Chapter 31
Territorial Zoning Based on Geopedologic Information: Case Study in the Caroni River Basin, Venezuela

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Abstract Geomorphology-based land surveys, founded on geoform-soil relationships, have been carried out in Venezuela at different scales and in a variety of environments using aerial photographs, radar and satellite images. The Caroni river basin is one of the most important watersheds in southern Venezuela, providing the largest part of the electric energy consumed in the country. To guarantee the sustainability of the hydroelectric production, a management plan of the natural resources of the watershed is needed. A territorial zoning of the catchment area based on geomorphic and soil information was undertaken as an initial step to propose land uses compatible with preserving the hydroelectric potential. Geomorphic units and their soil components, together with ancillary elements including the vegetation cover, were mapped at two scales using a multicategorial geoform classification system. From this information two zoning proposals were derived, one based on geomorphic landscape units at 1:250,000 scale and the other based on relief-type units at 1:100,000 scale. The zoning units were used for land evaluation and for establishing land use regulations required for the watershed management plan.

Keywords Geomorphology • Soils • Land use planning • Environmental planning • Caroni basin • Venezuela

31.1 Introduction

A watershed is a natural and functional biophysical unit for the management of natural resources. For each watershed there is a particular combination of biotic and abiotic interacting components. This allows differentiating watersheds according to their limitations, suitability, and capacity to provide environmental services, among others, water production. Not only is water one of the most important

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natural resources, it is also one of the most affected by human activities. As an economic system, a watershed encompasses resources that can be used to produce goods and services under diverse technological conditions. However, the lack of a holistic approach to characterize and evaluate the potentialities of the watersheds and the forms and operational ways of using the land units can cause the alteration of the hydrological cycle and that of other ecological functions commonly underestimated by planners, politicians, and users.

Watersheds are recognized as territorial planning frames for integrated management of natural resources. They represent a spatial arrangement of ecosystems with strong and complex relationships whose structure, functions, and environmental services must be taken into account when making management decisions.

Watersheds are under increasing anthropic pressure which generates serious problems of land degradation. There are many anthropogenic activities that cause environmental risks in watershed areas, including deforestation, inappropriate agricultural uses, overgrazing, degradation of wildlife habitats, loss of biodiversity, soil erosion, invading mining activities, water pollution, sediment load, river channel destruction, uncontrolled urban expansion, among others. Territorial zoning is a sound technical approach to prevent, control, and reduce watershed degradation. Zoning projects involve political decisions based on geospatial, environmental, social, and legal information that allows harmonizing land constraints and suitabilities with land uses and territorial occupation.

The Caroni river basin in southern Venezuela is a strategic watershed as it provides the largest part of the electrical energy consumed in the country. To guarantee the sustainability of the hydroelectric production, the formulation of a management plan of the natural resources of the watershed is needed. The objective of this study is to show how geomorphic and soil information can contribute to the partitioning of the watershed in zoning units as a basis for decision making on appropriate land uses and the preservation of the natural resources.

31.2 Land Inventories in the Neotropical Lowlands of South America

The neotropical lowlands of South America include a variety of large watersheds belonging mainly to the Amazon and Orinoco basins, with important natural resources that are increasingly threatened by uncontrolled exploitation. However systematic inventory of these resources is still lagging behind. One of the largest land inventory projects using remote sensing was the Radam Brazil Project carried out between 1970 and 1985 by the Ministry of Mining and Energy of Brazil (Projeto RADAM/RADAMBRASIL 1972–1978). This integrated natural resource inventory covered several regions of the vast and remote Brazilian territory, particularly the Amazon region. Radar images from SLAR were interpreted for the characterization and cartography of the physical and biotic environmental components. Geomorphic maps at 1:250,000 and 1:500,000 scales were generated and used as principal spatial information source for the cartography of soils, geology, vegetation, and potential land use. The integrated information was used for the ecological zoning of Amazonia. Similarly, in 1972, the Colombian Government initiated the "Proyecto Radargramétrico del Amazonas" (PRORADAM 1979) with the aim to carry out an exploratory study of the physical and human resources of the Colombian Amazonas as a basis for integrating the Amazon region into the development process of Colombia.

