

ENVIRONMENTAL FRAGILITY TO LINEAR EROSION PROCESSES IN AN URBAN PERIMETER

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Abstract

The present work about the study of environmental fragility to linear erosive processes in the urban perimeter of Rondonópolis brings new adaptations and complements to the methodologies and models of environmental fragilities to erosive processes, especially those carried out in urbanized areas or with tendencies for urbanization. It was found that the proposed analysis model, integrating new geoenvironmental variables, indispensable for the holistic diagnosis of urban-environmental systems, characterized the loss of material by linear erosion in the current scenario in a more coherent way.

Keywords: Environmental Fragility; Linear Erosive Processes; Urban-Environmental Systems

Resumo / Resumen

FRAGILIDADE AMBIENTAL A PROCESSOS EROSIVOS LINEARES EM PERÍMETRO URBANO

Este trabalho acerca do estudo da fragilidade ambiental a processos erosivos lineares do perímetro urbano de Rondonópolis traz novas adaptações e complementações às metodologias e modelos de fragilidades ambientais a processos erosivos, sobretudo aqueles realizados em áreas urbanizadas ou com tendências à urbanização. Verificou-se que o modelo de análise proposto, integrando novas variáveis geoambientais, indispensáveis ao diagnóstico holístico dos sistemas urbano-ambientais, caracterizou de forma mais coerente a perda de material por erosão linear no cenário vigente.

Palavras-chave: Fragilidade Ambiental; Processos Erosivos Lineares; Sistemas Urbanos-Ambientais.

FRAGILIDAD AMBIENTAL A PROCESOS EROSIVOS LINEALES EN UN PERÍMETRO URBANO

Este trabajo sobre el estudio de la fragilidad ambiental a procesos erosivos lineales en el perímetro urbano de Rondonópolis trae nuevas adaptaciones y adiciones a metodologías y modelos de fragilidad ambiental a procesos erosivos, especialmente aquellos realizados en áreas urbanizadas o con tendencia a la urbanización. Se encontró que el modelo de análisis propuesto, integrando nuevas variables geo-ambientales, indispensables para el diagnóstico holístico de los sistemas urbano-ambientales, caracterizó de manera más coherente la pérdida de material por erosión lineal en el escenario actual.

Palabras-clave: Fragilidad Ambiental; Procesos De Erosión Lineal; Sistemas Urbano-Ambientales.

INTRODUCTION

The environment, built and natural, of cities is a space that has an intentional political occupation, both by the State and by society, inserted in the areas of occupation and expansion in a functional and hierarchical way. In this sense, nature is seen as a resource and as a use value for the production of new spaces, transforming them into urbanizable areas (PENNA, 2002).

Various types of environmental analyses applied in urban areas have emerged in Brazil, with a focus on urban planning, both in unoccupied territorial portions and without installed infrastructure, as well as in places already occupied with a partial or total urban infrastructure (SOBREIRA; SOUZA, 2012).

Regarding the understanding and investigation of the processes of integration of society with the physical-natural environment, derived from applied geomorphology, some methodologies for mapping susceptibilities to natural risks applied in Brazil stand out, among them, the geo-environmental zoning diagnoses, vulnerability natural to soil loss, environmental fragility and geological-geotechnical mapping, the latter requiring fieldwork with measurements and specific instrumentation, demanding higher costs and logistics. These methods have in common integrated analysis of processes, which are mappable according to the scale of the event being investigated and the demand for forecasting the risk, threat or susceptibility. In general, they identify areas predisposed to processes of instability in the physical environment, such as flood events, mass movements, erosion processes, mud and debris runs, soil settlements, landslides, earthquakes, etc.

Urban expansion is a phenomenon that has been occurring in several regions of Brazil, mainly in municipalities that had their emancipation late (from the second half of the 20th century) and were encouraged to enter the commodity production circuit, mainly focused on the supplying international demands in order to achieve a balance in the internal trade balance. In this context, the municipality of Rondonópolis assumes relevant importance in the development of the Brazilian agroindustrial economy, in addition to functioning as a service offering hub in the south and southeast regions of Mato Grosso.

The urban perimeter of this municipality is located between the geographical coordinates SIRGAS 2000 $16^{\circ} 22'30''$ and $16^{\circ} 45'00''S$ and $54^{\circ} 43'30''$ and $54^{\circ} 31'30''W$, in relation to the 45° meridian west of Greenwich, or 745000 and 8149000 to the southwest and 765000 and 8186000 to the northeast in SIRGAS 2000 metric coordinates (Figure 1).

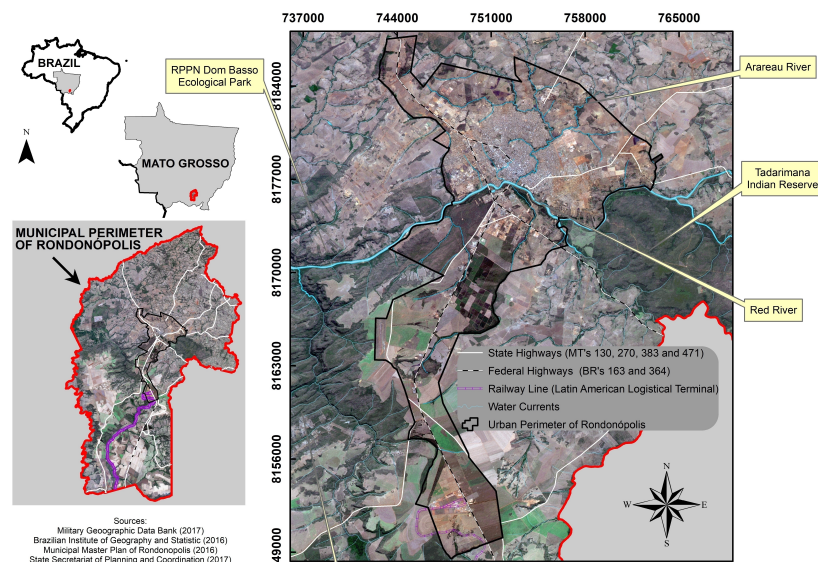


Figure 1 - Location of the study area. Source: Guirra (2017).

The area of this perimeter is approximately 305 km², located in the southeastern region of Mato Grosso, the municipality is approximately 215 km from the capital Cuiabá via the BR-163 / BR-364 highway, bordering the municipalities of: Itiquira, to the south; Pedra Petra and São José do Povo to the

east; Poxoréu and Jucimeira to the northeast and northwest; and Santo Antônio do Leverger to the west.

Based on this theme, Rondonópolis, a medium-sized Brazilian city with approximately 220,000 inhabitants (IBGE, 2017), is characterized by a typical example of low-eco-efficient urbanization (SANTOS et al, 2016), expanding due to the excessive progress of speculative real estate capital on non-urbanized green areas, as well as the limited control of the environmental agencies (departments, secretariats and agencies) responsible for the ordering of territorial occupation, printing various forms of impacts on the urban ecosystem, especially on the water bodies that make up the urban perimeter, whether superficial or underground (CASARIN, 2003; ALBACETE, 2008; CUTRIM; CAMPOS, 2010; SANTOS, 2010).

Based on the above, the present work had the central objective of carrying out an integrated analysis of the environmental fragilities of the urban perimeter of Rondonópolis (PUR), considering the methodology proposed by Santos and Ross (2012) and adapting it to the urban-environmental context of this study area. For that, complementary themes were used, among them: erosivity, geology, density of structural lineaments and density of intersections of lineaments, in order to weigh in this diagnosis, important integral elements of the physical environment used in other methodologies of multithematic nature with a plan of hierarchical spatial information.

The importance of the feasibility of the present work was supported by the need to review the Participatory Master Plan for Urban and Environmental Development of the Municipality of Rondonópolis, established by Complementary Law No. 043, of December 28, 2006, which, after the deadline of 10 (ten) years, with the changes that have occurred in this territory, we seek to adapt the demands for planning and management, integrating diagnoses in accordance with the current reality.

THEORETICAL-METHODOLOGICAL FOUNDATION

The level of fragility of the environments, based on their morphodynamic characteristics, is processed according to empirical analysis criteria, understood from the epistemological principles governed by Ecodynamics, originally postulated by Tricart (1977), where this author establishes classifications on three morphodynamic levels which are: stable means, integrated means (intermediate or transition) and unstable means.

The classification of environments with ecodynamics as the starting point of the evaluation, expresses the behavior of the terrain and its susceptibility to the risks of installation or evolution of erosive processes in the terrain, depending on the intensity of natural phenomena, the frequency and the interaction of current evolutionary processes, the latter pondered through the levels of urbanization and the degree of coverage and protection of the soil.

In other words, the concept of Ecodynamics based on Tricart (1977), is an empirical, systemic evaluation model, originally qualitative and cartographic, which spatially divides Territorial Units based on the dynamic balance between pedogenesis and morphogenesis in continuous flow in environments, from past to current environments, classifying them according to degrees of environmental stability / instability. This fundamental is based on the understanding that in natural systems there are constantly exchanges of energy and matter, developing dynamic equilibrium relationships, thus proposing an integrated analysis in the determination of Ecodynamic Units. Thus, Tricart (1977) ponders:

“The application of the concept concerning the pedogenesis / morphogenesis balance is apparent, as long as it is a superficial ablation of the soil. Nevertheless, the concept also applies to mass movements that affect the soil in all its thickness” (TRICART, 1977, p. 48).

The concept and conception of Ecodynamics is integrated with the concept of ecosystems, which have become fundamental to establish the theoretical foundation of what today presents itself as diagnoses of ecological-economic zoning (EEZ's) in Brazil. In this context, attention is called to the role played, primarily, by the Brazilian Institute of Geography and Statistics (IBGE) in the 1970s, with the use of this methodology to prepare some of the first regional management and planning documents, which served preliminary logistical support to meet the country's demand in full expansion of agricultural frontiers and strongly rising demographic growth, combined with the rural exodus at that

time.

Stable media, or even Stable Ecodynamic Units, are characterized by slow evolution, in conditions where phenomena of exogenous and endogenous origin act weakly, combined and for some cases individually. In this case, pedogenesis is favored over morphogenesis, which according to Tricart (1977) are identified in regions of high biotic influence, with a predominance of soft relief and in areas of weak aggressiveness in the performance of mechanical agents, where there is a predominance infiltration to the detriment of the superficial laminar flow. In conditions of stability, there is also dense vegetation cover and agricultural practices favorable to soil conservation. In these territorial units, the environment is in dynamic balance and is spared from depredating human actions, being, therefore, in a natural state, regenerated or subtly modified.

