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Analysis of environmental fragility on the city of Monte Alto-SP and proposals forenvironmental zoning

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ABSTRACT

The aim of this study is to identify the environmental fragilities on the city of Monte Alto-SP and propose a land use zoning for better environmental management in this region. For this, it was used the methodological proposals of Ross (1994), which addresses potential and emerging fragilities, of Ross and Fierz (2017), which updates some concepts and classifications, and of Gouveia and Ross (2019), which conducts a integration of areas subject to flooding with the proposal of environmental fragility. As a result, it was observed that the class with the greatest predominance was the strong, occupying about 92.29% and 73.58% of the total area of potential and emerging fragility, respectively. To validate the accuracy of the methodology, the coefficient of linear determination (R^2) between the obtained emergent fragility degrees and the occurrence of erosive processes present in the respective degrees was used. The erosions were made available by the Technological Research Institute – IPT (2012) and some additional ones were registered by the authors from Google Earth. The determined coefficient of linear determination is 0.6359, which means that the method used developed satisfactory results for the studied location. Finally, environmental zoning was proposed based on land use proposals to improve the environmental management and quality in the region, as the research shows a high environmental fragility in the municipality of Monte Alto-SP.

KEYWORDS: Geotechnologies. Erosion. Land use and occupation.

1 INTRODUCTION

Inappropriate land use associated with the lack of environmental management and administration can increase the environmental fragility of a region. To help eliminate these problems, several studies aim to define an environmental zoning, however, for this determination, an analysis of the weaknesses of the environment is necessary (ABRÃO and BACANI, 2018).

That said, it is extremely important to carry out environmental analysis in areas of interest, and these studies can contribute to a better knowledge of the region, which can be translated into future plans and actions for the management and preservation of natural resources (CUNHA et al, 2013).

An environmental assessment often used is the analysis of environmental fragility. This analysis classifies the susceptibility of the environment to undergo interventions or to be altered, and this instability may occur due to natural or anthropic processes (SPÖRL and ROSS, 2004; SCHIAVO et al, 2016).

Environmental fragility is classified as potential and emerging. The potential fragility is determined from the natural characteristics of the place, such as soil, geomorphology and climate, without considering human intervention. Meanwhile, emerging fragility is the association between land use and occupation and potential fragility (KAWAKUBO et al, 2005).

The methodology proposed by Ross (1994) is an empirical model that integrates geographic characteristics such as climate, soil, relief and land use and occupation. This method is widely recognized and is still used in environmental studies aimed at physical-territorial studies (GOUVEIA and ROSS, 2019).

Over the years, the method has been adapted several times, as can be seen in the works by Crepani et al (2001), Spörl and Ross (2004) Spörl (2007), Ross and Fierz (2017) and Gouveia and Ross (2019). However, in general, the model uses studies of relief, geomorphology, soil, climate and land use.

Another factor constantly present in analyzes of environmental fragility is the consideration of floodplains. It is extremely important to delimit these areas as areas of high fragility, due to the occurrence of frequent floods (ROSS and FIERZ, 2017).

That said, the present research selected as a study area the municipality of Monte Alto-SP, a city that has a history of landslides and erosion over the years, evidencing serious environmental problems in the region. Such superficial dynamics generate socioeconomic and environmental impacts (IG, 2008).

2 OBJECTIVES

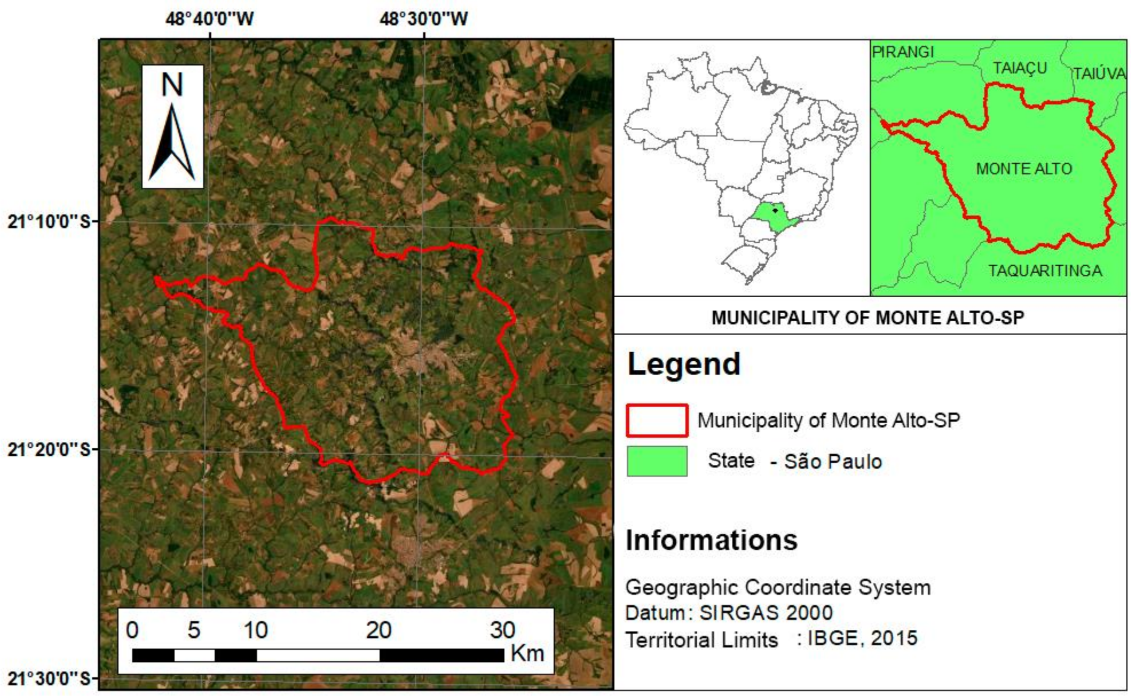
This work aims at the application of geotechnologies to study the potential and environmental fragility in the municipality of Monte Alto-SP, using the Ross method and its adaptations, in addition to proposing an environmental zoning with suggestions for land use in relation to natural and anthropogenic characteristics evaluated.

3 METHODOLOGY

3.1 STUDY AREA

The municipality of Monte Alto, located in the north of the state of São Paulo, is at a distance of 350 km from the capital of São Paulo. The limits of the municipality cover an area of 347.25 km² and lie between the geographic coordinates of 21°9'50.94” to 21°21'9.03” south latitude (S) and 48°25'27.23” to 48°42' 23.94” west longitude (W), as seen in Figure 1.