In the Venezuelan Guayana region, the Ministry of the Environment and Renewable Natural Resources (MARNR) in cooperation with ORSTOM, now IRD (Institut de Recherche pour le Développement, France) carried out during the period 1975–1981 the soil survey of the Venezuelan Amazonas territory. Geomorphic maps at 1:250,000 scale were generated including information related to geology, soils, and vegetation (MARNR 1981). Subsequently, one of the largest Venezuelan integrated land inventories was undertaken initially by the Venezuelan Guayana Corporation (CVG) and continued by CVG-TECMIN (1987). Under this project, an area of 468,000 km^2 in southern Venezuela (about 52 % of the national territory) was surveyed at 1:250,000 scale, making systematic use of remote sensing products (SLAR and Landsat images and aerial photographs at different scales). Field verification units were defined basically by geological and geomorphic attributes extracted by the multidisciplinary interpretation of the remote-sensed materials. Thematic geology, soil, and vegetation maps had as cartographic base the geomorphic delineations determined at the categorial level of geomorphic landscape according to the methodology developed by Zinck (1988).

31.3 The Study Area: National Importance of the Caroni River Basin

The Caroni river basin covers 92,170 km^2 in the Bolivar state, southern Venezuela, between 3°40′–8°40′ latitude north and 60°50′–64°10′ longitude west (Fig. 31.1). The Caroni river is the second largest of Venezuela with a length of 958 km and the principal tributary of the Orinoco river basin with an average discharge of about 4500 m^3/s.

The Caroni river basin is one of the most important strategic territories of Venezuela. It represents a unique area in which converge remarkable natural and socioeconomic features. It is one of the oldest earth surfaces (Precambrian age), with a large reserve of hydrological, vegetal, and mineral resources. With an average rainfall of 2900 mm/year, including areas with >4000 mm/year, the basin contributes 13 % of the country's annual runoff and has one of the highest hydroelectric potential in Latin America (around 30,000 MW). It provides about 70 % of the

Fig. 31.1 Location of the Caroni river basin, Venezuela

country's electrical energy consumption, which is generated by four hydroelectric power plants representing an investment of around 15,000 million US$. Other assets include 65 % of forest lands with high biodiversity, 48 % of the country's fauna species, mineral reserves (e.g. gold, diamonds, iron, bauxite), and singular scenic resources associated to large and fast flow wing rivers and table-shaped highlands called tepuies, with high endemism and spectacular waterfalls (i.e. the Angel Fall, the highest worldwide).

It is still a largely uninhabited geographic space with an average population density of nine inhabitants per km^2. Indigenous people, around 3 % of the total basin population, live mainly upstream, while 90 % of the population concentrates in the lower basin. There are significant contrasts in cultural patterns, religions, ways of living, and modalities of using the natural resources. Spontaneous human settlements and aggressive exploitation of the natural resources are causing environmental threats and damages. This includes illegal mining leading to river channel destruction, pollution and sediment production; deforestation for expanding shifting cultivation, intensive agriculture, illegal timber exploitation, extensive cattle raising using fire for natural pasture management, and uncontrolled urban expansion in the rural and suburban areas. The lower basin area is the most impacted by agriculture, livestock, and urban expansion, while the sparsely populated middle and upper stretches are seriously affected by deforestation, vegetation fire, and illegal mining. Increasing land degradation and inappropriate use of the natural resources are threatening the integrity of the hydrological cycle and the sustainable generation of energy, while affecting at the same time other environmental services provided by the watershed ecosystems. This situation calls for the need to better control the settlement trends and rationalize the use of the natural resources by means of a territorial zoning plan.

31.4 Methodological Approach

31.4.1 Introduction

Two levels of zoning were proposed for the study area, based on available geo-environmental information and criteria such as land use intensity, degree of land degradation, land suitabilities, ecological features, and the presence of legally protected areas (i.e. national parks). For that purpose, geo-environmental information was collected and evaluated at two resolution levels, using as basic determinants of the map units the concepts of geomorphic landscape and relief type (Zinck 1974, 1988) at 1:250,000 and 1:100,000 scales respectively. Other environmental components and attributes resulted to be usually well correlated with the geomorphic background.

Geoforms are conspicuous and distinguishable natural terrain tracts that can be recognized by their external attributes at different levels of abstraction. They are comprehensive cartographic units which are usually correlated with other landscape components, some of them being easily observable (e.g. topography, vegetation, rockiness, morphodynamic activity) or less observable (e.g. soil, internal drainage).

