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GEOENVIRONMENTAL CHARACTERIZATION OF AN ATLANTIC FOREST SLOPE IN SÃO SEBASTIÃO (SP)

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Abstract:-
The urban expansion and the growth of economic activities related to tourism, as well as those related to the port and sea, resulted in the occupation of the Serra do Mar slopes, in the municipality of São Sebastião - SP. This study was carried out in a clearing in an Atlantic Rainforest fragment of 4.8 hectares, located in the municipality of São Sebastião-SP, to provide subsidies to prevent and/or reduce the risks of land slippage on the slope. Thus, this work analyzed, characterized, and described the physiography and the properties of the soils on a slope of an Atlantic rainforest in the municipality of São Sebastião – SP, aiming to obtain a product on the risk of urban occupation. That is why, we used indicators associated with landscape physiography as a feature of slope (slope declivity), anthropic features (deforestation for crop cultivation and cattle raising) and soils (texture and pedogeochemistry). The results recommend structural actions, allowing the implementation of preventive measures such as revegetation of the area, thus minimizing the risks of land slippage and evolution of laminar erosion. Despite the dystrophic soil, the K, Ca and Mg levels only allow the vegetation implementation to be performed using NPK fertilization, reducing costs. Actions such as these are important as a way to prevent economic losses and accidents, since the area presents a Very High classification for mass movement processes.

Keywords:- *Environmental geotechnology; Erosion; Geomorphology; Soils.*

1. INTRODUCTION

Economic growth vectors in Brazil, such as agriculture, cattle raising, mining, urbanization, and industrialization have not always sought compatible ways and means for environmental conservation. The Atlantic Rainforest is a domain where two-thirds of the Brazilian population is concentrated as well as the main economic centers of the country are here. The municipality of São Sebastião is located along the Northern Seacoast of São Paulo State. It is an occurrence area of the Atlantic Rainforest. The most notable physiographic characteristic is the presence of the Serra do Mar throughout its entire extension is its slope ranges from 600 to 1,000 meters.

The Serra do Mar has always constituted a natural barrier for urban expansion of São Sebastião, in the past hindering communication of the city to the other regions of the State. Partially, this contributed to partial conservation of the Atlantic Rainforest in that stretch of the mountain range, currently; it is protected as a wilderness protected area. However, the growth of the economic activities related to tourism, as well as those related to ports and the sea, resulted in a greater demand for labor, leading to increased migration to the region (Marandola Jr. *et al.*, 2013) [1] . Thereby, bringing about the occupation of the Serra do Mar slopes, which are naturally unstable and lacking in the implementation of adequate protection worksite projects, bringing about the emergence of risk areas.

The technical-scientific studies performed in the region have definitely pointed out the increasing possibility of disastrous events, directly related to the increased use and uncontrolled occupation void of any consideration for the local geological-geotechnical characteristics (Bragança, 1987 [2]; Magro, 1995 [3]; IG, 1996) [4]. According to Dias and Griffith (1994) [5], degradation of environments occur through erosion and soil depletion, slope land slippages, waterway silting, floods, and decreased sources of drinkable water.

The characteristics of the physical environment, topological reliefs, and contrasting declivities, notable unevenness, and high precipitation rates, jointly with urbanization and occupation of areas without adequate planning are an integral part of the municipality of São Sebastião (SP) featuring favorable characteristics that may provoke the outbreak of natural disasters.

This study aims at the geoenvironmental characterization of an Atlantic Rainforest slope located in the municipality of São Sebastião, a touristic city along the São Paulo seacoast.

2. Case study area

The case study area is in the municipality of São Sebastião, and it is situated in the southeastern part of São Paulo State, along the northern seacoast. It occupies approximately 410 km², around 70% is in the Serra do Mar State Park. It is bordered on the north by the municipality of Caraguatatuba, on the northwest by Salesópolis and the west by Bertioga (Garcia, 2005) [6]. It is lapped by the Atlantic Ocean along its southern sector and the northwest and the east by the São Sebastião Channel (**Figures 1 and 2**).