Figure 1: Location of the municipality of Monte Alto-SP



Source: The authors.

Monte Alto has a population of 46,642 inhabitants (IBGE, 2010). According to Koppen's classification (1948), the city's climate is humid subtropical, with a rainy period between October and March and a dry period between April and September. Its average annual precipitation is around 1419.44 mm (DAEE, 2021).

In addition, the terrain where the municipality is located, due to geological characteristics and soil types, is highly susceptible to surface dynamics, according to the Geotechnical Chart of the State of São Paulo (IPT, 1994), the Erosion Map of State of São Paulo (IPT, 1995) and the Mapping of Risk Areas Associated with Erosion in the Municipality of Monte Alto-SP (IG, 2008).

3.2 MATERIALS AND METHODS

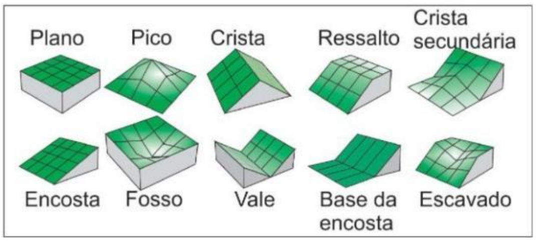
To determine the potential and emerging fragility, it was necessary to produce the following maps: floodplains, geomorphology, pedology, climate and land use and cover. To do so, the following operations were performed:

3.2.1 FLOOD PLAINS MAP

The floodplains were delimited based on the method used by Gouveia and Ross (2019), which consists of identifying ditches and valleys, which must be cut in regions where the slope is less than 2%. Generally, these plains are located close to water courses and are not associated with non-hydromorphic soils (JACOMINE, 2008).

Ditches and valleys are landforms, or geomorphons. The identification of geomorphons was based on the application performed by Jasiewicz and Stepinski (2013). The application is based on the use of the r.geomorphon tool, which can be found in the QGIS program (QGIS, 2021). This tool classifies the relief into ten types, which were represented in Figure 2.

Figure 2: Geomorphons classified using the r.geomorphon tool



Source: Robaina, Trentin and Laurent (2016).

As input to the methodology, a Digital Elevation Model (DEM) is required, in addition to the identification of two parameters for its use. The first is the radius, which is the maximum distance for angle calculations and the second is the relief threshold, which is the angle considered to determine the shape of relief in the analyzed area. Following the proposal of Jasiewicz and Stepinski (2013), for the radius, the value of 60 pixels (1800 meters) was applied and, for the relief threshold, the value of 2°.

The DEM used to generate the geomorphons was acquired from the Figures of the Shuttle Radar Topography Mission - SRTM (USGS, 2021) with a spatial resolution of approximately 30 m.

After their delimitation, the plains were assigned a specific level of fragility, entitled “Areas subject to flooding”, both for potential and emerging fragility, as proposed by Gouveia and Ross (2019).

3.2.2 GEOMORPHOLOGICAL MAP

The geomorphological map must be elaborated from the relief dissection indexes when the scale is less than 1:50,000 (ROSS, 1994), which is the case of the area of interest in this study.

For the elaboration of the Relief Dissection index map, the methodology proposed by Guimarães et al (2017) was used, which automates the index calculation using a Digital Elevation Model (DEM) and the ArcMap software version 10.3 (ESRI, 2013).

The DEM used to generate the Relief Dissection Index map was acquired from the SRTM Figures (USGS, 2021) with a spatial resolution of approximately 30 m. After elaborating the geomorphological map, it was classified based on the classes recommended by Ross and Fierz (2017).

3.2.3 PEDELOGICAL MAP

To assemble the pedological map, the pedological map of the state of São Paulo (ROSSI, 2017) was used, available in a shapefile at a scale of 1:100,000, available on the website: https://www.infraestruturameioambiente.sp.gov.br/institutoflorestal/2017/09/mapa-pedologico-do-estado-de-sao-paulo-revisado-e-ampliado/. State map data was specialized using ArcMap version 10.3 (ESRI, 2013). For the classification of soil data, the division suggested by Ross and Fierz (2017) was used.

3.2.4 WEATHER MAP

The rainfall variable map was developed from rainfall stations located in the municipality of Monte Alto-SP and in neighboring municipalities. The posts were obtained from the database of the Department of Water and Electric Energy (DAEE). Ross and Fierz (2017) classify the climate based on three parameters: rainfall distribution over the months, average annual precipitation volumes and the precipitation volume between the months of November and April.

The data present in the obtained spreadsheets were analyzed through annual and monthly averages. The data obtained and information for each station can be seen in Table 1.

Table 1: Pluviometric stations used in the presente study

MUNICIPALITY (EXTENSION OF THE HISTORIC SERIES)	Latitude	Longitude	DAEE PREFIX	AVERAGE ANNUAL VOLUME (mm)	MONTHS IN DRY PERIOD	PRECIPITATION VOLUME BETWEEN NOVEMBER AND APRIL (%)
vCândido Rodrigues (1941-2020)	21°19'32"	48°37'53"	C5-073	1320,96	7	79
Itápolis (1970-2020)	21°35'00"	48°49'00"	C5-093	1414,03	6	76
Jaboticabal (1963-2020)	21°19'59"	48°18'59"	C5-028	1410,00	7	78
Monte Alto (1941-2020)	21°15'31"	48°29'44"	C5-070	1419,44	7	78
Taiúva (1970-2020)	21°07'08"	48°24'49"	C5-113	1376,74	7	79
Taquaritinga (1970-2020)	21°28'00"	48°37'00"	C5-105	1324,89	6	77
Vista Alegre do Alto (1969-2020)	21°09'24"	48°37'44"	C5-092	1401,72	7	79

Source: The authors. Adapted from DAEE (2021).

All posts used in this study had the same behavior as shown below. Their average annual volume varies between 1300 and 1600 mm/year, so the fragility class of this parameter is average (3). The number of months in the dry period of the stations varies between 3 to 6, so the fragility class of this parameter is strong (4). The volume precipitated in the months between November and April varies between 70 and 80% of the total rainfall, so the fragility class of this parameter is strong (4). Finally, because two parameters classify the area as strong and only one classifies it as average, the climate map of the municipality of Monte Alto-SP was defined as highly fragile (4).

As all stations (and consequently, municipalities) presented the same behavior, it was not necessary to perform interpolations, since the map of the region has a single fragility value.

3.2.5 LAND USE AND COVERAGE MAP

The land use mapping was generated through the digital classification method, called supervised classification by regions, executed through the SPRING program version 5.4.3 (CAMARA et al, 1996). Current Figures from the Landsat 8 OLI/TIRS C2 L1 satellite, from February 2021, were taken from the same electronic site where the DEM was collected (USGS, 20210. The 4B5G6R color composition was used.