The utility of remote sensing for geomorphic survey in such a large, remote, and poorly accessible area as the Caroni river basin was immense, allowing relatively rapid inventory of the natural resources of this vast territory and the monitoring of land use changes. The interpretation of radar (SLAR) and satellite (Landsat) images permitted the identification and mapping of relatively homogeneous geomorphic surfaces used as reference for the cartography of other landscape components, particularly geology, soil, and vegetation cover, as well as for land evaluation, environmental planning, and territorial zoning.

Territorial zoning can be considered as a multidisciplinary and integrated process of partitioning the landscape in areas that show clear spatial arrangement and internal coherence in their components. These spatial units are evaluated in terms of limitations, suitabilities, and use potentials to assess their level of tolerance to human interventions, environmental management, and conservation policies.

In different countries and morphogenic environments, regional planning and environmental studies have been carried out based on geodata (COPLANARH 1973, 1974; MARNR-ORSTOM 1979; Steegmayer and Bustos 1980; MARNR 1983; Zinck 1970; Santosa and Sutikno 2006; Santos et al. 2006; India National Institute of Hydrology 2010; Ferrando and de Lucas 2011; Prakasam and Biswas 2012; Islam et al. 2014). In these studies, terrain features from diverse geo-environments were used for land survey, land zonation, regional and environmental planning proposals.

In this chapter, geomorphic data and information are used as basic input for the zoning projects of the Caroni river basin at the scales of 1:250,000 and 1:100,000. The work reviews and analyses the information generated by CVG TECMIN (Venezuelan Guayana Corporation) and subsequently updated and used by EDELCA (Caroni Electrification Company) to formulate the environmental Master Plan of the

Caroni watershed (CVG EDELCA 2004a). The information provided by the geomorphic units is evaluated and used to prepare a zoning proposal for the environmental planning and management of the basin.

31.4.2 Collecting Geo-environmental Information at 1:250,000 Scale

Zoning units were derived from the geomorphic units generated by the integrated land survey carried out by CVG and CVG TECMIN in the Caroni river basin as part of the Natural Resources Inventory Project for the Guayana Region (PIRNG). Cartographic units were delineated by visual interpretation of radar (SLAR) and satellite images (Landsat), both at 1:250,000 scale, and aerial photographs at 1:100,000 and 1:50,000 scales. Map units at the categorial level of geomorphic landscape were identified using the following attributes: drainage pattern (type, density), local and regional geo-structures (faults, fractures), lineaments, relief, dissection intensity, image texture (greytones, roughness), all derived by interpretation of radar images and aerial photographs (Table 31.1). Black and white multispectral Landsat and false color (bands 4, 5, and 7) images were interpreted for delineating changes in the vegetation cover. Image interpretation was complemented by using aerial photographs at different scales to identify the relief types included in each geomorphic landscape and classify types of vegetation communities according to attributes such as life form, height, density, and intervention degree. These preliminary delineations were verified through multidisciplinary fieldwork, and the field information was correlated for each cartographic unit.

At the 1:250,000 resolution level, cartographic units are basically associations of landscapes and relief types identified and mapped following the criteria included in Table 31.1. Figure 31.2 shows a hilland landscape unit originally delineated on a SLAR image and later updated and validated using a digital elevation model (Instituto Geográfico de Venezuela 2003). Soil is considered one of the physical components of the landscape unit, together with other physical variables. Soils in each landscape unit represent the dominant taxa surveyed in each of the relief types that integrate that landscape unit. The composition of the cartographic units is a combination of soil taxa classified at great group level (Soil Survey Staff 1975) and their phases (soil thickness, rockiness, stoniness, slope, among others). Geomorphic map units and zoning units are combinations of several attributes.

31.4.3 Collecting Geo-environmental Information at 1:100,000 Scale

For the lower Caroni river basin, information was collected at 1:100,000 scale because of more intensive land use, severe land degradation, and the presence of the hydropower plants potentially impacted by inappropriate land use trends.