The case study area is located near a 4.8 hectare fragment of the Atlantic Rainforest, precisely located from latitude 45º 25' 30'' to 45º 25' 37" and from longitude 23º 44' 10" to 23º 44' 19", the levels range from 105 to 235 meters in altitude **(Figures 1 and 2**). The native vegetation was composed by the same vegetation as borders the boundaries of the fragment, classified as Dense Ombrophile Forest (Veloso *et al.*, 1991) [7]. Currently, the fragment is now covered by pastures; however, it is surrounded by native vegetation, along the lateral slopes as well as on the mountains, where it dominates even at the highest altitudes. Regarding the fauna in the region, there are several kinds of wild animals, such as feral pigs, "quatis," lizards, "pacas," and diverse birds.

The beginning of the fragmentation and clearing of the areas for cattle raising and urban exploitation began slowly and progressively approximately 40 years ago, by the respective local residents for the cultivation of heart of palm, the need for construction lumber, and daily consumption, and for space needed for subsistence agriculture. Currently, the native population is aware of the importance of ecological balance, as those same people noticed great differences in the environment after clearing the vegetation, due to great concerns regarding water scarcity, as local supply is broadly linked to headwaters surrounding the area.

Pereira and Nunes (1997) [8] performed pluviometric (rainfall) compartmentalization after analyzing data for 25 years (1970-1994) in the municipality of São Sebastião (SP). The field of study is in an area where the annual rainfall average is around 1702 mm, based on the collected data by the above mentioned authors.

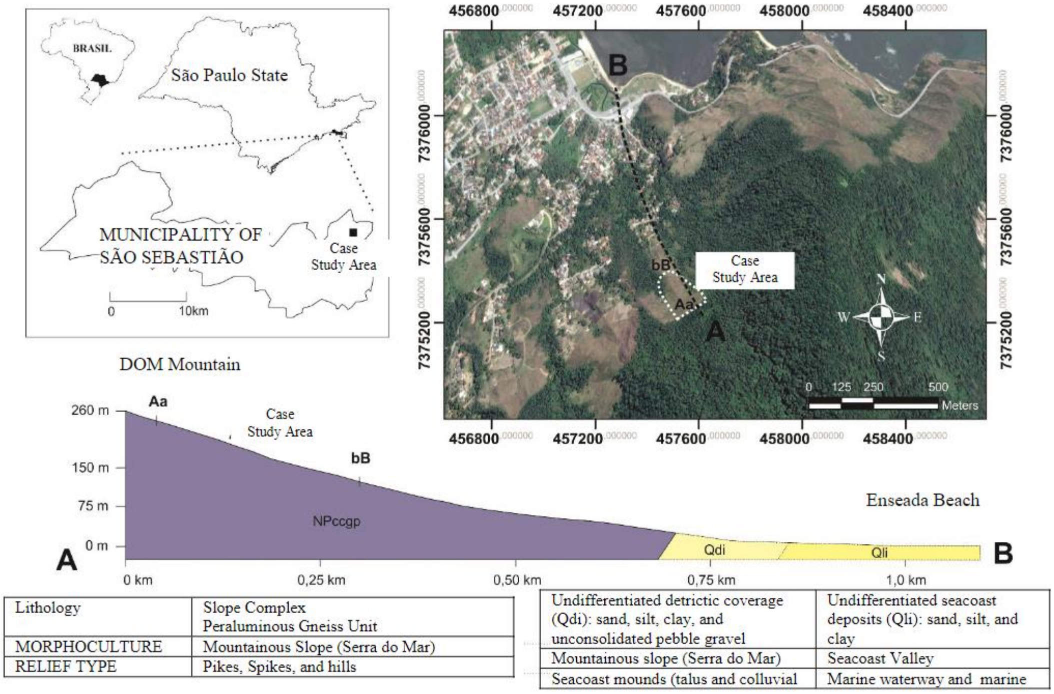


Figure1. Location of the (A-B) region and the (Aa-bB) case study area, lithology, morpho culture, and types of topological reliefs.