The spectral bands were inserted into the software and duly registered, and then contrast enhancement was applied to improve the visual quality of the Figures. Before starting the classification of land use and occupation from the Figures obtained, it was possible to evidentiate that the crops inserted in the municipality did not present forage between streets, which is one of the parameters used to classify crops in environmental fragility (ROSS and FIERZ, 2017).

In addition, the vegetation use and cover map prepared by the MapBiomas project (2019) for the site was analyzed, in order to better characterize the crops and pastures, as they are extremely important in environmental fragility (ROSS and FIERZ, 2017). Thus, it was possible to observe that the region's crops are mixed between crops of long and short cycle using conservationist practices, such as: sugarcane, mango, onion, lemon, orange, soybean, corn, among others (BACCARIN and SOUZA, 2012; MAPBIOMAS, 2019)

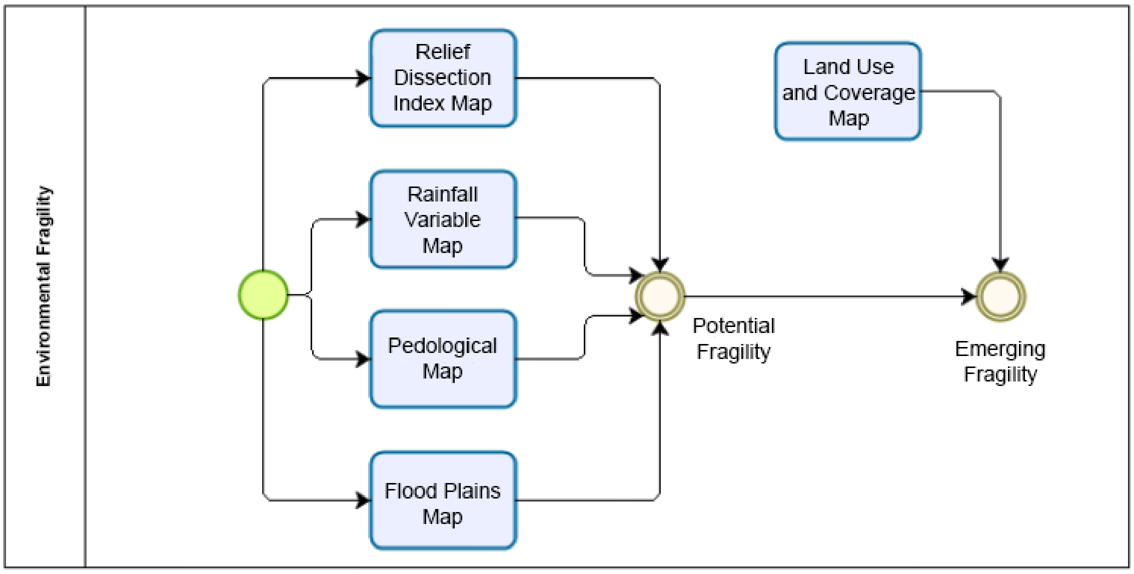
Subsequently, segmentation was performed, which aims to divide the Figures into spectrally similar regions. Similarity threshold 10 and area threshold 30 were used. Therefore, the classification by regions was performed using the Battacharya method. This step identified samples and trained the program to correctly identify the desired classes. Six sample classes were assigned according to the classification suggested by Ross and Fierz (2017): Primary and Secondary Forests, Low trampling pasture, Long and Short Cycle Cultivation without forage between Streets with Conservationist practices, Exposed Soil for Crops, Urban Areas and Water Bodies. It is noteworthy that these authors do not classify urban areas and water bodies, so these classes were classified according to Abrão and Bacani (2018).

The inconsistencies found in the final map were corrected based on the map prepared by MapBiomas (2019), which helped to identify the correct location of the pastures, a class of difficult training, since it generates confusion in the classification with the class of crops.

3.2.6 ENVIRONMENTAL FRAGILITY MAP

With all maps properly generated, map algebra was performed using the raster calculator tool of ArcMap version 10.3 (ESRI, 2013) to generate maps of potential and emerging fragility. Figure 3 presents the flowchart that was processed in the map algebra of this research, as recommended by Ross (1994) and Gouveia and Ross (2019). It is noteworthy that there was no weighting between the maps in the calculations for this method.

Figure 3: Flowchart of Environmental Fragility procedures



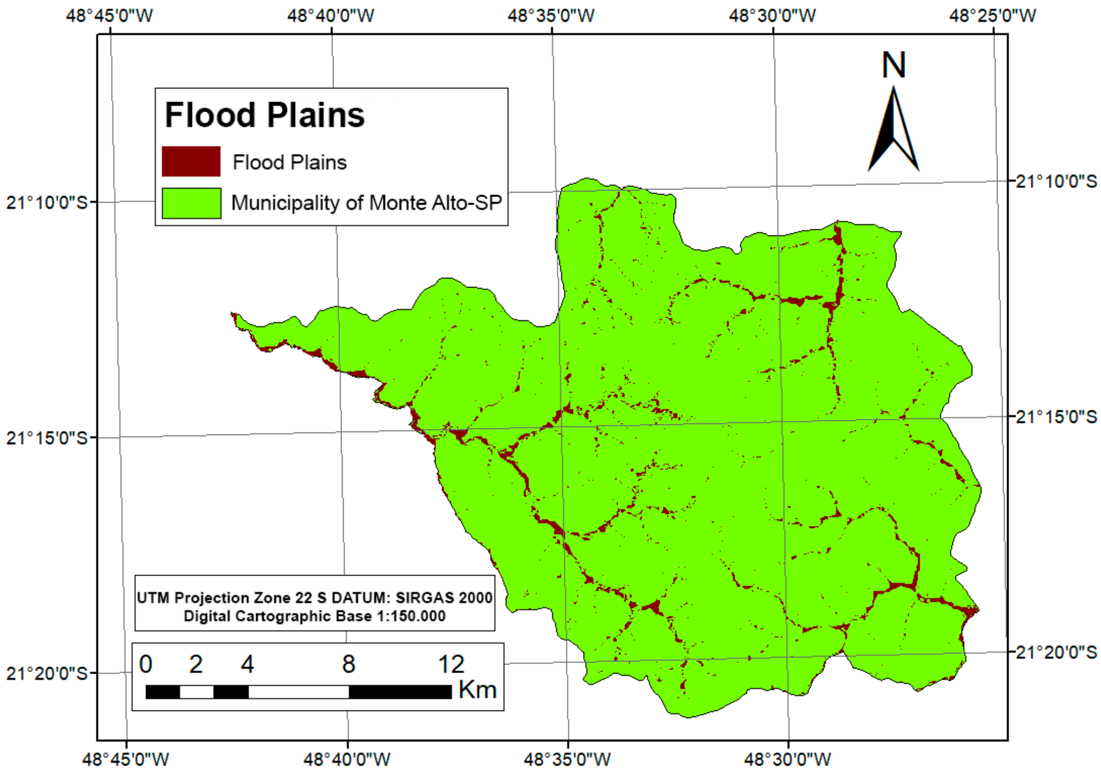
Source: The authors.