Table 31.1 Criteria for defining and mapping geomorphic landscape units at 1:250,000 scale

Attribute	Code	Mountain (Mo)	Plateau (Al)	Piedmont (Pm)	Hilland (Lo)	Peneplain (Pe)	Valley (Va)	Plain (Pl)
Altitude (masl)	1	Low	Low (<900)		Low	Low (<200)	Low	Low
	2	Medium	Medium (900–1,600)		Medium	Medium (200–500)	Medium	Medium
	3	High	High (1,600–2,600)		High	High (>500)	High	High
Topography (% slope)	1	Steep (30–60)	Flat (0–4)	Sloping (4–16)	Rolling (4–16)	Undulating (4–8)		
	2	Very steep (>60)	Undulating (4–16)	Mod sloping (16–60)	Hilly (16–30)	Rolling (8–16)		
	3		Steep (16–60)	Strong sloping (>60)	Steeply hilly (30–60)			
	4		Very steep (>60)					
Dissection	1		Slightly dissected	Slightly dissected				
	2		Moderately dissected	Moderately dissected				
	3		Strongly dissected	Strongly dissected				
Geo-substratum	1						Depositional	Depositional
	2						Residual	Residual
	3						Mixed	Mixed
	4						Rocky/stony	Rocky/stony
Drainage	1						Well drained	Well drained
	2						Poorly drained	Poorly drained
	3						Flooded	Flooded

CVG TECMIN (1987) modified by García
Dissection: remaining original terrain surface 1: >75 %, 2: 25–75 %, 3: <25 %
Code numbers indicate classes of attributes used to delineate cartographic units in each geomorphic landscape

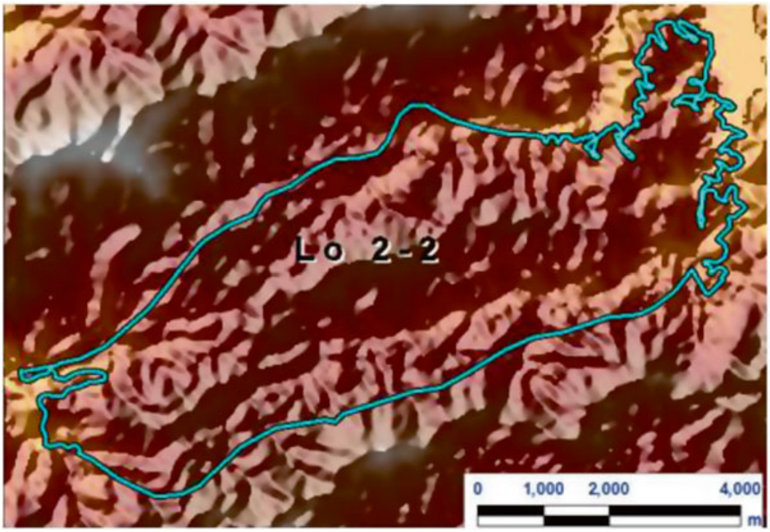

Fig. 31.2 Example of a hilland landscape (Lo 2-2) delineated for zoning at 1:250,000 scale (SLAR + DEM background)

Table 31.2 Examples of geomorphic units used for zoning in the lower Caroni river basin at 1:100,000 scale

Landscape	Relief type	Symbol
Hilland	High elongated hill	La (1–9)
	Medium elongated hill	Lm (1–11)
	Low elongated hill	Lb (1–17)
	Dome/inselberg	Di (1–7)
Peneplain	Medium rounded hill	Cm (1–7)
	Low rounded hill	Cb (1–9)

EDELCA (2004b)

The geomorphic units and types of vegetation cover were delineated by visual interpretation of aerial photographs at 1:50,000 and 1:100,000 scales, bands of radar images (SLAR) at 1:100,000 scale, and satellite images (Landsat) at 1:100,000 and 1:250,000 scales. At this resolution level, soil was the most important map unit component. The composition of the cartographic units is a combination of soil taxa classified at subgroup level (Soil Survey Staff 1993) and their phases (soil thickness, rockiness, stoniness, slope, among others). Table 31.2 shows the relief types mapped to construct the zoning units. The number added to the symbol indicates the different geomorphic units resulting from the combination of the attributes indicated in Table 31.1. For instance, Le 1-3 means “low, elongated hill developed on schist, 8–16 % slope”.

