# DEVELOPING A METHODOLOGY FOR A SILVICULTURE POTENTIALITY MAP USING GIS

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## ABSTRACT
*This study developed a methodology in order to identify the most appropriate areas for eucalyptus plantations based in the interactions among physical landscape elements using GIS. The area of study is the Paraiba do Sul basin (southeast of Brazil), which has been chosen for being an area where a cycle of great expansion of the eucalyptus plantation has begun in the last decades. This basin comprises nearly 15,300 km$^2$ and it characterized by a complex heterogeneous landscape. The analysis of the physical elements took into account thematic maps (geology, geomorphology and pedology) obtained from CEIVAP project in AUTOCAD format and later was converted and adjusted in ArcGIS® environment. To each landscape feature (rocks and structures, relief, and soil) it was applied a scale factor which corresponds the most suitable (5) or the less suitable (1) for the forest eucalyptus management. The final map (Silviculture Potentiality Map) indicated the areas, which might be considered the most favorable to the eucalyptus plantations. The most suitable areas are associated with well-drained, homogeneous and thick soils (oxisoils) and reliefs with low and intermediate steepness. The less favorable areas are associated with two types of very different physical substrates: a) areas of steeper relief with substratum of acid granites rocks and shallow soils (cambsols) and b), areas under conditions of poor drainage and high water table level associated with Paraiba do Sul River (gleysols). Results have showed that about 80% of the total area could be considered very good or good for eucalyptus plantation. Most part of these suitable areas represent vast region of migmatites rocks associated with Mountain with Steeper Hillslope relief and relatively shallow soils. The Silviculture Potentiality Map constitutes an important tool for eucalyptus plantation management particularly for the forestry activities in mountainous regions, which is the case of the studied area.*

***Key words:*** Eucalyptus management, physical elements, geographical information system

## INTRODUCTION

Brazil is a country of continental dimensions with a large geological, geomorphological and climatic diversity. Because of this large physical diversity, one of most challenge to the cellulose companies is to define the most suitable land for cultivate taking into account physical constraints and respecting environmental protection.

In Brazil, over 67% of Eucalyptus plantations are largely concentrated in the Southeast region that includes the states of São Paulo, Rio de Janeiro, Espirito Santo, and Minas Gerais. In this region, eucalyptus plantation (Eucalyptus *grandis* species) has increased significantly occupying mainly the mountainous regions associated with large variety of physical landscape features.

The diversity of geological, geomorphological and pedological elements needs to be understood in order to reduce the environmental impact of the silviculture activity especially erosional processes and, consequently, the high sediment yield that affect the natural drainage system. In spite of this importance, it is difficult to find papers that evaluate integrally the effects of physical landscape elements (rocks, soils, and relief) on silviculture potentiality.

This study intends to identify the potential regions that could be more suitable for silviculture considering the integration of physical landscape elements, at a regional scale. More specifically, this study was performed in the Paraiba do Sul basin, which is one of most important hydrographic basin in Brazil.

## CONTEXT OF THE STUDY AREA

The Paraíba do Sul river basin is located in Southeast Brazil covering an area close to 55,000 $km^2$ situated in the states of São Paulo (13.900 $km^2$), Rio de Janeiro (20.900$km^2$) and Minas Gerais (20.700$km^2$) with a population living inside the basin of 5.6 millions people. About 8.7 million living outside the basin also depends on its water resources via a diverted system that contribute to increase the freshwater supply for Rio de Janeiro Metropolitan Region. Important cities are located in the basin and the region concentrates one of the largest industrial activities in Brazil along part of the Paraiba do Sul River. The present study was concentrated in the upper part of the basin, which corresponds to the area of Sao Paulo State (Figure 1).

