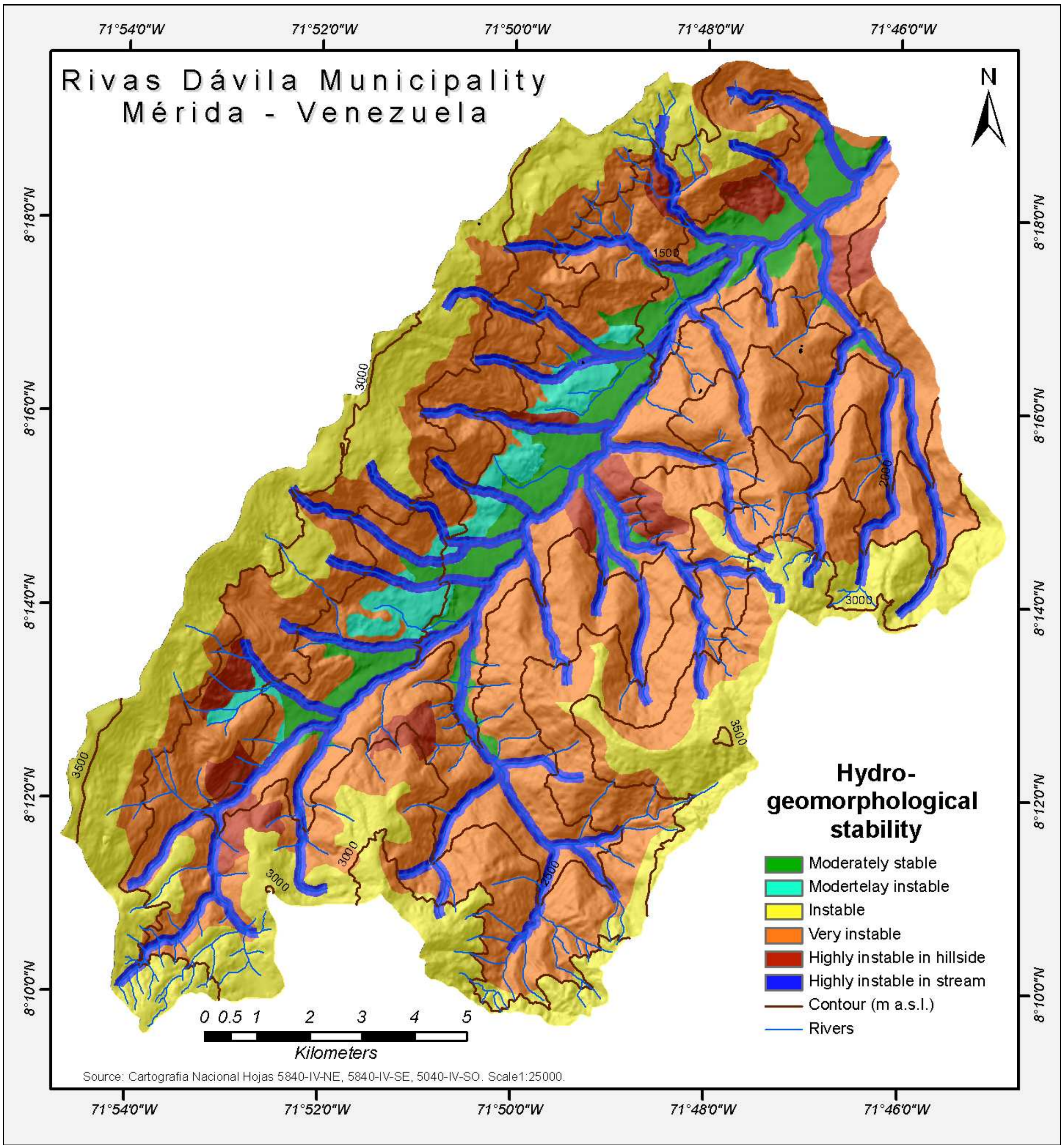
From this DEM the layers of slope, slope aspect and slope curvature were derived. The resulting maps are presented in section 5.2.3. Because of Rivas Dávila is a relatively high intermountain valley, its relief significantly influences on the behavior of many other environmental aspects, such as climate, geomorphology and even anthropogenic interventions. There various types of landform units can be identified. Thus, a map of geomorphological units was elaborated (Map 5.8) taking into account the localization of the Quaternary deposits, as well as the inclination of the slopes and slope curvature.



Map 5.8: Geomorphological units.

By means of this map, the physiographic restrictions of Rivas Dávila can be estimated. More than 60% of the hillsides are characterized by a high inclination grade. The second largest land units are the scarped and gentle summits, which make up about 26% of the whole area. Sectors of relatively low slopes are the low hills and the valley bottom which represent about 3% and 9% of the surface area.

Finally, the three layers, which were originally obtained as vector data, were rasterized and reclassified. In this classification lowest values (1 or 2) were assigned to the favorable conditions and highest values for unfavorable conditions (3 or 4). Subsequently, these raster layers i.e. stream buffers, mass movement risk and land-form units were summed by means of *raster calculator* which produced the map of hydro-geomorphological stability (Map 5.9). In this layer, the lowest values indicated stable or more stable areas and the highest values indicated instable or more instable areas.

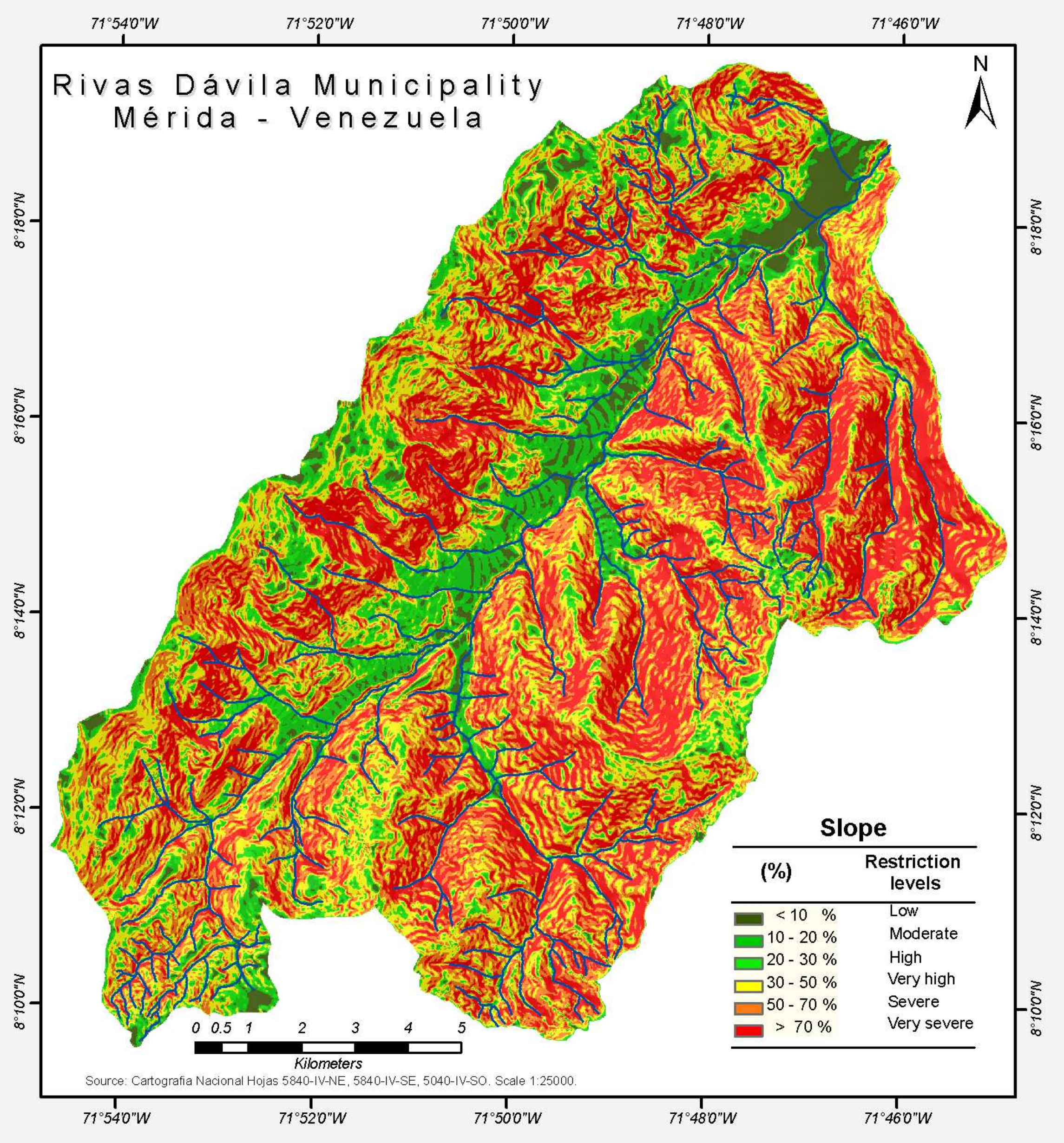


Map 5.9: Hydro-geomorphological stability.

5.2.3 Erosion susceptibility

The analysis of erosion susceptibility constitutes one of the most important components of the spatial analysis model SEPRA because it is the product of the integrated analysis of geomorphologic, soil and climatic aspects. The first section of this analysis is the analysis of the DEM and its derivatives, i.e. slope, slope aspect and relief curvature.

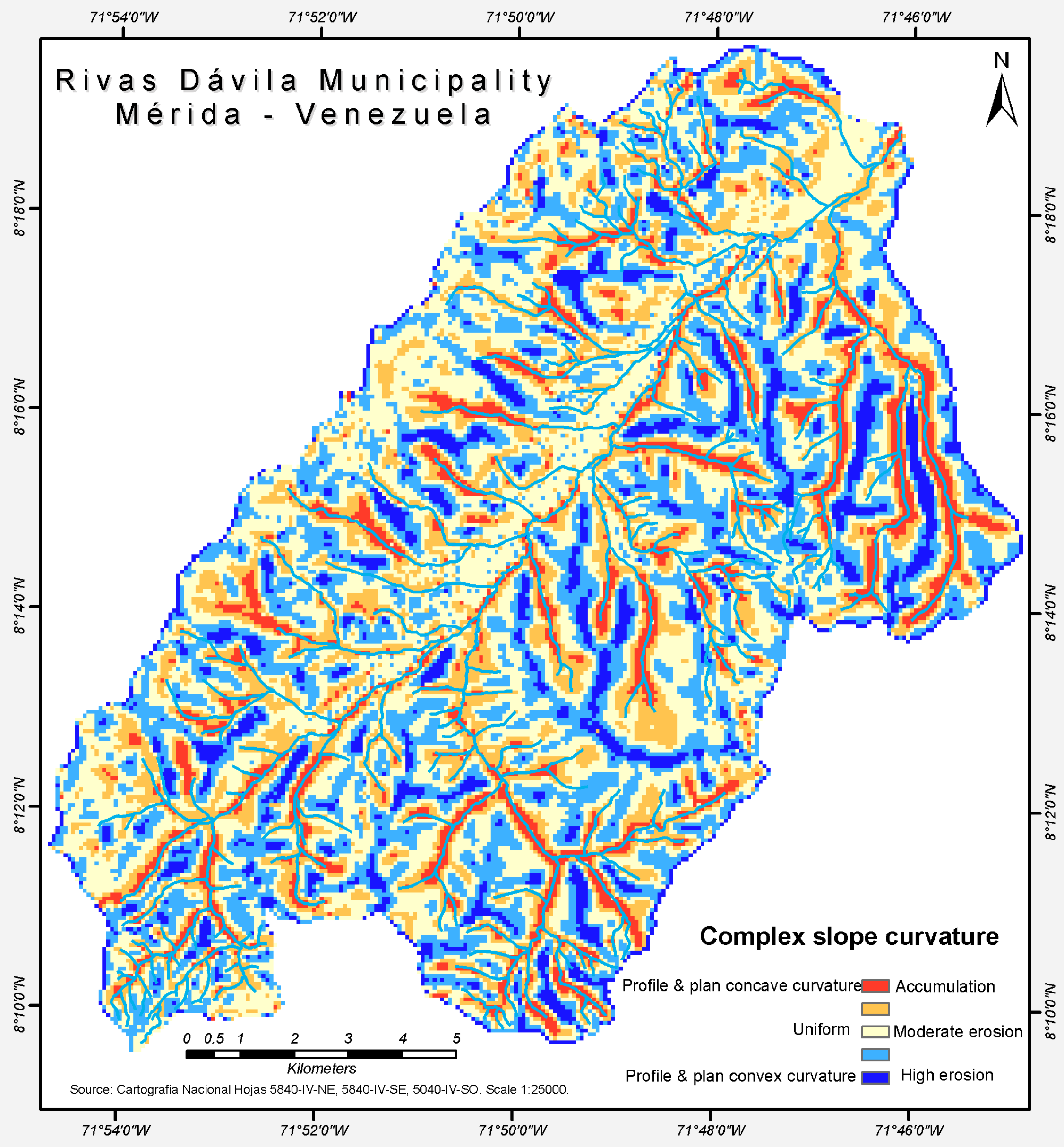
The slope map was constructed from the DEM with the use of *slope* tool (3D Analyst extension ArcGis 9.1) with a grid cell of 20 by 20 m and generated in percentage (%). The result (Map 5.10) indicates the predominant very steep slopes of the relief.



Map 5.10: Slope.

About 55% of the area is covered by slopes with more than 50% of inclination. Sectors with inclination lower than 10% are basically located on the lowest section of the valley, covering only about 4% of the whole area. The more intervened sectors of this study area, mostly located on the valley bottom have undulated, rolling and hill steep relief with inclination rates between 10 and 30%, which represent 17% of the Rivas Dávila. Taking into account that the potentiality of the erosive process could increase with the increase of the inclination a suitable classification was defined (Map 5.10).

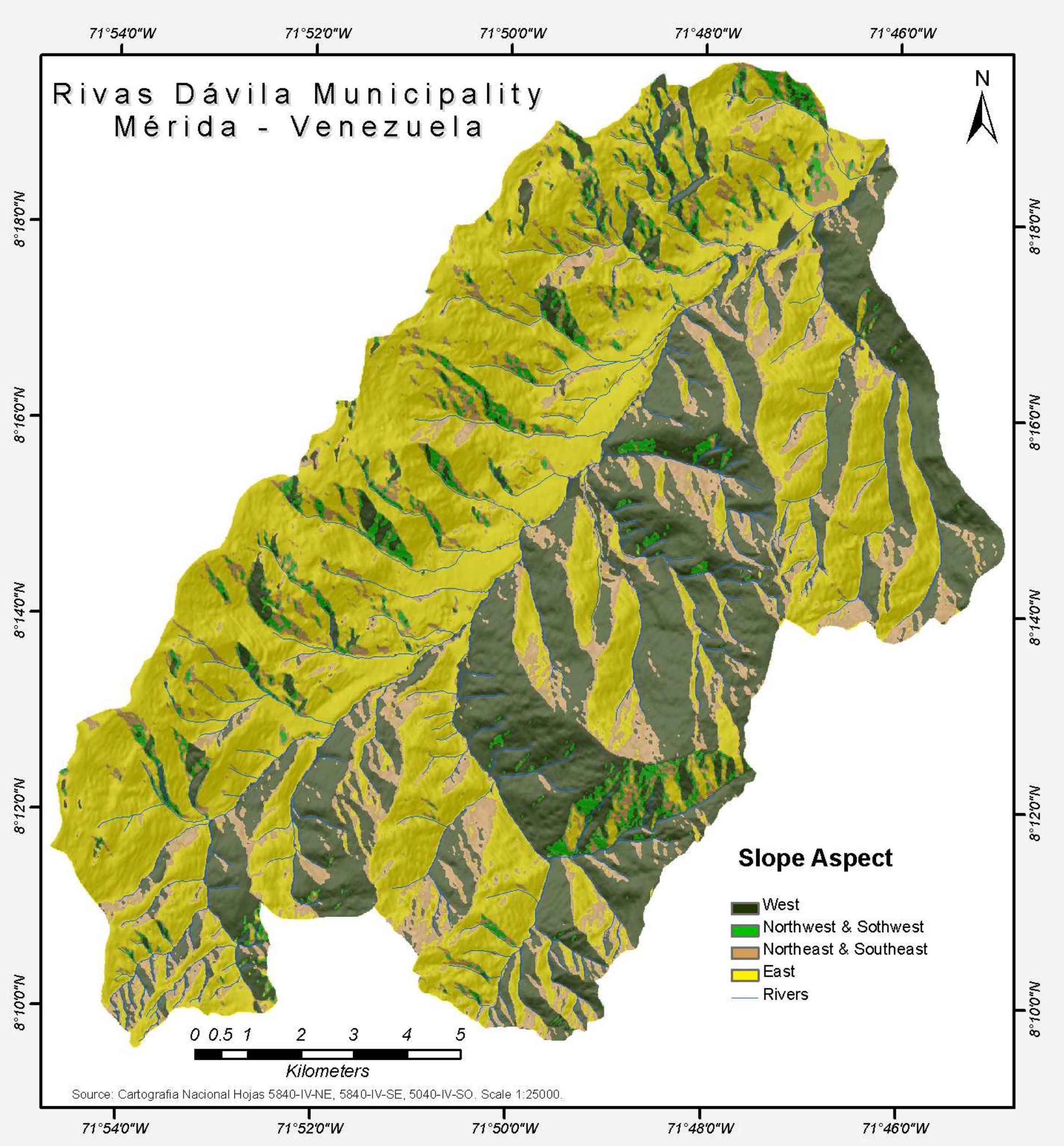
A curvature layer was also built by using the respective tool of ArcGis 9.1 (Map 5.11).



Map 5.11: Curvature.

In order to avoid very detailed results of smaller-size cells, this layer was computed with a cell grid of 70 by 70 m. The map delimits the profile convex and plain convex relief where the energy of surface runoff is increased and consequently increases erosion processes. In contrast, in profile concave and plain concave relief the energy surface runoff decreases and leads the accumulation of sediments (Thiemman, 2006). The values were reclassified by assigning the highest value (4) to convex relief and the lowest (1) value to concave relief. For profile and plain uniform mean values were assigned.

