

THE GEOMORPHOLOGY OF ANGRA DOS REIS AND PARATY MUNICIPALITIES, SOUTHERN RIO DE JANEIRO STATE

A Geomorfologia dos Municípios de Angra dos Reis e Paraty, Sul do Estado do Rio de Janeiro.

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ABSTRACT:

This paper analyses the geomorphology of Angra dos Reis and Paraty municipalities, Southern Rio de Janeiro State, regarding both environmental and anthropogenic characteristics. Several analytical procedures were adopted. These included bibliographic and cartographic surveys; geomorphological survey (with the aid of Rapideye images from 2012, at 1:50,000 scale); the construction of altitude class maps, cross-section diagrams and slope angle maps (using the Shuttle Radar Topography Mission (SRTM) at a spatial resolution of 90 m). The two contiguous municipalities are very similar in terms of environmental characteristics (i.e. geological formation, geomorphological features, soils, climate and vegetation). Serra do Mar mountain range has two distinct morphological units: (1) the Crystalline Atlantic Plateau, related to tectonic activity within the Serra do Mar, and (2) Paraíba do Sul Valley, related to tectonic episodes within the Serra do Mar and Serra da Mantiqueira. The other geomorphological units which constitute part of Paraty and Angra dos Reis are the fluvial terraces and fluvio-marine plains, and the main rivers, such as the Mateus Nunes and Perequê Açu (Paraty) and Mambucaba and Bracuhy (Angra dos Reis). The presence of four Conservation Units is another major factor promoting sustainable development in the study area. These Units are under pressure and, consequently, experience many forms of land degradation. Therefore, we hope to demonstrate the importance of understanding geomorphology for the sustainable development of these two municipalities.

Key-words: Geomorphology; Serra do Mar mountain range; Conservation Units.

RESUMO:

O objetivo deste artigo é analisar a geomorfologia dos municípios de Angra dos Reis e Paraty, localizados na porção sul do estado do Rio de Janeiro, considerando vários aspectos ambientais, juntamente com a influência antrópica na paisagem. Para a análise da geomorfologia dos municípios de Angra dos Reis e Paraty, utilizaram-se os seguintes materiais e métodos: levantamento bibliográfico e cartográfico; levantamento das características geomorfológicas, com auxílio das imagens RapidEye, ano de 2012, com escala de 1:50.000; elaboração do mapa hipsométrico, perfis topográficos, mapas de declividade a partir da Missão Topográfica do Radar Shuttle (SRTM), com resolução espacial de 90 m. Devido a proximidade geográfica, os dois municípios são bem semelhantes em termos de características ambientais (como por exemplo, formação geológica, características geomorfológicas, solos, clima e vegetação). No tocante a geomorfologia da área de estudo, evidencia-se que a Serra do Mar apresenta duas unidades morfológicas distintas: 1. O Planalto Cristalino Atlântico, que é considerado parte da Serra do Mar, e 2. O Vale do Paraíba do Sul, relacionado a episódios tectônicos nas Serras do Mar e Mantiqueira. As outras unidades geomorfológicas presentes nos municípios de Paraty e Angra dos Reis são os terraços fluviais e planícies flúvio-marinhas, que são encontrados ao longo da costa, e nos principais rios, como nos rios Mateus Nunes e Perequê Açu (Paraty) e Mambucaba e Bracuhy (Angra dos Reis). A presença de quatro Unidades de Conservação é outro fator importante que promove o desenvolvimento sustentável na área de estudo. Estas unidades sofrem pressões antrópicas e, conseqüentemente, experimentam várias formas de degradação do solo. Portanto, espera-se contribuir para a construção do conhecimento geomorfológico e a sua respectiva importância para o desenvolvimento sustentável desses dois municípios.

Palavras-chave: Geomorfologia; Serra do Mar; Unidades de Conservação.

1. Introduction

Selected environmental attributes of the two studied municipalities are considered, including climate, soils and vegetation. Patterns of human settlement are also reviewed, as they have major environmental impacts, which have increased in magnitude during recent decades. Rapideye (1:50,000 scale) satellite images from 2012 have helped the development of maps and analyses of the main geomorphological features. Geomorphological survey, with the aid of satellite images, can help us to identify environmental hazard zones (Thouret, 2010).

Angra dos Reis (23°00'24"S, 44°19'05"W) and Paraty (23°13'21"S, 44°42'50") are located in southern Rio de Janeiro State (**Figure 1**), with a total population of 169,511 inhabitants (Angra dos Reis) and 37,533 in Paraty (IBGE, Brazilian Geographical and Statistics Institute, 2010). Angra dos Reis was founded

in 1502, with a total area of 825 km² and Paraty, which is a colonial city, was founded in 1667, with a total area of 925 km². They are considered old cities by Brazilian standards. Throughout these centuries different economic cycles have played important roles in causing deforestation on the slopes and plains, as well as creating immense environmental impacts.