Finally, a registration of large-scale erosion processes was carried out with the aid of Google Earth PRO 7.3 (GOOGLE, 2021), aiming to calculate the erosion density by degree of fragility and conclude whether the method that was used correctly represents the reality from a linear coefficient of determination (R^2), according to the method employed by Gouveia and Ross (2019). According to Carneiro et al (2017) and Rodrigues et al (2019), using Google Earth for registration is extremely useful and effective in identifying erosions. The erosions obtained by the registration were added to the erosions identified by the Technological Research Institute - IPT (2012), in order to obtain more data for the density calculation.

4 RESULTS

Figure 4 shows the river plain mapped in the municipality of Monte Alto-SP. It is observed that the plain represents an area of 13.20 km², about 3.80% of the total area.

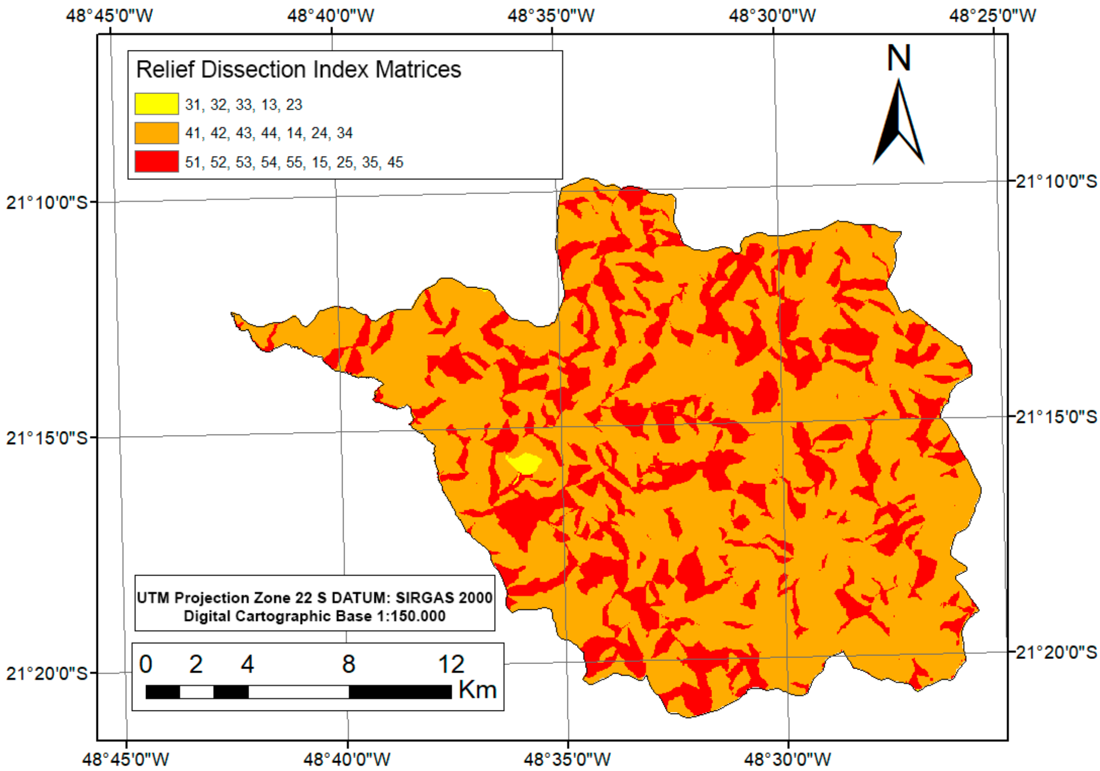
Figure 4: Fluvial plains in the municipality of Monte Alto-SP



Source: The authors.

Figure 5 shows the relief dissection index matrices for the municipality studied. Table 2 shows the matrices, their quantification and levels of fragility.

Figure 5: Relief dissection index matrices in the municipality of Monte Alto-SP



Source: The authors.

Table 2: Relief Dissection Index Matrices, Quantification and Frailty Classes

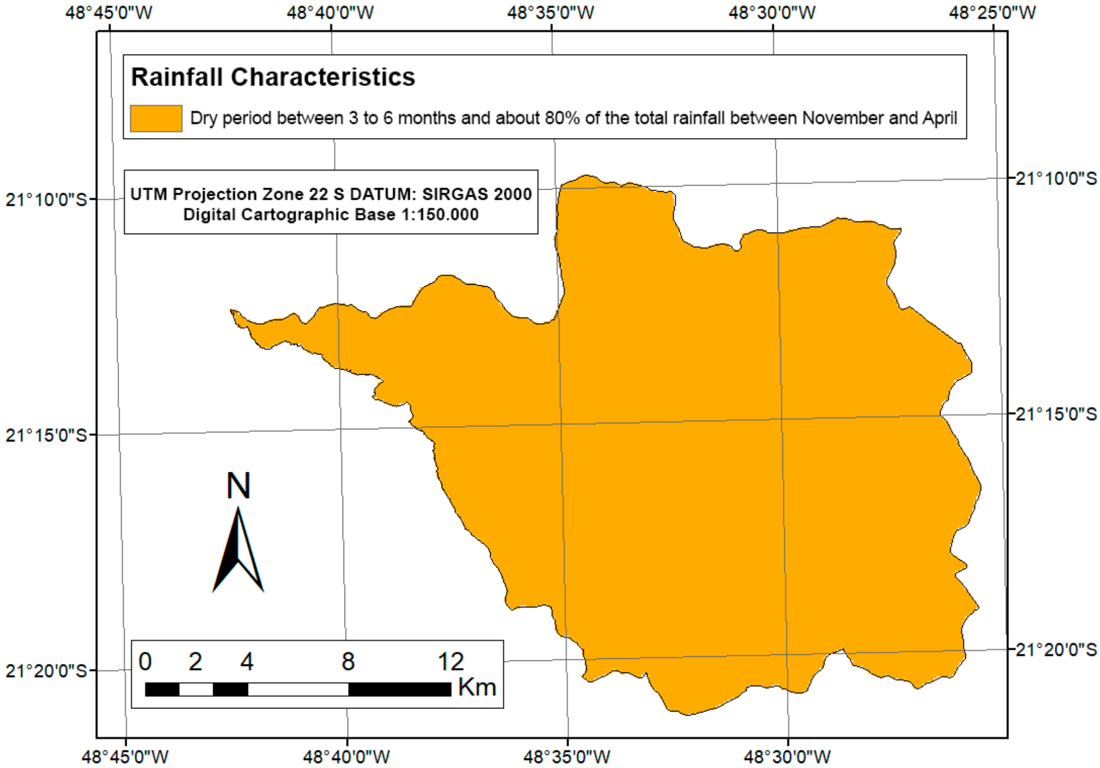
Relief dissection index matrices	Area (km²)	Porcentage (%)	Fragility Level
31, 32, 33, 13, 23	0,82	0,24	Average – 3
41, 42, 43, 44, 14, 24, 34	250,17	72,04	Strong – 4
51, 52, 53, 54, 55, 15, 25, 35, 45	96,26	27,72	Very strong - 5