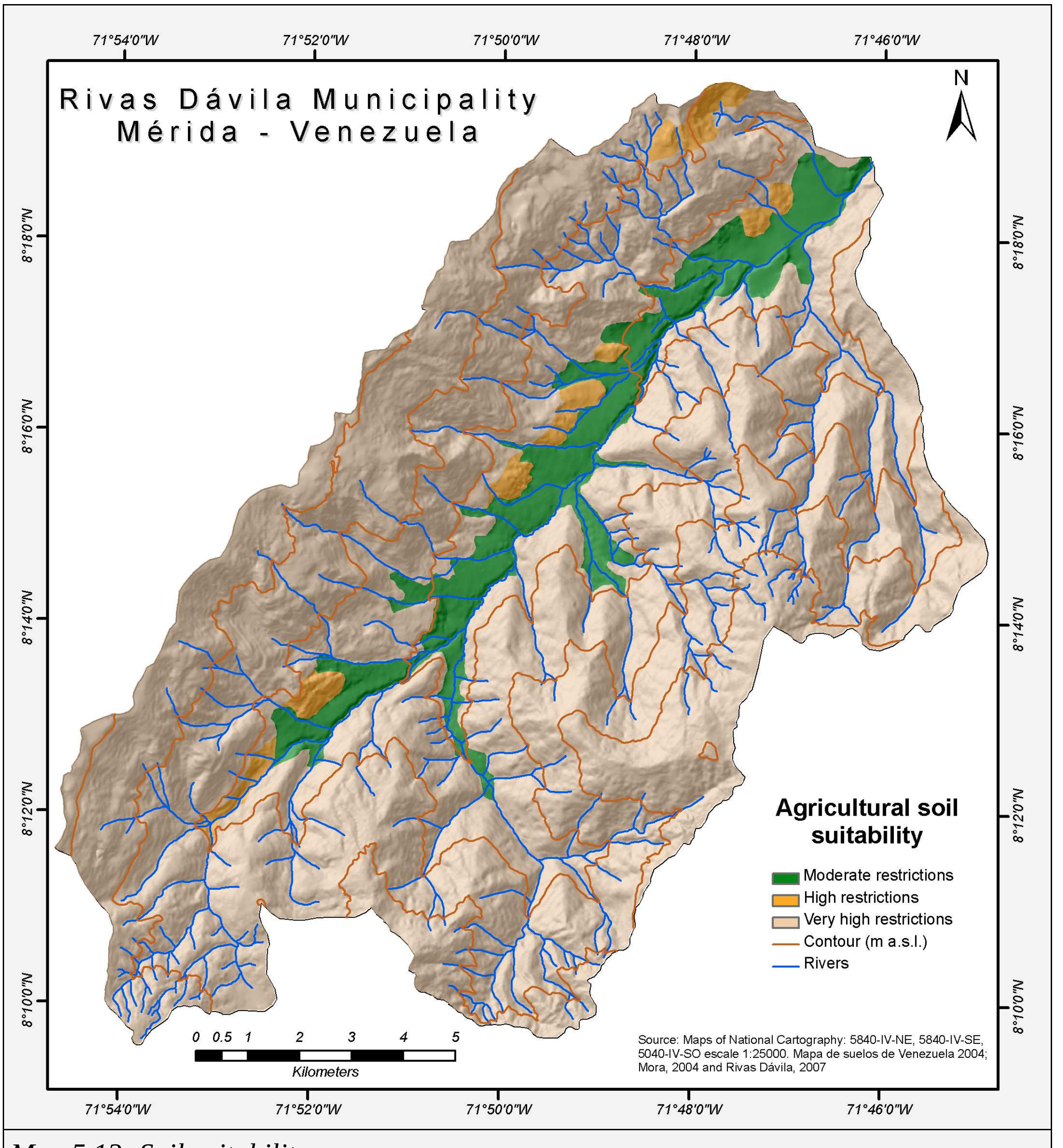
The relief analysis concluded with the evaluation of the slope orientation (Map 5.12).



Map 5.12: Slope aspect.

As a fundamental premise, it was accepted that the east-exposed slopes (sunny slopes) in tropical regions are warmer and dryer than west-exposed slopes. Subsequently, it is assumed that the sunny slopes conditions induce the erosion processes, because of its dryer microclimate and, consequently, more limitations for the development of dense vegetation cover. In accordance with the values shown in Table 4.2 (Chapter 4), the aspect layer was reclassified. The east-exposed slope was classified as 4, while the west-exposed slope was classified as 1. North and south exposed slopes were classified as mean values.

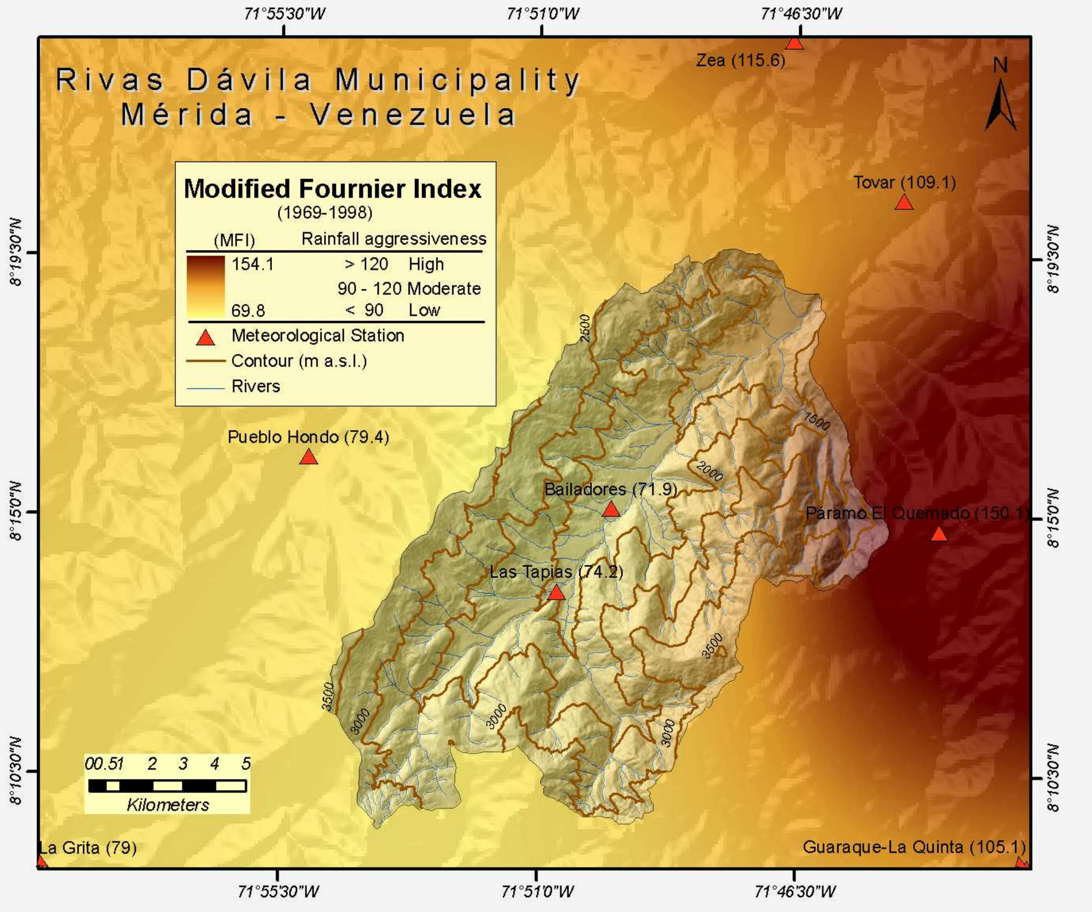
A map of agricultural soil suitability was also analyzed (Map 5.13).



Map 5.13: Soil suitability.

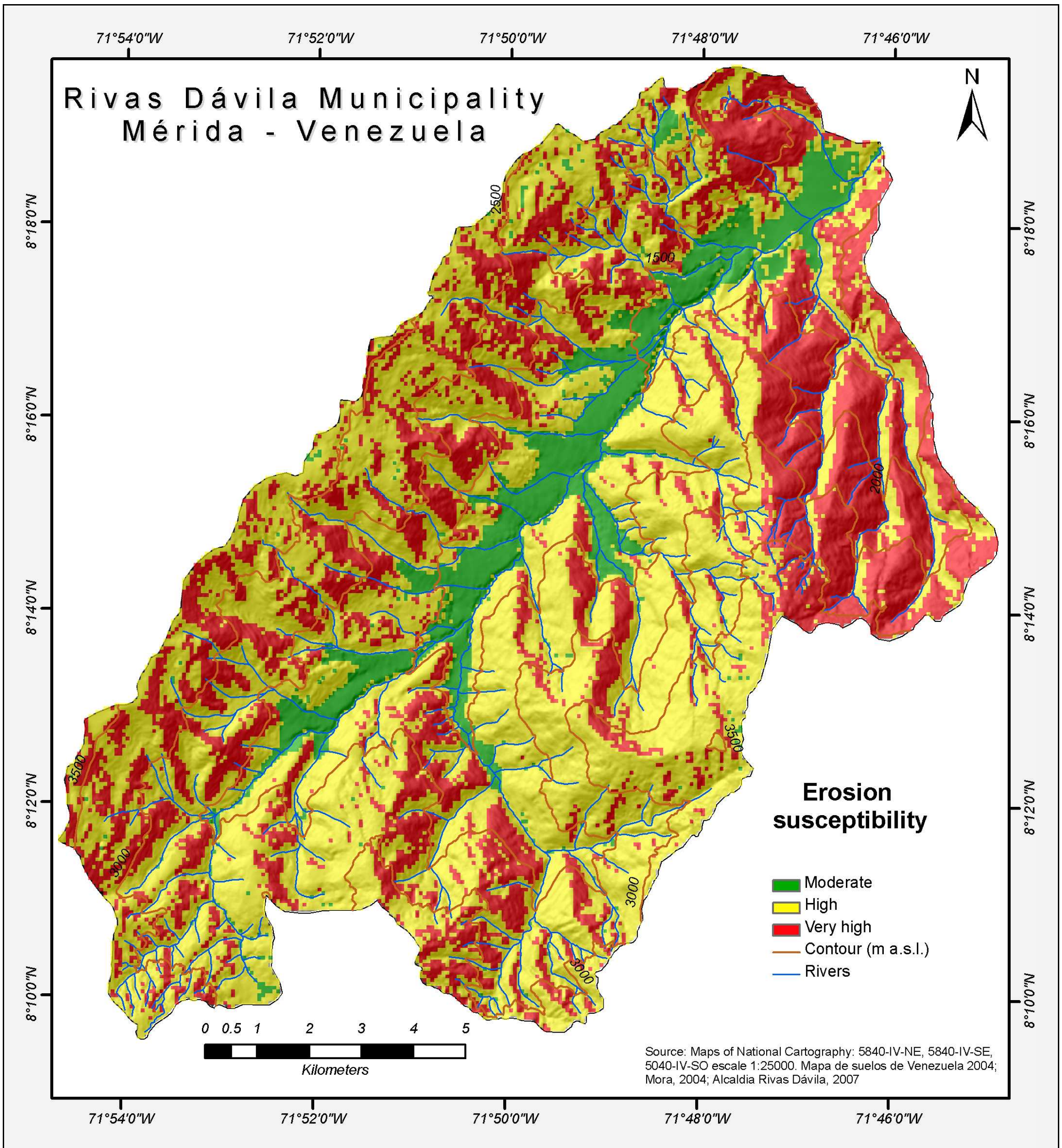
The map elaborated by Castillo (1972) established the agro-ecological suitability of the soils by means of seven soil classes, considering several factors such as soil depth, texture, inclination and susceptibility to erosion. Thus, taking into account this last factor, the original soil units were reclassified as was shown in Map 5.13. The resulting vector format map is converted to raster and reclassified. Moderate restriction was catalogued as 2, which means moderate susceptibility to erosion; high restrictions and very high restrictions were catalogued as 3 and 4, which mean high erosion and very high erosion, respectively.

The analysis of the erosion susceptibility is completed with the assessment of the aggressiveness of the rainfalls, according to the Modified Fournier Index. For this process, annual average precipitation and monthly average precipitation of nine meteorological stations are utilized. The result values are interpolated by means of the Kriging technique, with 12 neighborhoods, available on the 3D analyst extension of ArcGis 9.1 (Map 5.14).



Map 5.14: Modified Fournier Index.

The five raster layers prepared in this analysis are processed by means of the addition of the layers with the *raster calculator* tool. According to the established classes for each considered layer, the results can be understood as follows: highest values indicate highest susceptibility to soil erosion processes. Contrarily, lowest values indicate lowest susceptibility to the soil erosion processes (Map 5.15).

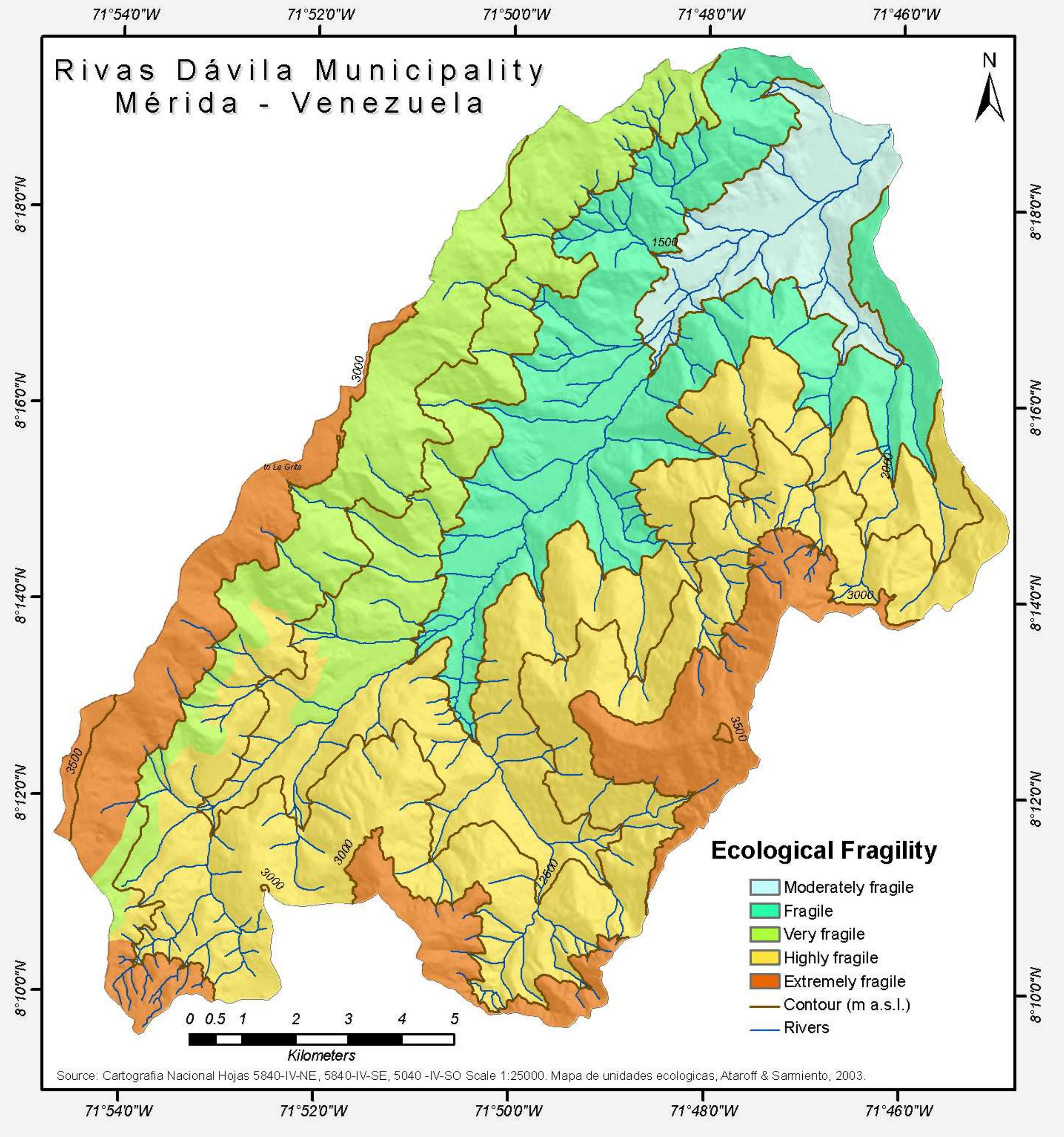


Map 5.15: Erosion susceptibility.

Areas classified as having very high susceptibility to erosion are constituted by those predominantly located on very steep slopes, sunny slopes or those where the rainfall aggressiveness shows the highest values, like the northeast of the valley. Areas with the lowest susceptibility to erosion appear basically for the valley bottom.

5.2.4. Fragility of vegetation units.

For the analysis of the vegetation cover a map of the ecological units of Rivas Dávila was utilized. This map, constructed by Ataroff and Sarmiento (2003) establishes the predominant vegetation units of the area taking climatic and physiographic aspects into account. In spite of theoretically all vegetation units can be defined as vulnerable to the intervention process. However, some indicators described by these ecological units allow several grades of fragility to be established, e.g., density, height, diversity and ecological complexity. Thus a map of the ecological fragility was constructed (Map 5.16)



Map 5.16: Ecological fragility.

The extremely fragile vegetation is integrated by the paramo unit, which represents a type of vegetation developed in elevations above 3000 m and cold and humid and sub-humid conditions. Due to the restrictive ecological characteristics, frequently, once this vegetation has been disturbed it has very few possibilities of recuperation. In the second place the high montane cloud forest was defined, which can be qualified as the vegetation cover that is most dense, diverse and the largest forest of the area. Due to its ecological complexity, after alterations the recuperation is very limited.