Figure 2. **(a)** Slope with a rectilinear profile and an angular summit located in the eastern part of the case study area. **(b)** Slope with a rectilinear profile and an angular summit located in the western part of the case study area. **(c)** The summit of the studied fragment with a convex shaped slope. **(d)** The base of the studied fragment with predominant talus deposits.

Regarding geomorphology, the case study area is on the northern slope of the Serra do Mar and, according to the geomorphologic map of São Paulo State (IPT, 1981) [9], showing cliffs with the formation of spikes, made up by large sub-parallel linear cliffs, angular summits, and rectilinear profile slopes (**Figures 2a and 2b**). Convex shapes are predominant on the stretch of the studied fragment, bordered by recessed valleys (**Figure 2c**). On lower altitudes, there is a talus body, which displays a large number of different sizes of surface and sub-surface blocks (**Figure 2d**). There is high-density drainage, a parallel-pinnacle pattern, and enclosed valleys.

Blocks and buried volcanic boulders are amidst modified coverage and they were noted during the course of the expedient mapping (**Figure 2a**). These blocks vary in size, as they are generally metric, and the largest is located in the central part of the area. They measure 4 x 5 meters (**Figure 2b**). There are gneiss rocks with migmatite structures (leucocratic grains and pockets) similar to a leucosome type. These leucossomes present medium to large granulometry and they are composed of quartz, feldspar, and muscovite; concentrations of centimetric garnet and biotite are viewed along the edges.

3. Methods and Material

An inventory was performed based on bibliographic studies and research studies on files from environmental, technical, and scientific entities during the first phase of the research, considering factors related to the physiography of the landscape, such as the aspect of slope instability (slope declivity), anthropic aspects (deforestation for crop planting and cattle raising) and soils (texture and pedogeochemistry).

A cartographic database was used for the topographic study at a 1:2000 scale for the preparation of the declivity map, made and based on the map prepared by the Geographical and Cartographic Institute (ICG, 1978 at a 1:10,000 scale) [10]. The abacus was made and then by calculating the distance between two levels and the ratio of the difference between levels and the slope angle between them, thereby diverse sectors were established corresponding to the variation of the terrain declivity.

The field data collection was performed for the purpose of expedient physiographic characterization of the physical environment, through descriptions of the land usage (vegetation coverage, farming, urban, or exposed soil), lithological (structure, texture, and mineralogical composition), geomorphological (summits, slopes, and declivity shapes) and changes in the coverage (changeability level, changes and thickness of the matter). A petrographic and Estwing stratigraphic hammer, a 21 mm pocket 30x magnifying glass and a Garmin - Map 62S GPS (*Global Positioning System)* equipment were used for this purpose.

The field study also consisted in performing a boring operation using a manual auger soil perforator (ST-1), and studying two trenches (T-1 and T-2), used for pedological recognition and collecting deformed soil samples for performing granulometric tests by sifting and sedimentation as stated in the 6457 and 7181 NBR standards (ABNT, 2016a [11] and 2016b [12]). The case study fragment was divided into three homogeneous plots (summit, middle, and base) based on the vegetation and topology.

Five differentiated samples were removed from the soil for the granulometric characterization. The samples were removed from the boring hole ST-1 (0 – 0.6m) at the beginning of the horizon B, from trench T-1 corresponding to the beginning of horizon B (0.2 – 0.7m) and trench T-2 (0 – 0.1m corresponding to horizon B; 0.3 – 0.6m a buried horizon A, and 0.6 – 0.9m from horizon B). The pedogeochemical sampling was performed by using a manual auger soil perforator, removing 15 single samples at a depth ranging from 0-20 cm and 15 single samples from a depth ranging from 20-40 cm from each plot of land. The samples were homogenized to compose a compound sample. Thus, two compound samples were removed from each plot (summit, middle, and base) at different depths ranging from (0-20cm and 20-40cm), whereby there was a total of 6 compound samples.