According to this author, the morphodynamically stable means are in regions endowed with a series of conditions, the main ones being listed by him:

- a) "Vegetation cover sufficiently closed to oppose an effective brake to trigger the mechanical processes of morphogenesis."
- b) "Moderate dissection, without violent incision of water courses, without vigorous sapping of rivers, and slopes of slow evolution."
- c) "Absence of volcanic manifestations that could trigger morphodynamic paroxysms of more or less catastrophic aspects" (TRICART, 1977. p. 36).

In the intergroup environment, actions that favor both pedogenesis and morphogenesis are processed in the current dynamics, promoting a sensitive balance between stability and instability and forming a continuous series where the rupture is arbitrary, as emphasized by Tricart (1977). In this environment, the interactions between morphogenetic and pedogenetic processes play an important role and can be easily changed by land use interventions and practices. Thus, Tricart (1977) makes some considerations, distinguishing two common cases that occur on a global scale, when morphogenesis goes a little beyond pedogenesis, being:

- a) "Superficial film morphogenesis (rain erosion, diffuse runoff, crawling, for example). The soil undergoes superficial ablation, but expands at the base. It is one of the most demonstrative cases of the application of the concept of pedogenesis / morphogenesis balance."
- b) "Morphogenesis by shallow, generalized or localized mass movements (two variants): laminar solifluxion or in the form of intrumescence. The pedological profile is affected" (TRICART, 1977, p. 97).

Unstable Ecodynamic Units are subject to soil erosion, where the intrinsic characteristics of each type of soil related to its morphological character and its position in the landscape will dictate its behavior, considering its uses and ways of handling it, making it possible to diagnose the propensity from these to physical deterioration, giving them low resilience and making their post-disturbance recovery capacity sometimes irreversible (TRICART, 1977; CASTRO; HERNANI, 2015).

In this sense, Tricart (1977) distinguishes recurrent and/or frequent localized phenomena as being those that can instigate both denudation/ablation and accumulation environments, where in the first, the main process is the flow, with incision of erosive grooves that tend the final evolution for the voçorocamento process in more extreme cases, while for the second, there is the contribution of crude mineral material, commonly sterile, not allowing the development and or fixation of plants, as occurs in the silting events of the water bodies or in sandstones.

The evaluation of the Stable, Intergrades and Unstable Ecodynamic Units, conditions the valuation of some attributes and characteristics presented by the ecosystem, initially in an isolated way and, later, integrating the themes (geomorphology, soils, climate, among others) allowing an analysis and overall perception. Thus, fundamental concepts related to ecology are considered, such as the ecosystem, which according to Odum (1985) apud Guapyassú and Hardt (1998) is configured in the

interaction and dynamics of biotic and abiotic factors. These authors call attention to the fact that, among the biotic factors, man should not be forgotten, his interferences and the degree of modification that they cause to ecosystems, considering urban ecology as one of the branches of current ecological science.

It is evident that the evaluation of Ecodynamic Units when taking into account each of the factors that condition the current environment to processes acting in the physical environment also allows to mathematize, through deliberation, their interactions, evidencing among these factors, which or which have greater influence in the instability of these units with greater effectiveness and or intensity. At this juncture, it must be guided by the type of activity that is to be implemented, consisting of the fundamental point of the work philosophy, the benchmark of the evaluation, which needs to be as objective as possible, eliminating the character of subjectivity, except when it results in judgment based on the experience of the technical staff involved (GUAPYASSÚ; HARDT, 1998).

One of the creators of these analytical and multithematic cartograms suitable for integrated assessment of classes and categories of factors such as development, soil, climate, land use and occupation, vegetation cover, among others was Ross (1994), promoting a new perspective on what until then was done on environmental analyses in Brazil, now carried out with a qualitative and quantitative approach of several physical attributes of the landscape, as described below:

“The integrated studies of a given territory presuppose an understanding of the dynamics of the functioning of the natural environment with or without the intervention of human actions [...] occupation that guides the development and appropriation of the territory and its resources.” (ROSS, 1994, p. 64)

In this context, the diagnosis of environmental fragility emerges as an effective technical-scientific apparatus in promoting planning and management tools, and can even be used to subsidize geoenvironmental and socioeconomic zoning of various types, such as in hydrographic basins, in the installation of hydroelectric plants, in the construction of dams, in the opening of linear works and in the expansion of urban or agrarian areas. This is an important and advantageous tool in the identification of priority areas for environmental recovery, not replacing, however, field analysis for the validation of its' model.

The Environmental Fragility (EF) methodology originally developed by Ross (1994) integrates the result of the combination of the synthesis maps of potential fragility (PF) and emerging fragility (EF). The study of Potential Fragility is the result of the spatial analysis of thematic maps of geomorphology (considering the index of dissection of the relief or slope), soils and climate, while the emerging fragility map is the product of the overlapping of the maps - Potential Fragility and use and occupation from soil.

The hierarchy of the resulting fragilities is expressed in alphanumeric codes: very weak (1), weak (2), medium (3), strong (4) and very strong (5), which spatially represent the fragility of the environment in relation to the processes caused by the diffuse and concentrated runoff of rainwater (FRANCO; HERNANDEZ; LIMA, 2013). With the use of geotechnologies and the algebraic map tool available in the Geographic Information Systems (GIS) environment, Ross (1994) manages to solve a problem posed by Tricart (1977) when he stated:

“From a quantitative point of view, we rely on the pedogenesis/ morphogenesis balance. Since instability is weak, pedogenesis gains an advantage with a whole series of transition terms for stable environments. As in soil mechanics, the distinction between stable and intergrated means could only be conventional, but this would require numerical criteria that are yet to be defined. It remains to be seen whether this will be possible. Here, too, the transition is continuous and problems arise” (TRICART, 1977, p. 48).

Motivated to diagnose environmental fragilities in areas already effectively urbanized, Santos and Ross (2012) promote a methodological adaptation in relation to the hierarchical categories of slope and soil fragilities previously diagnosed in primarily rural areas, considering in this new model the effects of urbanization, as well as they overlapped another class called: degrees of fragility in relation to the level of urbanization.

For the soil fragility classes, Santos and Ross (2012) understood the need to qualify the different types of soils in view of the influence of various stages of urbanization, taking into account that many of these were altered by landfills and compaction and/or are overlapped by asphalt waterproofing, directly changing their geotechnical behavior in the face of weather conditions or civil constructions. When implementing the class of fragility regarding urbanization, the authors understood that the main factors that rank this variable are the intensity of runoff, the possibility of infiltration and drainage, natural susceptibility to flooding of the lowered areas or the possibility of mass movements.

Thus, Santos and Ross (2012) complement the information acquired by Ross (1994), Araújo et al. (2005) and Santos (2006) in the understanding that it is possible to determine new typologies derived from the combination of the use and occupation of the territory associating them to the conditions of infrastructure with aspects of the natural environment. These authors find that, with the adaptations that have been made to analyses of environmental fragility, they are important instruments for assessing the physical-natural environment, including socio-environmental transformations. Among other factors, the increase in urbanization levels may also provide technical subsidies for the realization of more inclusive planning, capable of minimizing socio-spatial inequalities.

METHODOLOGICAL PROCEDURES

The spatial databases used were available on government platforms, such as: National Water Agency (ANA), Alaska Satellite Facility (ASF), Ministry of Environment (MMA), State Secretariat for Planning and Coordination (SEPLAN-MT), Geological Survey of Brazil (CPRM), and Rondonópolis City Hall (PMR).

It is noteworthy that the cartographic base produced in the present study reached a regional representation level of 1: 250,000, due to the use of soil and geology charts that cover Folha SE-21-X-B (Rondonópolis). However, the spatial resolution worked on free satellite images (CBERS-4) and radar (ALOS PALSAR), after treatment, reached a spatial resolution of 05 meters, which allowed the refinement of the thematic and synthetic products generated.

In the spatialization of classes and degrees of fragility of the environments, both in thematic and synthetic cards, the representation of choroplethic letters / maps was adopted as a semiological device for apprehending the real, using the boolean gradient of semaphoric colors (Table 1).

CLASS	DEGREE OF FRAGILITY OF COLOR PALETTE SATURATION			
	RED	GREEN	BLUE	COLORS
VERY HIGH/VERY STRONG	255	0	0	
HIGH/STRONG	255	192	0	
MEDIUM	255	255	0	
LOW/WEAK	146	208	80	
VERY LOW/VERY WEAK	84	130	53	

Table 1 - Color palette consecrated in the representation of the fragilities of the environments. Source. Guirra (2017).

Ross (1994), in the definition of the fragility of the relief, in medium and small scales, originally follows as a parameter the definition of the shape patterns with the topographic roughness or the matrix of the relief dissection indices, which is calculated by the relation between the average interfluvial dimension in the horizontal plane and the degree of notching of the thalwegs in the vertical plane. While, for investigations that require a higher level of detail, the author proposes the use of classes previously established in agricultural aptitude studies associated with those known as critical geotechnical values, which express the intrinsic risks of the occurrence of mass movements, such as such as: landslides, mud flows and debris or frequent flooding, among others (SANTOS; ROSS, 2012).

In these cases, the author referred to the possibilities of preparing morphometric documents that can be generated from the radar image of PROJETO RADAM BRASIL (MIRANDA, 2005), where originally the spatial resolution is 90 meters, not envisioning future possibilities with the increase in the spatial resolution of radar images and/or the use of geostatistical interpolators suitable for the treatment of altimetric data (MARCUIZZO et al., 2011).

In the present study, an ALOS PALSAR radar image (FBD mode, double polarization of thin beam) of 12.5 meters of spatial resolution was used, which enabled the generation of level curves equivalent to topographic maps of 1:100,000, as demonstrated by Gonçalves (2010), when analyzing the feasibility of topographic mapping in the Amazon region (Serra dos Carajás) through the integration of altimetric information SRTM-3 and planimetric PALSAR.

The definition of the slope classes as well as the degrees of fragilities adopted is shown in Table 2.

DECLIVITY (%)	CLASS	DEGREE
0.0 to 3.0	VERY WEAK	1
3.0 to 8.0	WEAK	2
8.0 to 16.0	MEDIUM	3
16.0 to 30.0	STRONG	4
> 30.0	VERY STRONG	5

Table 2 - Hierarchical slope categories (%), best suited to the specificities of the PUR, with class assignments and degrees of fragility to erosive processes. Based on Santos and Ross (2012) and adjusted to the study area. Source. Guirra (2017).

Next, we proceeded with the association of classes and degrees of environmental fragility associated with the curvatures of the slopes (horizontal and vertical), which demonstrate how the different flows of surface runoff result in different erosivity potentials in the terrain. The operational tool used was the Curvature (3d Analyst), the input raster file being the MNT from ALOS PALSAR, resampled to 5.0 meters of spatial resolution by the top to raster interpolation method used after slicing. In the Curvature window, the creation of vertical (profile) and horizontal (plan) curvatures was selected. It is necessary to perform curvature tests manually, using the histogram, considering three classification intervals for each of the curvatures in Symbology> Classified> Classify.