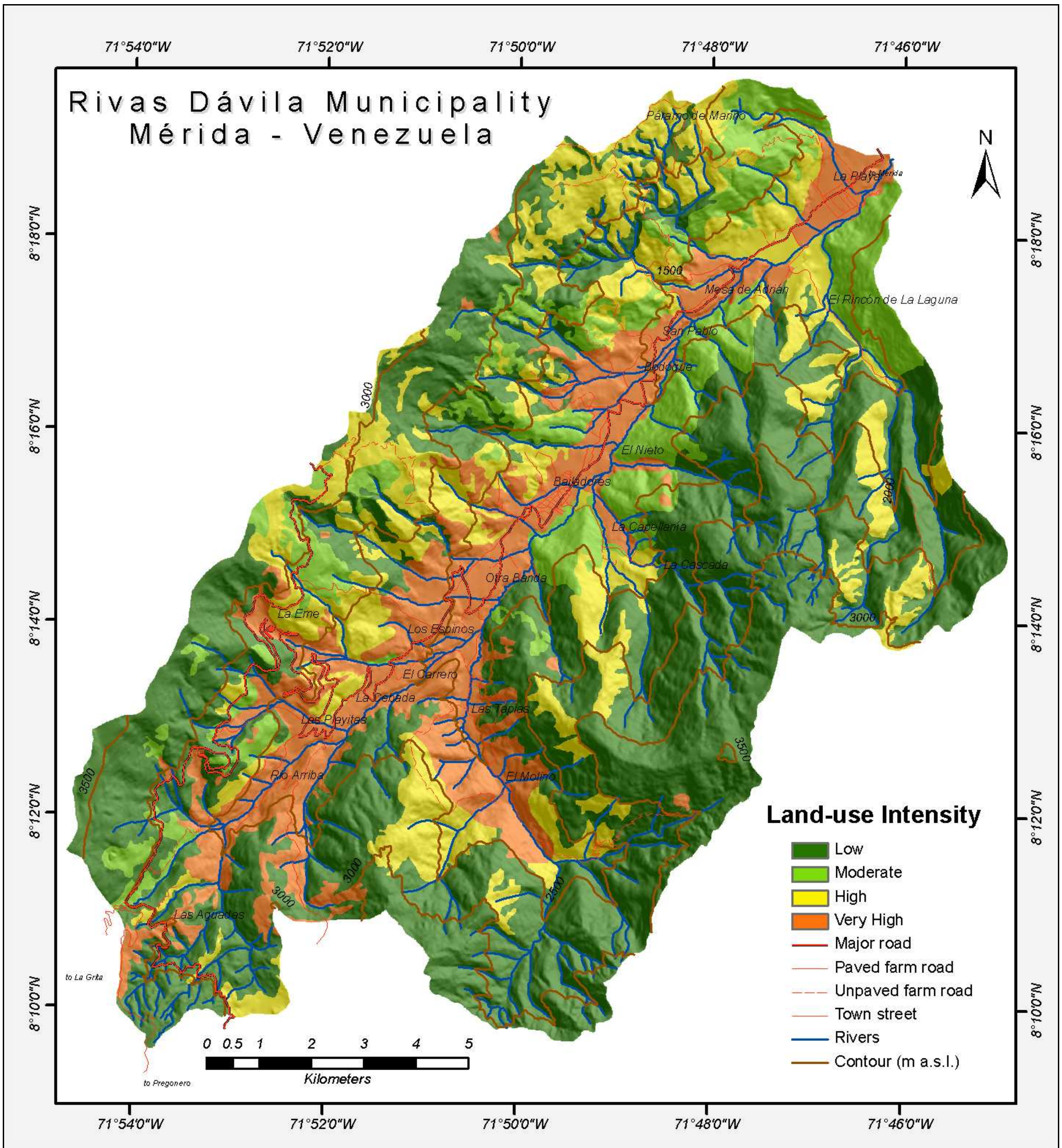
In contrast, other vegetation units located in areas with more favorable ecological conditions, once intervened could be recuperated in a relatively shorter period of time. This could be the case of the montane semideciduous forest, qualified as moderately fragile or the low montane dry evergreen forest, defined as fragile.

5.2.5 Land-use intensity

The human impact on the physical and ecological conditions of the environment is assessed by means of the evaluation of land uses. In the case of Rivas Dávila, the elaborated layer of the land-use types is used as the basis for this analysis. To carry out this assessment it is assumed that land uses that implicate high disturbances on the natural resources are classified as high intensity. In other sense, those land use where natural resources can be maintained unaltered or scarcely altered, are considered as low intensity.

In accordance with these basic references, a map about the intensity of the land uses is obtained (Map 5.17). In this map, the areas subjected to intensive croplands are classified as those most affected by anthropogenic use. These areas are basically located on the valley-bottoms where due to the favorable conditions, human activities have been traditionally carried out. However some hills, summits and other areas with steep slopes are included in this category due to the increase of agricultural land in these zones.

In contrast, the most inaccessible areas, characterized by very steep slopes, especially located on the east side of the watershed, were classified as low intensity. In these zones only incipient human uses have been carried out, consequently the natural conditions have been maintained.

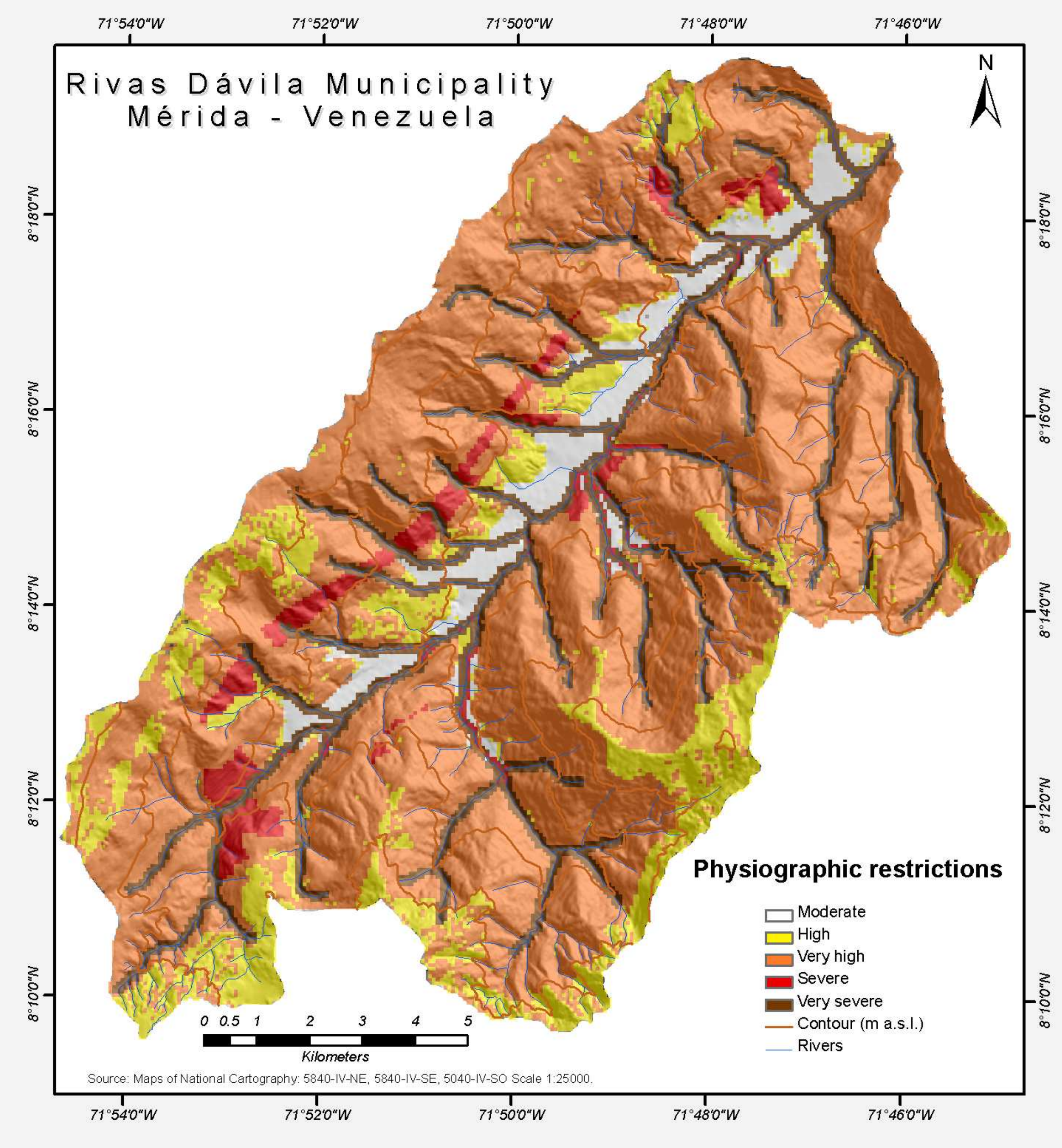


Map 5.17: *Intensity of the land uses.*

5.2.6. Physiographic restrictions

The last five obtained maps are the basis for a second analysis level. Thus, a map that summarizes the restrictions for human interventions in accordance with the physiographic conditions of the area, is produced (Map 5.18). The generation of this layer is embedded into the sequential process of decision making on which this model of spatial analysis is based.

In this case the maps 5.4, 5.9 and 5.11 are considered, i.e. geostructural stability, hydro-geomorphological stability and soil erosion susceptibility. The result (Map 5.18) is the product of the addition of the values contained in the attribute table of every layer. This process was computed by means of the already explained *raster calculator* tool. In accordance with the utilized evaluation system, the obtained high values indicate high restriction levels, whereas the low values indicate low restriction levels.

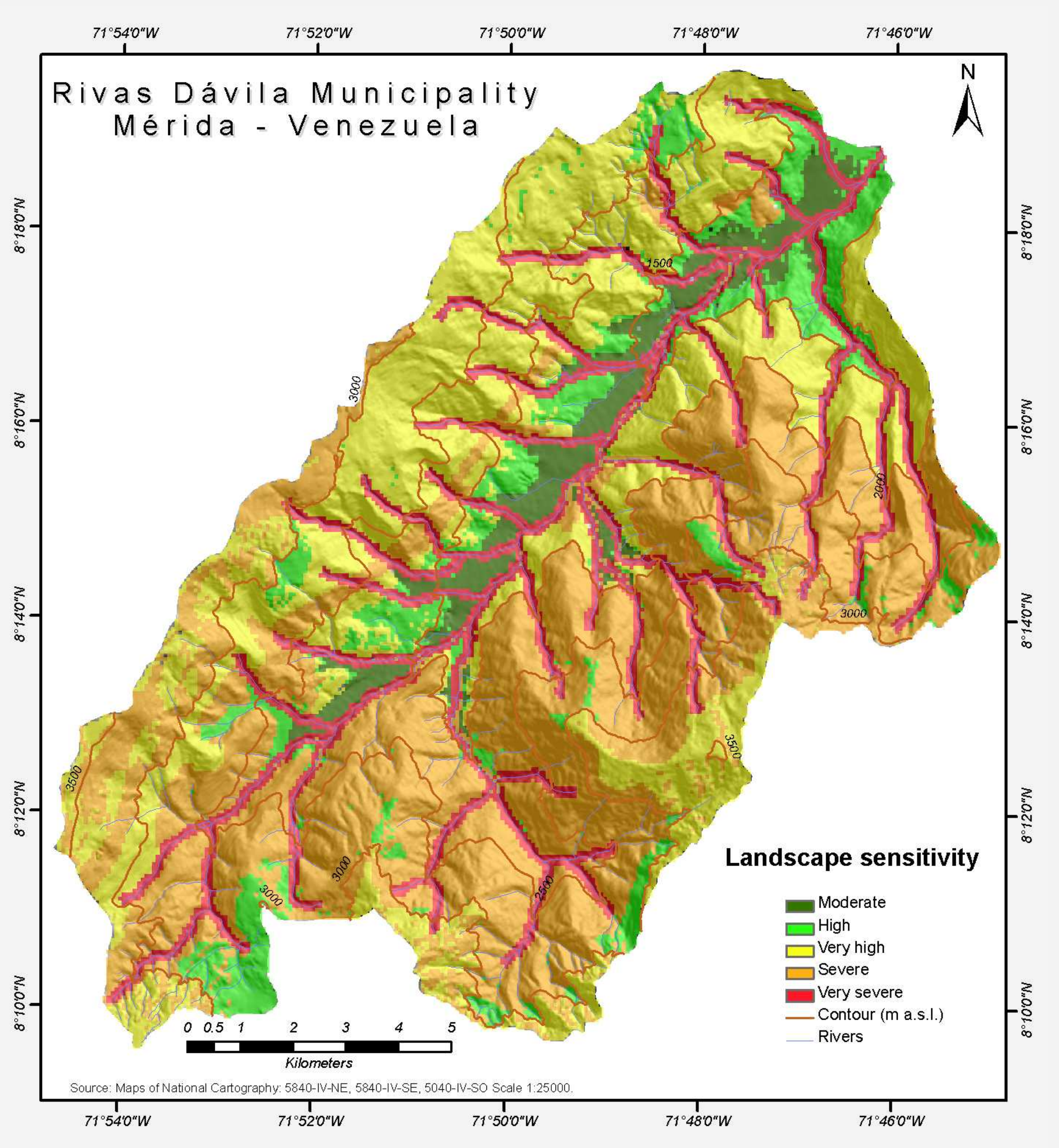


Map 5.18: Physiographic restrictions.

A suitable classification is defined with five restriction level: moderate, high, very high, severe and very severe. The very severe restrictions are found around the principal hydrographical network, where the flow dynamics of the flow determine a high level of restriction adjoining to the channels (100 m according to the established threshold). Lands of severe restrictions ware located on the west slope of the valley, along the faulting zone, dominated by very steep slopes, high hydro-geomorphological instability and very high susceptibility to erosion process. According to the previous results, most of the valley bottom is identified as having moderate physiographic restrictions.

5.2.7. Landscape sensitivity

Based on the physiographic restrictions (Map 5.18) and the ecological fragility (Map 5.16), a new layer is processed. In this case, the objective was to produce an integrate analysis of the physiographic and ecological issues (Map 5.19).



Map 5.19: Landscape sensitivity.

As in previous cases, the addition of the layers by means of the *raster calculator* was the applied method.

The principal results obtained by the map of physiographic restrictions were maintained: the hydrological network is valuated as very sensible, whereas elevated and relatively plain areas of the valley bottom are valuated with the lowest sensitivity level. However, some specifications could be found, especially on very steep slopes. For example, some slopes that had been classified with very high physiographic restrictions are divided into two classes: very high and severe sensitivity. It occurred as consequence of the different levels of fragility assigned to the vegetation cover that characterizes these terrains.

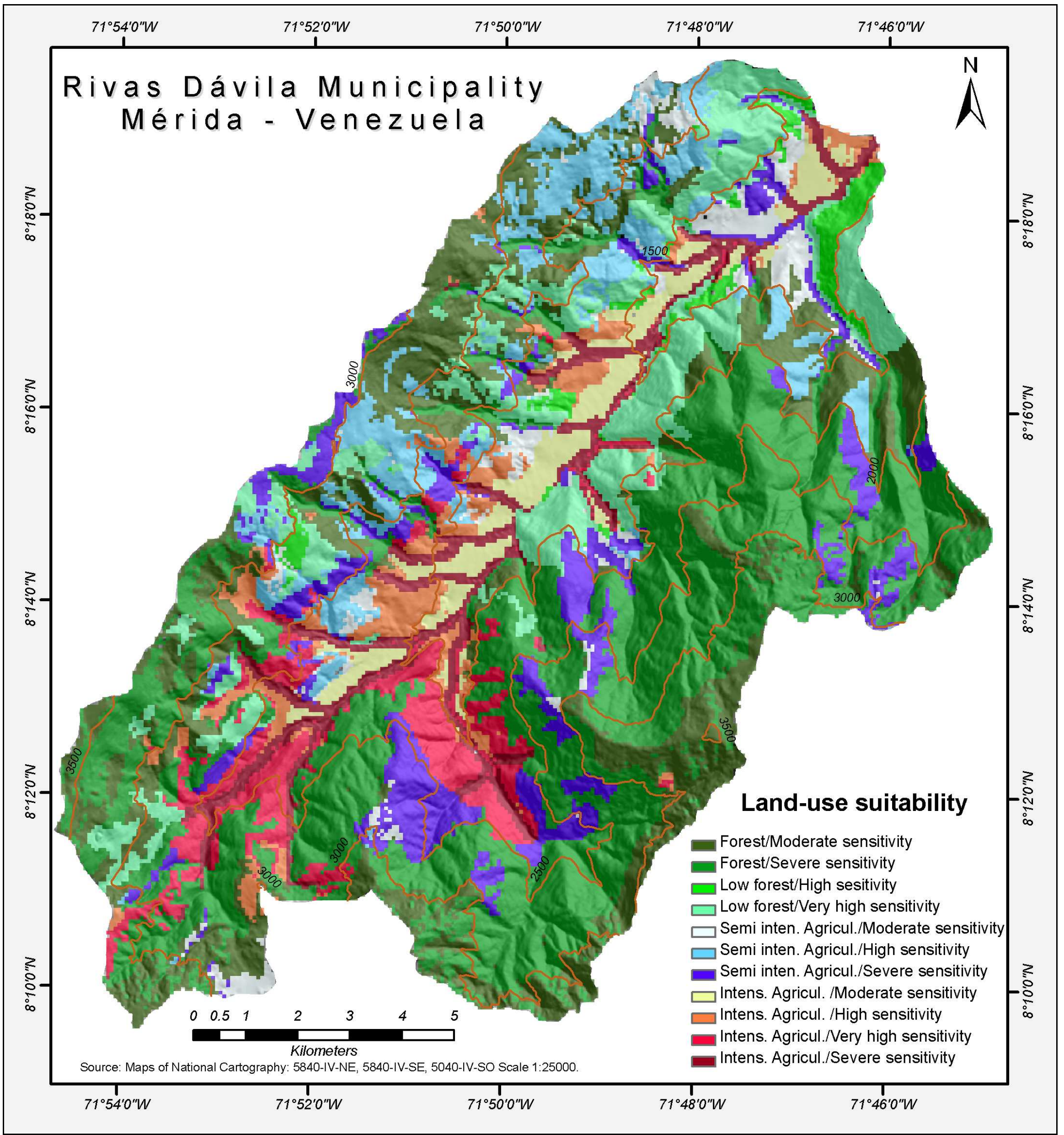
5.2.8. Land-use suitability

Finally, a last layer was generated by means of the integration of the layer's landscape sensitivity (Map 5.19) and the one of intensity of the land uses (Map 5.17). The objective of this analysis is to compare the physiographic and ecological conditions of the landscapes.

This layer was generated by means of a suitable process adding the respective attribute table and applying the *raster calculator* (Map 5.20). The map offers an overview of what intensity the land uses have on each level of landscape sensitivity. Thus, the land units of Rivas Dávila classified as having very severe landscape sensitivity and are currently used by very high intensive land-use types can be located. These zones will be the most problematic areas in which very strong measures of environmental control need to be applied. In contrast, those areas classified as having low sensitivity and occupied by the lowest land-uses intensity, are precisely the land units where the lowest environmental problems are expected. By means of this layer the most important references needed to produce a land-use plan can be obtained.

In this case, the map indicates that a large part of the Rivas Dávila, about 35%, is characterized by forest and natural uses, located in areas of severe landscape sensitivity. It suggests that these areas, due their natural restrictions, are used by the most indicated land-use type: natural protection, which needs to be maintained in order to avoid negative consequences that could be caused by other land-use types. Secondary it is found out that 17% of the study area is covered by forest, located in zones of moderate landscape sensitivity. This also seems to be the most suitable use of these areas for preserving the natural resources and guarantee conditions of environmental sustainability.

The more critical conditions, in the relation between anthropogenic uses and landscape sensitivity, occur in c. about 5% of the area. These intensive uses, such as intensive cropland, are developed on areas classified as having severe sensitivity. Most of these sectors are integrated by intensive agriculture carried out on the nearness of riverbanks and in their floods plains. All of these considerations are taken into account in order to produce a final proposal of land-use planning for Rivas Dávila Municipality, which is finally presented in Chapter 6.