Paraiba do Sul basin (or Paraiba Valley) resulted from a geological complex evolution and comprises a long and large Cenozoic rift valley (IPT, 1981) bordered by two mountain chains, Serra da Mantiqueira e Serra do Mar with altitudinal variation between 450m and 2,000m. Three very distinct geological units are identified: a) Precambrian rocks associated with mountain with steep hillslopes; b) Tertiary sedimentary rocks associated with mountain with gentle hillslopes, and c), Quaternary sedimentary sequences associated with extensive flood plain. This large diversity of the physical environment was directly responsible for the evolution of several distinct pedological units such as oxisols, ultisols, inceptisols, and histosols (Oliveira *et al.*, 1999). The average annual precipitation is 1,400mm/year, but exhibits a large inter-annual variability with ranging values between 1,300 and 2,400mm/year (Simoes, Barros 2007), and a large spatial variability (Silva, Simoes, manuscript in revision).

This basin has a great historical importance for Brazil development, characterized by cycles of different agricultural activities in the past (coffee, sugar cane and pasture), and an intensive process of industrialization from the 60´s decade. Human activity imposed a dramatic transformation of the regional landscape with a significant reduction in natural forest over 300 years. Nowadays, the landscape is a complex mosaic where dominate the pastures (53, 4% of total area), followed by patches of forests (30, 7%), reforestation (9%), agriculture (6, 4%), and urban areas (2, 9%) (CEIVAP, 2000). In the last decades, land use has changed significantly replacing degraded pasture with eucalyptus plantation especially in the mountainous regions.

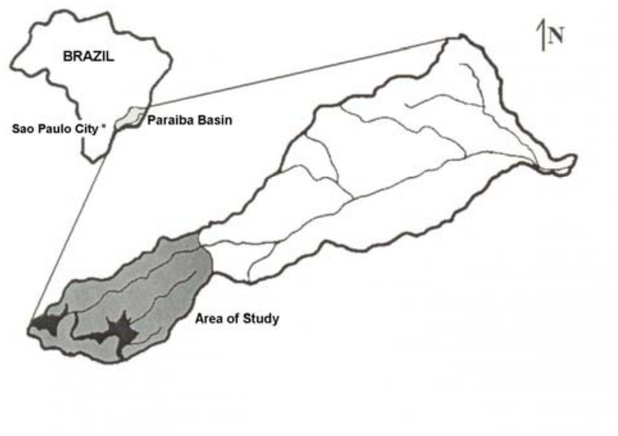


Figure 1 – Area of study

**METODOLOGY**

The methodological procedure is based on the assumption that it is possible to identify and to evaluate the regional potential for silviculture from the physical elements interaction. Most of the thematic maps were obtained from CEIVAP (2000), which were adjusted and converted from AutoCAD® format to ArcGIS® environment (Figure 2).

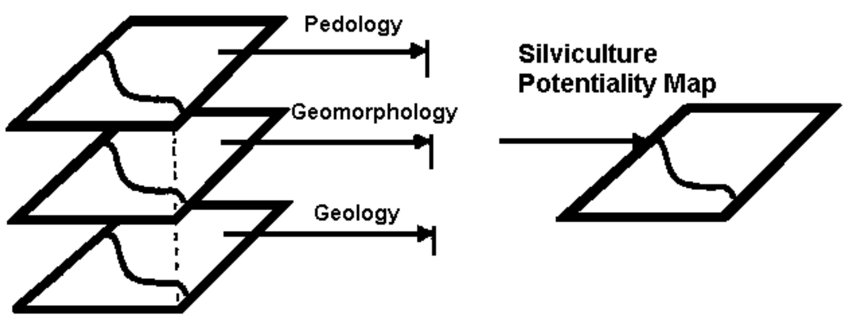


Figure 2 – Physical elements interaction to produce a final thematic map

A multidisciplinary expert group in the field of Earth Sciences and Geotechnical Engineering provided interpretation and factorings for each physical element (rocks, relief and soil). In the present study, each expert was asked to define, from their own perspective and experience, the degree of suitability for silviculture of each landscape feature applying a scale factor from higher potentiality (5) to lower potentiality (1).