LAND CURVATURE		HYDROLOGICAL BEHAVIOR ON THE LAND SURFACE		FRAGILITY	
HORIZONTAL	VERTICAL	DOMINANT FLOW	RESULTING FLOW	DEGREE	CLASS
CONVERGENT	Concave	CONCENTRATION	Hyperconcentrator	5	Very High
	Retilinear		Mesoconcentrator	5	Very High
	Convex		Hyperconcentrator	4	High
PLANAR	Concave	TRANSITION	Mesoconcentrator	4	High
	Retilinear		Transition	3	Medium
	Convex		Mesodispersor	2	Low
DIVERGENT	Concave	DISPERSION	Hyperdispersor	2	Low
	Retilinear		Mesodispersor	1	Very Low
	Convex		Hyperdispersor	1	Very Low

Table 3 - Association between terrain forms with classes and degrees of fragility, parameterized according to the flow resulting from surface runoff. Source. Guirra (2017).

The minimum and maximum and for the planar and rectilinear surfaces, the range of values from -0.14 to 0.14 and -0.24 to 0.24, respectively, was considered. After this stage, the representative ranges

of the shapes of the slopes (vertical and horizontal) were reclassified, informing the values 1, 2 and 3 for each one. With this, the two matrix files generated informing three classes are combined, providing the indication of the shape of the relief per cell unit (pixels), generating a file of nine classes. This step was developed using the Combine tool from 3d Analyst. Table 3 shows the classes and degrees of weakness adopted.

For the elaboration of the soil chart of the PUR, the State Planning Secretariat of Mato Grosso (SEPLAN-MT) was obtained together with the vector files resulting from mapping performed on a scale of 1: 250,000. These data were edited in the ArcGis 10.1® GIS environment, where, from the delimitation of the study area, the polygons of the types of soils existing in the PUR were delimited.

After the previous procedure, the soil fragility classes were defined based on the proposal of Santos and Ross (2012), which consider how the different stages of urbanization interfere in the classification of the intrinsic fragility to the soil (Table 4).

TYPE OF SOIL AND URBANIZATION LEVEL	CLASS	DEGREE
LEd1 LEd7 - RED LATOSOLS Argisolic eutrophic, Typical Eutrophic RED LATOSOLS and RED-YELLOW LATOSOLS Argisolic dystrophic. Soils located preferably in sectors with a low degree of urbanization contained in areas of low to medium declivity.	Very Low	1
LEa2 - Typical Eutrophic RED LATOSOLS. Soils located in sectors of effectively consolidated urbanization and places for industrial activity, with moderately efficient drainage, with predominance of waterproofing by asphalt and concreting, presenting low to medium declivity, with low to medium presence of equipment for flood control, infiltration and reduction flow in circulation routes, subdivisions and establishments.	Low	2
PVe2 PVe7 - RED-YELLOW ARGISOLS Latosolic eutrophic and RED-YELLOW ARGISOLS Abrupt abrupt plintolic. Very low to very high slope locations. Existence of drainage heads in the upper third of dissected hills with converging concave slopes. Low efficiency in urban drainage and high rate of unpaved roads with compacted soils. Cattle grazing / trampling can occur, with siltation and mass movement of the crawling and repression of soils on the banks of water courses being common.	Medium	3
THE URBAN REALITY OF PUR DOES NOT APPLY / IS NOT COMPATIBLE	High	4
Ra1 AQa2 AQa5 - Fragmentary dystrophic LITHOLIC NEOSOLS. Typical dystrophic NEOSOLS, QUARTZARENIC NEOSOLS Ortics and RED-YELLOW LATOSOLS Humic hybrids superimposed on sandstone and siltstone substrates, with rocky outcrops, in addition to alluvial deposits, confined in the river valleys of the Red and Arareau rivers. Unconsolidated urban network with exposed soil in an industrial area with a high flow of large vehicles. Cultivation of short cycle crops, predominantly soy or corn in addition to eucalyptus. Soils remobilized by human activity and or mass movements on the banks of the Red River. Water-saturated (hydromorphic) and / or friable / powdery soils occur when dry. Low to very high slope locations.	Very Strong	5

Table 4 - Relationship between classes and degrees of environmental fragility of soils considering the effects of urbanization. Based on SEPLAN-MT (2011) and Santos and Ross (2012). Source. Guirra (2017).

For the characterization of the climatological aspects of rain, data were obtained free of charge, made available by the hydrometeorological network of the National Water Agency (ANA, 2016) through the National Water Resources Information System (SNIRH), aggregating data from 12 stations, adding to the data of more 03 pluviometric stations collected by Sette (1996), in his master's dissertation, totaling 15 pluviometric stations, which cover part of the southeast and central-south region of Mato Grosso. The value of rainfall intensity according to Crepani et al. (2001) is obtained by dividing the average annual rainfall (in mm) by the length of the rainy period (in months), and for the state of Mato Grosso, Marcuzzo et al. (2011) determined the wet season in 6 months (October to March). The interpolation of the pluviometric intensities was performed using the method of isoetes available in the Geographic Information System (GIS) ArcGis 10.1 (ESRI, 2013) in order to identify the best contour of the isolines of each interpolator, considering the existing morpho-sculptural compartments. The

interpolation techniques used in the present study were idw (inverse of the distance square) with 2nd order power, idw with 4th order power, spline (minimum curvature), trend (2nd order power), top-to-raster with enforce and kriging. All interpolation categories were used for the spatial spatialization of point data, which, in this case, are homogeneously distributed across the study area. Table 5 shows the intervals of pluviometric intensities and the degrees of fragility adopted.

PLUVIOMETRIC INTENSITY (MM/MTH)	DEGREE OF FRAGILITY	CLASSES OF FRAGILITY
>525	5	Very Strong
500-525	5	
475-500	5	
450-475	5	
425-450	4	
400-425	4	Strong
375-400	4	
350-375	4	
325-350	3	
300-325	3	
275-300	3	Medium
250-275	3	
225-250	3	
200-225	2	
175-200	2	
150-175	2	Weak
125-150	2	
100-125	1	
75-100	1	
50-75	1	
<50	1	Very Weak

Table 5 - Environmental fragilities associated with intervals of rainfall intensity. Adapted from Crepani et al. (2001). Source. Guirra (2017).

The procedures adopted for obtaining the data and drawing up the rainfall erosivity map can be seen in Figure 2.

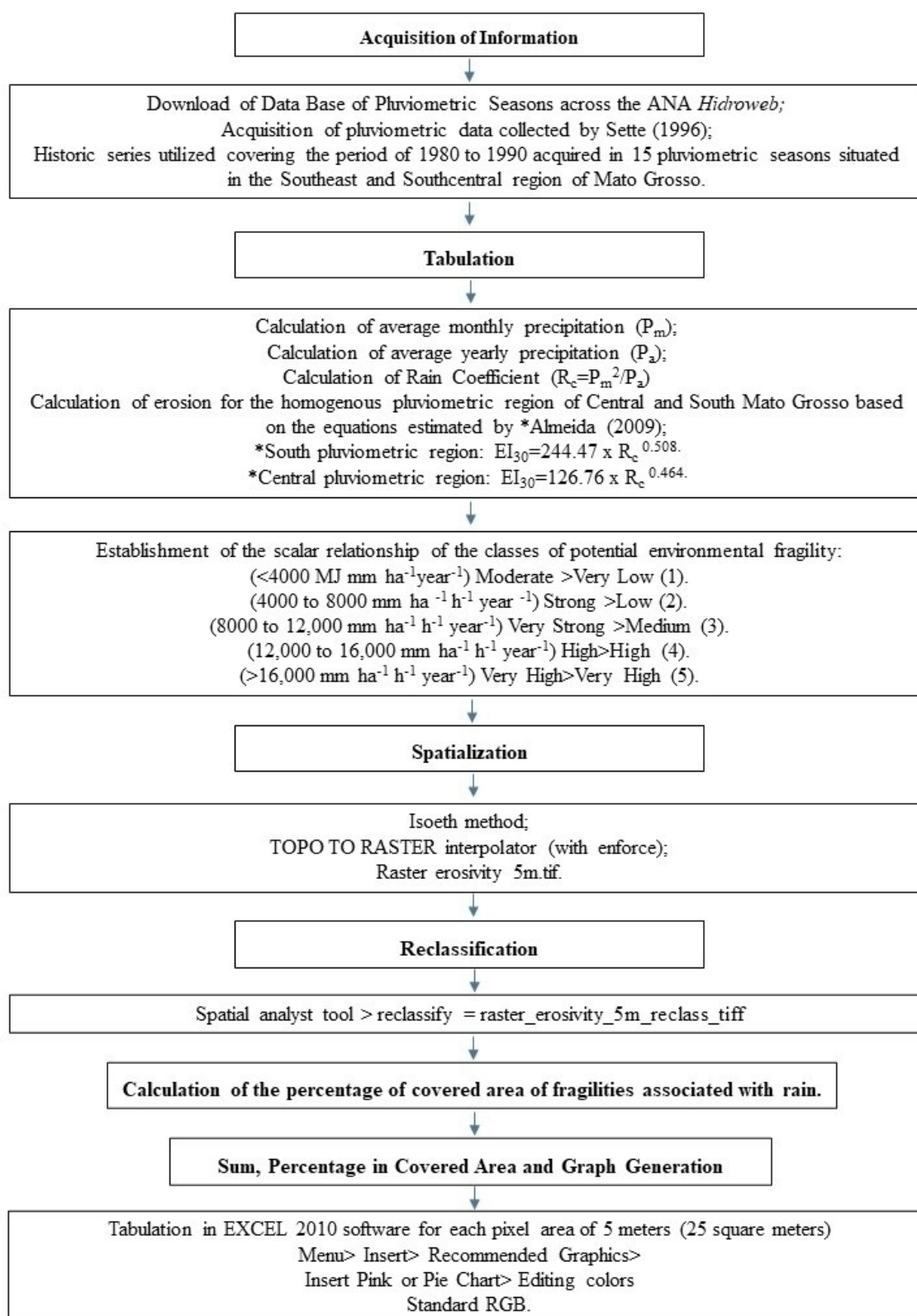


Figure 2 - Methodological scheme for obtaining, qualifying and quantifying the fragility associated with erosivity. Source. Guirra (2017).

Coming from the correlation between pluviometric intensity and rain erosivity, and knowing that both have 5 (five) ordinal qualitative and quantitative classes, the present study proposes a gradual

scaling relationship between their values, where moderate erosivity will be equivalent to fragility of very weak erosivity and strong erosivity will, consequently, correspond to the weak fragility of erosion by rain, thus, successively, until reaching in both modes of analysis the very high class (Table 6).