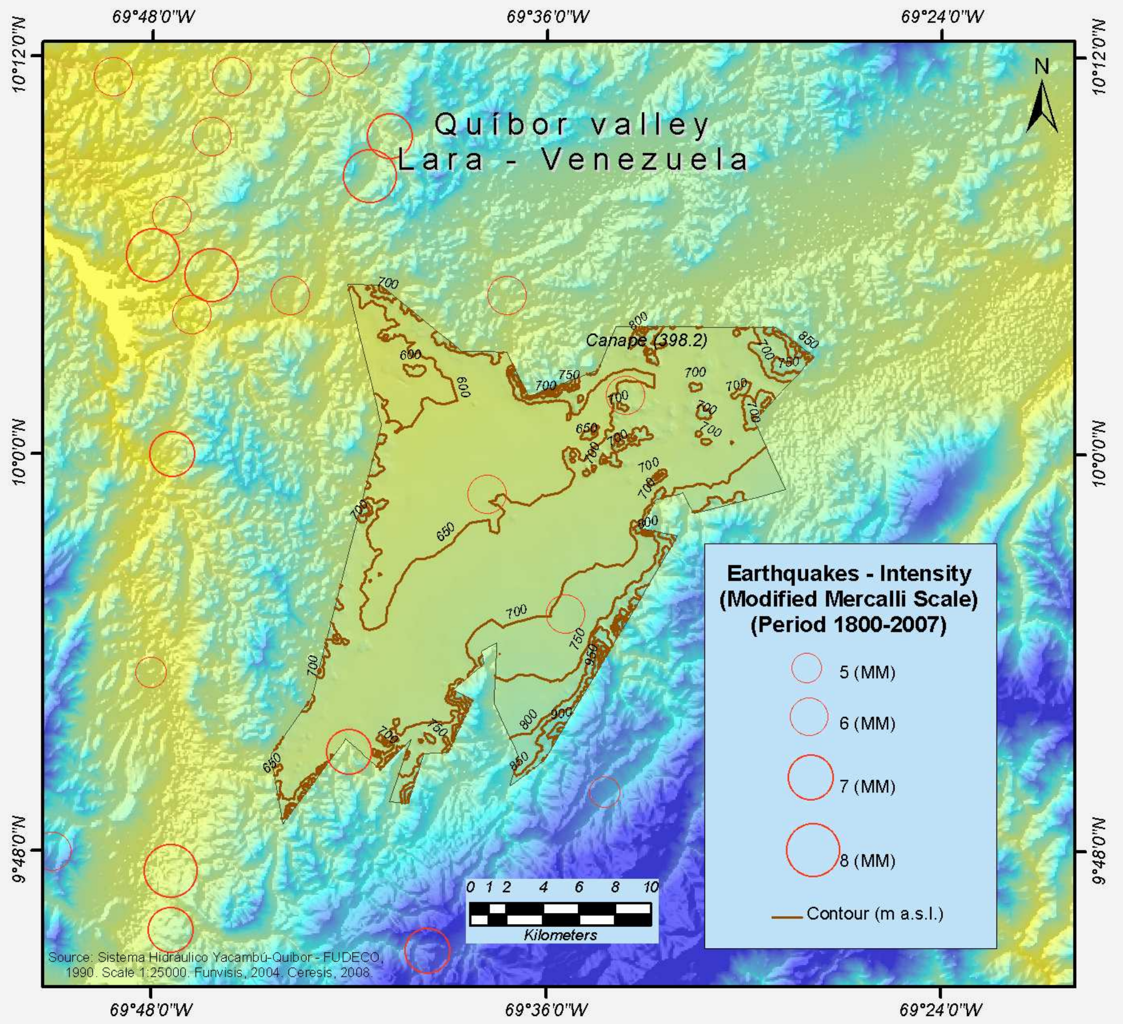
Map 5.20: Land use suitability.

5.3 Quíbor Valley

The application of the model of spatial analysis in the case of Quíbor Valley is presented in this section. The analysis follows the sequence indicated in Figure 5.1.

5.3.1. Geo-structural analysis

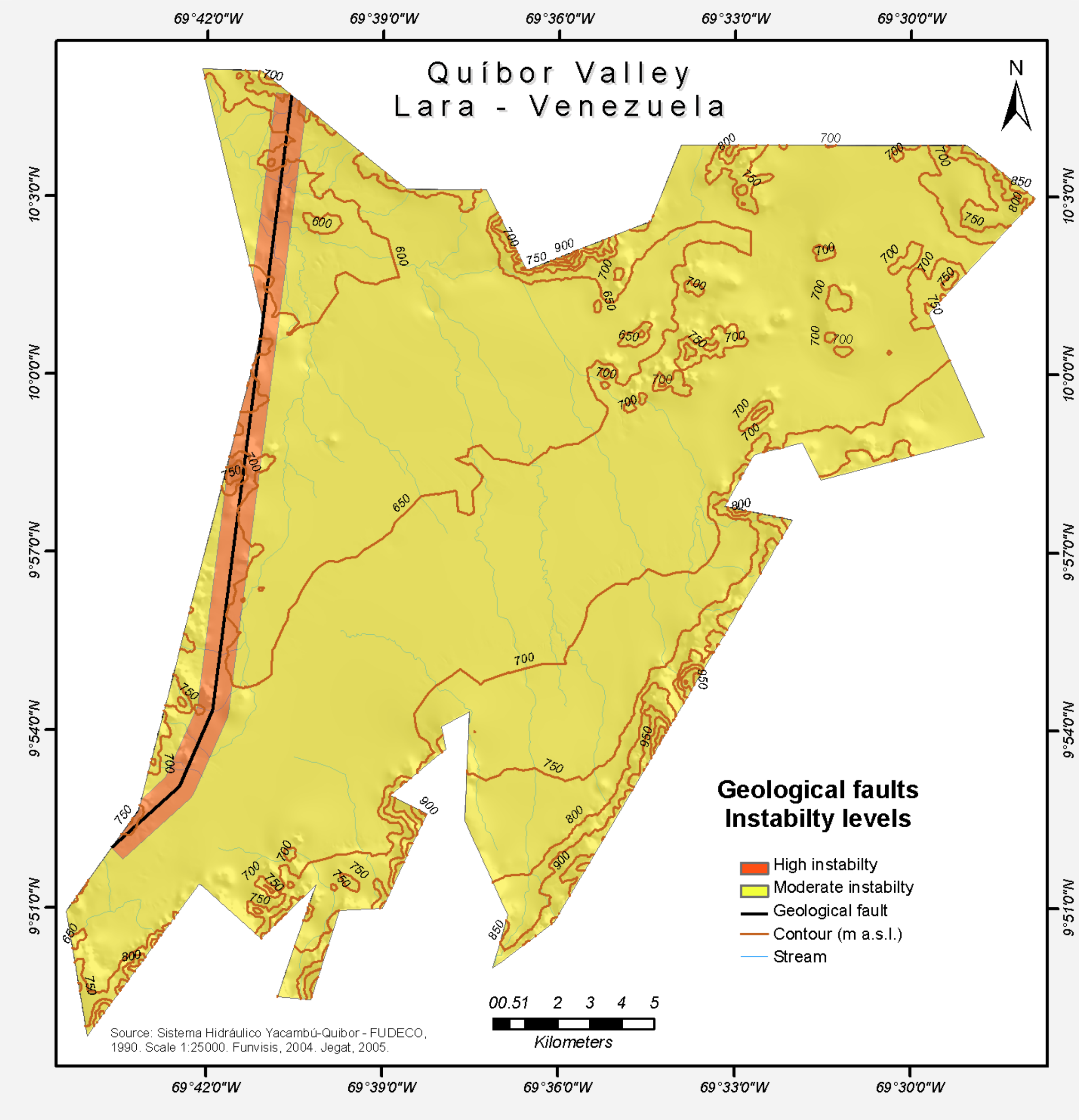
A seismic map was constructed taking into considering the intensities of 24 earthquakes registered during the period 1800 to 2007 according to the Modified Mercalli scale (MM) (Map 5.21). The earthquakes, larger than 4 MM, indicate the high seismicity risk of the region. About 40% of telluric movements were classified as larger than 7 (MM), which means that they have been very strong or destructive. The other 60% of the earthquakes reached classified as rather strong or strong.



Map 5.21. Intensity of the recorded earthquakes, period 1800-2007.

In accordance with the relatively small surface of this study area, it was decided that Quíbor Valley is wholly affected by high seismicity.

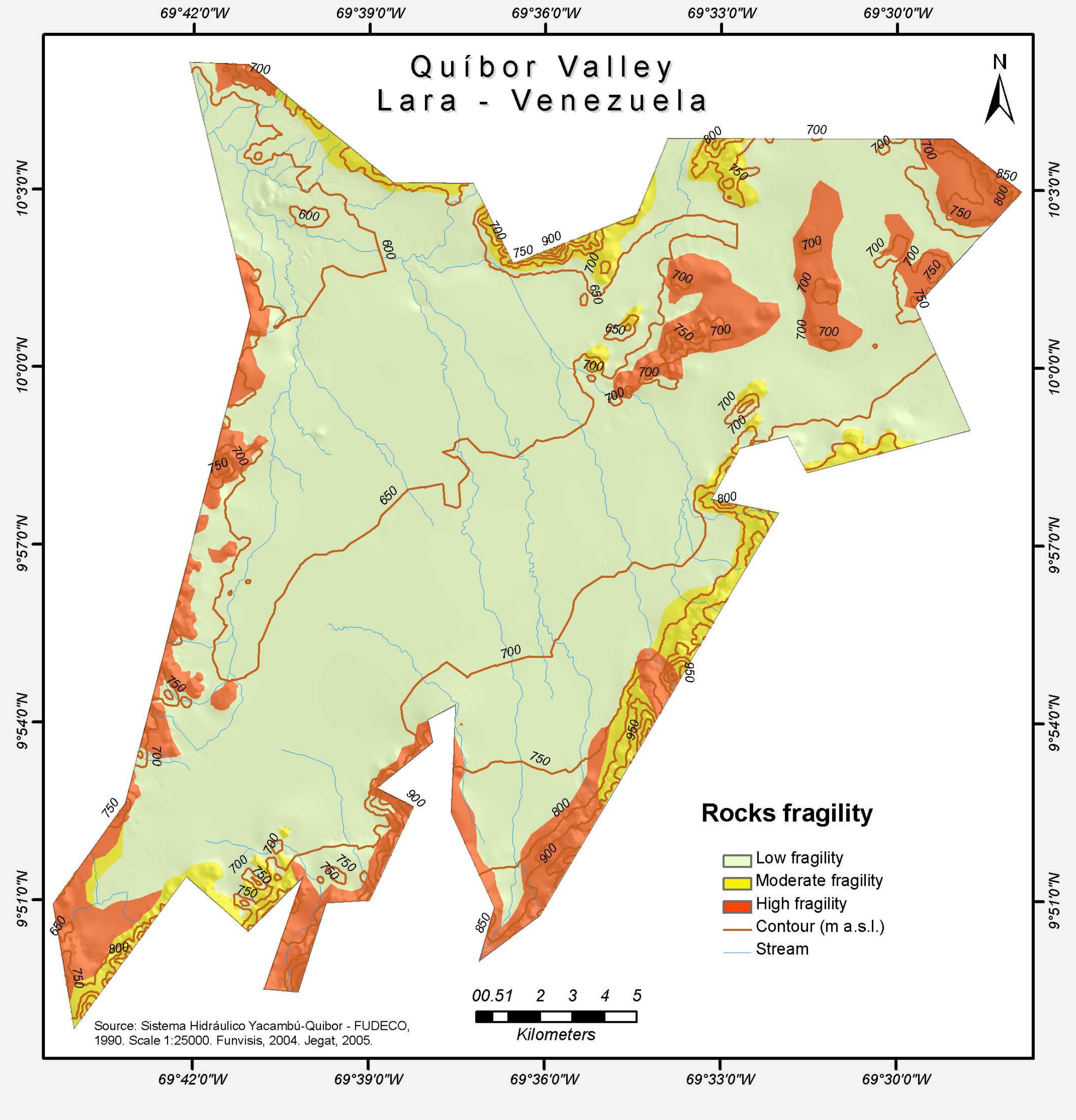
The second aspect involved in this analysis is referred to the geological faults. As was explained in Chapter 3, this study area is strongly influenced by the faulting zone associated with the Boconó fault (CIDIAT, 2004). This fault, the most active geological fault of the Venezuelan west, is located only about 8 km from southeast of the valley (Ecology and Environment, 2004). For this analysis, buffer zones were built around the geological faults with a width of 500 m on both sides of the fault line (Map 5.22.).



Map 5.22: *Instability due to geological faults.*

Thus, the areas within the buffers were catalogued as having high instability, whereas the remainders were classified as having moderate instability. The areas more directly affected by the fault are also the zones with more inclined relief of the valley, constituted by the low hills around the alluvial flat. In these areas, processes of rocks fracturing, landslides or even erosion with more intensity are expected.

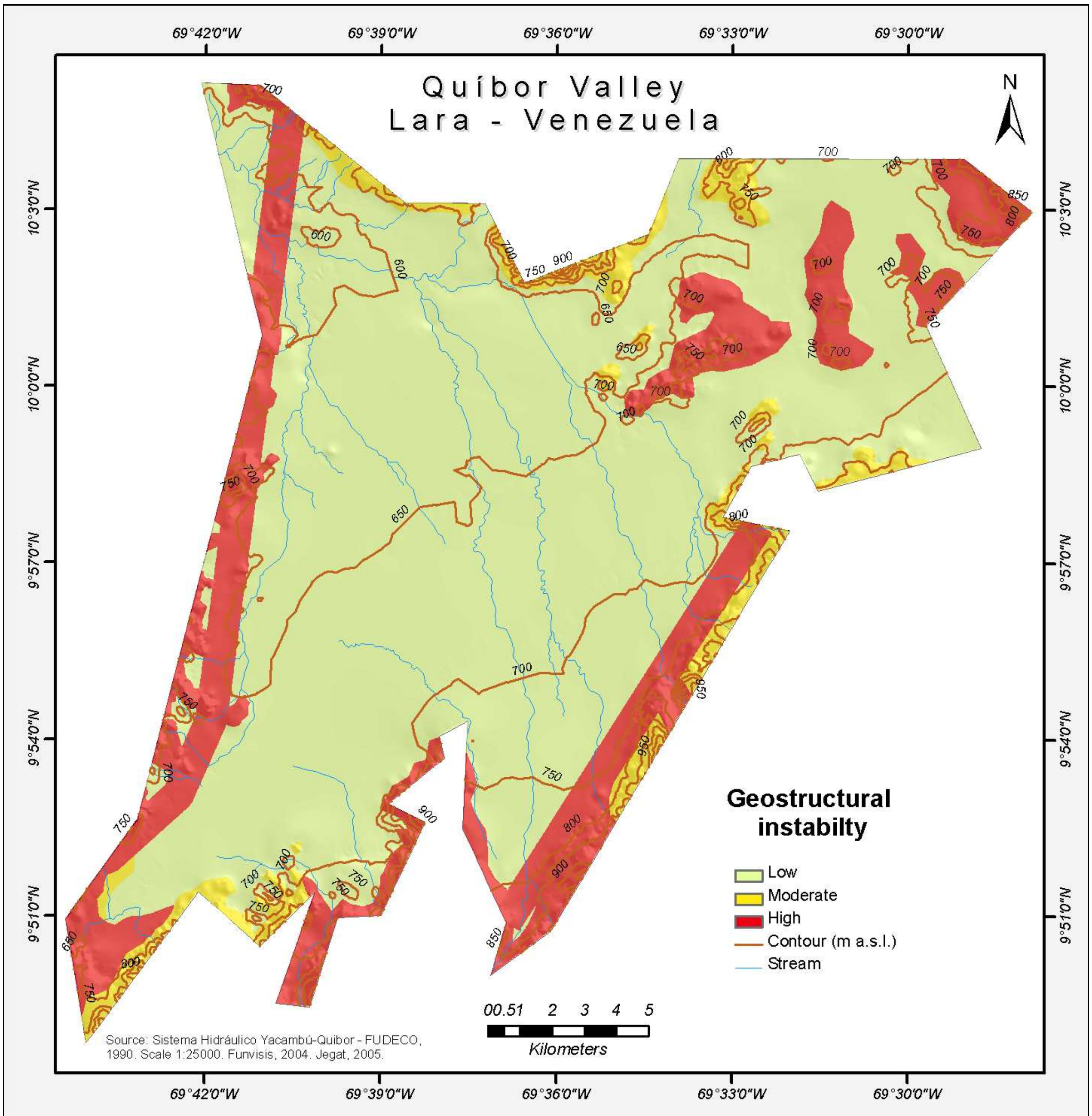
The fragility of the rocks of the geological formations was also identified. The Quaternary deposits were valuated as of low fragility because their rock materials, constituted by unconsolidated conglomerates, are found in the subsoil, below the surface materials constituted by clay and silt.



Map 5.23: Fragility of the rocks.

The bedrock of the Eocene formations Morán and Matatere constituted by sandstone and lutites were classified as highly fragile due to its high grade of softness and weathering. The Barquisimeto formation (Cretaceous) composed of limestone, lutites and marlstones were classified as moderate fragility, due to lower grade of metamorphism.

The resulting raster layers were processed by the *raster calculator* in order to generate the map of geo-structural stability. The product allowed it to be concluded that the hill zones of the valley present the highest geo-structural instability in accordance with the predominance of the extended faulting zone and the high fragility of the lithological units. By means of combining the two last layers, i.e. instability of the geological faults and rock fragility, a map of geo-structural stability was constructed (Map 5.24).