Geomorphic units are combinations of relief types discriminated by criteria such as lithology, morphometric attributes (e.g. slope, relative height, configuration),

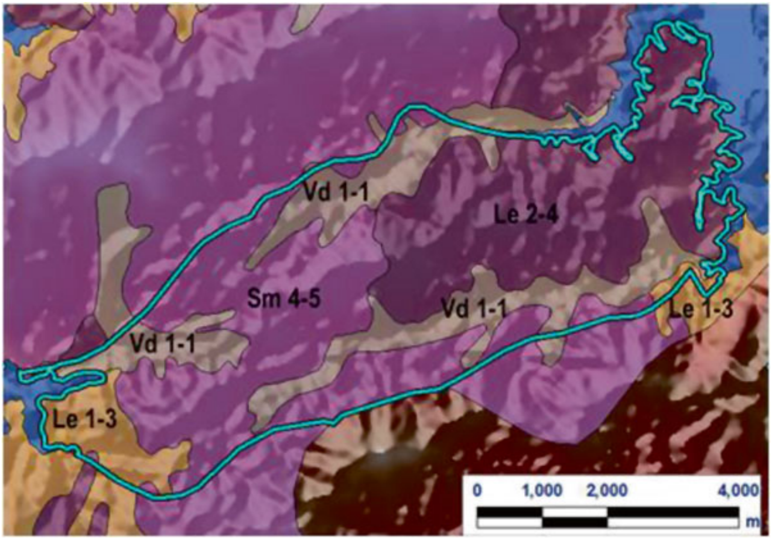

Fig. 31.3 Relief types identified in a hilland landscape (Lo 2-2 in Fig. 31.2) for zoning at 1:100,000 scale (Vd1-1: narrow Holocene floodplain, 0–4 % slope; Sm 4-5: ridges developed on metabasite, slope >30 %; Le 1-3: elongated hills developed on schist, 8–16 % slope; Le 2-4: elongated hills developed on schist, 16–30 % slope) (SLAR + DEM background)

surface features (rockiness, stoniness), and ancillary information particularly vegetation. Soil cover and actual erosion information was collected during fieldwork, when each geomorphic unit was surveyed following the hillslope model, specifically in undulating landscapes (CVG EDELCA 1990; CVG TECMIN 1995). Figure 31.3 shows four map units originally delineated on a SLAR image at 1:100,000 scale and later updated and validated using a digital elevation model (Instituto Geográfico de Venezuela 2003). This allowed disaggregating the landscape unit Lo 2-2 shown in Fig. 31.2. Each of the resulting cartographic units differs from the others in terms of soil cover, topography, limitations, suitabilities, and other land attributes. For the zoning proposal, the original soil classification was updated (Soil Survey Staff 1998).

At this resolution level, a zoning unit can be the summation of several geomorphic units having similar limitations and suitabilities, although they may have developed on different lithological substrata. For that reason, it is common to have different geoforms integrating a particular zoning unit.

31.5 Zoning Proposals

The use of geomorphic units at two levels of spatial resolution allowed the division of the Caroni river basin in zoning units suitable for different land uses and for supporting the creation of a system of protected areas subjected to specific environmental and administration regulations. The resulting territorial organization would be the basis for designing management programs allowing EDELCA and other national and regional public institutions to control the land uses, address the territorial occupation according to land limitations and potentialities, and promote environmental programs that guarantee the conservation of the natural resources and associated ecosystems, and the sustainability of the hydro-energy generation.

Table 31.3 shows the zoning units proposed at regional level (1:250,000). These units are associations of geomorphic landscapes with some similarity in bio-physical attributes, constraints, and potential uses. The geomorphic landscape units allowed the differentiation, description, and evaluation of 19 territorial zoning units at 1:250,000 scale for the whole Caroni river basin. They have been the basis for proposing a system of protected areas called Special Administration Regime Areas according to Venezuelan environmental laws, including two National Parks, one Natural Monument, two Protection Zones, one Public Work Protection Area, and five National Forest Reserves. Within this frame of protected areas there is a wide range of permitted land uses, including agriculture and forest exploitation.

The zoning proposal for the lower Caroni river watershed at 1:100,000 scale divided the territory of about 1268 km^2, representing 1.4 % of the total basin area, into 35 zoning units conformed by combinations of geoforms at the level of relief types. Two categories of areas with special administration regime were recognized: (1) a Public Protection Work Zone composed of 17 zoning units, and (2) the Guri Dam Protection Zone that assembles 18 zoning units including the Caroni River Zone and one Indigenous Community Zone. At this resolution level there is a relatively higher homogeneity in the zoning unit components and attributes. Zoning units have larger land use options because of the presence of soils suitable for multiple uses that have been better discriminated a 1:100,000 scale. At this scale, soil was one the most relevant factor for selecting land uses and determining the final vocation of the zoning units. Table 31.4 shows some zoning units proposed for the lower Caroni watershed. At this level, the geomorphic landscapes mapped at 1:250,000 scale are disaggregated in various relief types (Fig. 31.3) to conform the zoning units. In addition to the general objectives pursued by the territorial zoning for the entire basin, the zoning of the lower watershed focused especially on promoting environmental programs that guarantee the conservation and appropriate use of the land areas adjacent to the hydropower plants.