The previously homogenized samples were properly labeled and sent to the Soil Fertility
Laboratory at the "Faculdade Integral Cantareira" (Integral Cantareira College), for pedogeochemical characterization. The percentages of B, Cu, Fe, Mn, and Zn were measured by extraction by diethylenetriaminepentaacetic acid (DTPA) in a microwave oven with focalized radiation and nominal power of 950 ± 50 W. The measurements were performed by atomic absorption spectrometry (AAS). The exchangeable K^{+}, Ca^{+2}, Mg^{2+} and Al^{3+} cations were measured by extraction using exchange ion resin, as described by Raij *et al.*, (1987) [13]. The organic matter percentages, pH values, and potential acidity were performed using the EMBRAPA methodology (1997) [14].

3. Results and Discussions

According to the information obtained from the declivity map (**Figure 3**) and the field observations, the numerical values are calculated on the morphometric attributes of the fragment being studied, which are grouped in **Table 1**. Based on those data, the topological relief shapes were classified according to the criteria of (Moreira and Pires Neto, 1998) [15] and they are listed in **Table 2**. The case study area abides by the classification as a high-susceptibility domain for surface soil erosion and a very high-susceptibility to land slippage (natural and induced). According to Tatizana *et al.* (1987) [16], the susceptibility of land slippages is extremely variable in each sector of the Serra do Mar, as a reflex from the geological, geomorphology, declivity, vegetation coverage, and rainfall regimes.

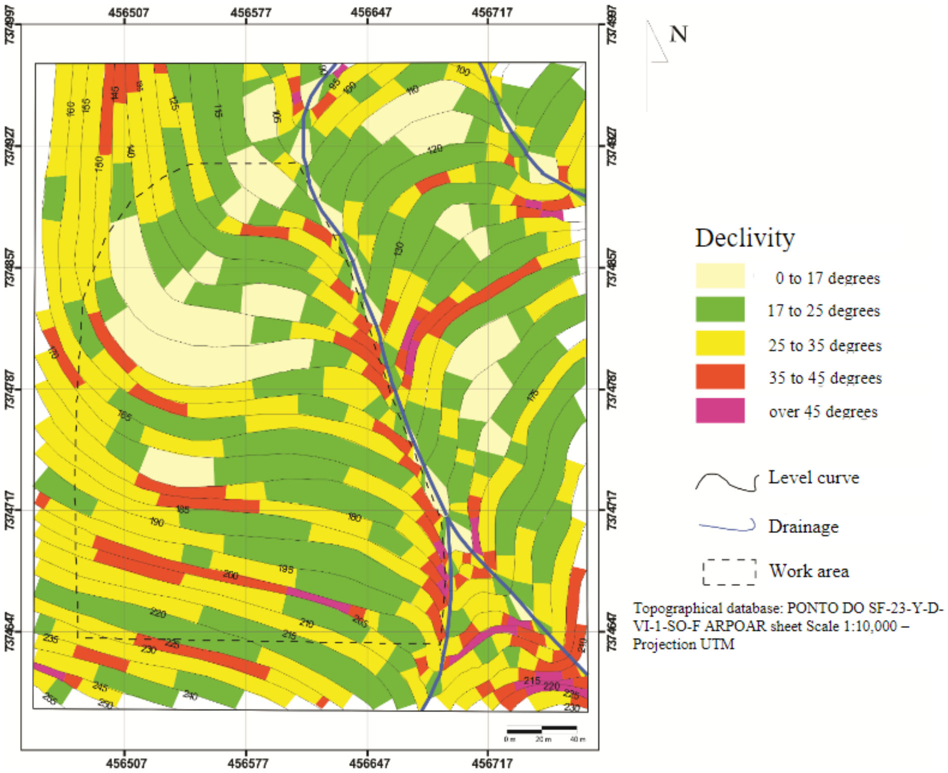


Figure 3. This declivity map shows the location of the case study area.

The change in the vegetation pattern of the fragment has accelerated due to the erosion process and the shifting of matters to thereby increase the increase of sediment and blocks in the downstream regions, where there are some houses and residential plots at the foothill of the slope. Regarding this, the presence of geological risks from slope slippages and the rolling of blocks, as declivity (**Figures 2 and 3** and **Tables 1 and 2**) is an important parameter for evaluating geotechnical stability.