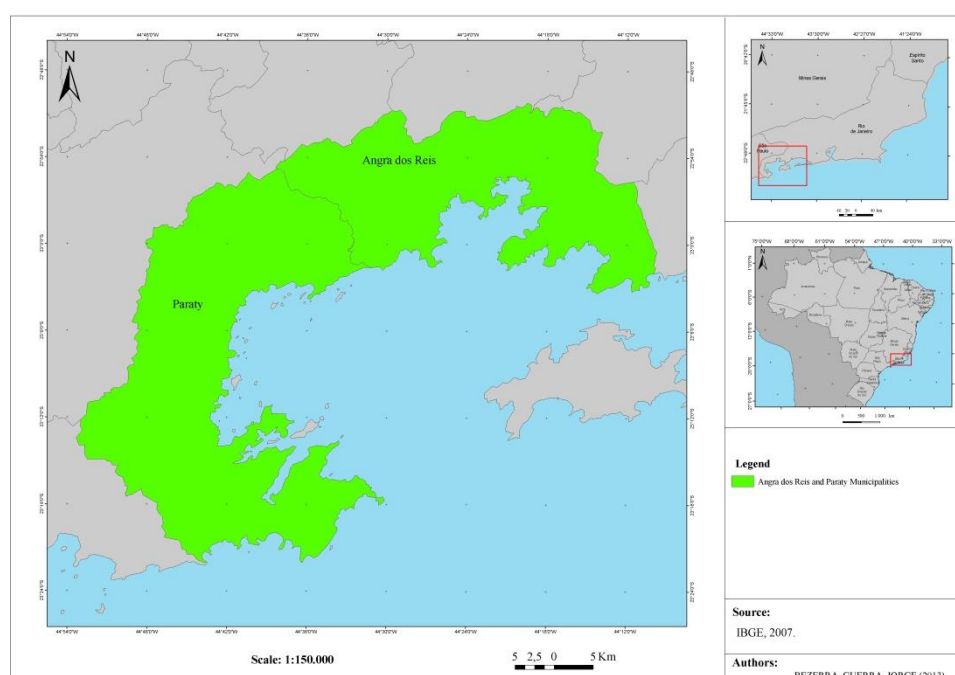


Figure 1: Location of Angra dos Reis and Paraty municipalities.

The two contiguous municipalities are very similar in terms of environmental characteristics (i.e. geological formation, geomorphological features, soils, climate and vegetation). Soils are mainly Inceptisols, which occupy nearly 70% of the total area, distributed widely throughout the two municipalities, followed by Oxisols (~10%). Both of these soil types are especially frequent on upland areas. Another significant soil type is Entisols, which occur in both municipalities. On the coast, there are some mangrove soils and sand bars.

Proximity to the Atlantic Ocean plays a very important climatic role, together with the Serra do Mar mountain range, which presents a barrier to moist polar fronts and thus induces intense rainstorms, especially during summer. In some years, these heavy thunderstorms, combined with poor land management, have caused dozens of deaths, especially in Angra dos Reis. The hillslopes facing the Ocean tend to be more humid, due to orographic rains, whereas hillslopes situated

in the lee of the very high watersheds, tend to be drier, because these air masses lose moisture as they advect over the mountain range. Using yearly rain data from INEA (2012), it is evident that coastal areas, both in Angra dos Reis and Paraty, tend to be more humid, with yearly averages between 2,000-2,300 mm. On the highest parts of Serra do Mar mountain range, yearly rainfall totals are 1,400-1,700 mm. These differences stress the importance of the high and steep hillslopes. Although only a few kilometres from the coast to the interior of these municipalities, major mesoscale climatic differences exist.

With the construction of the *Rio-Santos* Highway (BR101) during the 1970s, access to this region became much easier, which accelerated urbanization and associated vegetation clearance. Therefore, there is much pressure on remaining forest fragments from new developments (condominiums, hotels and seaside resorts). Despite the presence of Protected Areas, such as Serra da Bocaina National Park, Cairuçu Protected Area, Juatinga Ecological Area and Mambucaba State Park, most of the original vegetation has been cleared since the beginning of Brazilian colonization by Portuguese settlers in 1500. Tropical forest remains today only on very steep slopes and in some parts of the Protected Areas. There are mangroves in some coastal areas, along with sand bar vegetation and some typical species on the rocky slopes of the Serra do Mar Mountains (Rio de Janeiro State Secretary of the Environment, 2011).

The geological characteristics of Angra dos Reis and Paraty are similar. In both municipalities, ~50% of their rocks are granitoids, ~30% gneisses, with minor proportions of migmatites, granites and Holocene sediments. Although granitoids are dominant, gneisses and granites are present in several parts of the Serra do Mar Mountains and they are usually folded and faulted. Holocene sediments are mainly distributed on the coast, represented by beach sediments and on the fluvial plains, which stretch from the footslopes of the Serra do Mar to the Ocean. These geological features play very important roles in local geomorphology, in terms both of landforms and drainage basin characteristics.