31.6 Discussion

Geomorphic studies are essential to understand the chorology of the land units as a basis for characterizing and evaluating the natural resources they encompass, with influence on the potential economic and social development of a region. Although geoforms were the most relevant criteria for delineating the zoning units in the study area, information on climate, geology, soils, vegetation, land suitability, land use, actual erosion, among others, was used to characterize and evaluate the land areas

Table 31.3 Zoning proposal at 1:250,000 scale for some areas of the Caroni river basin

Zoning unit	Area km^2	Geomorphic landscape	Soils	Recommended uses
Integral Protection Zone (ZPI)	1094	Plateau, piedmont	Rock outcrops, Udorthents, Kanhapludults, Kanhaplohumults	Protection of unique and fragile ecosystems, biodiversity and genus reservoir, headwaters, riparian forests, wildlife habitats, peatlands and scenic sites. Carbon sinks. Environmental monitoring. Scientific research
Primitive Zone (ZP)	707	Mountain, plateau, piedmont, hilland, and valley	Udorthents, Kanhaplohumults, Haplohumults, Kanhapludults, Paleudults, Rock outcrops	Protection of fragile and high biodiversity forest ecosystems, wildlife habitats, and water sources. Carbon sinks. Ecotourism and research
Integral Protection Zone (ZPI)	2062	Mountain, plateau, hilland, piedmont, peneplain, and valley	Kanhaplohumults, Hapludults, Kanhapludults, Rock outcrops	Protection of unique and fragile ecosystems, biodiversity and genus reservoir, headwaters, riparian forests, wildlife habitats, peatlands and scenic sites. Carbon sinks. Environmental monitoring. Scientific research
Integral Protection Zone (ZPI)	107	Peneplain	Kanhaplohumults, Kandihumults, Kanhaplustults, Kandiustults, Rock outcrops	Protection of unique and fragile ecosystems, biodiversity and genus reservoir, headwaters, riparian forests, wildlife habitats, peatlands and scenic sites. Carbon sinks. Environmental monitoring. Scientific research
Preservation Zone for Intensive Agriculture (ZPAI)	32	Peneplain and hilland	Kanhaplohmults, Kandihumults, Kandiudults	Intensive agriculture, irrigated or rainfed, with soil conservation practices; agroforestry, forestry, and intensive cattle raising

EDELCA (2004a) modified by García

Table 31.4 Examples of proposed zoning units at 1:100,000 scale for the lower Caroni river basin

Landscape unit	Relief type % slope	Zoning unit	Area km^2	Soils	Recommended uses
Peneplain	High elongated hills and low rounded hills; 4–8	Z2	38,698	Udic Kanhaplustults, Lithic Ustorthents; high rockiness and stoniness	Protection of stream headwaters, high biodiversity forest lands and wildlife habitats
Hilland and peneplain	High and low elongated hills and low rounded hills; 4–8	Z3	106,503	Udic Kanhaplustults, Typic Haplohumults, Kanhaplic and Udic Kandiustalfs; moderate rockiness	Cattle raising, agroforestry and locally forestry and intensive agriculture
Hilland	High elongated hills; >30	Z5	12,009	Lithic Kanhaplohumults, Kanhaplic Haplustalfs, Lithic Ustorthents, moderate to high rock outcrops	Protection of stream headwaters, high biodiversity forest lands and wildlife habitats
Hilland	Medium elongated hills; 16–30	Z9	22,805	Kanhaplic Haplustalfs, Udic Kanhaplustults, Ustic Kanhaplohumults; low to moderate rockiness	Cattle rising, agroforestry and forestry
Peneplain	Medium and low rounded hills; glacis; 4–8	A2	50,193	Typic and Lithic Kanhaplustults, Typic and Arenic Kandiustults, Lithic Ustorthents, high rockiness	Protection, Locally, agroforestry and forestry
Peneplain and hilland	Medium rounded hills and low elongated hills; 8–16	A6	161,215	Lithic Ustorthents, Typic and Lithic Kanhaplustults, Typic Kandiustults; low rockiness	Protection, Locally, agro forestry and forestry
Hilland	Medium and low elongated hills; 16–30	A8	20,714	Lithic Ustorthents, Typic and Lithic Kanhaplustults, high rockiness	Protection of stream headwaters, high biodiversity forest lands and wildlife habitats