Therefore, each landscape elements has its intrinsic features that influence the silviculture's potentiality of the terrain. Specific features of the landscape permit the identification of the land portion that has higher (or lower) silviculture potentiality. The scale factor presented in Table 1 was used to characterize the land portion for each layer according to its influence in the silviculture activity. The silviculture potential areas were calculated by the sum of the scale factors divided by the numbers of landscape elements using the ArcGIS® program. These layers were combined in order to obtain the map of silviculture potentiality.

Table 1 – List of qualifiers and their respective factors

| Qualifiers | Factor |
|---|---|
| Very low | 1 |
| Low | 2 |
| Fair | 3 |
| Good | 4 |
| Very good | 5 |

## RESULTS
### Geology

For this study, rock analysis includes both lithologic composition and structures features such as lineaments and metamorphic foliation obtained from the Geological Map of Sao Paulo State at scale 1:500,000. The regional geology complexity is responsible for a significant geological diversity as observed in Figure 3. More precisely, 15 units were identified (Carneiro et al., 1978), which are included in the main three types of rocks (igneous, metamorphic and sedimentary). Some of these units are very similar and were regrouped into eight units as shown in the Table 2.

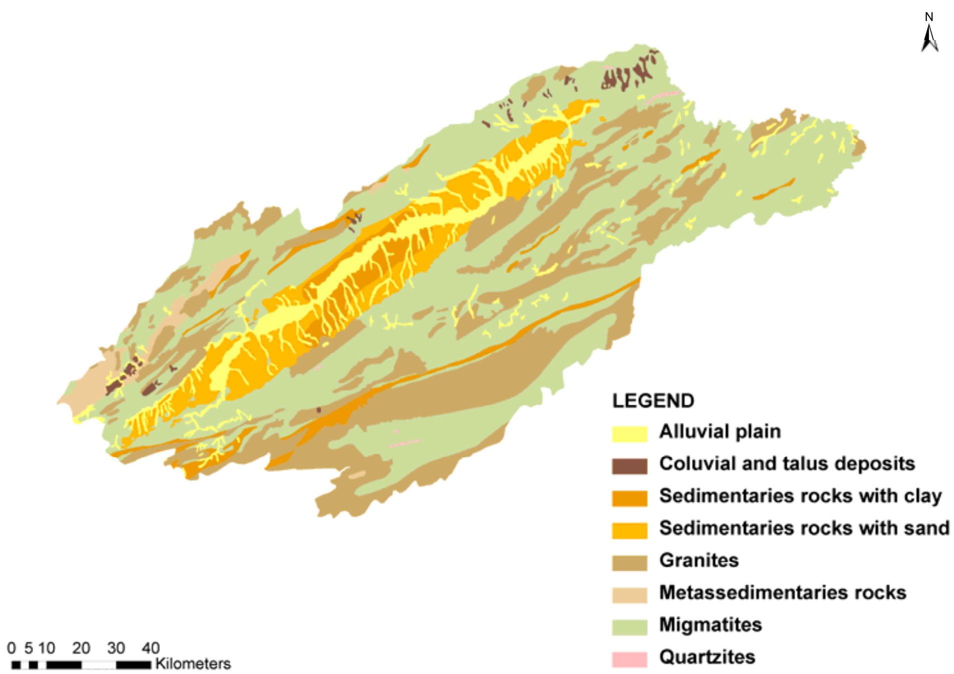


Figure 3 – Geologic Map of Sao Paulo State (Carneiro et al., 1978)

The sedimentary rocks were considered as the most suitable for silviculture because their mineral composition and good porosity and permeability condition. Tremembe Formation composed of lacustrine sediments, presents the most favored geological condition (factor 5) due to high clay content of these rocks (Table 2). Cacapava Formation composed mainly of fluvial sandstones deposits are slightly less favorable to silviculture than Tremembe Formation due to the higher sand content that reduces eucalyptus productivity (factor 4). In the same way metasedimentaries rocks, such as amphibolites and fillites, have been also attributed a factor 4. Biotite-rich metasedimentaries rocks produce clay-rich soils, which are suitable for silviculture.