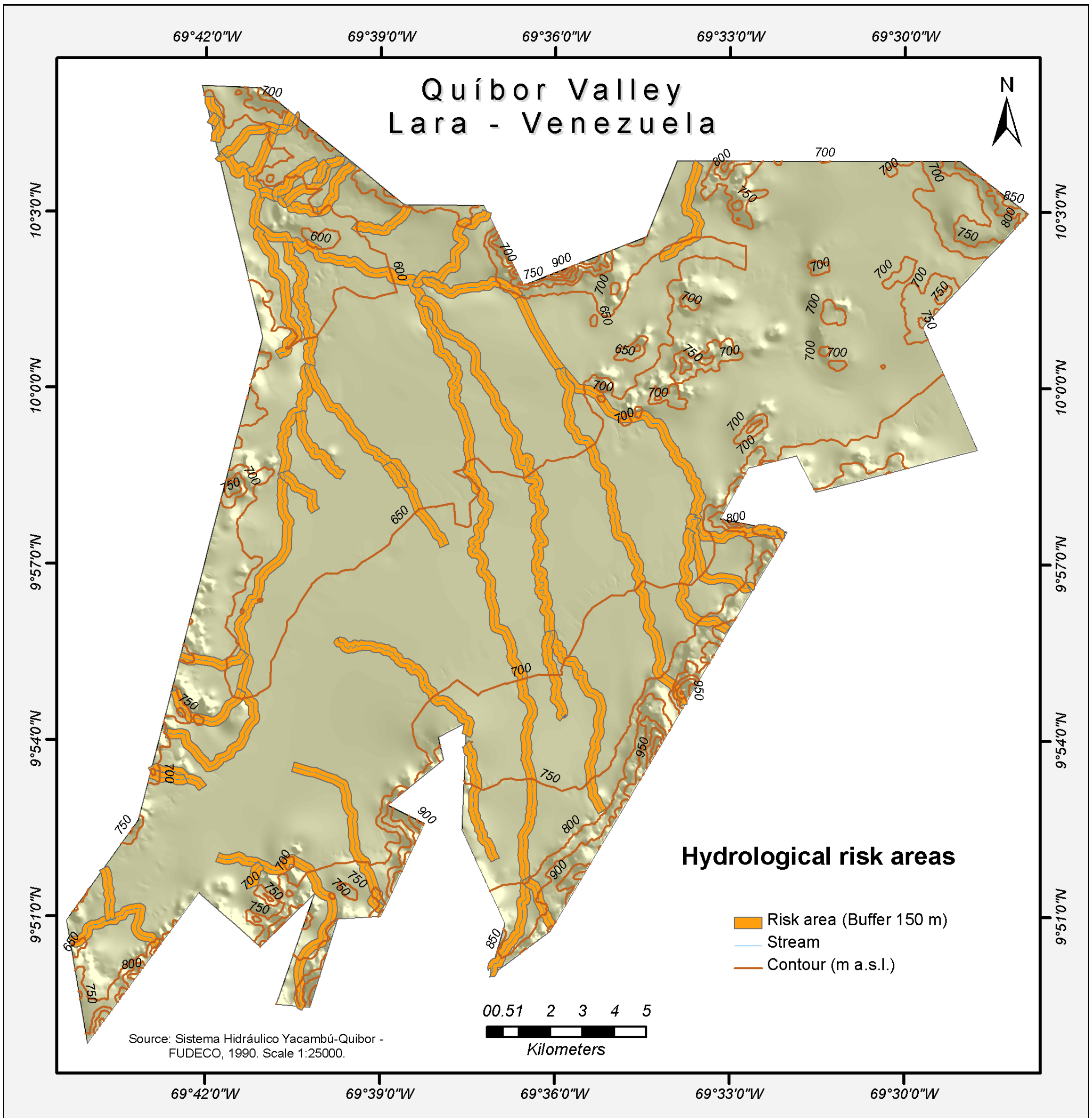


Map 5.24: Geostructural instability.

The results indicated high geo-structural instability of the hills in the area because of the fragility of the rocks as well as the faulting structure that were identified there.

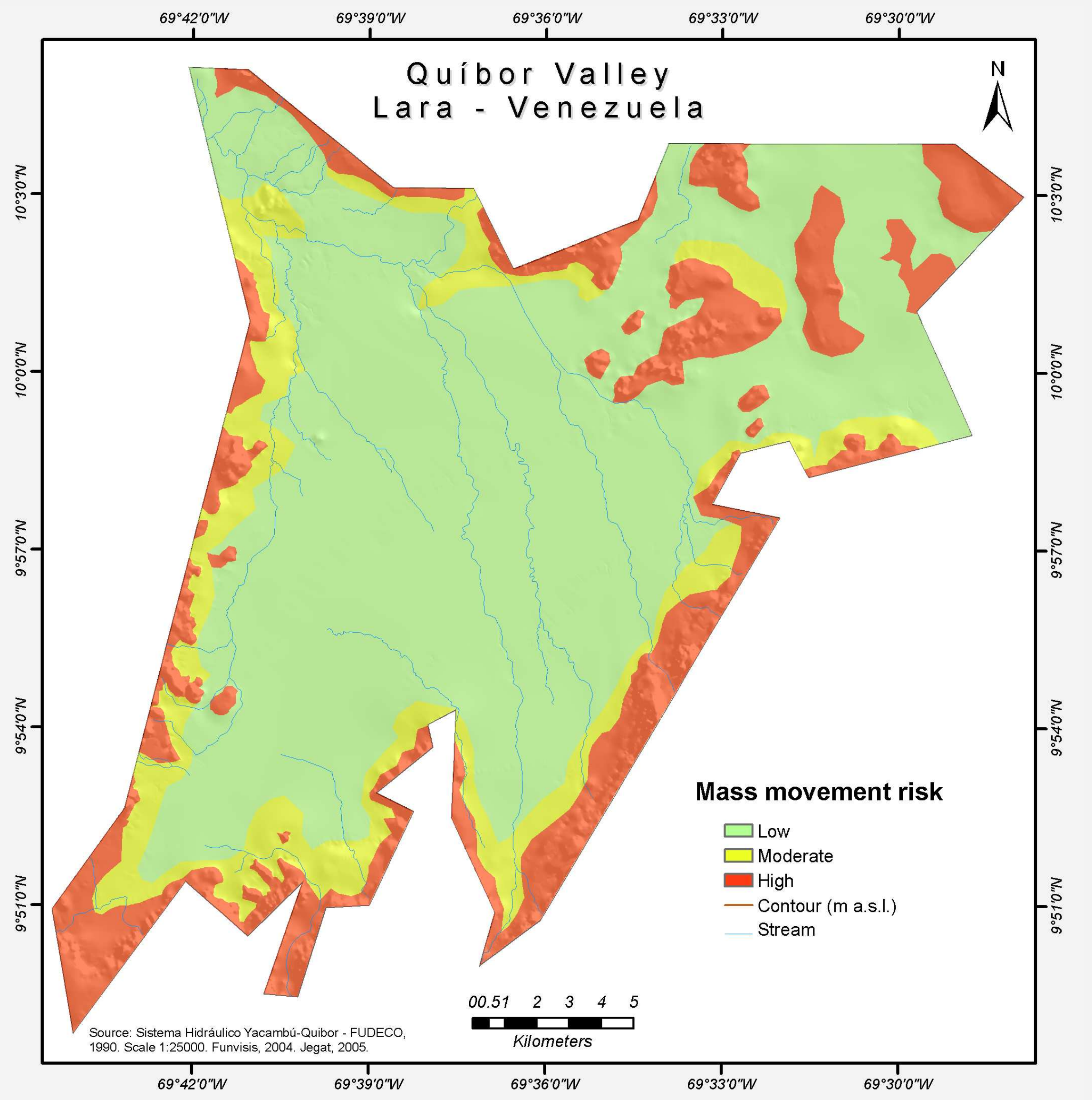
5.3.2 Hydro-geomorphological stability

The hydrological network of the valley was processed by means of the buffer tool in order to identify the area subjected to conditions of highest instability around the stream. This instability is determined by the larger risk of overflows, floods, undermining or landslides due to the hydrological dynamic. In this case, the buffers were built with a width of 150 m around the streams (Map 5.25).



Map 5.25: Hydrological risk areas.

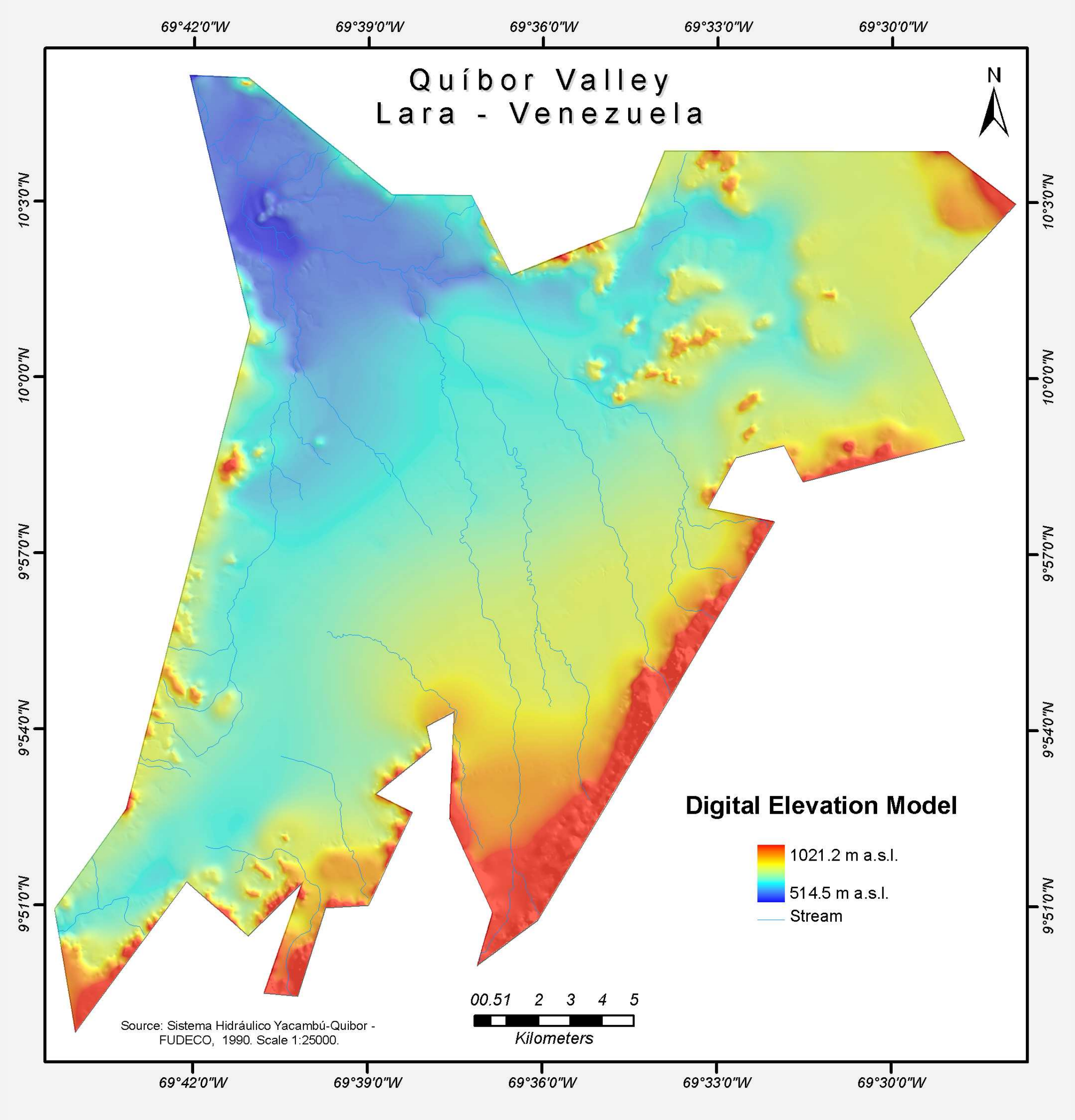
Due to the semiarid conditions of the area, the plain relief of the valley bottom as well as the intensive use of the surface water, several very intermittent streams are identified in only some stretches of the alluvial flat. Normally, these streams conclude in natural depressions or lagoons, where they lose their connection with the hydrological network Geomorphological aspects were analyzed in relation to the process and land forms. Thus, the predominant mass movements were identified in order to establish a zonation of the mass movement risk (Map 5.26).



Map 5.26: Mass movement risk.

The largest risks were identified in the hills and the alluvial fans where slopes, lithology and the structural instability are the principal triggers of these processes.

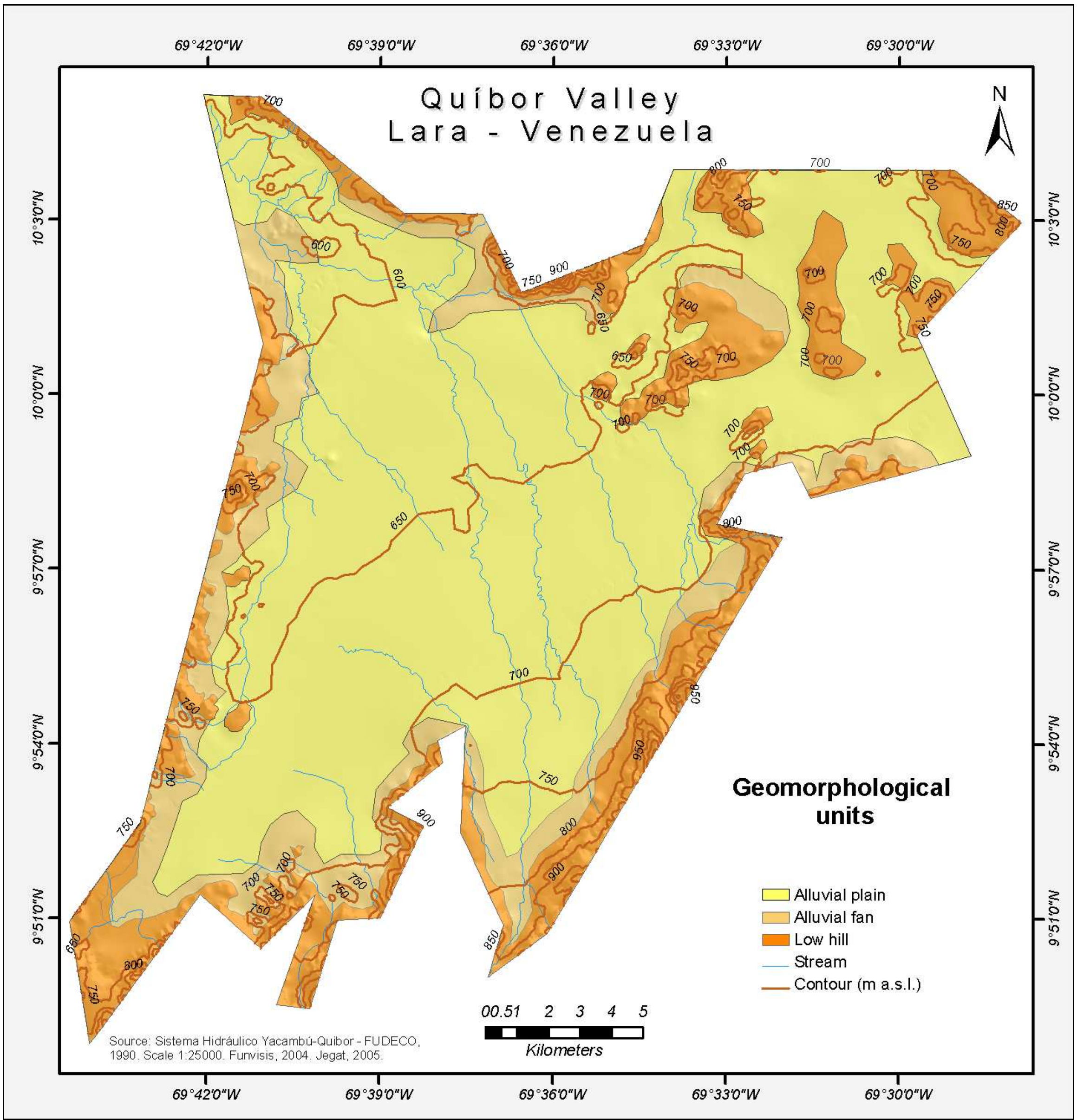
Land forms were analyzed in accordance with the digital elevation model DEM that was built by means of the 3D Analyst extension of the ArcGis 9.1 (Map 5.27).



Map 5.27: Digital elevation model.

From this DEM, and using the respective tools offered by ArcGis 9.1, the derivatives slope, slope aspect and slope curvature were obtained. The resulting maps are presented in section 5.3.3. According to this DEM the predominance of plain relief in the valley bottom can be observed. Besides the lowest and highest sections of the area most of the valley bottom varies between 600 m a.s.l., in the northwest, and 700 m a.s.l. in the southeast: this is the area more intensively occupied by agricultural activities.

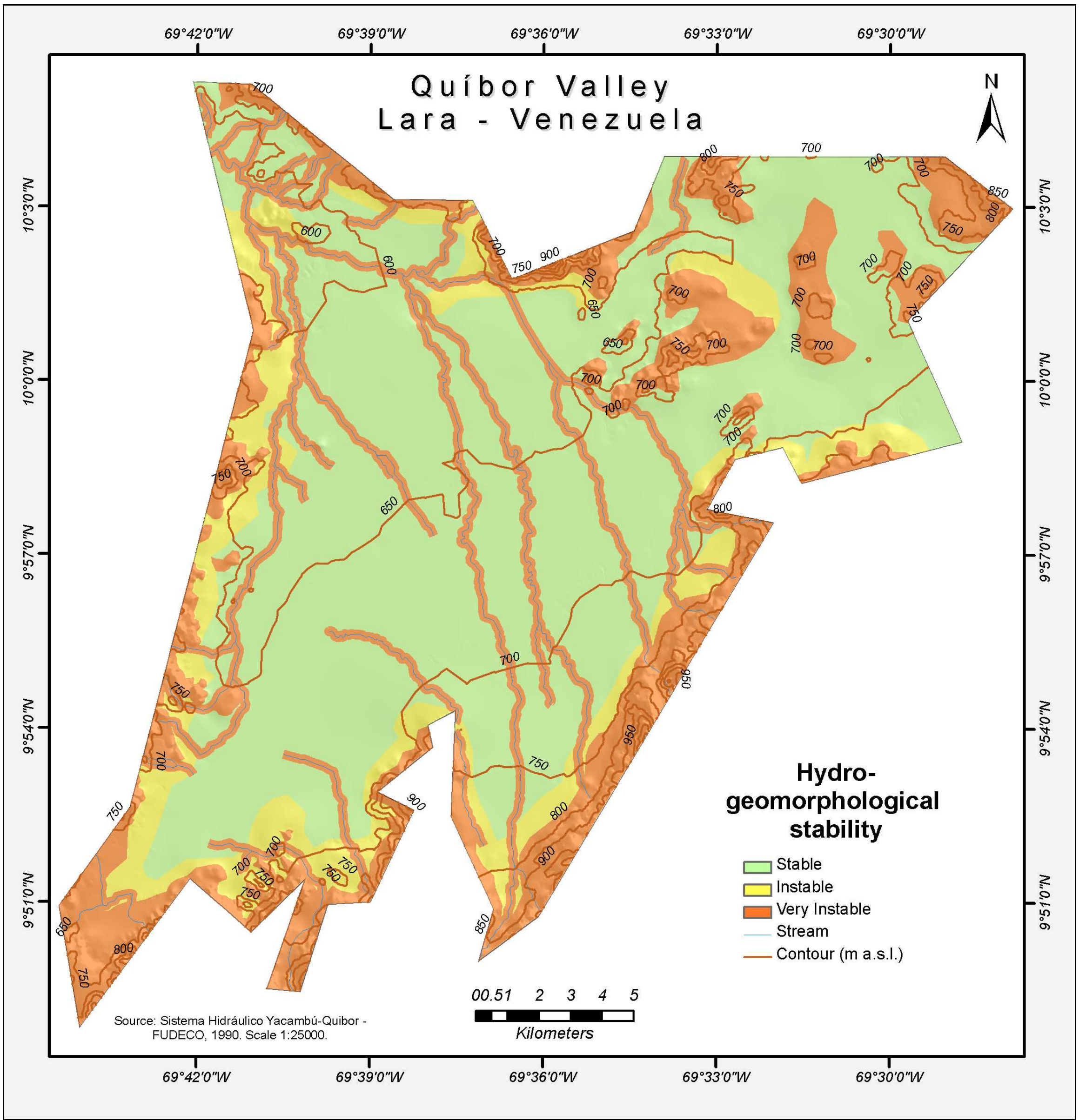
According to the land forms, three geomorphological units were identified: alluvial flat which covers about 66% of the area; alluvial fans, covering about 14%; and low hills, covering about 20% of this study area (Map 5.28).