Table 1. Numerical values on morphometical attributes from the case study area.

Indexes	**Longitudinal profile**
Summit altitude	215 m
Waterway altitude	110 m
Amplitude	260 m
Ramp length	280 m
Average declivity	25º

Table 2. Classification of the topological relief shapes of the case study area: Adapted by (Moreira and Pires Neto, 1998) [15].

Criteria	**Classification**
f profile and active surface processes	Slope slippage and water distribution
On the amplitude	Dissected hill
On declivity	Steep
On amplitude and gradient	Hill

It was possible to observe and describe a The S-N profile of the case study area (Aa - bB) at the boring site perforated by the manual auger (ST-1).B Horizon with a 0.6 m thickness at the summit, a sandy-loamy texture mixed with quartz, micas (muscovite and biotite), a yellow and homogenous color, and predominant quartz and kaolinite, with the preservation of the rocky structural features (**Figure 4**).

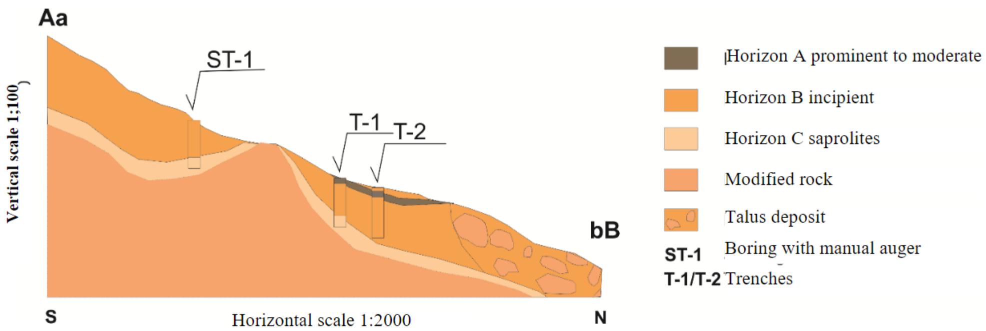


Figure 4. **The S-N profile of the case study area (Aa - bB) highlighting the pedological structures with boring points by using a manual auger (ST-1) and trenches (T-1 and T-2) for collecting soil samples.**

In trench (T-1) at the summit measured at approximately 0.2 m into prominent Horizon A, it was dark colored, followed by Horizon B in the middle, ranging in thickness from 0.6 to 0.7 m and its texture is sandy-loamy with quartz, micas (muscovite and biotite), homogenous, and Horizon C is 1.5 m at its base, and its texture is sandy-loamy with quartz, micas (muscovite and biotite), and there are predominately quartz and biotite, with clustered fragments (saprolites). Since trench (T-2) measured at 0.2m Horizon B at the summit, as there is a sandy-loamy homogenous texture mixed with quartz and micas, ochre coloration, in the middle, there is buried mineral organ at Horizon A,
0.3 m, homogenous, dark brown color, medium thick granulation, and at the base there is a 1.5 m sandy-loamy texture of Horizon B that is a homogenous, light brown color (**Figure 4**).

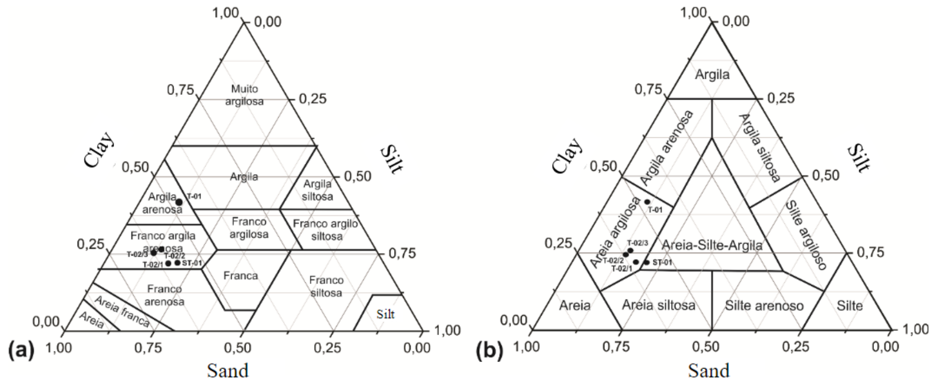
The sampled points have predominately displayed **(Table 3)**, a sandy texture, ranging from fine to coarse sand, except for trench T-1 (0.2-0.7m) where there is 40% clay (a loamy texture), 11 % silt, 45% sand fraction values based on granulometric analyses in the case study area. The percentages of fine sand are lower than coarse sand in all of the samples, a factor that can interfere with the availability of water in the analyzed profiles. There was less than a 10% fraction of pebble gravel measured, except for point ST-01; the fraction was 12% there.