CLASS OF EROSIVITY	INTERVAL VALUES OF EROSIVITY (MJ mm ha ⁻¹ h ⁻¹ ano ⁻¹)	CLASS OF FRAGILITY	DEGREE OF FRAGILITY
Moderate	0-4000	Very weak	1
Strong	4000-8000	Weak	2
Very strong	8000-12000	Medium	3
High	12000-16000	Strong	4
Very high	16000-20000	Very strong	5

Table 6 - Relationship between erosivity values and degrees of environmental fragility. Compiled from Ross (1994); Crepani et. al. (2001); Salton, Comunello and Fietz (2013). Source. Guirra (2017).

When integrating information related to the existing rock units in the PUR (CPRM, 2014), of the geological map on a scale of 1: 250,000 referring to Sheet SE-21-XB (Rondonópolis), the study area was delimited for later clipping polygons related to lithostratigraphy. The assessment of classes and degrees of fragility was based on the scale of vulnerability to denudation of the most common rocks, established by Crepani et al. (2001), considering that this is not a topic originally considered in studies of environmental fragility (Ross, 1994). The resistance of the mineral constituents and the chemical and textural stability of the structural arrangement of the crystals that make up the rocks are considered as parameters, grouping them in a decreasing sequence of weathering resistance. For igneous rocks, these authors took into account the degree of saturation in silica as a relevant factor to diagnose the tendency of these rocks to resist weathering. Table 7 shows the lithologies and geological materials found in the urban perimeter and the degrees of fragility adopted.

LITOLOGICAL GROUPS	CLASS	DEGREE
Unconsolidated sediments, colluvial and alluvial deposits	Very High	5
Unconsolidated detritus-lateritic covers and regoliths	High	4
Sedimentary Rocks	Medium	3
Metamorphic Rocks	Low	2
Igneous Rocks	Very Low	1

Table 7 - Environmental fragilities associated with the types of rocks and other geological materials. Compiled and adapted by Crepani et. al. (2001). Source. Guirra (2017).

The procedures and steps adopted to obtain data, information and mappings about the densities of geological-structural discontinuities and intersections of geological-structural discontinuities can be seen in Figures 3, 4, 5, 6 and 7. All refer to Guirra (2017).

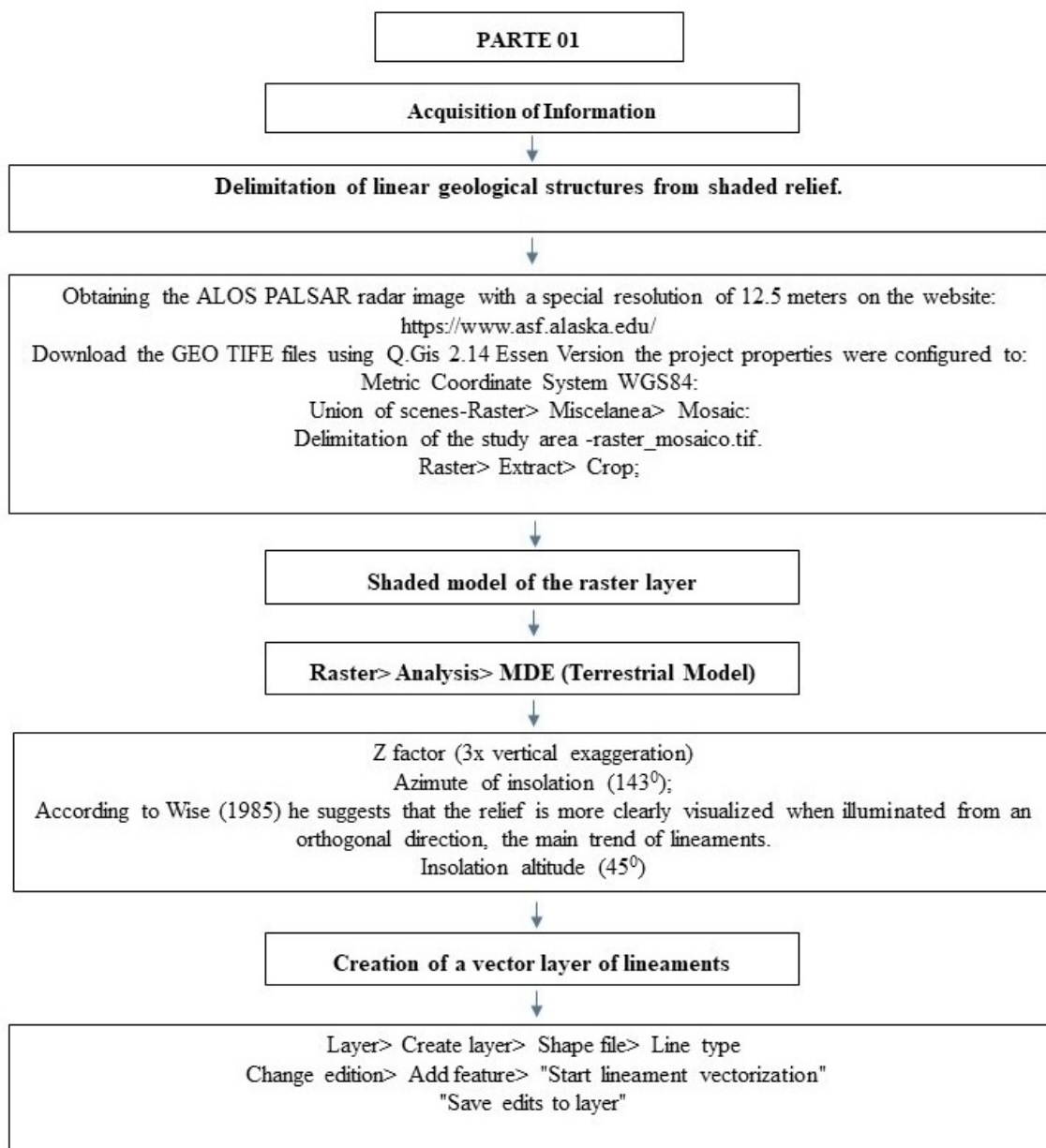


Figure 3 - Radar image treatment for semi-automatic extraction of geological-structural discontinuities evidenced in the subsurface (PART 01).

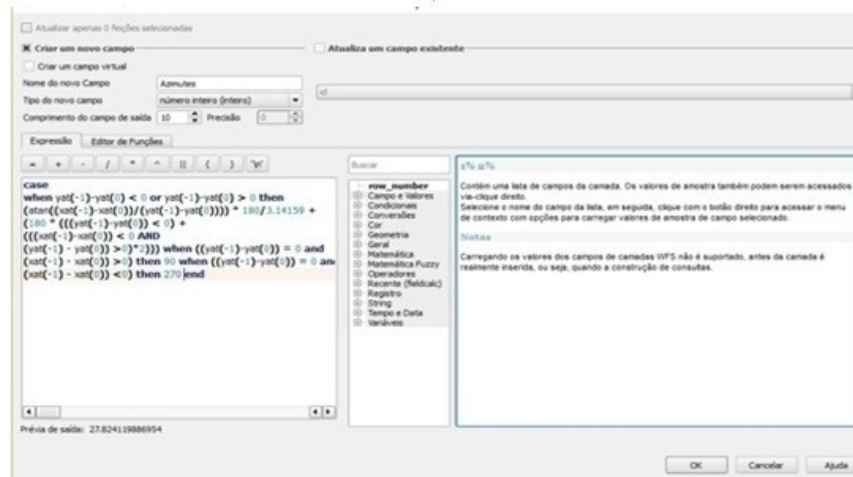
PARTE 02

Filtering geological lineaments by quadrant in QGIS.

"Lineaments.shp"> Open attribute table> Change Edition> Open Field calculator> Create a new field> Name of the new field = Azimuth> Type of the new field "Integer"> Output length "10."

Addition of the geological lineaments of SE-21-XB Leaf in the scale of 1: 250,000 of CPRM (2014); Linking of lineaments through Vector> Manage data> Merge Shapefile into one = "lineament union .shp."

According to a website: Geographic Information Systems Stack Exchange, in the topic: How to add Direction and Distance to attribute the table? And demonstrating how to obtain the azimuths of each linear structure interpreted, it is necessary to type in "Expression" the following code:



Then, click "o.k," the attribute table will be updated automatically with the azimuth values of each vectorized linear.

Figure 4 - Algorithm used to filter geological-structural discontinuities extracted from the shaded surface of the terrain. (PART 02).

PARTE 03

Creating a Rosette Diagram

Add-ons> Manage and Install Add-ons "Line Direction Histogram"> Install Add-on:
Menu> Line Direction Histogram> Select the vector layer "lineaments.shp."
Disable the "Selected Features Only" option
Set the number of intervals in the specific case: Number of bins = 8;
Indicate if you want to take into account the length of the lines and if the plotted area will be proportional to the radius of the diagram in the options located in the bottom corner of the window and click "OK."

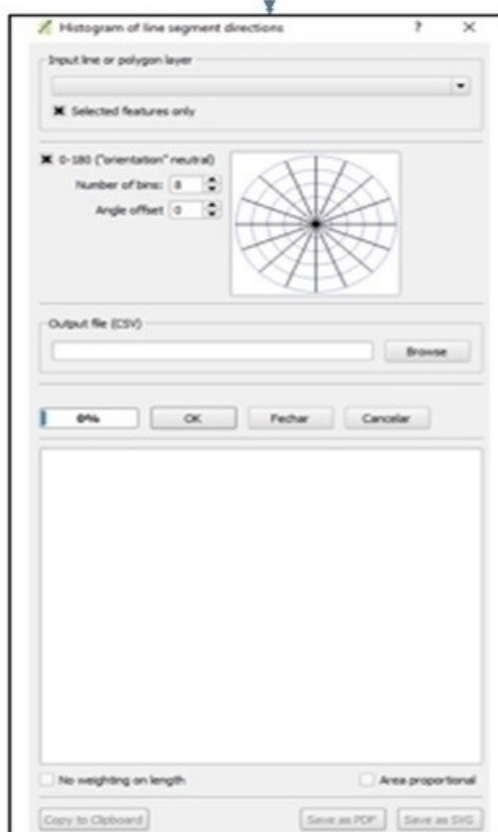


Figure 5 - Dividing the intervals in the rosette diagram by the line direction histogram (PART 03).