EDELCA (2004b) modified by García
Z2, Z3, Z5, and Z9 represent zoning units mapped in the Protector Zone of the Guri Dam; A2, A6, and A8 are zoning units mapped in the Public Work Protection Zone of the hydropower plants downstream the Guri dam

included in each zoning unit. In all zoning areas, clear soil-geoform relationships were observed whatever the scale. Soil forming factors, pedogenic processes, and land suitabilities were identified in observable spatial limits corresponding to the boundaries of the zoning units. These land tracts possess some homogeneity in terms of characteristics, properties, conditions, and expected behavior in response to human activities. What is considered homogeneous depends on the use purpose, but generally each zone contains a mixture of environmental elements such as lithology, relief, slope, soilscape, vegetation, and other features, that allows for multi-purpose uses.

At 1:250,000 scale, attributes belonging to the geomorphic surfaces such as, for example, topography and level of dissection can be relevant to decide about land use options in large, relatively pristine, highly fragile, and poorly accessible areas like de Caroni river basin where the offer of land suitable for multiple uses is limited. At this resolution level, zoning for land use planning can be preliminarily supported by geodata provided by the geomorphic units together with some ancillary information (e.g. vegetation cover). In this situation, geomorphic information is very cost-effective, especially when the general objective is the protection of natural resources, the management of national parks, the control of areas with strong use restrictions or vulnerable to geo-hazards, among others. At 1:100,000 scale, the potential use of the zoning units is mostly based on soil suitability that sets the recommended uses of the different zones. In the Caroni case study, the territorial zoning generated on the basis of geopedologic information can be considered acceptable for land use planning purposes and for defining environmental policies and priority actions geared towards the protection of this strategic territory.

The mapping of geomorphic surfaces provides reliable spatial information for generating a variety of thematic maps. Cartographic units based on geomorphic criteria facilitate the landscape reading and understanding by non-specialists and planners. They provide means for correlating known and unknown areas, thus permitting terrain conditions to be reasonably predicted in the case of areas devoid of environmental information.

31.7 Conclusions

The morphometric elements of the geoforms are the result of morphogenic and morphodynamic forces acting on a particular geological substratum (rock or saprolite), under specific conditions and combinations of climate and vegetation cover, during a particular span of time. This is the main assumption to support using the geomorphic surface as a relevant and relatively stable source of data and information to map zoning units for environmental and land use planning purposes.

The geomorphic approach, in which the form and spatial distribution of terrain features are analyzed in an integrated manner, relates recurrent geomorphic surface patterns expressed by the interaction of environmental components, allowing the partitioning of the landscape into relatively homogeneous land units. Geoform classification and characterization may be used as part of the land-use planning decision making. In the examples of zoning presented here, classification schemes were based on knowledge of the bedrock geology, topography, surface formations, soils, and ancillary information such as vegetation cover and climate. Most of the information for geoform classification was derived from remote-sensed documents and complemented by low intensity fieldwork. From a practical point of view, territorial zoning based on geomorphic surfaces is a very useful approach in large, pristine, and remote areas like de Caroni river basin. It allows delineating land units for zoning objectives. At 1:250,000 scale where the key purpose may be formulating conservation proposals, as in the case of National Parks and Natural Monuments, land units founded on geomorphic surfaces can contribute to identify fragile areas susceptible to erosion, guide integrated and higher resolution land inventories, and formulate research projects, monitoring environmental programs, and preliminary regulations. At 1:100,000 scale where land use decisions are related to multiple uses, more intensive interventions, and higher risk of environmental impacts, zoning based only on geomorphic units introduces uncertainty because decisions on land use and planning require knowledge of other use determining factors such as soils. Geoforms, regardless of their abstraction level, are not only soilscape units; they are also useful multi-attribute territorial units for environmental planning and other land use decisions. Combining geoform and soil information, as it is intended in the geopedologic approach, offers a balanced way of tackling the territorial zoning issue.

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