Table 3. Granulometric analyses performed in the case study area.

Sample	Prof	Clay	Silt	Sand					Pebble Gravel
				F	MF	M	MC	C	
	(m)	%	%	%	%	%	%	%	%
ST-01	0.0-0.6	20	18	7	4	11	12	16	12
T-01	0.2-0.7	40	11	8	4	10	7	16	4
T-02/1	0.0-0.1	21	17	7	6	16	9	18	6
T-02/2	0.3-0.6	25	14	11	5	13	9	19	4
T-02/3	0.6-0.9	23	13	10	6	14	7	20	7

Prof: depth; F: fine sand; MF: medium fine sand; M: medium sand: MC: medium coarse sand; C: coarse sand.

The textural analysis (**Figure 5**) indicates samples ST-01, T-02/1, T-02/2, and T-02/3 are classified as Loam Sandy clay soil, and sample T-01 as Sandy clay soil, according to the Gomes and Silva classification (1962). All of the samples were classified as Loamy sand. However, sample ST-01 is situated in the interface between the sand-silt-loam classification by Shepard's classification diagram (1954) [16]. The results contribute to the analyzed and described data in the field.



Legend:
Muito argilisa = Very loamy
Argila arenosa = Sandy clay
Argila = clay
Argila siltosa = Silty clay
Franco argila arenosa = Sandy loamy clay
Franco argilo siltoso = Silty loamy clay
Silte = Silt
Franco argilosa = Franco argilosa

Silte argiloso = Loamy silt
Silte arenoso = Sandy silt
Areia –Silte-Argila = Sand-Silt-Clay
Areia argilosa = Loamy sand
Franca = Loam
Areia franca = Loamy sand
Franco arenosa = Sandy loam

Figure 5. **(a)** The triangular diagram is used for the basic classification of soil textures, Gomes & Silva (1962) [17] for the ST-01, T-01,T-02/1, T-02/2, and T-02/3 samples. **(b)** The Shepard's [18] classification diagram (1954) is used for the ST-01, T-01,T-02/1, T-02/2, and T-02/3 samples.

The case study area was divided into three different plots for chemical analysis of the soil (**Figure 6**): (1) The summit refers to the highest part of the case study area. In this location, the soil is covered by grassy plants, such as molasses grass and some very sparse bushes. There is also native vegetation nearby, darker soil is noted due to the deposition of organic matter arising from the native brush; (2) The middle slope is between the highest part and the lower part of the case study area. The vegetation is made up by grassy plants and also a few bushes, the soil is apparently a little lighter than the summit, probably because the area is a little more deforested and far away from the native brush; (3) The base is the lower part of the case study area. The soil coverage is made up of grassy plants. However there are some places where the soil is exposed and lighter than the other plots. As it is an area where there are accentuated declivities and little vegetable coverage, matter can be moved due to bad weather conditions and erosion.