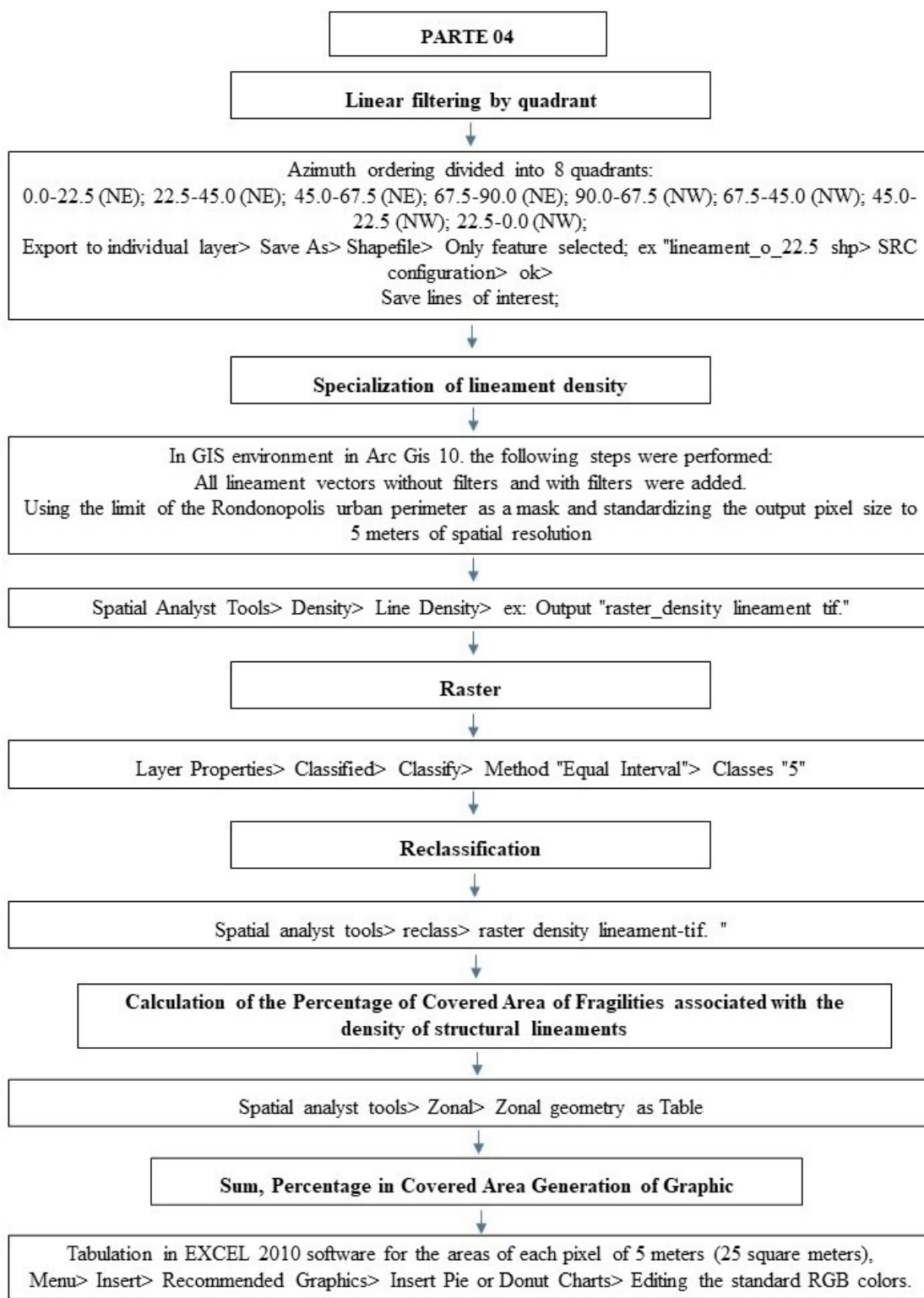


Figure 6 - Methodological scheme for obtaining, qualifying and quantifying the geological-structural environmental fragility (PART 04).

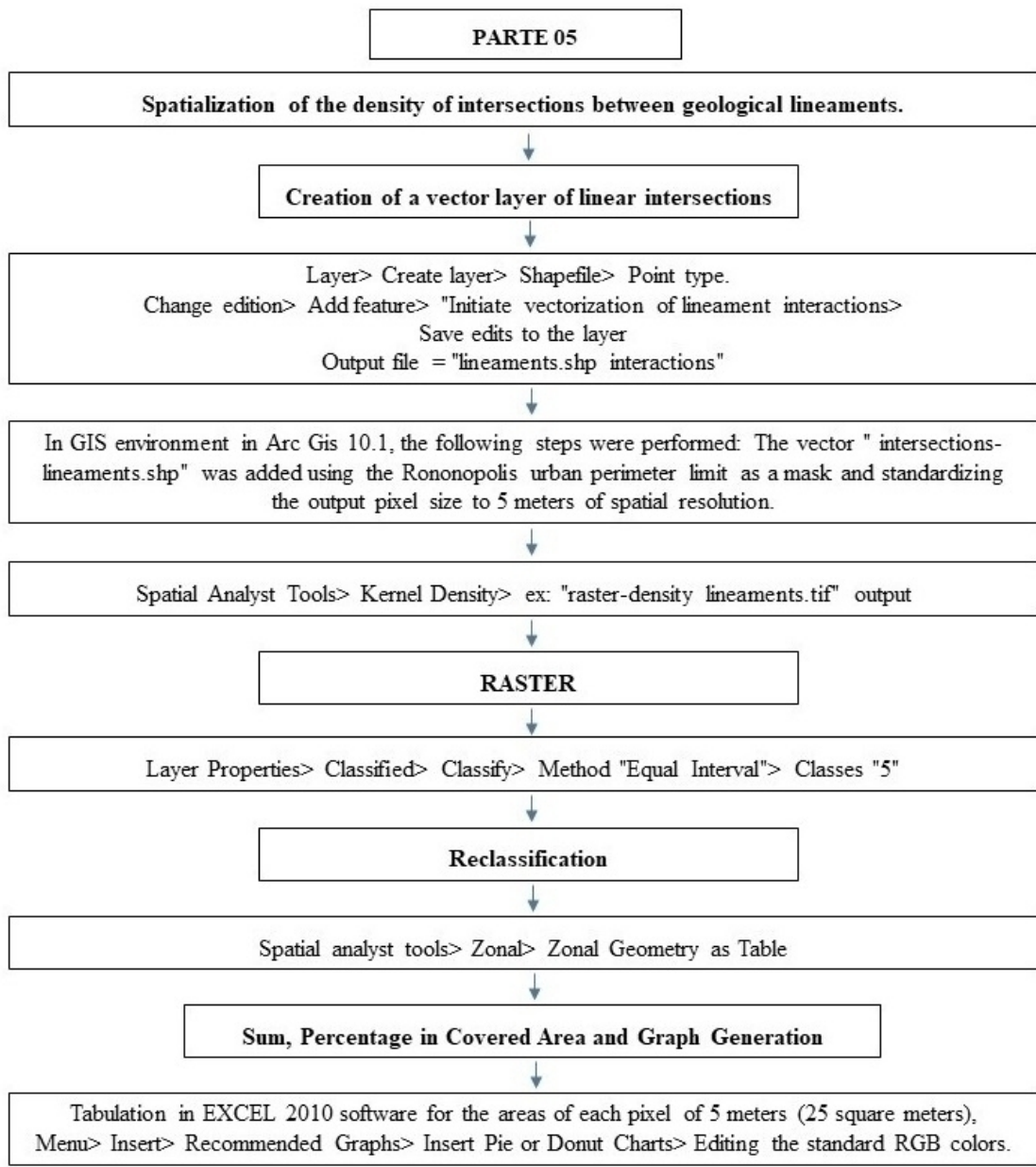


Figure 7 - Methodological scheme for obtaining, qualifying and quantifying the geological-structural environmental fragility (PART 05).

In determining the fragility in terms of urbanization levels, 04 scenes of orthorectified images from the Sino-Brazilian satellite, CBERS-4, from July 28, 2017 were made available for free at the Ministry of the Environment's Geocatalogue. Four scenes from the WFI sensor with a spatial resolution of 10 meters (bands 1, 2 and 3) and four scenes complementary to the previous scenes, the panchromatic band with 5 meters of spatial resolution (band 4), necessary to operate the image fusion and improve the resolution of the band composition. After acquiring these images, the georeferencing was performed in relation to the panchromatic image right after the mosaic between the scenes was executed, in the GIS environment, cut out through the buffer of 100 meters from the limit of the PUR of each scene. After this step, the false color R3G4B2 composition and fusion with the 5 meter panchromatic band was performed, using the ArcGis 10.1 tool, Create Pan-sharpened Raster Dataset, making the mosaic with the Esri algorithm.

With the defined limit of the study area and the image ready for the supervised classification, it was performed with the Classification tool, obtaining 15 samples for each class of land use and occupation, segmenting them into Large Vegetation (Arboreal or Dense Ciliary Forest); Consolidated

Urban Network / Paved Roads / Buildings; Small vegetation (Agriculture / Pasture / Grasses in general); Exposed soil; Water bodies. Due to the fact that the PUR does not have characteristics of a fully consolidated or densely urban network, and in this territory activities related to agriculture and livestock are developed, there was a need to correlate the degrees and classes of environmental fragility both with regard to urbanization levels according to the criteria signed by Santos and Ross (2012), and by the type of vegetation cover, based on the methodology of Ross (1994), when establishing the degrees of soil protection. Thus, adaptations of degrees and classes of environmental fragility were elaborated, integrating attributes of these from the themes of land use, which proved to be better adjusted to the reality found in the PUR.

Table 8 shows the relationship between the degrees and classes of urbanization levels, type of vegetation cover and the proposal adapted to the PUR.

DEGREE OF FRAGILITY	URBANIZATION LEVEL Based on Santos and Ross (2012)	DEGREE OF PROTECTION	TYPE OF VEGETABLE COVERAGE Based on Ross (1994)	DEGREES OF INTEGRATED FRAGILITY	URBANIZATION LEVEL AND TYPE OF PLANT COVERAGE OF THE URBAN PERIMETER OF RONDONÓPOLIS Adapted by ROSS (1994), SANTOS and ROSS (2012) WITH SUPERVISION
1 – Very low	Predominance of natural conditions with a well-developed plant layer and / or in an advanced stage of regeneration that favors infiltration, minimizing runoff. Medium urbanization sectors located in higher areas that present low slope and have structural and non-structural measures for flood control, such as sink boxes, permeable beds, obstacles to reduce runoff speed, reservoirs for collecting and reusing rainwater	1 – Very high	Forests / Natural Woods, forests cultivated with biodiversity.	1 – Very low	Shrub and tree formations with dense herbaceous layer close to sectors of low to medium urbanization contained in areas of low slope. Reforestation and / or afforestation areas. Presenting efficient drainage favored by the well-developed plant layer, infiltration predominating and minimizing runoff.
2 - Low	Urbanized area with efficient drainage. Low declivity, presence of actions to control floods, infiltration and reduction of runoff in the circulation routes, in lots and buildings.	2 - High	Natural shrub formations with dense herbaceous layer, dense shrub formations (secondary forest Cerrado Denso, Capoeira Densa). Homogeneous forest and Pinus densa. Pastures cultivated with low cattle trampling, long-cycle cultivation like cocoa.	2 - Low	Permeable to semi-permeable unconsolidated urban network. Environments with very low slope for very high. Presence of grasses and shrubs. Pastures with cattle trampling. Short-cycle crops, predominantly soy or corn in the off-season along contour / terracing curves.
3 - Medium	Urbanized area predominantly impermeable with drainage problems and constant flooding and flooding. Environments with practically no slope precariously incorporated into the drainage, susceptible to seasonal floods, which may have built old floodplains of water and lake bodies affected or not by anthropogenic activities.	3 - Medium	Long cycle cultivation on contour / terracing curves such as coffee, orange with forage between streets, low trampling pastures, eucalyptus forestry with native understory.	3 - Medium	Urban network effectively consolidated, with low to medium drainage efficiency, with the presence of asphalt and totally impermeable soil, where flooding episodes recur more than once a year. Low slope, medium presence of equipment for flood control, infiltration and reduction of flow in the circulation routes, in the lots and in the constructions.