In order to understand the geomorphology of Angra dos Reis and Paraty we must consider several environmental features together with anthropogenic imprints, especially planning. Inadequate planning may have contributed to catastrophic and fatal mass movements and major floods, which have occurred in recent decades, especially in Angra dos Reis. Paraty has suffered heavy floods,

due to its location on the coastal plains near the mountains. The lack of urban planning, together with irresponsible local authorities, must be considered, when one tries to understand the combination of physical and human factors. These authorities should adhere to the advice of Van Western (2010) that hazardous events cannot be ignored and, consequently, one must include the concepts of disaster risk management into spatial planning. Otherwise, whenever concentrated and heavy rainfall events occur, it is likely to cause many deaths and property damage. Contributory factors in the two municipalities include very steep slopes, vegetation clearance, the type and form of urban infrastructure, inadequate and poorly designed rainfall drainage and sewage systems and unpaved roads.

This paper discusses these issues, summarizes the local geomorphology and advocates concepts of sustainable development. Geomorphology can assist us, as it describes, analyses and predicts relief evolution. Thus, geomorphology may help us investigate natural hazards and risk assessment and so contribute to risk reduction (Hufschmidt and Glade, 2010).

2. Materials and Methods

In order to analyse the geomorphology of Angra dos Reis and Paraty municipalities, the following materials and methods have been used:

1. Bibliographic and cartographic surveys.
2. Geomorphological survey, with the aid of Rapideye satellite images from 2012, at 1:50,000 scale; combined with field work in Angra dos Reis and Paraty municipalities, in order to identify geomorphological features and environmental hazard zones.
3. Altitude class maps, cross-section diagrams and slope angle maps were constructed using a Digital Elevation Model (DEM) using data gathered from the Shuttle Radar Topography Mission (SRTM) at a spatial resolution of 90 m. These maps were processed using GIS (Geographic Information System) software.

3. The Geomorphology of the municipalities

Several geomorphologists and geologists have investigated the origin and evolution of the Serra do Mar Mountains, which form the main relief feature of Angra dos Reis (**Figure 2**) and Paraty. The coastal plain is only ≤ 30 km wide and extends from the Ocean to the mountains. The coastal plains form important, but secondary, landforms. The south-eastern relief differs from other Brazilian regions, due to its morphological diversity, resulting from tectonic uplift, faulting and fracturing, which have affected the Brazilian shield since the Mesozoic period. The present humid tropical climate also fundamentally affects the morphoclimatic domain (Moreira and Camelier, 1977).

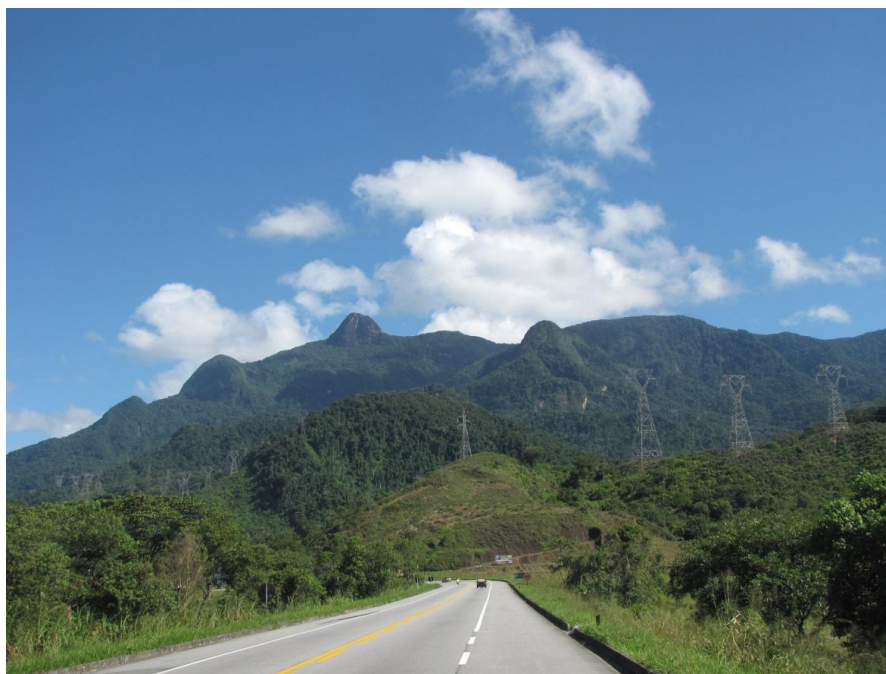


Figure 2: View from BR-101. Frade Peak (1,560 metres above sea-level) is in the background. It is the second highest peak in Angra dos Reis Municipality. Photo Antonio Jose Teixeira Guerra.

Freitas (1951) discussed the tectonic origin of the mountains, considering it as a huge tectonic “wall,” resulting from uplift of the crystalline shield. In some parts, uplift was without crust rupture and, therefore, the structure retains monocline characteristics. These concepts have been developed by Rich (1953) and Rosier (1957), who interpreted the Serra do Mar Mountains as a monocline produced by uplift, followed by local faulting and folding. These tectonic processes are accompanied by soil erosion.