Table 2 – Geological units and their respective factors

| | |
|---|---|
| Sedimentary rocks with clay | 5 |
| Sedimentary rocks with sand | 4 |
| Metassedimentaries rocks | 4 |
| Migmatites | 3 |
| Granites | 2 |
| Quatzites | 1 |
| Coluvial and talus deposits | 1 |
| Alluvial plain | 1 |

The units with intermediate position correspond to different types of migmatites, which are a mixture of granite-gneiss and biotite-gneiss (factor 3). The last one is more suitable to siviculture because can produce homogeneous and red soils. Because its coarse facies and predominance of quartz and K-feldspar, a factor 2 was attributed to these granites (called Cantareira Faceis). This type of rock facilitates the development of intense erosional and landslides processes. Thin quartzites lenses within the metassedimentary sequence present high quartz content. This rock is responsible for acid-light soils that contain excessive quantities of sand particles. Unconsolidated sediments of various granulometric compositions associated with colluvial/talus deposits and alluvial plain do not constitute suitable areas for silviculture (factor 1).

**Geomorfology**

The relief analysis was based on the Geomorphological Map of the São Paulo State at the scale 1:1,000,000, which was produced by researchers of São Paulo Technological Institute (Figure 4). The geomorphological map is divided into eleven units reflecting the regional geological diversity. In the same way as geology, geomorphology units were regrouped in five units due to their similar characteristics (Table 3).

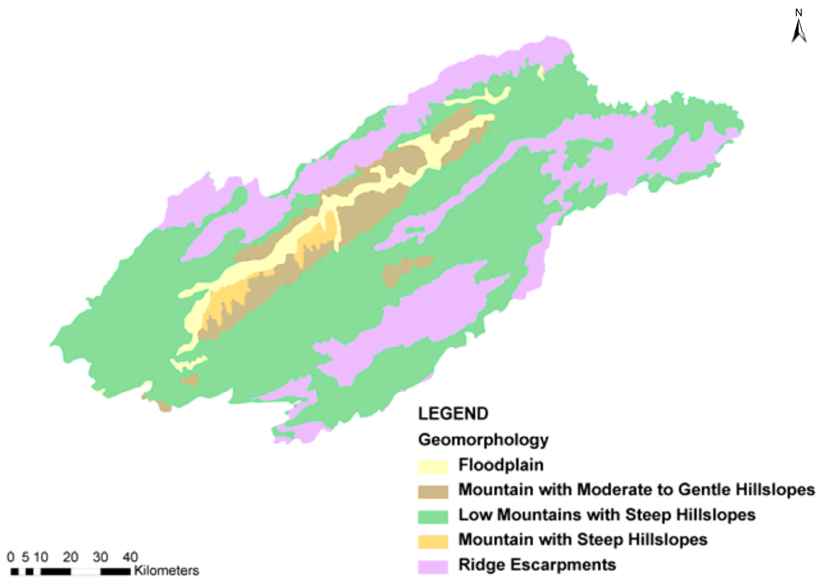


Figure 4 – Geomorphological Map (Poncano et al., 1981)

The unit *Mountain with Moderate and Gentle Hillslopes* is characterized by gentle valley, relatively low slopes (less than 12%) and low amplitudes (less than 60 m hight). This geomorphologic unit has the most favorable condition for silviculture corresponding to the maximum scale factor (Table 3). The unit *Mountain with Steep Hillslopes* presents round tops, closed valley, intermediate slopes (generally stepper than 15%) and relatively medium amplitudes, which a factor 4 was attributed. The unit *Ridges Escarpments* shows several situations that reduces the potential to the silviculture including intensive soil erosion and landslides. In this unit, steep slopes (between 20 and 50%) associated with exposed bedrocks are commons. For all these reasons a factor 2 was attributed to this unit. The *Floodplain* unit represents the worse condition for silviculture found in this region (factor 1). Although species Eucalyptus *Grandis* can tolerate extreme conditions such as low rainfall, salinity and inundation they are not totally physiologically adapted to alluvial plains. Furthermore, in the Paraiba do Sul basin, these areas are highly degraded ecosystems and different human activities should be avoided.