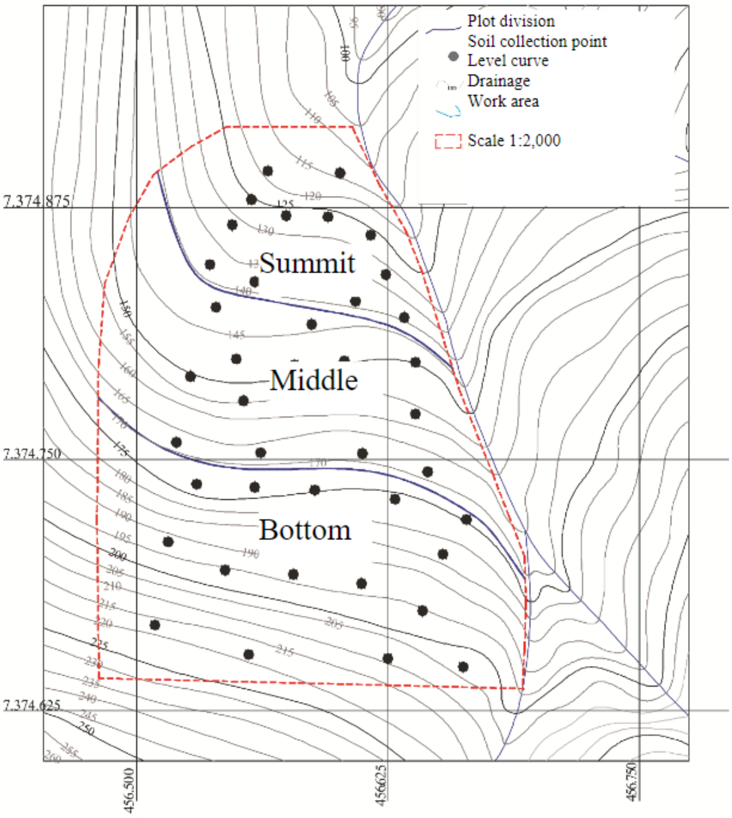


Figure 6. The map of the soil sampling points displaying the location in the case study area.

The pedogeochemical results are shown in (**Table 4**) indicating the behavior of pH in the analyzed soils dominated by mineral soil matter, as reported by Ebeling *et al*., (2008) [19]. There is the formation of organic acids from the process of organic matter decomposition, and due to this, carbonic acid can be found in a greater abundance and thereby modifying the pH of the soil. Though, as it is a weak acid and thus, probably it cannot be held responsible for the low pH values of the soil. Low pH values are common in mountainous areas of the Atlantic rainforest, due to higher temperatures and low rainfall indexes facilitating the lixiviation of the basic cations and the relative concentration of iron and aluminum. Organic matter normally concentrates on the soil surface and surface horizons in these areas.

The highest concentration of organic matter has been observed from the summit samples, probably due to proximity to the area related to the forest fragment making it possible to show the greatest increase of vegetable matter. Besides that, there is lower declivity of the summit, and this can increase the period of the residence of OM and thereby make it possible for it to be incorporated in the soil, and in higher declivities, the OM accumulates much less as the matters are shifted more rapidly. Declivity can also be impacted when there are percentages of Ca^{2+} and Mg^{2+}, as seen in **Table 4**.

Low percentages of CTC and medium and high levels of active acid were observed from the middle and base slope samples. As the exchangeable potassium, calcium, and magnesium can be considered as ranging from medium to good, yet they are insufficient for reaching the 50% value of saturation of bases. Regarding the concentrations of B, Cu, Fe, Mn, and Zn higher concentrations have been observed from these surface soil horizons (0-20cm), maybe due to the removal of the vegetal coverage and consequently the surface horizon (A) and exposure of the horizon (B) where there is less mobility of these elements. Another important fact is the concentrations of elements, especially the progressive decrease of Mn at the summit to the base of the case study area, probably because of the lixiviation of the sandy soils.

Table 4. Pedogeochemical characteristics of the case study area.

Position	Prof	pH	OM	H+Al	K^+	Ca^{2+}	Mg^{2+}	SB	Al^{3+}	CEC	V	B	Cu	Fe	Mn	Zn	m
	cm		g/Kg			mmolc/dm³					%		mg/dm³				%
Summit	0-20	5.3	29	29	2	27	13	42	1	71	59	0.3	2	52	30	2	2.4
	0-40	4.8	8	28	2	11	8	21	2	49	42	0.3	2	37	20	1	8.7
Middle	0-20	4.8	26	32	3	11	9	23	2	55	41	0.3	2	45	18	1	9.5
	0-40	4.5	3	30	2	6	6	14	2	44	31	0.2	1	30	14	0	9.5
Base	0-20	4.6	10	36	2	10	9	21	3	57	37	0.2	2	52	12	1	21
	0-40	4.7	4	28	2	10	8	20	2	48	41	0.4	1	30	5	0	10

D: depth; OM: Organic Matter; SB: Sum of the Bases (SB = Ca^{2+} + Mg^{2+} + K^+); CEC; Cation Exchange Capacity (CEC = SB + (H + Al)); V%: Saturation per base (V% = SB/CTC x 100); m:
saturation by aluminum.