Differential erosion on the crystalline shield, together with faulting and folding, helps explain the topographic diversity of the Serra do Mar Mountains. Almeida (1953) and Birot (1960) explained the rectilinear sectors of the relief, with their SW-NE orientation, as fracture lines explored by thalwegs, rather than fault scarps.

It is difficult to reconstruct the geomorphological evolution of the Serra do Mar Mountains. Analysis of cyclic denudation suggests intense faulting occurred during the Mid-Tertiary (King, 1956). Fault movements have continued to the present. This agrees with Dantas (2001), who suggested that tectonic processes uplifted some plateau remnants from Late Cenozoic planation surfaces, such as the Bocaina Plateau.

The Serra do Mar Mountains have two distinct morphological units: (1) the Crystalline Atlantic Plateau, related to tectonic activity within the Serra do Mar, and (2) the Paraíba do Sul Valley, related to tectonic episodes within Serra do Mar and Serra da Mantiqueira.

The Serra do Mar Mountains form the eastern side of the crystalline shield, uplifted to altitudes which generally range between 800-1,200 m. There are higher surfaces from 1,200-1,800 m, and the mountain peaks exceed 2,000 m. Its main characteristic is that of a huge barrier, approximately parallel to the Atlantic Ocean. It presents different features along its trajectory, including large and high mountain scarps, especially in Paraty Municipality. Where the mountains are further from the Ocean, there are fluvio-marine plains. The main towns and settlements in both municipalities are concentrated on these plains, which makes it easier for construction and urbanization. Several districts, mainly in Angra dos Reis, are located on the hills, which is hazardous for the resident population. Thus, there are many hazardous areas, due to a combination of environmental conditions and the nature of urban settlement on the slopes.

Serra do Mar represents a huge watershed between the short rivers, which flow to the Ocean, and the longer rivers, which flow inland towards Paraíba do Sul River, between Serra do Mar and Serra da Mantiqueira. A small portion of Angra dos Reis and Paraty territory is in the Paraíba do Sul Valley, since it is situated landward of the Serra do Mar mountain interfluvium. Thus, the river interfluvium is not used as the administrative border between these and other municipalities, as often is the case in Brazil.

Taking into account the long series of research investigations conducted into the relief of Paraty and Angra dos Reis by several geomorphologists and geologists, it is possible to suggest a characterization which defines two great relief domains. These are: (1) the morpho-structural domain of the Atlantic Plateau and (2) the morpho-structural domain of the Cenozoic tectonic depressions (Silva, 2009). Besides those two major domains, there are also fluvial terraces near the coast. These belong to the drainage basins located on the fluvio-marine plains (with some small hills). Examples include the Mambucada drainage basin in Angra dos Reis, and the Perequê-Açu drainage basin in Paraty.

The morpho-structural domain of the Atlantic Plateau is situated in south-west Rio de Janeiro State, mainly in Paraty, heading towards São Paulo State, on the border with Rio de Janeiro. Here there is the large scarp of Serra do Mar, which is locally known as Serra da Bocaina (**Figure 3**). The scarp is characterized by high altitude, steep slopes and hilly relief, with rounded tops. The scarp is limited in the south by fluvio-marine plains, both in Paraty and Angra dos Reis (Silva, 2009). This domain has altitudes from 400-2,100 m, with a general E-W orientation, and some segments are NE-SW. The scarp decreases in altitude towards the Paraíba do Sul River.



Figure 3: View from Paraty City. Serra da Bocaina National Park is in the background, where we can see Macela Peak (1,840 m). On the top of this peak one has a 360° view of Cunha Municipality (São Paulo State) and on a clear day it is possible to see Paraty and Ilha Grande Bay. Photo: Maria do Carmo Oliveira Jorge.

The morpho-structural domain of the Cenozoic tectonic depressions is characterized by pre-Cambrian metamorphic rocks, dominated by gneisses with banded structures. The main features are a set of NE-SW oriented pre-Cambrian faults. The segment with the E-W orientation is characterized as a large regional compartment, with altitudes between 400-600 m, decreasing in altitude towards the Paraíba do Sul River. The southern limit of this domain is represented by the Serra da Bocaina Mountains, with an altitude difference between 500-600 m. Although this domain has a general E-W orientation, this large compartment is subdivided into smaller units with NE-SW orientations, including a set of dissected hills (Silva, 2009). The other geomorphological units which constitute part of Paraty and Angra dos Reis are the fluvial terraces and fluvio-marine plains and the main rivers, such as Mateus Nunes and Perequê Açu (Paraty) and Mambucaba and Bracuhy (Angra dos Reis) (**Figure 4**).



Figure 4: River Mambucaba, whose springs are situated in Serra da Bocaina National Park; the river forms the border between Angra dos Reis and Paraty municipalities. Photo: Antonio Jose Teixeira Guerra.