Table 8.1 - Degrees of environmental fragility and level of urbanization and type of vegetation cover in the urban perimeter of Rondonópolis. Source: Guirra (2017).

DEGREE OF FRAGILITY	URBANIZATION LEVEL Based on Santos and Ross (2012)	DEGREE OF PROTECTION	TYPE OF VEGETABLE COVERAGE Based on Ross (1994)	DEGREES OF INTEGRATED FRAGILITY	URBANIZATION LEVEL AND TYPE OF PLANT COVERAGE OF THE URBAN PERIMETER OF RONDONÓPOLIS Adapted by ROSS (1994), SANTOS and ROSS (2012) WITH SUPERVISION
4 - High	Urbanized and / or semi-urbanized places with precarious construction and infrastructure for medium / low intensity rainfall events. Areas of natural flooding, such as lake plains, and more sheltered sectors of the river and marine fluvial plains.	4 - Low	Cultures of low density long cycle (coffee, black pepper, orange with exposed soil between streets), cultures of short cycle rice, wheat, beans, soybeans, corn, cotton with cultivation in contour / terracing curves.	4 - High	Consolidated urban network, associated with exposed soil, where there is a recurrence, more than once a year, of concentrated flows of runoff in the form of mud and debris, during periods of intense rain, which can sometimes prevent and / or hinder the flow vehicles and people.
5 - Very High	Critical areas that should be aimed at maintaining their original systemic functionality. Absence of infrastructure and total precariousness of human constructs, the result of disordered use and occupation of the soil. Environments naturally favorable to flooding, such as water bodies and flood plains. Sectors with a large slope susceptible to mass movements.	5 - Very Low	Areas recently deforested and burned, soil exposed by plowing / grading, soil exposed along paths and roads, earthworks, short cycle crops without conservationist practices.	5 - Very High	Bodies of water, urbanized areas susceptible to flooding and / or seasonal flooding, with medium to very high declivity incorporated into the drainage. Situated in a fluvial plain environment with the presence of sandy, powdery or collapsible banks on its drainage margins. Cattle grazing / trampling. River waters with high turbidity and recurrence of solid waste discharges in its tributaries.

Table 8.2 - Degrees of environmental fragility and level of urbanization and type of vegetation cover in the urban perimeter of Rondonópolis. Source. Guirra (2017).

After presenting the procedures adopted for obtaining data, information and mapping the environmental fragility to linear erosive processes of the PUR, we proceed to the presentation of the results achieved and their analysis.

RESULTS

We chose in the present work to present the individualized thematic maps, linked with their respective analyses as a way to demonstrate how the different mapped aspects offer their degrees of environmental fragility in the study area. Subsequently, the final synthesis maps, results of the conjunction of the individual maps, are shown.

The first aspect is the fragility map of the relief, which is the conjunction of the declivity factor and horizontal and vertical curvatures of the slopes (Figure 8). There is a preponderance of the degree of medium fragility (36.9% of covered area), followed by weak (36.3%) and strong (17.4%) fragilities.

ENVIRONMENTAL FRAGILITY TO LINEAR EROSIVE PROCESSES IN AN URBAN PERIMETER

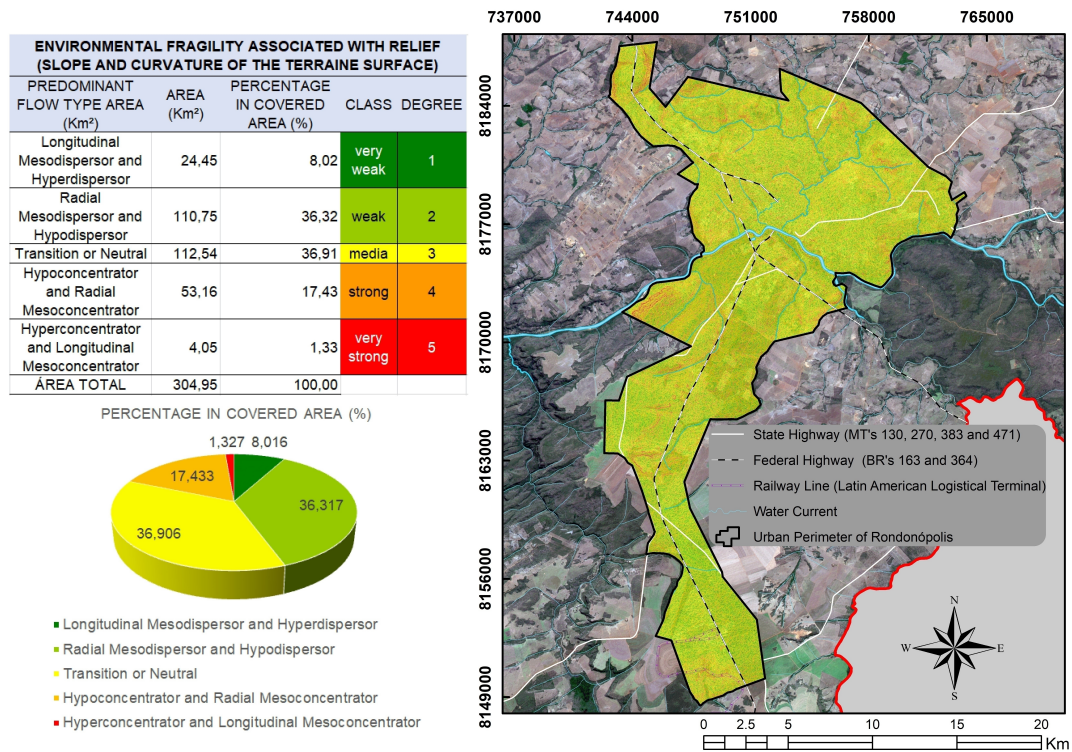


Figure 8 - Chart of environmental fragility associated with the relief considering the slope and the shapes of the terrain.Source. Guirra (2017).

The second aspect is the environmental fragility map associated with soils and type of urbanization (Figure 9). It can be seen that the oxisols, with their variations in physical and chemical characteristics, predominated with 69% of combined area covered, varying from low to very low degrees of fragility.

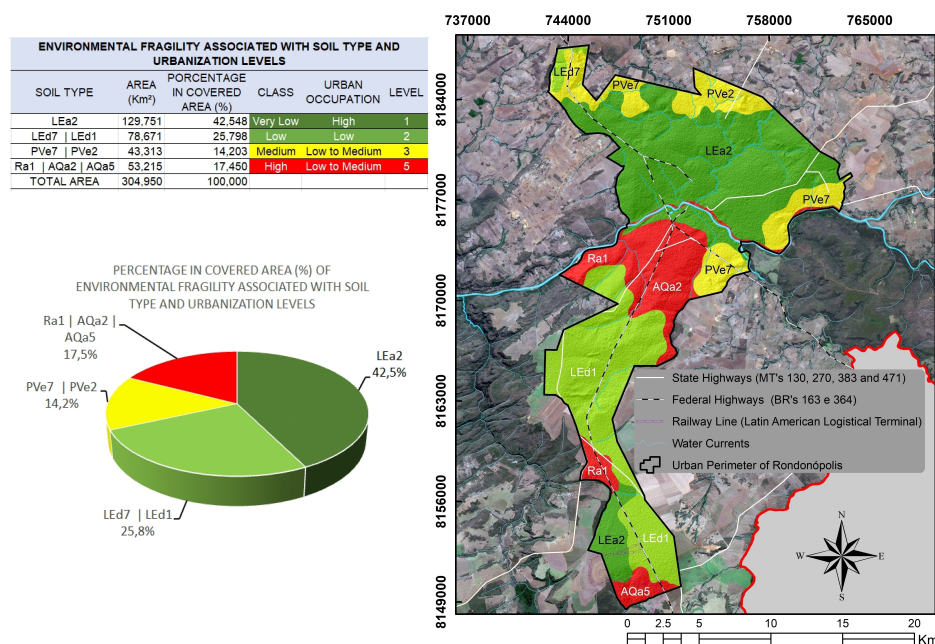


Figure 9 - Chart of environmental fragility associated with soil types in terms of urbanization level. Source. Guirra (2017).

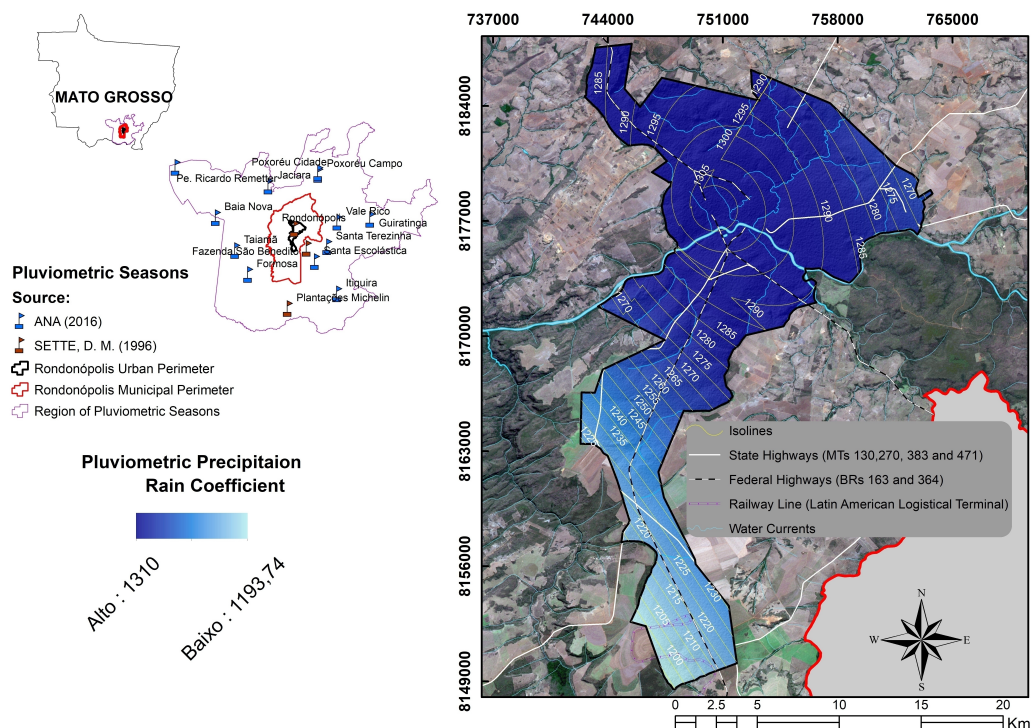


Figure 10 - Chart of the rainfall intensity of the PUR, with average fragility for this geoenvironmental variable. Source. Guirra (2017).