Source: The authors.

It was possible to identify that about 99.76% of the municipality of Monte Alto-SP is composed of a relief with strong or very strong dissection, which translates into carving of valleys greater than 80 m and an average interfluvial dimension of less than 750 m (BERTOLINI and DEODORO, 2018).

Figure 6 shows the rainfall characteristic observed in the region, which characterizes the climate of the place with a class of strong fragility (ROSS and FIERZ, 2017).

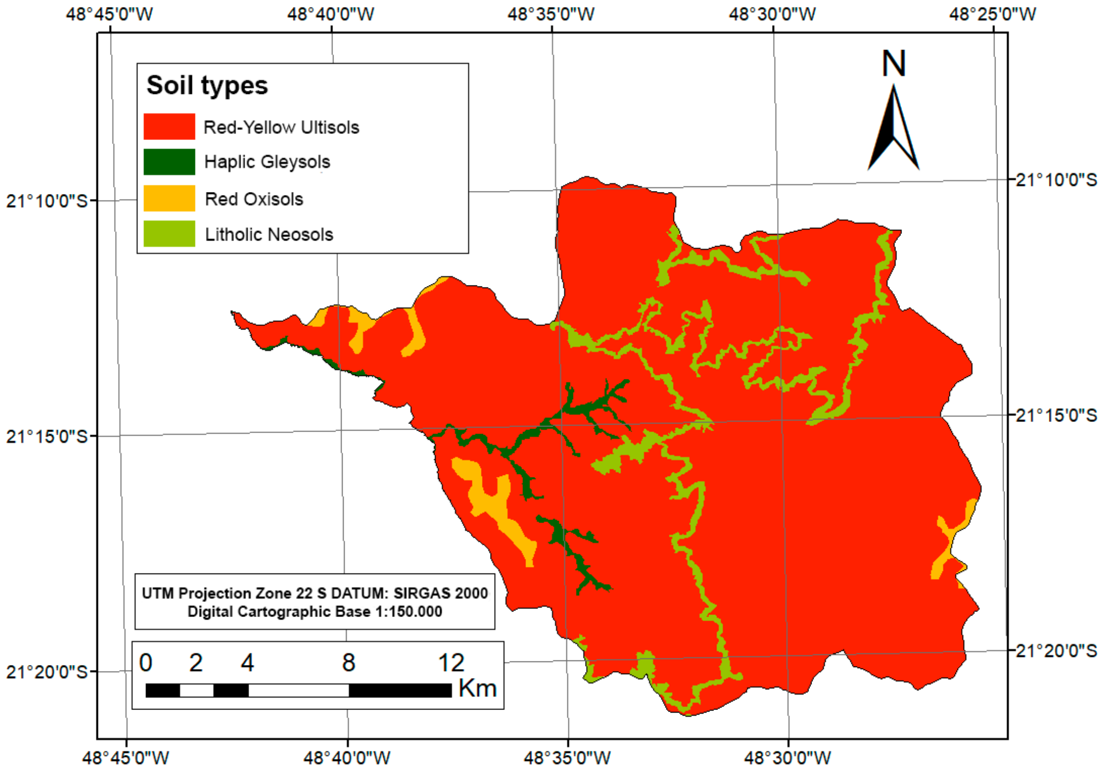
Figure 6: Rainfall characteristics of the municipality of Monte Alto-SP



Source: The authors.

Figure 7 shows the types of soil for the municipality studied. Table 3 shows the soils, their quantification and levels of fragility.

Figure 7: Types of soils in the municipality of Monte Alto-SP



Source: The authors.

Table 3: Soil types, quantification and fragility classes

Soil Types	Area (km²)	Percentage (%)	Fragility Level
Red Oxisols, Average Clay Texture	7,43	2,14	Weak – 2
Red-Yellow Ultisols, Average-Sandy Texture	312,52	90,00	Average – 3
Litholic Neosols, Average-Sandy Texture	21,15	6,09	Very strong – 5
Haplic Gleysols	6,15	1,77	Very strong – 5

Source: The authors.

Figure 8 shows land use and land cover for Monte Alto-SP. Table 4 shows the usage classes and land cover, its quantification and levels of fragility.