Map 5.28: Geomorphological units.

Finally the above three layers, which were originally obtained in vector format, were converted to rater format (*convert to raster*) and reclassified in accordance with the indicated thresholds. These raster layers where, subsequently, summed by means of the *raster calculator* tool. The highest values indicate unfavorable conditions of hydro-geomorphological stability, whereas the lowest values indicated the more favorable conditions of hydro-geomorphological stability (Map 5.29).

The map indicates moreover that the stable areas are constituted by about 25,000 ha (56%) of the area; the zones with instable hydro-geomorphological conditions represent about 5,000 ha (11%). The remaining 14,400 ha (33%) of the area were classified as very instable. These areas are constituted by the zones of more inclined relief in the hills around the valley, and the nearness of the streams in the alluvial flats.



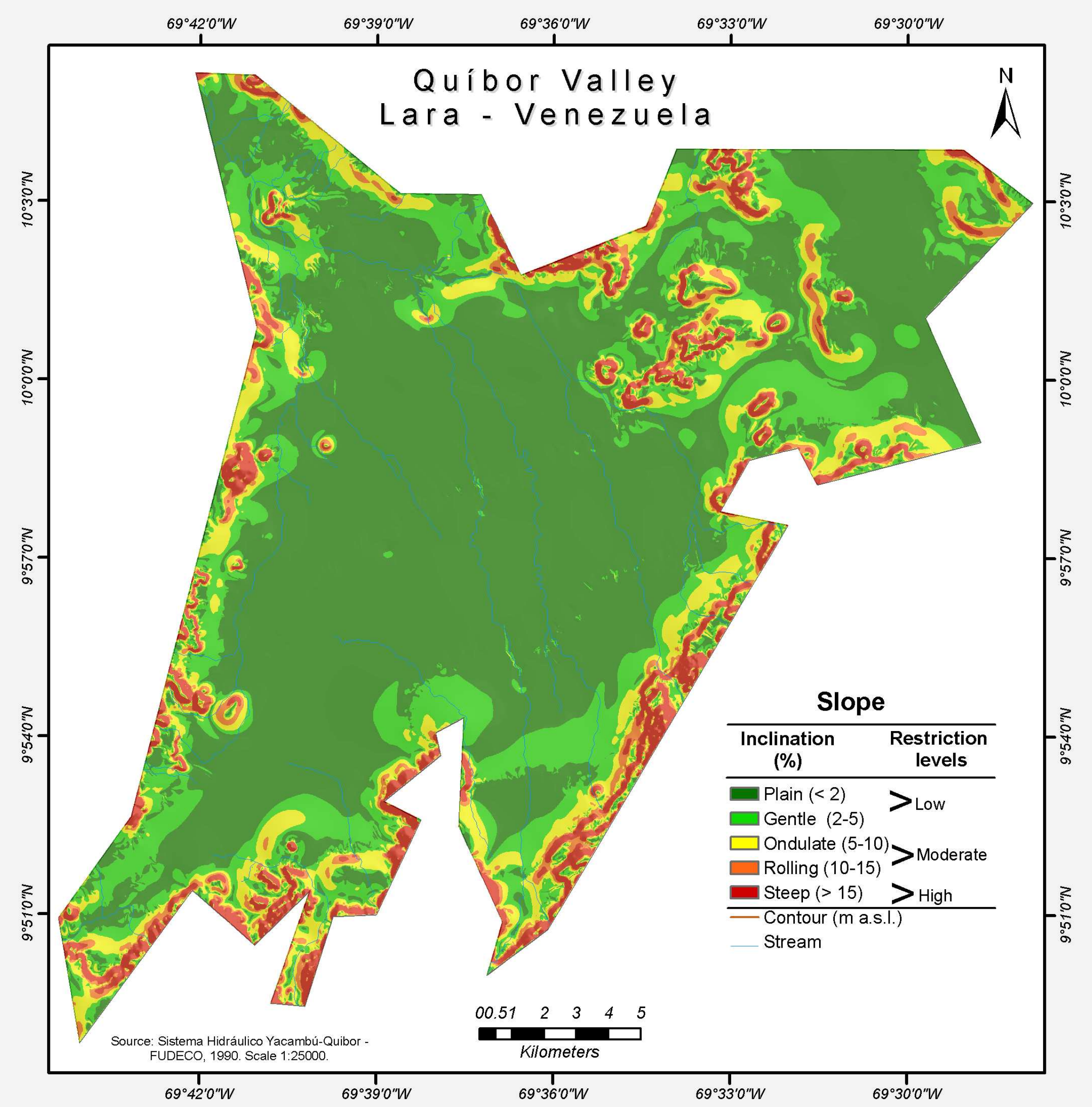
Map 5.29: Hydro-geomorphological stability.

5.3.3 Erosion susceptibility

This analysis integrates geomorphological, soils and climatic aspects which are the some of the most important physiographical features responsible of the erosional processes.

The first step was the analysis of the DEM derivatives: slope, slope aspect and relief curvature.

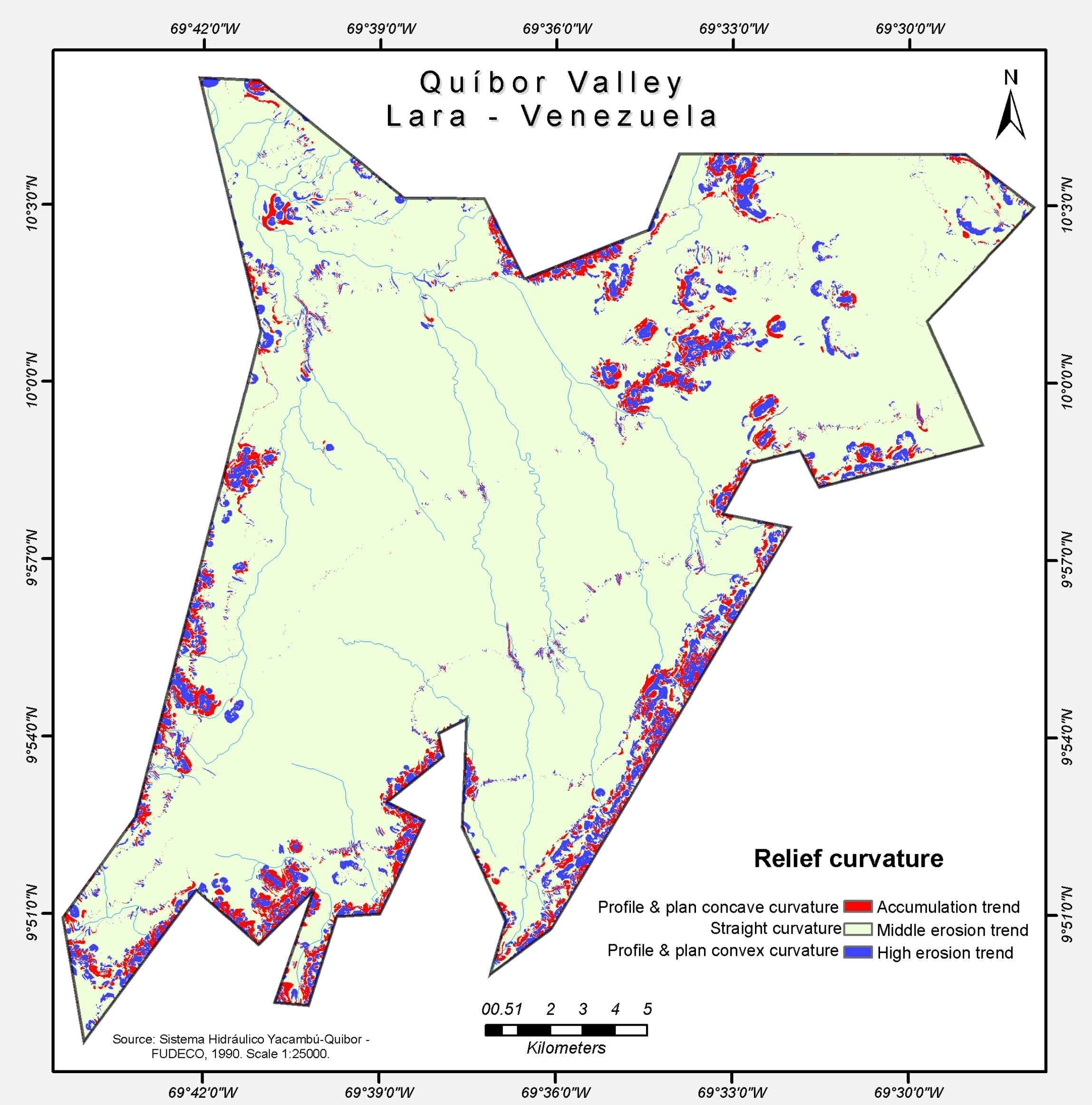
The slope map, constructed using the *slope* tool (3D Analyst extension ArcGis 9.1) with a grid cell of 10 by 10 m, is show in Map 5.30.



Map 5.30: Slope.

The plain relief with slope less than 2% dominates most of the surface of the valley, covering about 58% of it, while only 6% of the valley has a relief inclination larger than 15%. Taking into account that the potentiality of the erosive process could be the largest in those more inclined areas, the largest erosion rate is expected in those sections constituted by hills and alluvial fans.

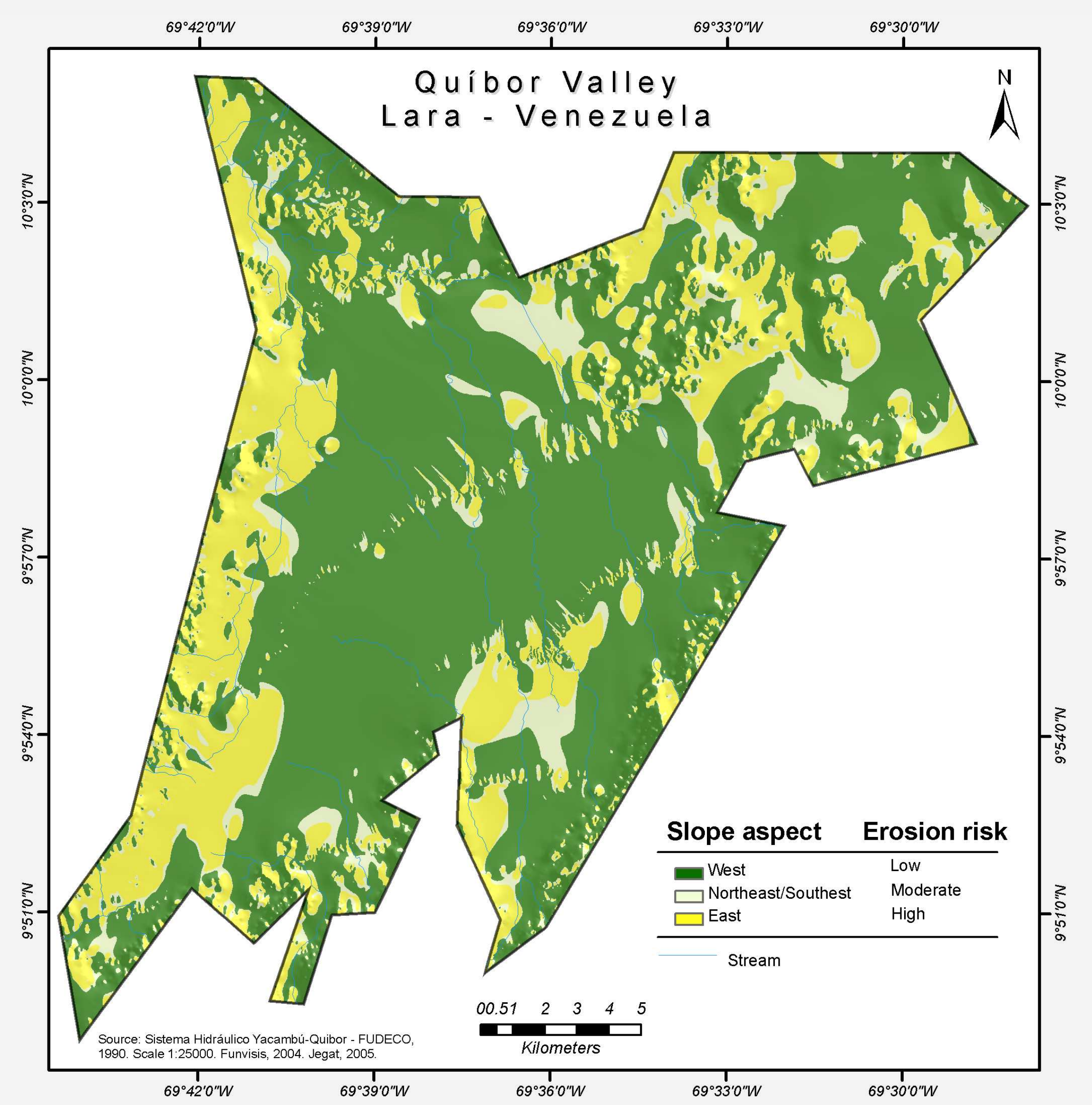
A curvature layer was also built using the respective tool of Arc-Gis 9.1. (Map 5.31).



Map 5.31: Curvature.

This second derivative of the DEM delimits the profile convex and plain convex relief where the energy of surface runoff is increased and consequently the erosion processes increased. In profile concave and plain concave relief the energy surface runoff decreases and leads to the accumulation of sediments (Thiemman, 2006). Here, as was done in the other study case, the values were reclassified by assigning the highest value (4) to convex relief and the lowest (1) value to concave relief. For profile and plain straight curvature mean values were assigned. Due to the more homogenous relief forms, the most of the valley has a straight curvature and, in accordance with the grid cell used (10 by 10 m) only concave and convex curvature were found in the hills and alluvial fans of the valley.

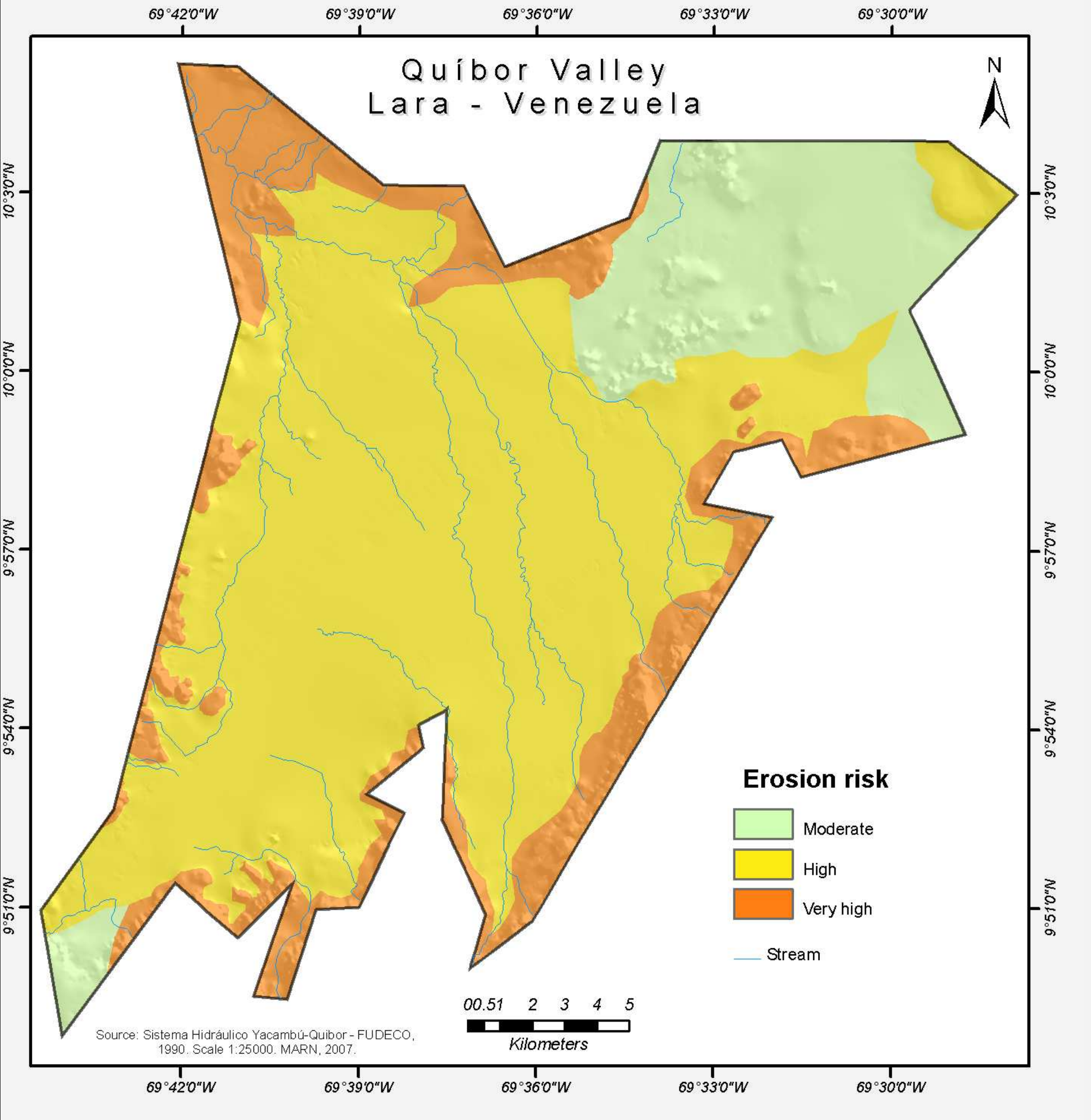
As the final part of this relief analysis the slope orientation was also evaluated (Map 5.32).