Table 3 – Geomorphological units and their respective scale factors

| | |
|---|---|
| Mountain with Moderate to Gentle Hillslopes | 5 |
| Mountain with Steep Hillslopes | 4 |
| Low Mountain with Steep Hillslopes | 3 |
| Ridge escarpments | 2 |
| Floodplain | 1 |

**Pedology**

For this criterion, the potentiality of the region for silvicuture was based especially on soil homogeneity, texture, and horizon depth. In the region are found oxisols, ultisols, inceptsols, and histosols, which can be observed in the Pedologic Map at scale 1:500,000 (Figure 5). The types of soils found in the basin have a good correlation with the geomorphologic units described above. The ultisols are mainly associated with *Ridge Escarpments* and *Mountain with Steep Hillslopes* units while the oxisols are mainly associated with the *Mountain with Moderate to Gentle Hillslopes* unit. Obviously, the presence of histosols is associated with large floodplains along the Paraiba do Sul River.

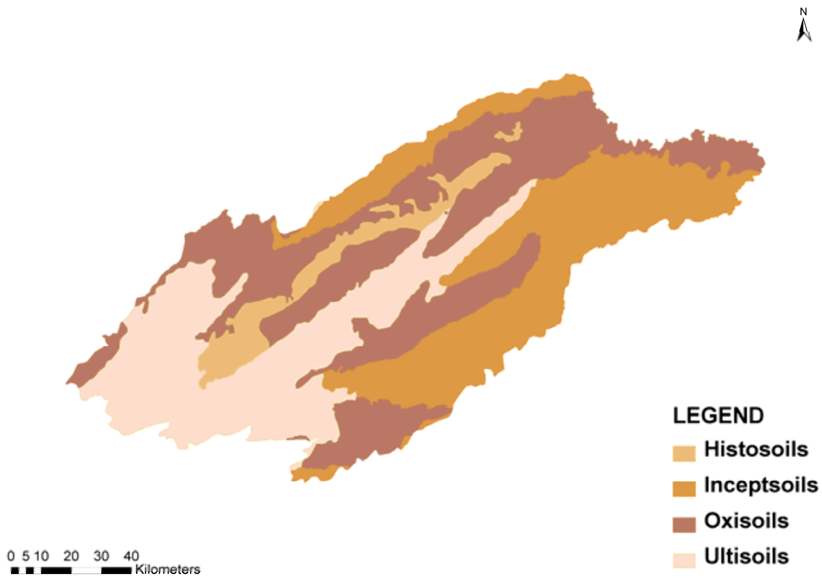


Figure 5 – Pedological Map (Oliveira et al., 1999)

More than half of the basin surface area corresponds to different types of oxisols. These soils present the most favorable condition for silviculture (Table 4) with well-drained and homogeneous soil profiles and absence of primary minerals residues. In addition, these clay rich soils are resistant to detachment (low erodibility).

Table 4 – Pedological units and their respective factors

| | |
|---|---|
| Oxisols | 5 |
| Ultisols | 4 |
| Haplic Cambsols (Inceptsols) | 3 |
| Humic Cambsols (Inceptsols) | 2 |
| Histosols | 1 |

Both haplic and humic cambisols (inceptsols) represents intermediate situation are characterized by weak to moderate development of B horizon and the presence of partially weathered rock (primary minerals residues). The haplic cambisols have a little most favorable condition for silviculture (factor 3) than the humic cambisols (factor 2) because are richer in organic material and clay in superficial layers. The melanic gleysols (histosols) associated with alluvial plain represents the less favorable situation (factor 1) for the similar reasons described previously.

## Silviculture Pontentiality Map

From the thematic maps it was possible to define the potentially or suitable areas for silviculture in the Paraiba Basin using the ArcGIS® program. The map showed in the Figure 5 defines four different grades for eucalyptus productivity: very good, good, fair and poor.