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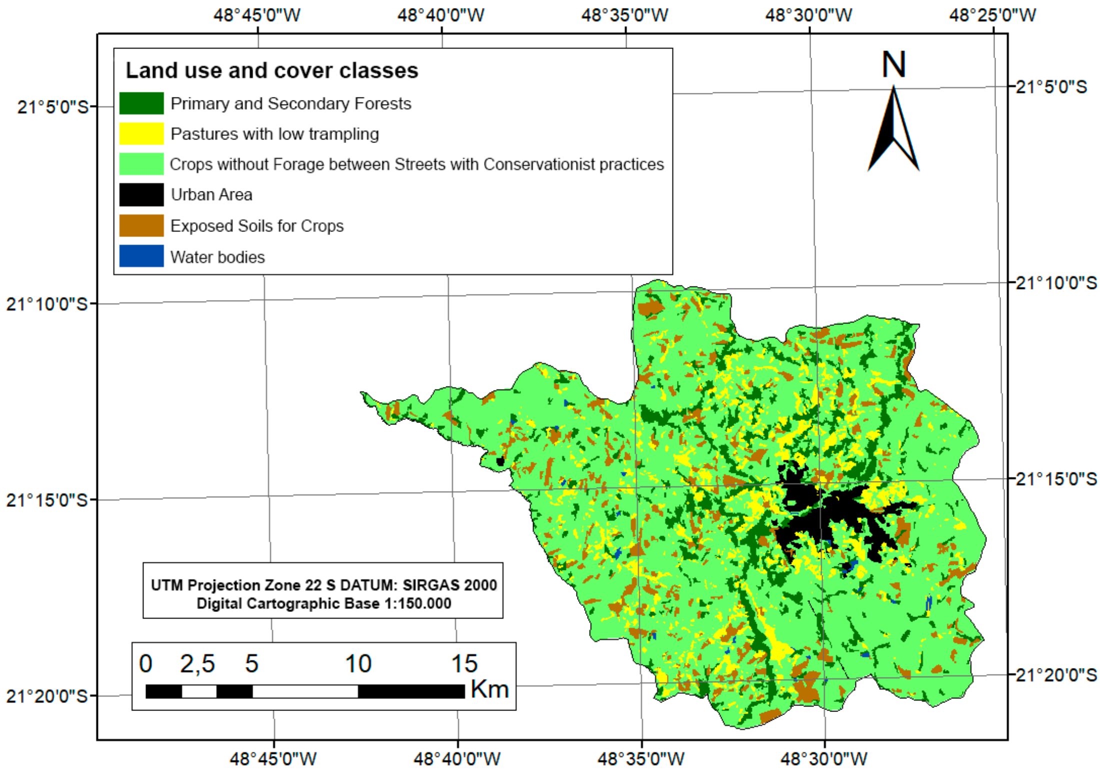
Figure 8: Classes of land use and land cover in the municipality of Monte Alto-SP



Source: The authors.

Table 4: Land use classes, quantification and frailty classes

Land use classes and vegetation cover	Area(km²)	Percentage (%)	Fragility Level
Primary and Secondary Forests	38,46	11,08	Very weak – 1
Pastures with low trampling	32,78	9,44	Average – 3
Crops without Forage between Streets with Conservationist practices	235,98	67,96	Strong –4
Urban Area	11,92	3,43	Very strong – 5
Exposed Soils for Crops	27,09	7,80	Very strong – 5
Water bodies	1,02	0,29	Very strong – 5

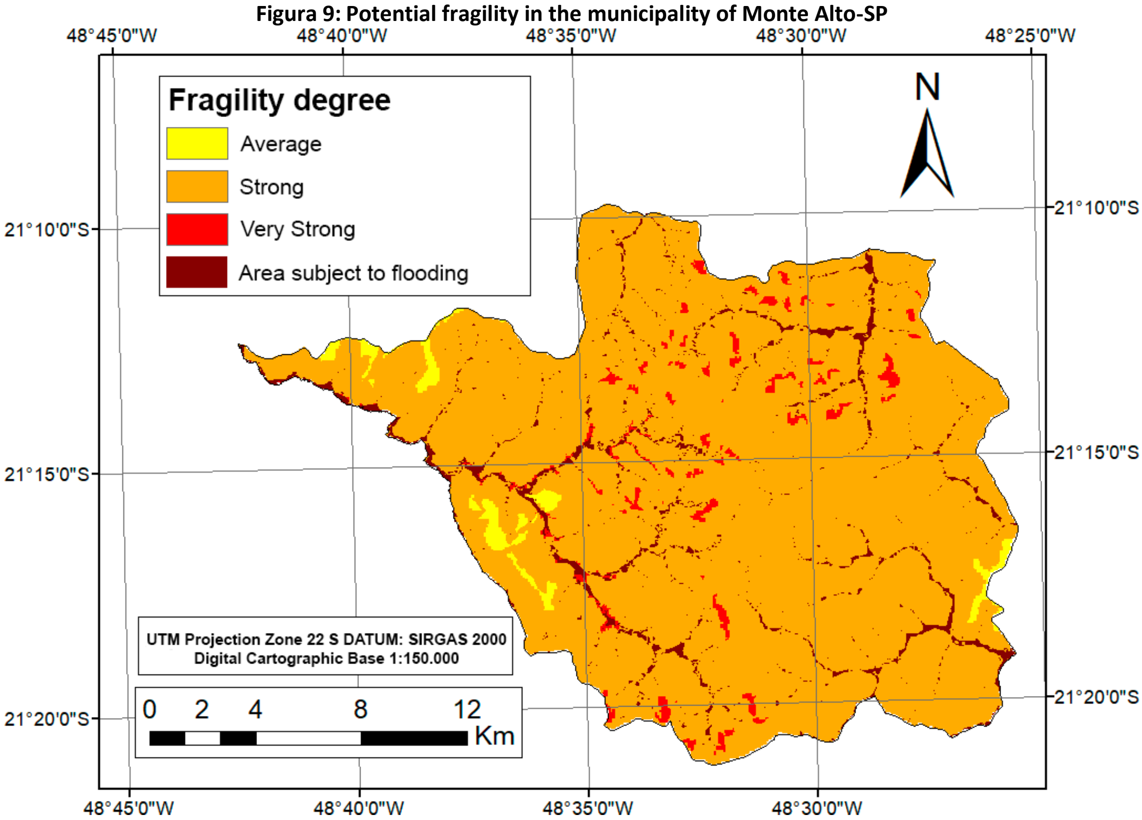
Source: The authors.

The municipality of Monte Alto-SP has an agrarian structure consisting of an expressive number of small rural establishments, with about 306 km² of area destined to different crops (BACCARIN and SOUZA, 2012). For this reason, it is noted that the classification was successful, since the sum of the Pastures, Crops and Exposed Soils classes (which make up the rural areas), in this classification, is worth 295.85 km².

Analyzing land use and occupation in areas subject to flooding, it was observed that about 85% of land use in these plains is related to agriculture (crops, pastures and exposed soils), which denotes high economic and environmental risk in these places.

Figure 9 shows the generated map of potential frailty. Table 5 shows the degrees of potential fragility, the areas subject to flooding and their respective quantifications.

Figura 9: Potential fragility in the municipality of Monte Alto-SP



Source: The authors.