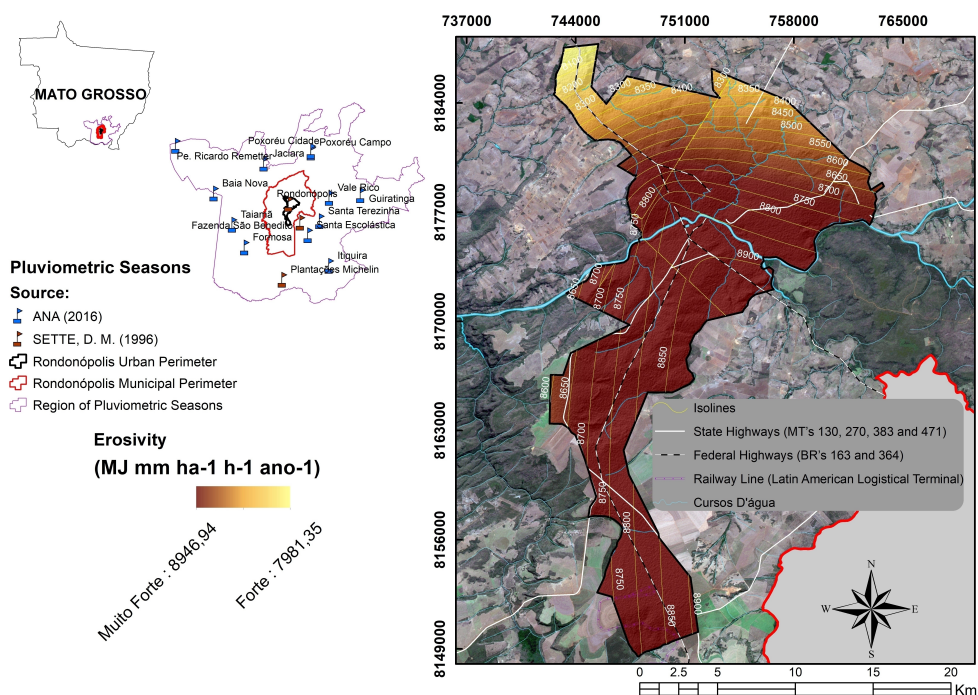


Figure 11. Erosivity chart, with a predominance of medium fragility, and low restricted to the northwest end of the PUR. Source. Guirra (2017).

The third aspect concerns the degrees of environmental fragility associated with rainfall intensity (Figure 10). The range of intensities that covers the study area is 100% classified as medium fragility.

The fourth factor was to associate degrees of fragility with the erosivity of the rains. The data can

be seen in Figure 11. What can be seen is that 99.7% of the study area has a medium degree of fragility with regard to this aspect. The fifth aspect refers to the degrees of fragility associated with the lithostratigraphic units (Figure 12). It is observed that the Ponta Grossa Formation is present in an area of 42% of the urban perimeter, with a high degree of fragility. It is followed by the Furnas Formation, with a 33% average fragility area. The unconsolidated debris-lateritic cover, associated with residual soils and alluvial deposits correspond together to 25% of the area, presenting high fragility.

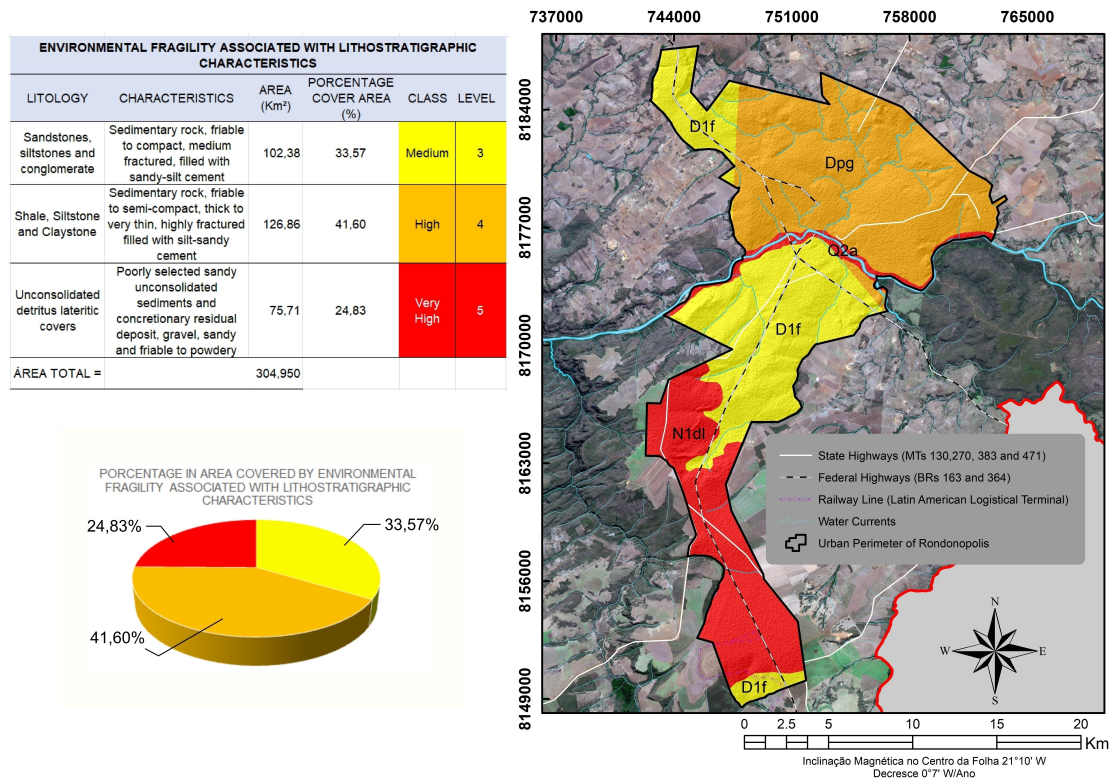


Figure 12 - Chart of environmental fragility associated with mechanical resistance to erosion of rock groups. Source. Guirra (2017).

The sixth and seventh aspects concern the degrees of fragility associated with the density of geological-structural discontinuity (Figure 13) and density of geological-structural intersections (Figure 14). It can be seen that the perimeter covering by the density of discontinuities has a preponderance of degrees of weak and very weak fragility, with 35% and 34% respectively. As for the density of intersections, the degree of fragility is very low, with 52% coverage in the study area.

ENVIRONMENTAL FRAGILITY ASSOCIATED WITH GEOLOGICAL STRUCTURAL DISCONTINUITIES			
AREA (Km²)	CLASS	DENSITY	DEGREE
105,0393	Very Weak	Very Low	1
106,5263	Weak	Low	2
60,7489	Medium	Medium	3
28,1778	Strong	High	4
4,4580	Very Strong	Very High	5
304,9503			

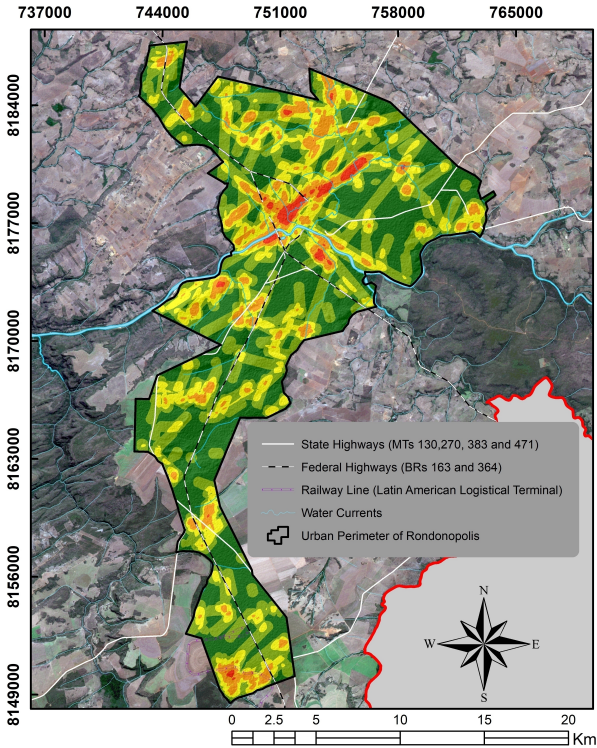
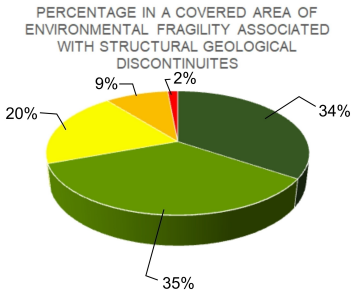


Figure 13 - Chart of environmental fragility associated with the density of geological-structural discontinuities. Source. Guirra (2017).

ENVIRONMENTAL FRAGILITY ASSOCIATED WITH GEOLOGICAL STRUCTURAL DISCONTINUITIES			
AREA (Km²)	CLASS	DENSITY	DEGREE
105,0393	Very Weak	Very Low	1
106,5263	Weak	Low	2
60,7489	Medium	Medium	3
28,1778	Strong	High	4
4,4580	Very Strong	Very High	5
304,9503			

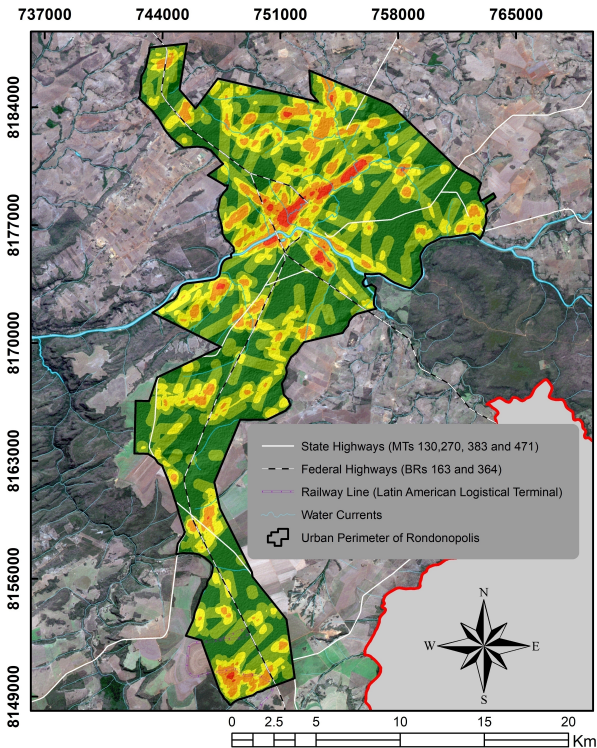
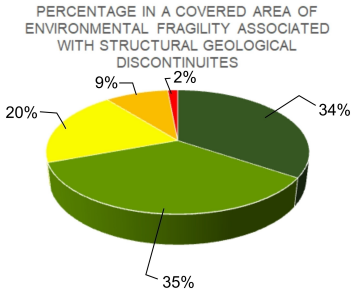


Figure 14 - Chart of environmental fragility associated with the density of geological-structural intersections. Source. Guirra (2017).