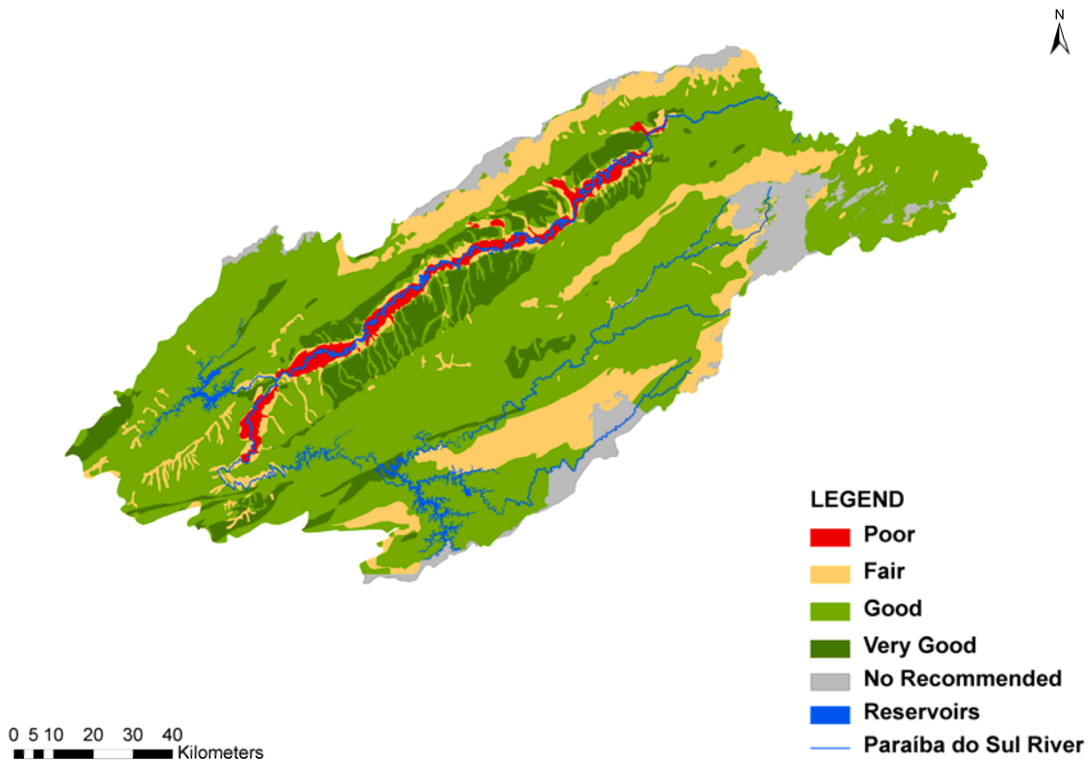


Figure 5 – Silviculture Potentiality Map

According to the figure 5, the most suitable areas for silviculture (very good grade) correspond to a narrow zone near the water divisor, which separates the Paraíba do Sul and Paraibuna/Paraitinga sub-basins (in the middle of study area). Another very suitable region represents the results of the interaction among sandy sedimentary rocks, oxisols, and gentle hillslopes located along the Paraiba do Sul River. Both areas account for only 10% of the total area. The area that can be considered good for silviculture, (in light green) represents around 70% of the total basin surface where the terrain are composed of migmatites and granites rocks associated with inceptsols and ultisols. The portion along the Paraiba do Sul River constitutes the most critical area for silviculture (poor grade, figure 5) and accounts for around 3% of surface area. These areas represent a vast alluvial plain with near-surface aquifer and acid organic soils and should be planted only species that are adapted to this environment. Finally, some areas near the natural water divisor of the basin have not been considered because represents state and federal conservation units and law forbids any human activity.