Table 5: Quantification of potential fragility degrees and areas subject to flooding in Monte Alto-SP

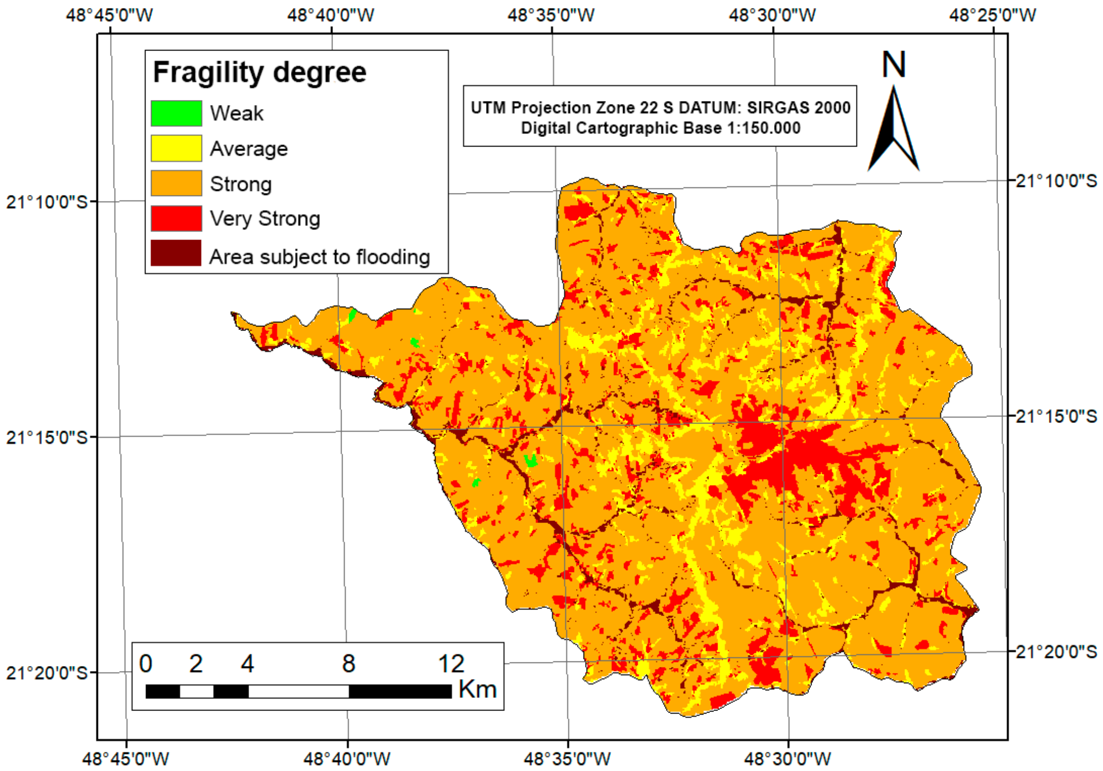
Potential fragility degree	Area (km²)	Percentage (%)
Average	5,90	1,70
Strong	320,47	92,29
Very strong	7,68	2,21
Areas subject to flooding	13,20	3,80

Source: The authors.

It was observed that the potential fragility that predominates in the municipality is the strong one, showing the high natural fragility of the terrain. Regions of average fragility are associated with Red Oxisols, while regions of strong and very strong fragility are associated with Gleysols, Neosols and high relief dissection rates. Areas subject to flooding were located close to water courses, in addition to not associating with non-hydromorphic soils in the region (neosols), as expected.

Subsequently, the emerging fragility map was generated. The developed map can be seen in Figure 10, as well as the numerical information can be seen in Table 6.

Figure 10: Emerging weakness in the municipality of Monte Alto-SP



Source: The authors.

Table 6: Quantification of emerging fragility degrees and areas subject to flooding for Monte Alto-SP

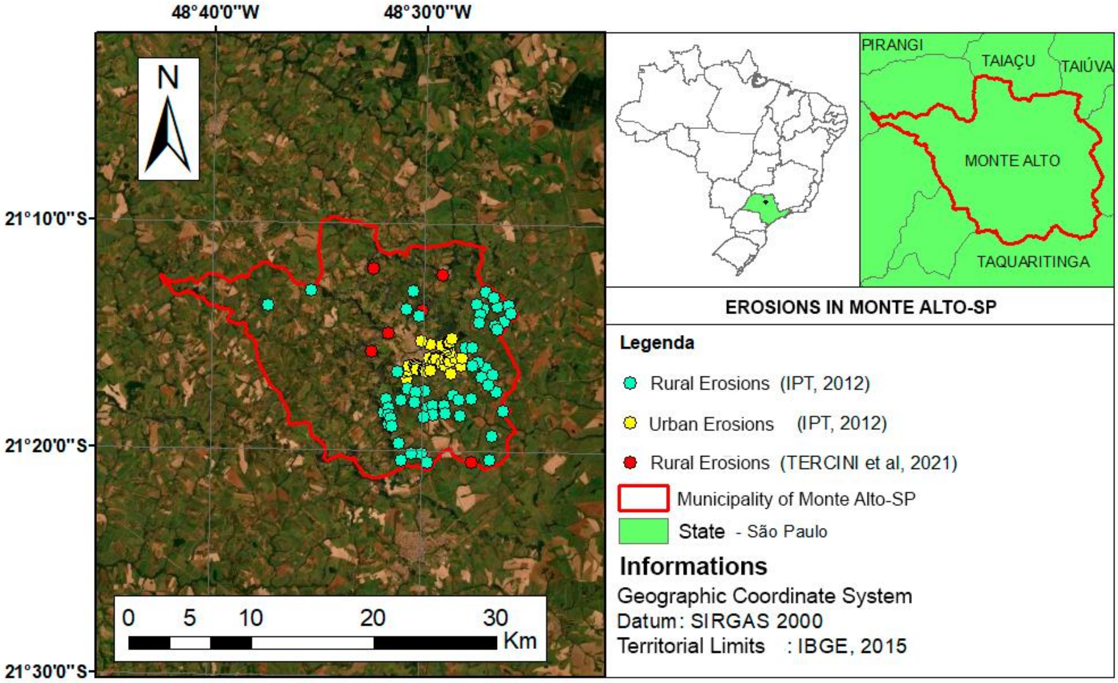
Emerging fragility degree	Area (km²)	Percentage (%)
Weak	0,42	0,12
Average	34,42	9,91
Strong	255,50	73,58
Very Strong	43,71	12,59
Areas subject to flooding	13,20	3,80

Source: The authors.

The degree of emerging fragility that predominated in the studied region was strong, as well as the potential fragility. It was possible to verify that the weak fragility only occurs in the areas that share the dissection classes of the average relief, acrisol and forests. Average fragility occurs in regions occupied by forests with strong and very strong relief dissection. Strong fragility occurs in most areas occupied by the crops and pasture classes, regardless of the relief and soil characteristics, and very strong fragility occurs in most areas occupied by the urban area, exposed soil and water bodies classes, regardless of the relief characteristics and the soil. Finally, the areas subject to flooding were mostly located in areas of high fragility, denoting that the analysis intrinsically indicated that these areas contain high fragility.