The rivers are separated by coastal hills, which represent the interfluves of these drainage basins. The fluvio-marine plains stretch along the coast, between the Ocean and the footslope of the Serra do Mar Mountains, and they interpenetrate the estuaries, lakes and beaches, along the plains. They occupy

most of the plains and the dominant geomorphological process is deposition. The topography is subdued and most slopes are $<5^{\circ}$. Thus, there is very little erosion. The beaches, mangroves and sand bars form part of this geomorphological unit (**Figure 5**). Some of the most famous and beautiful beaches in these two municipalities are: Tarituba and São Gonçalo (Paraty) and Praia do Frade and Mambucaba (Angra dos Reis).

Morphometric data were extracted from the Digital Elevation Model (DEM) using data gathered from the Shuttle Radar Topography Mission (SRTM) at a spatial resolution of 90 m. The data were used for spatial analysis, using GIS (Geographic Information System) software to acquire the information necessary for the geomorphological analysis.



Figure 5. Meio beach (Trindade District, Paraty Municipality). Photo: Maria do Carmo Oliveira Jorge.

The highest slope angles in Angra dos Reis and Paraty municipalities are located on the edges of the Bocaina Plateau, specifically in the Serra do Mar landscape, and are $\leq 90^{\circ}$, being characterized by rocky outcrops, with talus deposits on lower slopes (**Figure 6**). The different landforms/geomorphic units of the study area include hillslopes associated with higher slope angles located mainly in the Serra do Mar Mountains, towards the coastal plain. *Mar de Morros*

(Sea of Hills) is an important geomorphological unit described by Ab'Saber (1966) and is located on the steeply sloping highlands of the Bocaina Plateau. These areas are protected by environmental legislation, represented by the Permanent Preservation Areas (APP), as well as the National Park status of the Serra da Bocaina. The steep relief associated with deforestation in both municipalities triggers mass movements, intensified by high rainfall. Gentler slopes are found on the Bocaina Plateau and the coastal plain. The river systems drain the mountains, cross the coastal plain and discharge into the Atlantic Ocean (**Table 1**).

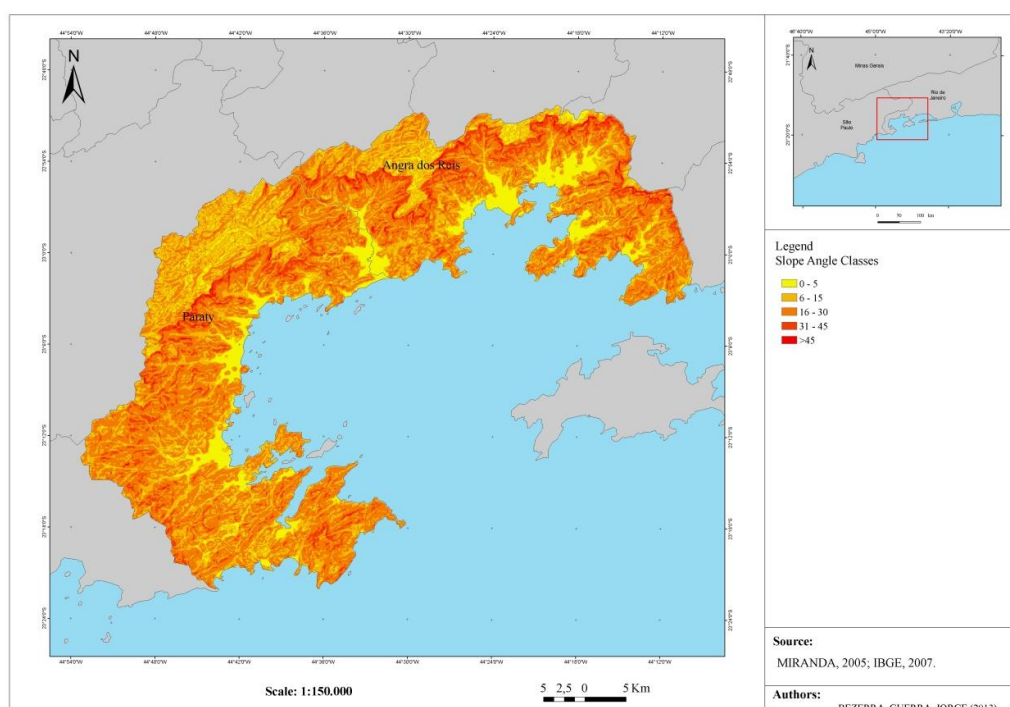


Figure 6: Slope angle map of Angra dos Reis and Paraty municipalities.

Table 1: Slope angle classes.

Slope angle classes (Degrees)	Percentage of area
0-5	11.60
6-15	30.44
16-30	47.37
31-45	9.93
>45	0.66

Flat to gently sloping areas (0-15°) total 42.04% of the area. Prolonged fluvial action has sculptured the coastal interfluves at the river mouth, resulting in gentle slopes. These gentle slopes were selected as the locations of the cities. The steeper slopes of the coastal plain have not impeded either illegal land

settlements or extensive agriculture. The steeper slope angle classes are between 16-45° and total 57.30% of the area, which correspond to the steep mountain slopes. Most mass movements occur on these slopes. The type of urban settlement on these steep slopes has been responsible for many landslides, especially in recent years, causing the death of dozens of people and severe material losses (Figure 7, Table 2).