Map 5.32: Slope aspect.

This analysis was based on the premise that in tropical zones the east-exposed slopes are frequently warmer and dryer than the west-exposed slopes due to these slopes receiving more radiation. In accordance with the scale of evaluation shown in Table 4.2 (Chapter 4) it was assumed that in the sunny slopes conditions could increase erosion, because of their dryer microclimate and, consequently, higher limitations for a dense vegetation cover. Thus, larger value (4) was assigned to the east-exposed slopes, while the west-exposed slopes were classified as 1. North- and south-exposed slope were classified as mean values.

The intrinsic conditions of erodibility of the soils were also analyzed. MARN (2007) classified the soil of the Quíbor Valley as aridisols, entisols, and inceptisols. A map of soil erodibility was built taking into account the general characteristics of these soils, as well as several soil assessments carried out in Quíbor Valley (Map 5.33).



Map 5.33: Erosion risk.

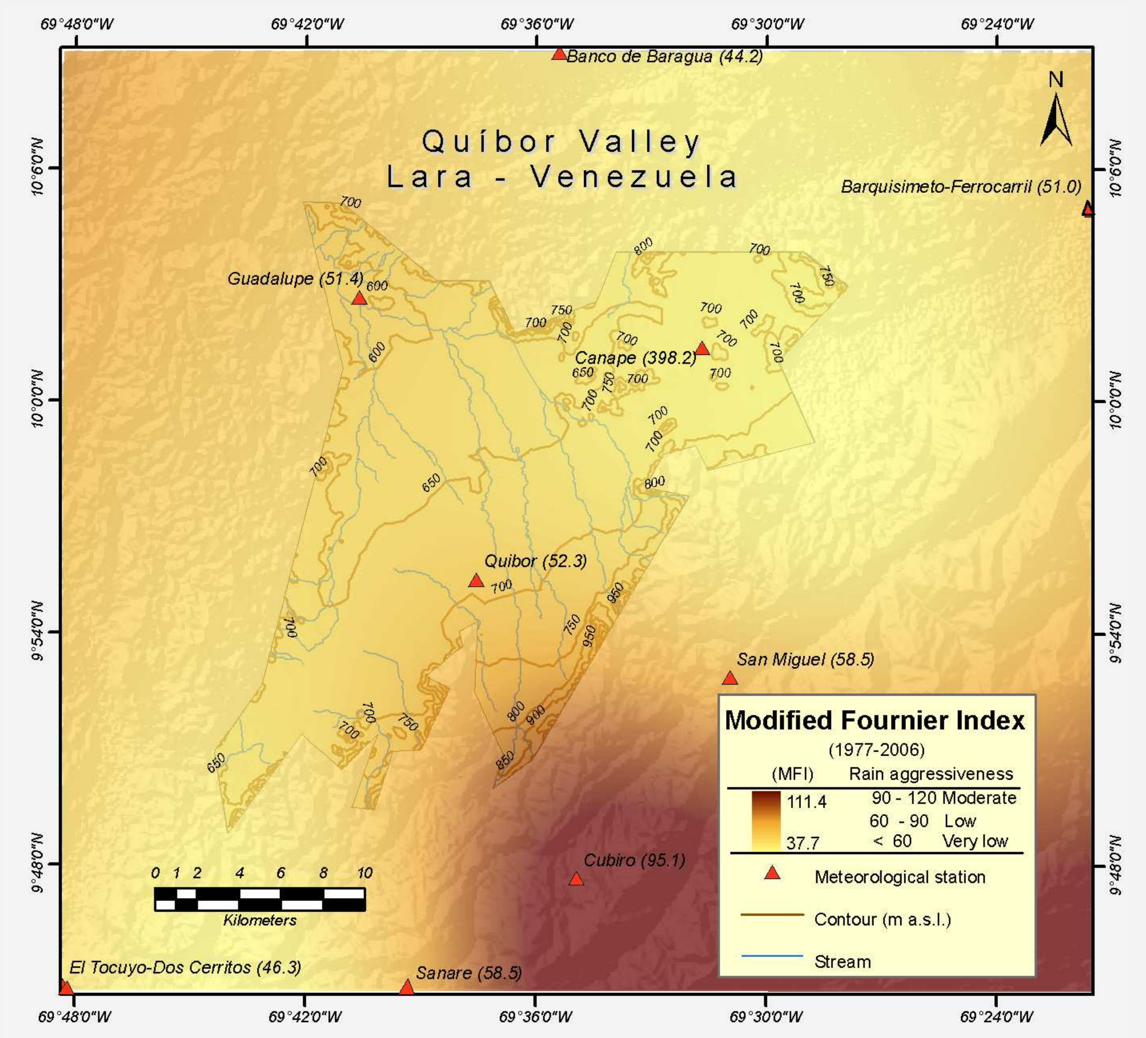
The soils of the valley are characterized as being highly affected by erosional processes (Ecology and Environmental, 2004). Thus, the soils in the hills have a very high erodibility. They are shallow, very fine textured and relatively impermeable, with problems of calcite salinity; and are considered unsuitable for agriculture or ranching use. These soils are covered by an association of the columnar cactus cardón (*Cereus* *deficiens1*) and cují (*P. juliflora*), and a practically non-existent ground cover. As a result, soil erosion rates are extreme, with very pronounced gully erosion (UPND, 2005).

In the valley bottom -despite it being deeper-, the soils constituted basically by entisols, present important limitations as they are located in the hills and are considered very susceptible to degradation (UPND, 2005). Here, the soils vary between clay and clay loam, presenting a silt fraction larger than 50% in most part of the area. This determines a low structural stability and a high susceptibility to the water and wind erosion (Villafañe, 1999). In spite of them being likely affected by erosion processes, the aridisols located mostly in the northeast were classified as of moderate erodibilty, due to its sensible higher grade of development and a content of organic matter.

The map obtained in vector format was converted to raster and subsequently reclassified assigning a value of 2 to those catalogued as moderate erodibility, and 3 and 4 for those considered as high and very high erodibility, respectively.

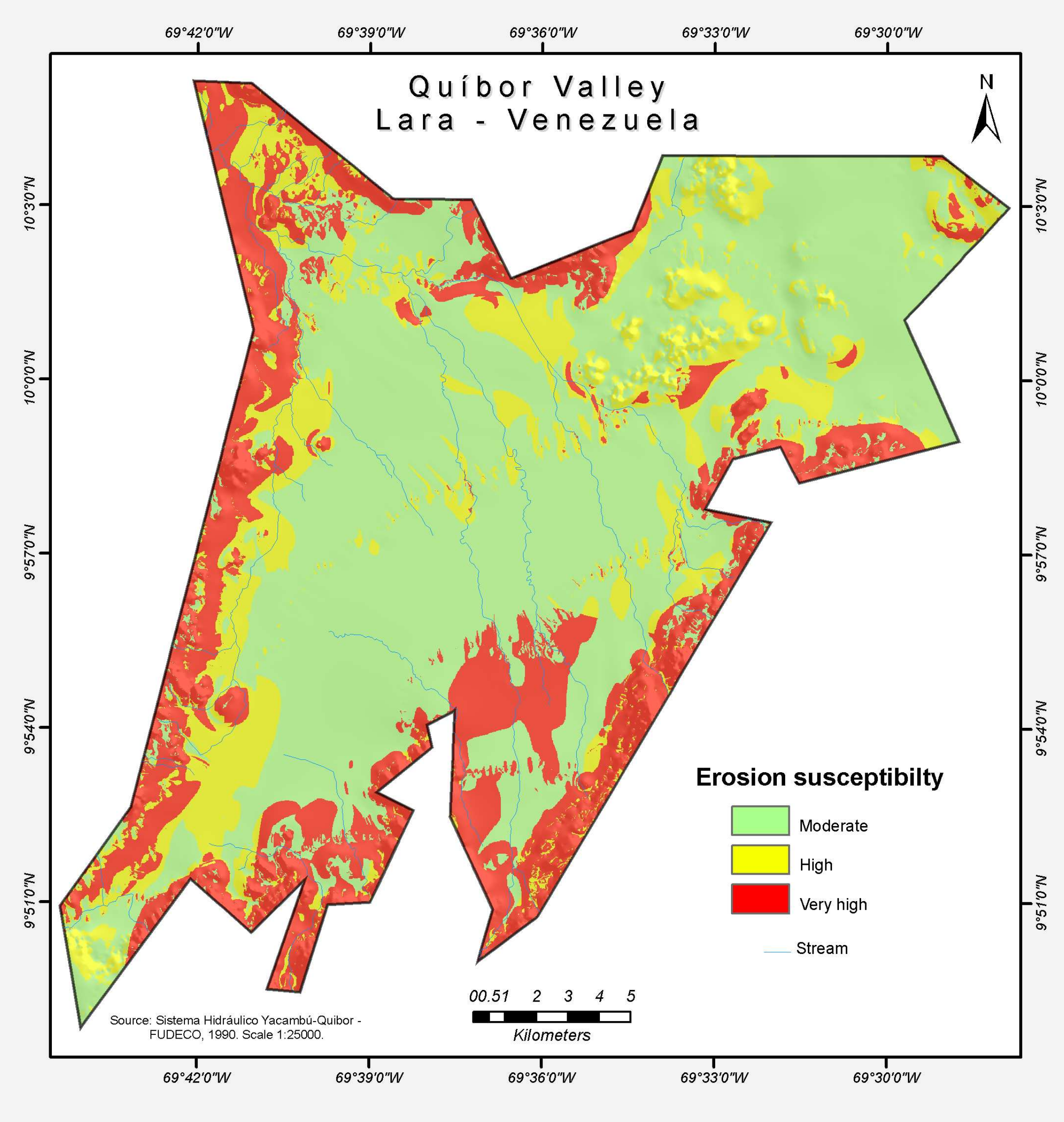
Finally, the Modified Fournier Index (MFI) was employed as an indicator of the aggressiveness of the rainfalls. For this process, annual average precipitation and monthly average precipitation of nine meteorological stations were utilized. The resulting values were plotted on a digital layer and, subsequently, interpolated by means of the Kriging technique, with 12 neighborhoods, available on the 3D analyst extension of ArcGis 9.1 (Map 5.34).

The results indicate a predominant low aggressiveness of the rainfalls in Quíbor Valley. However, it should be taken into account that the low structural stability, the scarce organic matter and the very sparse vegetation cover could increase the condition of the erodibility of the soils.



Map 5.34: Modified Fournier Index.

The final step of this partial analysis consisted in the addition of the five raster layers by using the *raster calculator* tool of ArcGis 9.1. In accordance with the established classes for each considered layer, the results indicate that the largest grade of erosion susceptibility is related to the soil located in the hills and alluvial fans of the study area. However, some lands of the valley bottom were included in this class as a consequence of their slope, slope aspect and their physical conditions of erodibility. Values of moderate erosion susceptibility were obtained for almost the whole valley bottom. The result allows a summarized overview of the potentiality of this natural or induced process of soil degradation

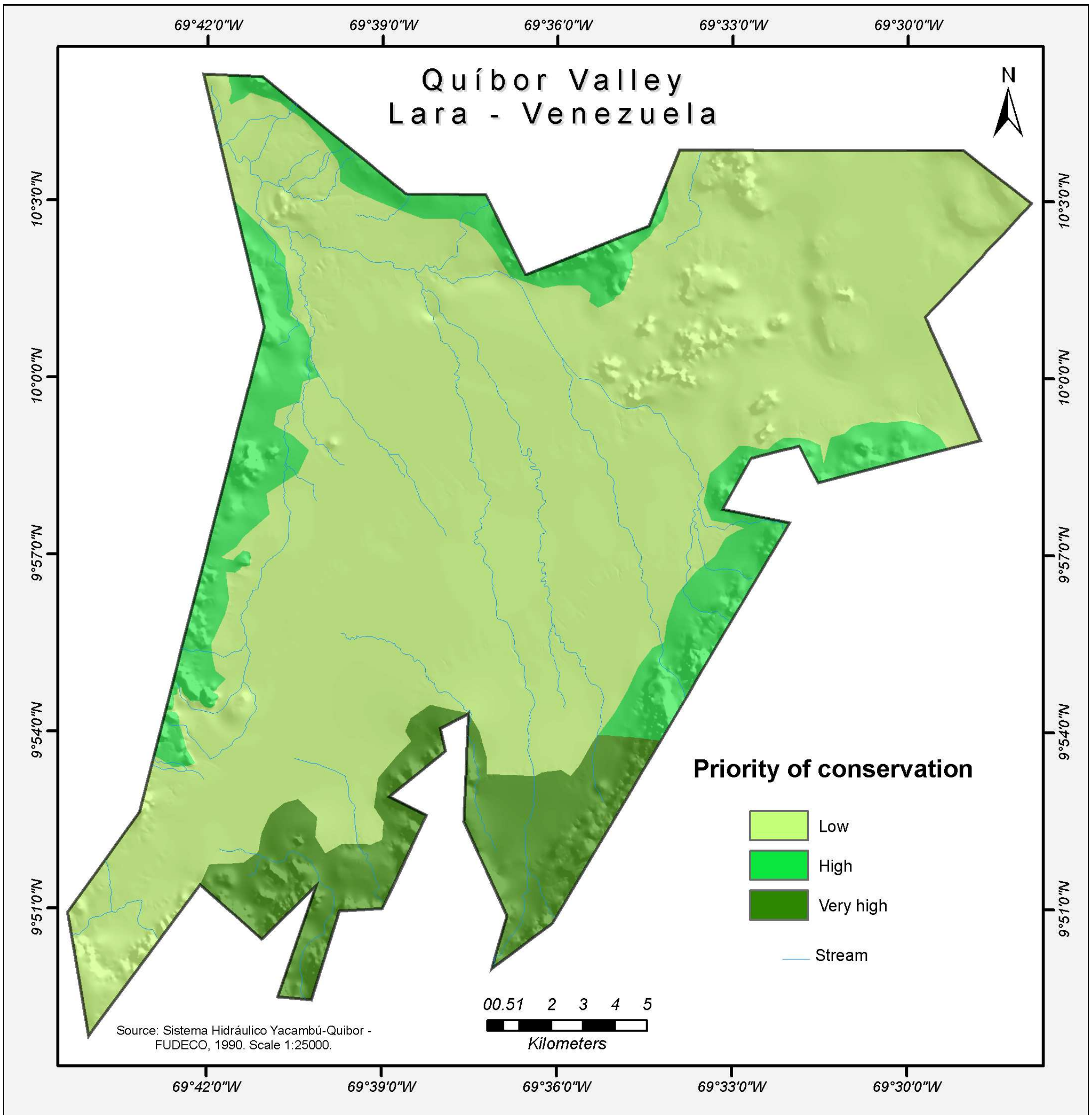


Map 5.35: Erosion susceptibility.

Areas classified as having very high susceptibility to soil erosion are constituted by those predominantly located on steep slopes, sunny slopes or where the rainfall aggressiveness shows the highest values, such as those of the southwest of the valley. Areas with the lowest susceptibility to soil erosion are integrated basically by the lands of the valley bottom.

5.3.4. Fragility of vegetation units

The vegetation cover was analyzed by means of the three dominant vegetation types of the area. Due to the limited conditions of atmospheric humidity, which determine a very high deficit of soil moisture, the natural vegetation is composed by thorny shrub and very dry forest which are highly vulnerable to the disturbances. In spite of some zones of the area presenting vegetation cover in relatively natural conditions such as some sections of the hill around the valley, most of the valley bottom lacks of natural vegetation. When this vegetation is present in these zones represent primaries or secondary successions as a result of ancient processes of disturbances. In this sense, the analysis of this parameter was oriented to determine priorities of conservation. This means that the areas where natural vegetation can still exist were identified as the highest priority for conservation (Map 5.36).



Map 5.36: Priority of conservation of the vegetation cover.

According to this map the highest priority for conservation should be given to the very dry tropical forest, located in the southwest of the area, where more favorable bioclimatic conditions allow its development. This is the most complex and dense vegetation cover of the area. The dense thorny shrub located in the hills around the valley was classified as high priority. In the valley bottom the vegetation has less ecologic importance, due to its high grade of disturbance and the predominance of agriculture lands. However, particular relicts of natural vegetation that can be found in small scale, basically around the streams, lagoons or in abandoned areas, could be protected by means of specific projects which could be conceived as part of a plan of environmental management of the agricultural areas.

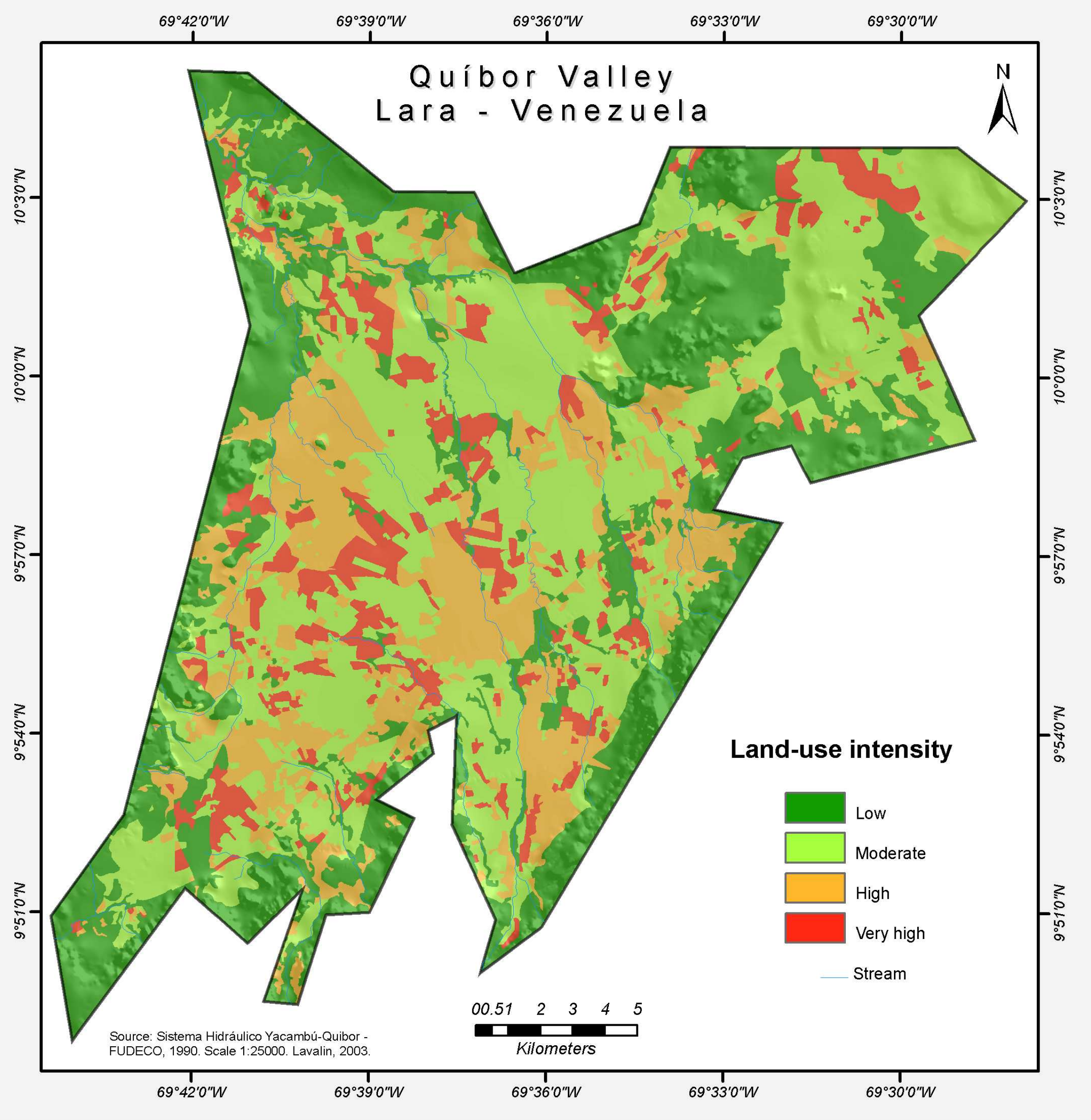
5.3.5 Land-use intensity

The anthropogenic impacts on the physical and ecological conditions of the environment were assessed by means of the evaluation of the land uses. To carry out this evaluation, it was concluded that the land-use types developed that implicate intensive affectations of the natural resources, would be classified as high intensity. At the same time, those land uses, in which the natural resources can be maintained, unaltered or scarcely altered, would be considered as low intensity.