Table 5 – Quantification in relation to total area

| Classification | Area (hectares) | Occupied percentage area |
|---|---|---|
| Poor | 42.311,79 | 3,1% |
| Fair | 226.887,80 | 16,8% |
| Good | 945.570,99 | 70,2% |
| Very Good | 133.421,04 | 9,9% |
| Total Area | 1.348.191,62 | 100% |

The most suitable condition for eucalyptus plantation in the Paraiba do Sul Basin (Sao Paulo State portion), accounts for 80% of the basin as can be seen in Figure 6. Integrated physical analysis has shown that clayed sedimentary rocks associated with gentle hillslope terrains represents one of the most suitable areas for silviculture. However, if it takes into account others factors such as the social and economic conditions, this area could have others priority for land use purposes other than silviculture as, for instance, urbanization and industrialization. In contrast the vast region of migmatites rocks associated with *Mountain with Steeper Hillslope* and shallow soils represents the most suitable areas for silviculture because little economic alternatives exist for this region. These areas have suffered significant land degradation process and, nowadays, they represent a mixture of degraded pasturage areas and discontinuous forest fragments. However, granite areas associated with *Ridge Escarpments* should be avoided because the development of the accelerated erosive disturbance (rills and gullies) and local landslides, particularly associated with unpaved roads for timber harvesting operations.

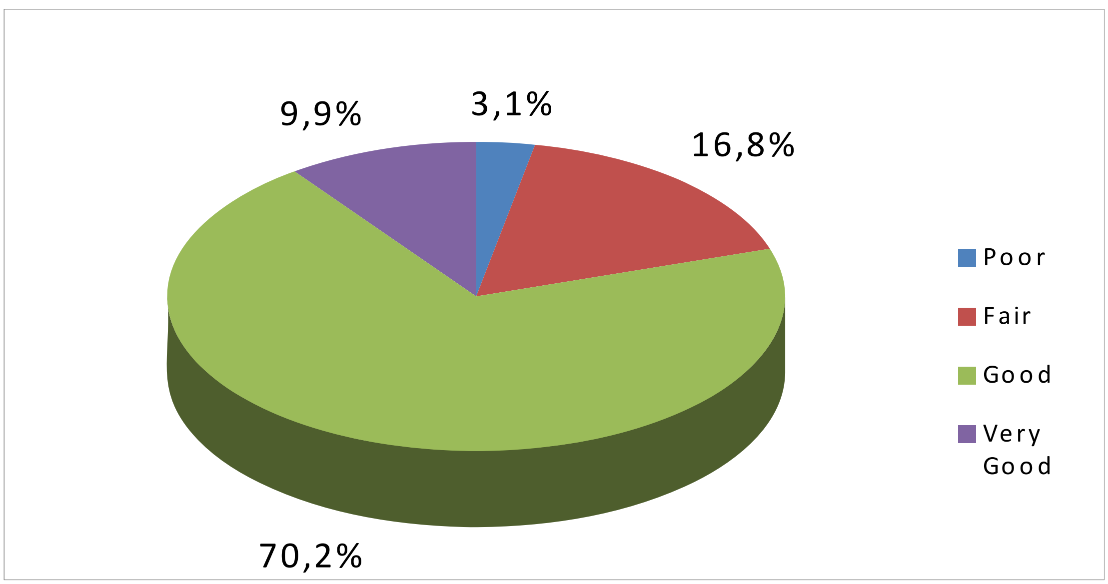


Figure 6 – Percentage of each grade

## CONCLUSIONS

This paper explores the importance of considering the analysis of the physical landscape elements in the planning and operation of silviculture activities. The importance of the integrated physical elements analysis increases in the mountain regions, which present high spatial heterogeneity and diversity of rock, relief and soil types. On this region, it is necessary to recognize the areas that could be more affected by intense physical processes such as accelerated erosion and landslides and could contribute to the high amount of sediments delivered to the stream network. Therefore, Silviculture Potentiality Map may make possible the identification of the most critical area in order to reduce or avoid eucalyptus plantation. In the study area, about 20% of the total area represents less suitable regions for eucalyptus plantation (poor and regular condition). On the other hand, the results have showed that about 80% of the total area could be considered very good or good for eucalyptus plantation.

Although this methodology has been applied to the silviculture, it could be used for others purposes. For example, future studies will focus on the effects of the physical landscape elements on unpaved road construction that could contribute to the design of the roads minimizing their impacts on the environment.

## AKNOWLEDGEMENTS

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