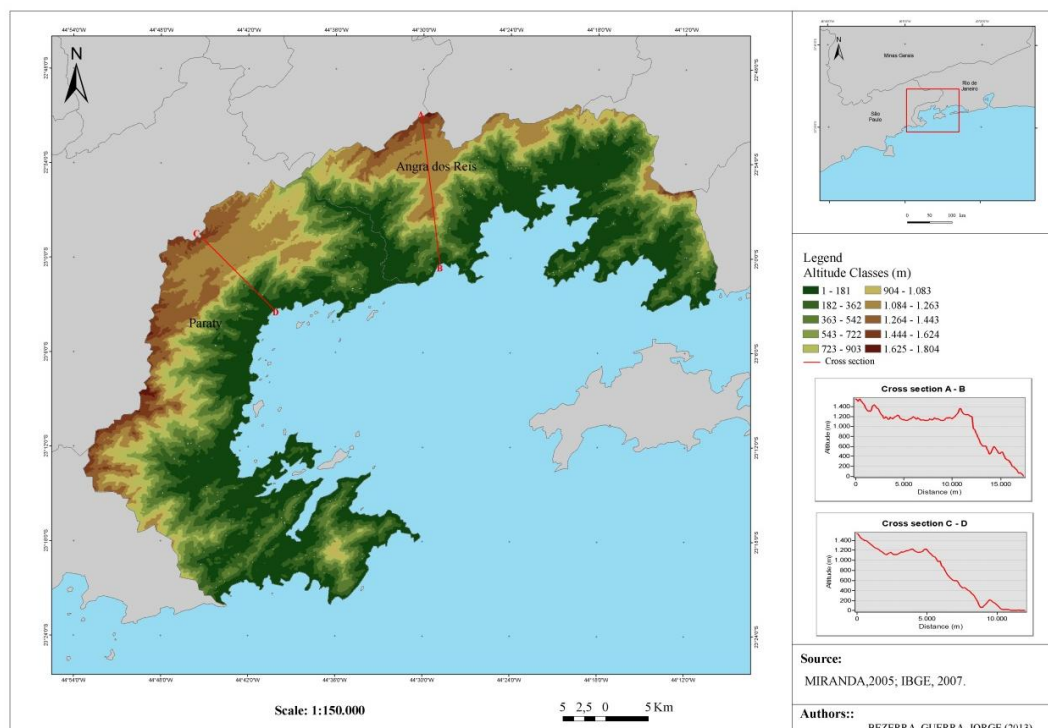


Figure 7: Altitude class map and cross-section diagrams of Angra dos Reis and Paraty municipalities.

Table 2: Altitude classes.

Altitude classes (metres)	Percentage of area
1-181	30.67
182-362	17.32
363-542	12.07
543-722	7.64
723-902	5.71
903-1082	6.55
1083-1263	12.16
1264-1443	5.96
1444-1623	1.79
1624-1804	0.13

According to SRTM data, the hypsometric values of the study area range from 1-1804 m. The highest elevations in the two municipalities are on the border with São Paulo State, in the Bocaina Plateau geomorphological unit, with an average elevation >1,000 m. The lowest elevations are on the coastal plain, ranging from 1-181 m altitude, which corresponds to 30.67% of the total area (**Table 2**). The coastal plain is mainly covered by Quaternary sediments. Table 2 shows that altitudes are generally normally distributed within the 10 classes, with the exception of the lowest class. The next class (182-362 m) corresponds to 17.32% and is mainly situated on the lower mountain slopes. The higher altitude classes, from 1083-1804 m, correspond to the Bocaina Plateau surface. Although the altitudes are high, slope angles tend to be gentle.

The two cross-section diagrams (**Figure 7**) were constructed using a DEM of the municipalities. The cross-sections start on the Bocaina Plateau, cross the Serra do Mar Mountains and terminate on the coastal plain. The diagrams show a predominance of convex and rectilinear slope forms, which implies a tendency for dispersion in ground-water flows. They also demonstrate slope ruptures (knick-points), especially in the transition between the Bocaina Plateau and Serra do Mar. They both show high slope angles, especially on the Serra do Mar Mountains, which emphasizes the risk of mass movements.

4. Geomorphology and Planning

The spatial distribution of morphological features, documented through geomorphological maps, is a very important source of environmental information (Cooke and Doornkamp, 1991). These maps are essential tools for engineers, planners, geographers and other professionals who work with land use, land management and environmental issues. The understanding of landscape evolution and its interaction with geomorphological issues are important in understanding environmental problems and thus making appropriate planning interventions (Modenesi-Gauttieri and Hiruma, 2004).