In regard to these premises the land uses were analyzed in order to generate a map of intensity of the land uses (Map 5.37). The map indicates that areas subjected to intensive croplands are classified as those with the highest potentiality of alteration of the physic-natural conditions. These areas are constituted by those in which agricultural activities by intensive processes of land exploitation are carried out, frequently without measures to prevent potential environmental impacts are not considered. There, the agriculture use irrigations systems which do not consider rational use of the water, such as drop irrigation, and with an over-exploitation of the aquifer. This causes a lowering of the water table and salt-water intrusion which has been proved through an increased electrical conductivity (an indicator of salt content) UPND, 2005.

Areas occupied by human settlements as well as abandoned land without vegetation cover or cropland, were classified as of high intensity. In the towns, the environmental impacts are related to the generation of noise, waste and wastewater, as well as the frequent anarchical forms of urban expansions. Abandoned lands represent frequently degraded areas as a consequence of intensive agricultural uses. Actions of natural recuperations must be developed in these areas.

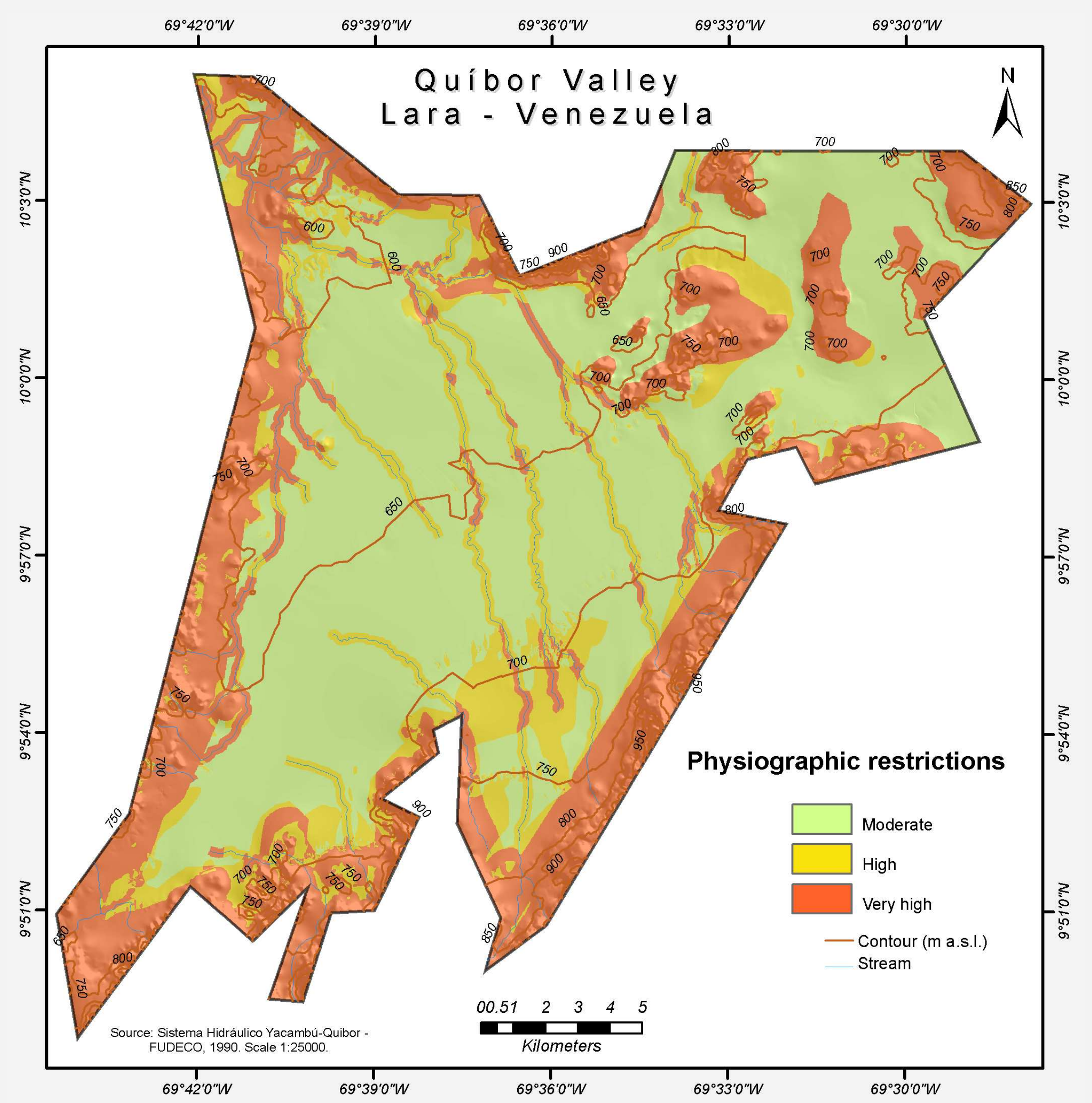
The least affected areas are constituted of those in which vegetation cover can still be found in conditions of relative naturalness. Those lands are basically located on the hills around the valley as well as in some particular sections of the valley bottom.



Map 5.37: Land-use intensity.

5.3.6. Physiographic restrictions

The first five results of the proposed spatial model were used for further analysis in order to achieve global results. The first analysis is related to the physiographic restrictions of the area. For this integrate analysis the geo-structural stability, the hydro-geomorphological stability and the erosion susceptibility were considered. These three raster layers were processed by means of additions with the *raster calculator* tool. The results indicate the general restrictions of the physiographic aspects involved in this spatial analysis (Map 5.38).



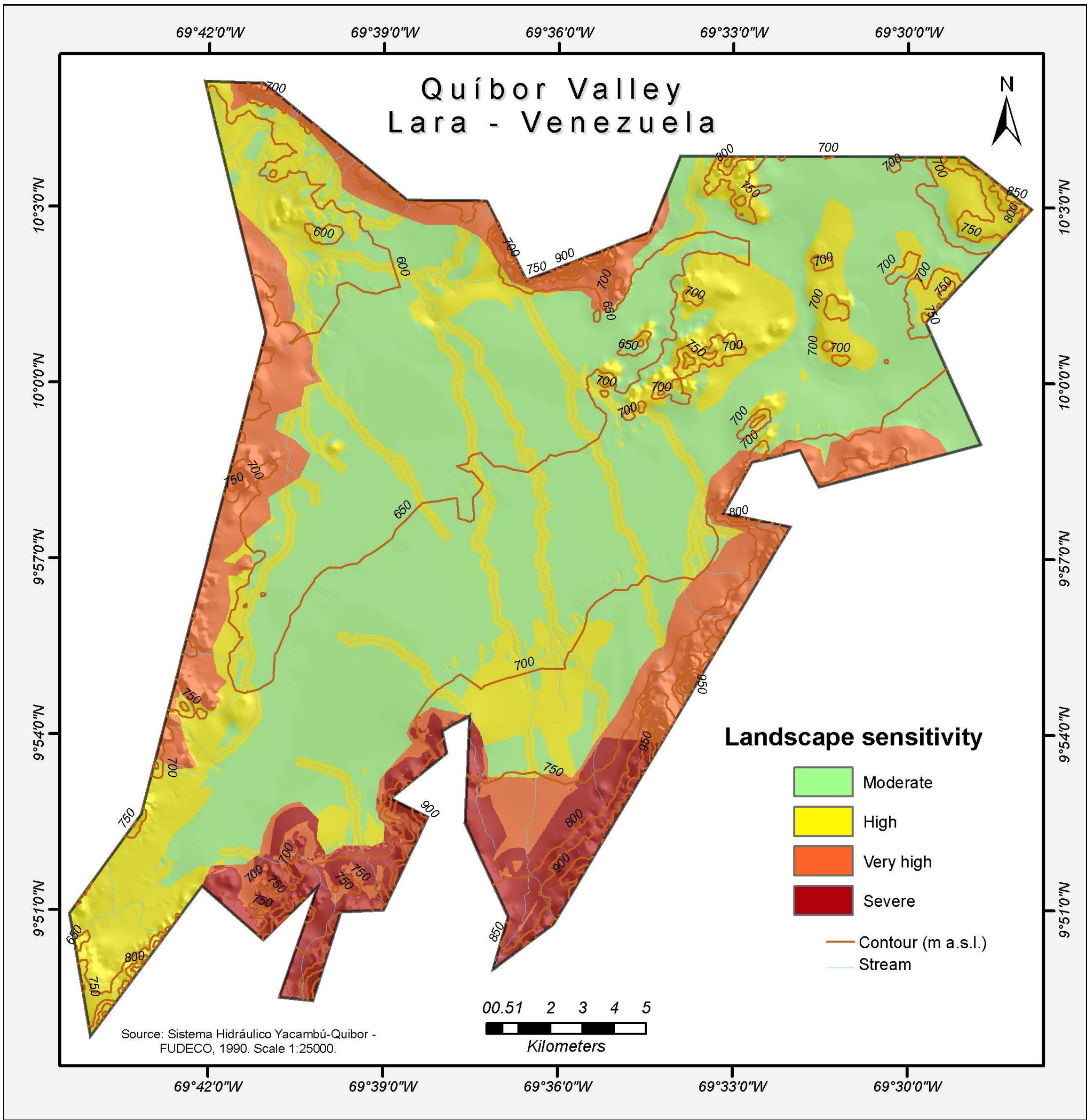
Map 5.38: Physiographic restrictions.

In accordance with the earlier results, in this layer it can be identified that the areas of the highest physiographic restrictions are located in the hills and the alluvial fans. These are precisely the lands affected by the instability geo-structural, with the highest relief inclination and extremely vulnerable soils. Principally the areas potentially affected by the hydro-geomorphological dynamic of the streams were defined as having high restrictions. Finally, the lands of the valley bottom were identified as having moderate restrictions. This means that, in spite of the geo-structural characteristics, relief and soil allowing anthropogenic uses to be carried out with the most favorable conditions.

However the interventions need to be developed considering its moderate level of physiographic stability.

5.3.7 Landscape sensitivity

The assessment of the landscape sensitivity is obtained through the integrated analysis of the physiographic restrictions (Map 5.38) and priorities of conservation (Map 3.36). The objective of this evaluation is to produce a layer in which the dominant landscape issues, i.e. physiographic and ecological features, can be synthesized (Map 5.19).



Map 5.39: Landscape sensitivity.

This layer was also computed by means of the addition of the basic layers with the *raster* calculator. The landscape sensitivity maintains previous results. Thus, the sectors of the valley located in the southwest, where very high physiographic restrictions with very high priority of conservation of the vegetation are combined, were classified as having severe conditions of sensitivity.

Very high sensitivity areas were found in the low hills and alluvial fans of the valley. Previous analysis had identified the restrictive physiographic conditions as well as high priority of preservation of the natural vegetation in these zones.

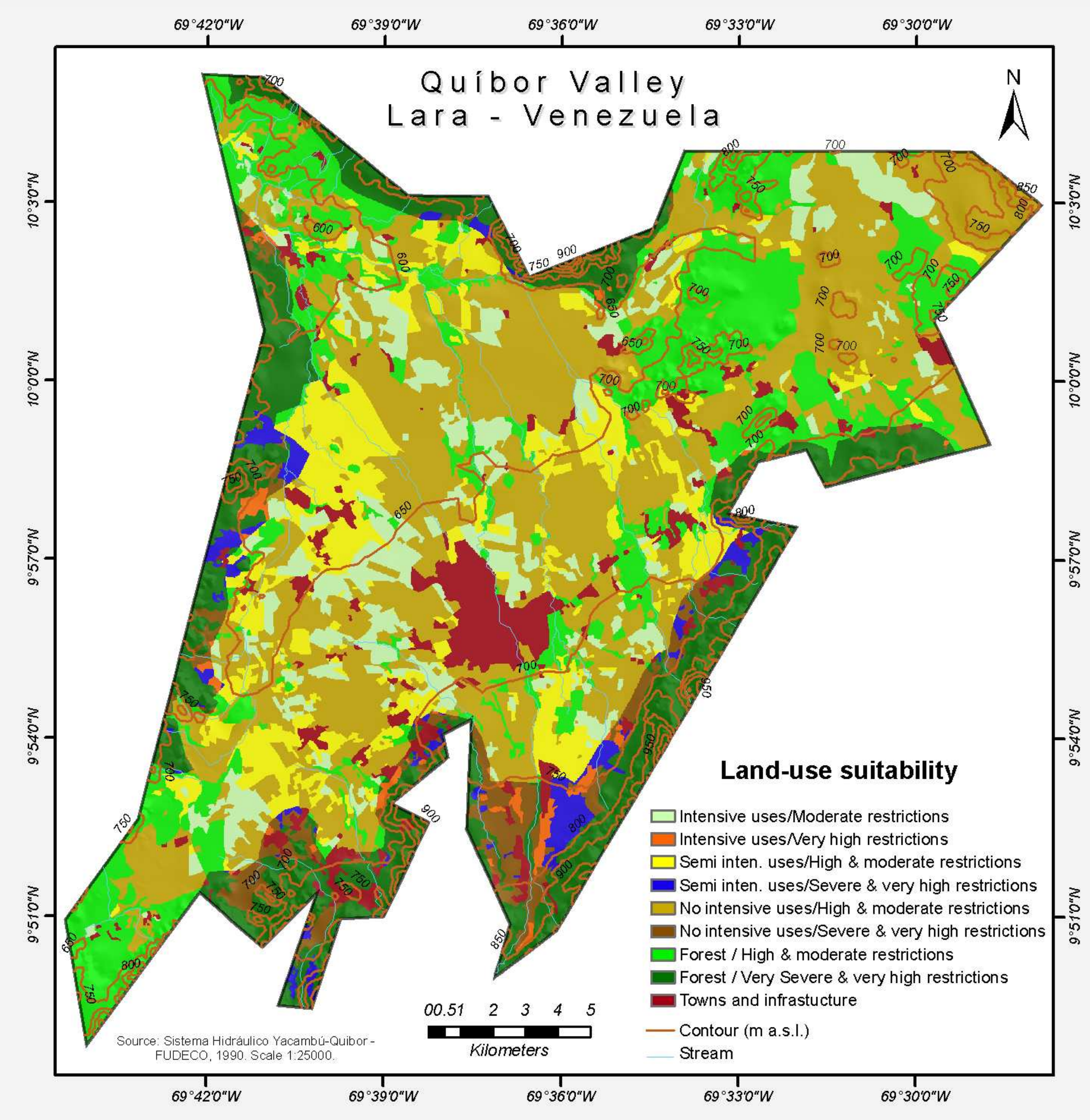
Sections of the hydrographical network in the valley bottom as well as the lowest zones of the alluvial fans resulted in landscapes with high sensitivity. Finally, most of the valley bottom was classified as landscapes of moderate sensitivity.

5.3.8. Landscape suitability

As a final product of the proposed spatial analysis a layer for the landscape suitability was generated. This map integrates the layers of landscape susceptibility (Map 5.39) with intensity of the land uses (Map 5.37). The objective of this analysis was to compare the physiographic and ecological conditions of the landscapes with the intensities of the land uses.

The technical process implicated the addition of the layers using the *raster calculator*. The product is presented in Map 5.40. By means of this map it can be located which land unit of Quíbor Valley, classified as landscape of very severe sensitivity, is currently used by land use types of very high intensity. These zones are constituted of the areas in which the largest environmental problems such as impacts, damages, hazards and risks could be expected. There, strong measures of environmental control need to be implemented in order to control current and potential negative effects. In another sense those areas classified as having low landscape sensitivity, in which land uses with the lowest intensity are located, are those land units in where the lowest environmental problems would be expected. Potentially these areas could be selected for anthropogenic uses, embedded into the principles of environmental sustainability or, also could be selected as areas of natural preservation. By means of the use of this layer the most important references needed to produce a land-use plan can be obtained.

The obtained layer indicates that about 34% of the Quíbor Valley is characterized by forest and natural uses, located in areas categorized as severe and high sensitivity. These comprise the hills around the valley, as well as in different sections of the valley bottom, especially in the north of the area. In these areas, programs of environmental management in order to maintain their natural resources should be implemented.



Map 5.40: Land-use suitability.

Another important zone which covers about 34% of the valley constituted of those lands of moderate landscape sensitivity, where currently uses are developed with low intensity. Most of these are lands that were used by agriculture, but currently are in a condition of fallow. These areas, embedded into programs of sustainable agriculture, could be used has the expiation areas for the future irrigation system which have been projected for the Quíbor Valley.

The larger environmental problems are represented by areas of severe and very high landscape sensitivity in which very intensive agriculture is developed. Programs of environmental management addressed to recuperation and conservation should be applied there. This must be considered in the formulation of the land-use plan.