The identification of erosions by Google Earth and the erosions surveyed by the IPT (2012) were presented in Figure 11. There were several erosions surveyed by the IPT that coincided with those identified in this study and, for better visualization, these were presented as erosions by the IPT.

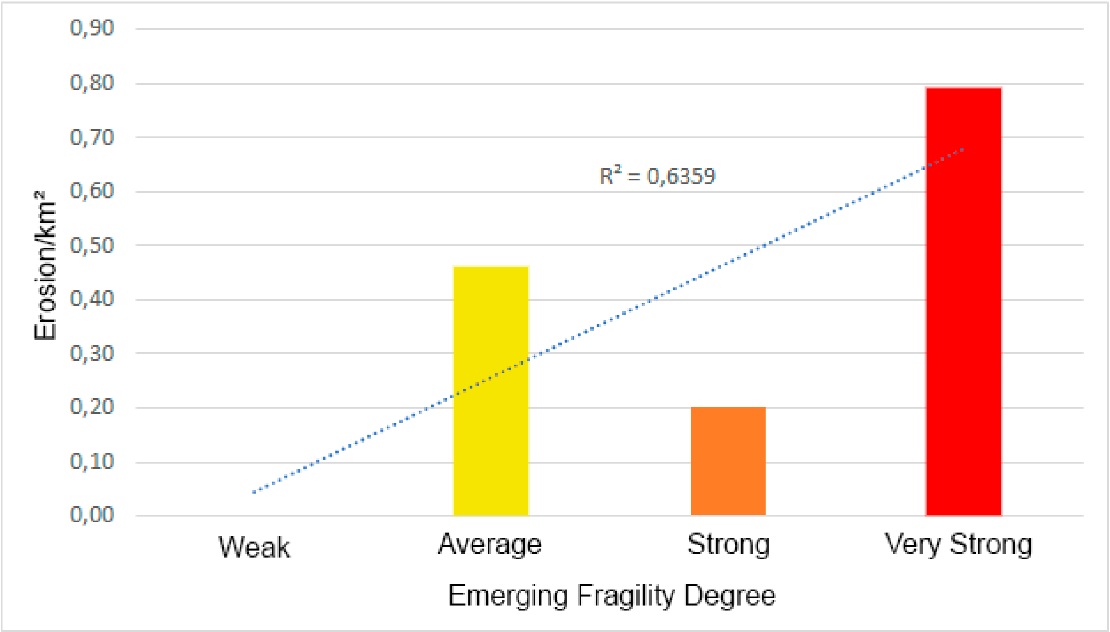
Figure 11: Great magnitude erosions surveyed and registered for the municipality of Monte Alto-SP



Source: The authors. Adapted from IPT (2012).

The calculation of erosion density for each emerging fragility class obtained was shown in Figure 12.

Figure 12: Erosion density for each degree of emerging fragility of Monte Alto-SP



Source: The authors.

The methodology used in this work showed good adjustments for the weak, average and very strong emerging fragility classes, however, the strong class did not conform to erosion density. Thus, the R^2 of the methodology used in this work was 0.6359.

The work of Pereira and Gouveia (2019) accepts values of $R^2=0.75$ as satisfactory, while the work of Gouveia and Ross (2019) argues that an $R^2=0.8427$ is considered acceptable, while R^2 lower than 0.3503 may have discrepancies. Thus, it is observed that the method developed in this research had satisfactory results.

With the results obtained through the emerging fragility and calculation of the density of erosive processes, it was possible to present proposals for an environmental zoning based on the use and occupation of the land. Chart 1 shows the proposals, which aim to ensure the conservation and environmental quality of natural resources in Monte Alto-SP.

Chart 1: Environmental zoning proposals for the municipality of Monte Alto-SP

Zone (Degree of Environmental Fragility)	Environmental Factors	Anthropogenic Factors	Diagnosis	Management and maintenance proposal
Low restriction use zone (Weak).	Presence of Oxisols and relief with strong dissection.	Not included.	Area with good environmental protection, as no erosive process was found in this region.	Introduction of crops with conservation practices and low pastures trampling.
Average restriction use zone (Average and Strong).	Presence of Neosols, Ultisols and Gleissolos and relief with strong dissection.	Pastures and Crops.	Area with average environmental protection, with erosion density ranging from 0.20 to 0.46 erosions/km².	Correctly handle pastures, keeping low trampling and maintaining conservationist practices in the crops.
Highly restricted use zone (Very Strong).	Presence of Neosols, Ultisols and Gleissolos and relief with very strong dissection.	Crops, Exposed Soils, Urban Areas and Reservoirs/Lakes.	Area with low environmental protection, with an erosion density of approximately 0.79 erosions/km².	Maintain conservationist practices in crops, replace exposed soils with crops and arboreal vegetation. It is recommended that urban expansion takes place in the north and northwest of the urban area, as these are regions with lesser weaknesses around the urban area.
Recovery zone for permanent preservation areas (Areas Subject to Floods).	Presence of Gleysols and Acrisol and relief with strong dissection.	Pastures, crops and exposed soil.	Area with low environmental protection, given the possibility of flooding.	Replace the use of anthropogenic land with arboreal vegetation, restoring preservation areas.

Source: The authors.

5 CONCLUSIONS

In general, the study obtained results that made it possible to verify that the municipality of Monte Alto-SP is located in a region where classes with greater environmental fragility predominate. It was observed that the predominant degree for potential and emerging weaknesses was strong.

Due to the dissection of the relief, the potential fragility is quite homogeneous and aggressive, distributed practically only in the degree of strong fragility. Because of this, the emerging fragility, for the studied region, is directly associated with land use and vegetation cover. Areas subject to flooding are located mainly in highly fragile regions. This showed that the method employed would properly classify these areas even if the floodplains had not been determined.

Finally, the results obtained from the use of geotechnologies and adapted methods of environmental fragility in the municipality of Monte Alto-SP proved to be effective and satisfactory. Based on the generated maps, proposals for environmental zoning were recommended based on suggestions for land use and vegetation cover to assist in the management and environmental quality of the region. As a recommendation for a future work, it is suggested that modified methods of environmental fragility be used in Monte Alto-SP to verify if any of them obtain a linear determination coefficient similar or superior to the one obtained in this work.

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