Environmental geomorphology aims at understanding relationships between urban, rural and planning issues and discussing applications of geomorphological knowledge. Relevant topics include tourism, sewage systems, conservation units, coastal areas, land degradation assessment, mass movements, soil erosion,

floods, energy transmission lines and land rehabilitation (Guerra and Marçal, 2012). In discussing technical issues, planning regulations and institutional frameworks, we need to consider the concepts of risk and sustainability. However, in many countries, including Brazil, sustainable development has only become a focus of public policy over the last 10-20 years (Higgitt, 2010).

The study area has several conservation units, which should be better protected and maintained by local authorities and State and Federal government. The structure of government administration means some of these protected areas come under different regulations. Several scientific surveys have shown the importance of biological diversity, in terms of increasing ecosystem resilience to degradation (Castro Jr. *et al.*, 2013). These authors also identified the risks of reducing the functional diversity of ecosystems, which could destabilize them, at both global and local scales.

There are four conservation units in this area: Serra da Bocaina National Park, Cairuçu Protected Area, Juatinga Ecological Area and Mambucaba State Park. In each case, some of their territory is degraded. The geomorphological survey aims at assisting the understanding of the different types of degradation, identifying appropriate preventative measures and advising rehabilitation strategies.

These four conservation units are part of the Atlantic Forest Biosphere Reserve, which are part of a world network of protected areas. Management policy aims at the maintenance of conservation, through a continuous ecological corridor along the Brazilian coast and unifying several forest fragments. Geomorphological knowledge is fundamental to assess environmental damage inside these conservation units, by surveying vulnerable areas and contributing to actions which help mitigate damage to impacted areas and maintain their biodiversity.

Bocaina National Park is in a good state of conservation, because it is surrounded by several municipalities, both in São Paulo State (Ubatuba, Cunha, Areias, São José do Barreiro and Bananal) and Rio de Janeiro State (Angra dos Reis and Paraty) and is thus subject to multiple legislative instruments. The Park contains several geomorphological units, from the coastal plains to the steep upland slopes of the Serra da Bocaina Mountains. Different land use types inside this Park and its surroundings have caused environmental impacts, which can be assessed using local geomorphological knowledge. Gullies and mass movement

scars are evident, both inside and outside the Park. According to Brazilian legislation, minimal human activity is allowed inside a National Park. However, rangelands exist inside the conservation area.

Cairuçu Protected Area (Paraty) has a peculiar legal status, due to spatial overlay with Bocaina National Park. This makes administration even more difficult, since there are two legal statuses for the same protected area. According to Brazilian legislation, within Protected Areas (*Área de Proteção Ambiental* (APA)), it is possible to have some limited economic activity. This must be permitted by the manager of the Protected Area and the decision should be based on the compatibility of the proposed activities with sustainable development. However, unfortunately, this rarely occurs. Therefore, it is common for there to be different negative environmental impacts, including soil erosion, mass movements and river siltation.

Mambucaba State Park (Angra) is the most recent of the four conservation units. According to Brazilian legislation, in theory, the Park should have a similar high level of environmental protection as the National Parks. For effective environmental protection, farmers and other landowners should be subsidized by the government to cease their economic activities and move outside the Park. However, this does not occur and negative environmental impacts ensue. In Mambucaba State Park these negative impacts include vegetation clearance, soil erosion, mass movements and land degradation.

Juatinga Ecological Area (Paraty) is the smallest conservation unit in the study area, covering only 80 km², and overlays with the Cairuçu Protected Area. It was created in 1992, with the aim of conserving different ecosystems, especially sand-bar vegetation, mangrove and Atlantic Forest. The area is occupied by 12 small groups of traditional population, called *caiçaras*, who survive on subsistence agriculture, fishing and, more recently, tourism. They travel using narrow tracks and boats. These traditional communities are well preserved, compared with those in the other three areas.

One should expect good environmental health due to the presence of conservation units. However, land degradation is encountered within and on the periphery of these protected areas. Due to a combination of factors, there are different types of degradation. Causal factors include deforestation, steep slopes, shallow soils and intense summer rainstorms (between December-March). Land

mismanagement and lack of public empowerment also cause degradation within the conservation units.

Outside the conservation units, local authorities almost always turn a 'blind eye' to the type of settlement and, consequently, mass movements often occur. These cause many deaths and damage to property (houses, blocks of flats, streets and highway BR101, which links Rio de Janeiro City to Paraty, via Angra dos Reis). Thus, the highway has great importance for tourism in the two municipalities. Moreover, because there is a nuclear power plant in Angra dos Reis, the highway is the main escape route in the event of an accident at the station. The highway was mostly built on talus deposits of the Serra do Mar Mountains. This has caused slope disequilibrium, which promotes different types of mass movement during rainstorms. This occurs both in Paraty and Angra dos Reis, but mainly in Angra, where nearly 100% of BR-101 is located on talus deposits, without the necessary civil engineering works to protect the highway against catastrophic events. Some remedial works are sometimes carried out after mass movements occur.