This case study area presents a Very High classification, related to the susceptibility to the risk potentializing processes for moving mass, as that is due to the declivity of the terrain (approximately 25º), or because of the high pluviometric index of the region (1700 mm), as that is the most important climatological element in launching the gravitational movements of the masses. The case study area was confirmed to undergo laminar erosion as determined by the hole from boring and trenches, which turn into more impacting processes, such as erosion in ravines, gullies, or slippages. In order to minimize the erosive processes, mass movements, and rolling of blocks, it is suggested to perform vegetable replacement with surrounding native species, making it possible for ecological interactions and thereby contribute to the reestablishment of other important elements to the sustainability of the system, such as microorganisms, wild fauna, and landscape recovery, fixation elements for the soil, among others.

In spite of the dystrophic nature of the soil, the average percentages of K^+, Ca^{2+}, and Mg^{2+} allow for the revegetation of the area by planting native species (30×30×40cm), thereby there will only be fertilizing using NPK. It is also recommended the utilization of structural actions, technical training for municipal civil servants, modernizing laws on public policies, and the preparation and/or awareness of the population. Thus, it is suggested for the municipality to review its Civil Defense Preventive Plan (CDPP), making it possible to implement preventive measures, reduce the possibility of possible economic losses, and human lives, creating the conditions for the coexistence with relative safe levels for the local population.

4. Conclusions

The physiographic characterization and the field study were extremely important for the gradual understanding of the geological processes that have occurred in the case study area. In the fragment whose declivity is approximately 25º and the rainfall index is 1700 mm, slippage and water distribution is predominant on the slopes, the convex shape on a dissected hill, bordered by recessed valleys, and talus deposits. These characteristics classify the location as very high risk for mass movements.

Regarding the changing profiles, the highest part of the summit in the case study area (ST-1) there is a sandy-loamy texture in Horizon B, followed by a heterogeneous, sandy-loamy Horizon C. In the middle slope, between the highest and lowest parts is (T-1) an incipient Horizon A, followed by Horizon B and C, and the base and/or the lower part is (T-2) a Horizon B followed by a Horizon A, a mineral buried organ followed by another Horizon B. The pedogeochemical results indicate that the slope, where the declivity is less, and grassy plants and bushy vegetation cover the soil, there is a greater amount of organic matter, $Ca^{2+,}$ and Mg^{2+}, contrary to the higher declivities, where the soil is exposed, and there is little vegetal coverage, and where there is movement of these elements. These results contribute to the described and analyzed physiographic aspects in the field trench (T-2), Horizon B resulted in moving the matter to the higher areas, burying mineral organ in a Horizon A, and, in the talus deposit located in the lower areas of the fragment.

Based on the geoenvironmental characterization of the case study area, it was possible to identify potential situations that could result in serious environmental problems, recommending preventive measures related to the use and occupation of the soil in the case study area. Development of the urban area occurred from Enseada Beach to the Serra do Mar. Thus, urban growth proceeded towards the steep slope on the deforested hills and mountains and remaining forests. This type of urban development occurs mainly due to physical environmental characteristics and the trend of occupying improper areas towards the Serra do Mar.

Thus, planning actions and territorial management must be put on the agenda of public policy focused on protection and civil defense, guiding urban development and protecting the forest areas and the risk at the Serra do Mar. Besides that, for the families who live in this area, we suggest managing the risks and disasters, by way of preventive actions, mitigation, preparation, response, and recovery, to provide the conditions to coexist with risks safely.

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