In March 2008, very heavy rainstorms (~200 mm, in <24 hours), caused mass movements on the highway between Angra dos Reis and Paraty, closing traffic in one lane. This recurred in April 2008, closing a lane very close to the nuclear station. On 1 January 2010, 52 people died in Angra dos Reis, due to slope instability induced by ~200 mm of rain in <24 hours. The victims were living on steep ($\geq 40^\circ$) poorly vegetated deforested slopes. The movement of slope boulders proved particularly damaging. Moreover, there was deficient urban planning (i.e. lack of paved roads, sewage and rain water systems), which increased the risk of mass movements (Silva and Botelho, in press).

Issues related to tourism must be addressed, especially the adoption of ecological and sustainable tourism, which has not been generally adopted in the two municipalities. Furthermore, there is insufficient attention to local communities. Groups have been devastated by the development of industry and tourism. These include Indians, *quilombolas* (the descendants of slaves) and *caiçaras* (a tribe of coastal inhabitants, who used to live from fishing). Later, the term *caiçara* came to designate cultural items of the Brazilian coast, more precisely from the southern regions. The *caiçara* communities originated from the 16th century from the mixture between white people of Portuguese origin and the Indians of the Brazilian

coast. Tourism in the two municipalities tends to cause environmental damage and generally ignores the target of sustainable development (**Figure 8**).



Figure 8: Grataú Farm, located adjacent to Frade District, in Angra dos Reis Municipality. The 19th century farm was built between the plains and Paraíba do Sul Valley, where there used to be trails linking Paraíba do Sul Valley to Frade Port. On the trails, mules transported coffee to be exported to Europe. The same mules transported goods brought from Europe to Paraíba do Sul Valley and hundreds of slaves to work on the coffee plantations. Photo: Antonio José Teixeira Guerra.

Hunting, fishing and bird catching are some of the activities which cause environmental impacts in the two municipalities. Road and house construction also have marked environmental impacts, especially due to the steep slopes, shallow soils and high rainfall amounts. Linked to these building activities, there is timber exploitation from the forest, which is often illegal. There is also rock and soil exploitation for building purposes. Often these resources are illegally extracted within the conservation units.

Although tourism generates jobs and income to Angra dos Reis and Paraty, this activity can cause land degradation, water pollution, deforestation and negative socio-environmental impacts. Often the *caíçaras* and *quilombolas* are

expelled from their lands, and many of them live in *favelas*, which causes even more land degradation. Unfortunately, local authorities take little or no remedial action (Aranha and Guerra, 2011).

Different techniques can be used to stop soil erosion and mass movements, which are the main forms of local land degradation. Nevertheless, the ideal situation would be to work preventively, to avoid such damage. But once damage occurs, there should be a combination of traditional civil engineering measures, such as the construction of concrete walls on slopes affected by mass movements, together with bioengineering techniques, using natural materials from the forest and the local knowledge of the *caiçaras* and *quilombolas*. The indigenous knowledge of these peoples can help arrest damage and rehabilitate affected areas.

The scenic touristic beaches of Paraty and Angra dos Reis attract economic activities, which generate income and employment. However, there are often negative environmental impacts caused by urban construction near the beaches. These activities cause much destruction to the natural environment, including water pollution of both the Ocean and rivers. Often raw sewage is discharged directly into the waters. Mangroves tend to be situated on the river estuaries adjacent to the Ocean. Many mangroves are destroyed to construct embankments, houses and block of flats. Mangroves play crucial roles in the food chain and fisheries (both for employment and leisure). Mangroves also help decrease siltation, because most sediment eroded from slopes is retained within this vegetation unit. The conservation and protection of mangroves is enshrined in Brazilian legislation, but is not properly or fully enforced.

5. Conclusions

In a relatively small area, by Brazilian standards, of 1750 km², there are complex interactions between geology, geomorphology and human interference, which cause land degradation. Much of the mountain slopes are very steep ($\leq 90^\circ$). According to Brazilian legislation, slopes $>45^\circ$ are classified as 'Permanent Preserved Areas' (APPs). However, many such slopes have been settled without any conservation measures. Combined with the very erosive rainfall regime and

the generally shallow soils, there have been mass movements, causing many deaths and catastrophic material damage.

Geomorphological knowledge is fundamental to arrest these mass movements and related processes and to prevent land degradation. Potentially this should lead to sustainable development, an environmentally-sensitive tourist industry and environmental protection for the Angra dos Reis nuclear power station.

The presence of four Conservation Units is another major factor promoting sustainable development in the study area. These Units are under many pressures and, consequently, experience many forms of land degradation. Therefore, we hope we have demonstrated the importance of understanding geomorphology for the sustainable development of these two municipalities. We must scientifically assess land degradation, predict the different forms of land degradation and construct strategies to rehabilitate degraded areas. There needs to be shifts in attitudes. Local authorities, local people and tourists must recognise and respect the uniqueness of this area, manifested in its natural beauty, natural resources and cultural heritage (such as the *caiçaras* and *quilombolas*).

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