The eighth aspect adopted refers to the degrees of fragility associated with urbanization and the degree of protection and land cover (Figure 15). It is observed that 63% of the study area has a low degree of fragility in relation to this factor.

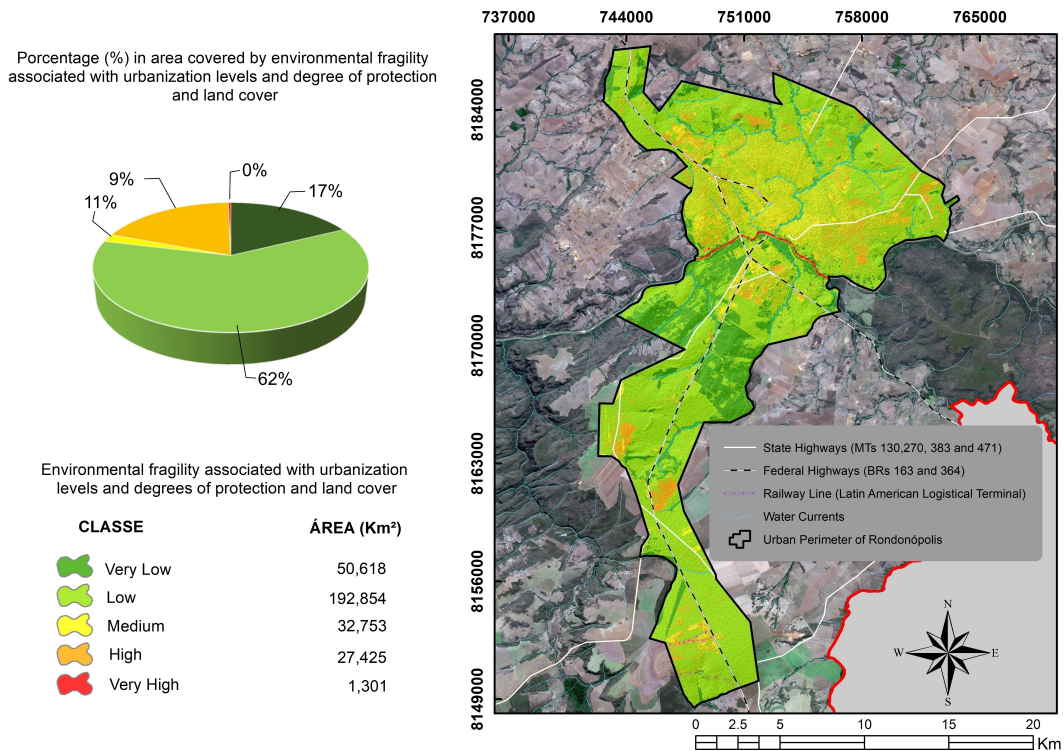


Figure 15 - Chart of environmental fragility associated with the level of urbanization and degree of protection and land cover. Source. Guirra (2017).

After presenting in an individualized way the results achieved regarding the degrees of environmental fragility to linear erosive processes of the eight aspects taken into consideration in order to elaborate the synthesis maps of potential and emerging fragility, the table of synthesis of the most prevalent degrees of fragility is summarized in Table 9 each one of them.

ENVIRONMENTAL FACTORS	DEGREES OF FRAGILITY	OCCURRENCE (%)
Relief	Medium	36.9
Soils	Low	43
Pluviometric intensity	Medium	100
Rain erosion	Medium	99.7
Lithostratigraphic Units	High	42
Density of geological-structural discontinuities	Low	35
Density of geological-structural intersections	Very low	52
Urbanization and degree of protection and land cover	Low	62

Table 9 - Summary of the biggest occurrences for each of the environmental factors adopted and respective degrees of fragility.

It can be seen, from the previous table that among the eight environmental factors selected, only the lithostratigraphic units presented the degree of high fragility as the greatest preponderance. All other factors have medium, low or very low fragility.

Figures 16 and 17 refer, respectively, to the potential and emerging fragility maps. In relation to the first, there is a preponderance, with 59% of the area of the urban perimeter, of the degree of weak fragility, followed by the average degree (23%), very weak (17%) and strong (1%).

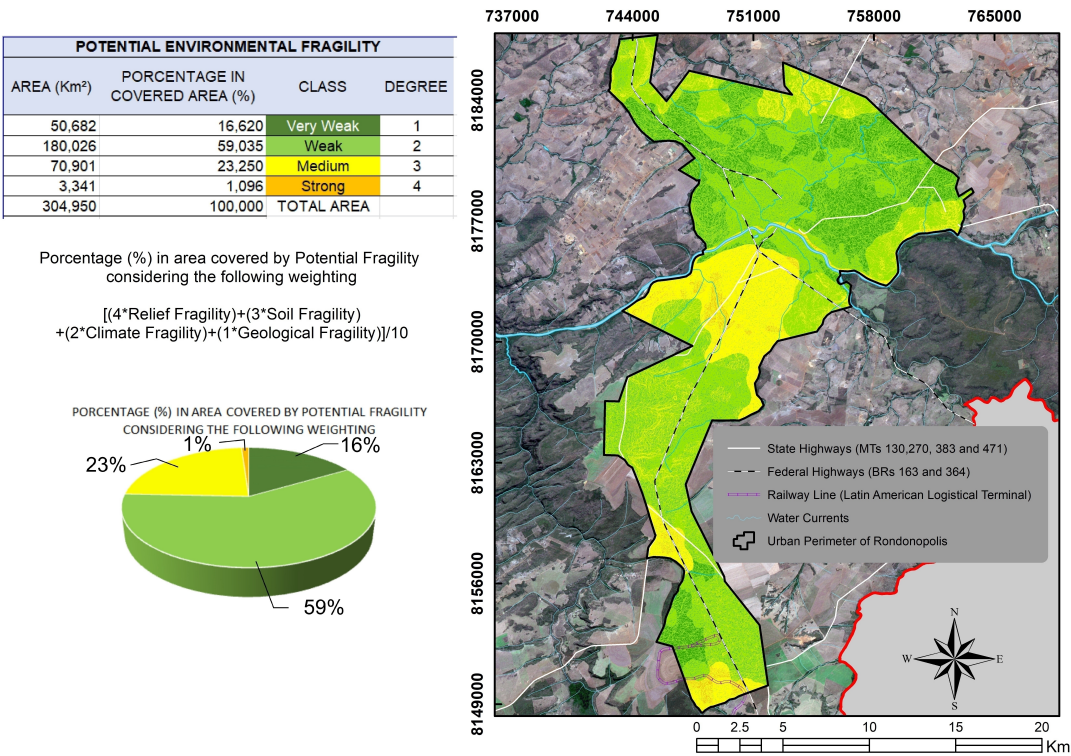


Figure 16 - Map of potential environmental fragility to linear erosive processes. Source. Guirra (2017).

In the emerging fragility map, the preponderances have changed. The largest areas of coverage followed with the degree of weak fragility (61%), followed by the degrees of very weak (21%), medium (18%) and strong (0.31%).

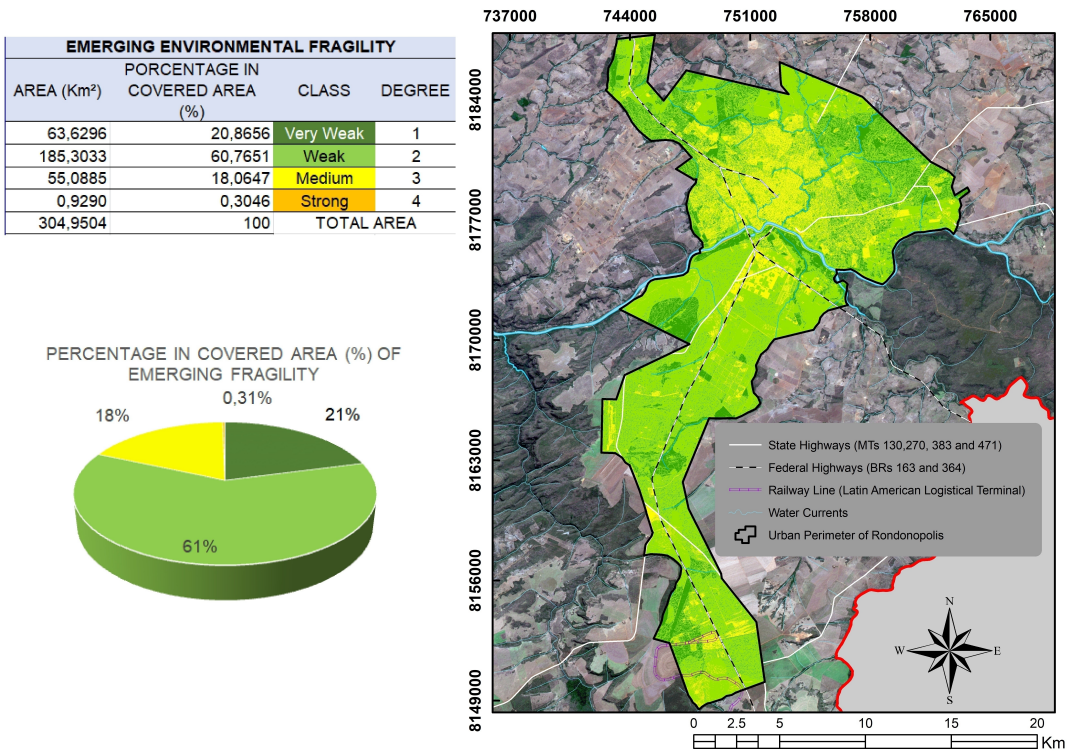


Figure 17 - Map of emerging environmental fragility to linear erosive processes. Source. Guirra (2017).

There is an aspect to be highlighted regarding the changes in the predominant percentages of the degrees of fragility. In the emerging fragility map, with the inclusion of the urbanization factor and the degree of protection and soil cover, it was imagined that the higher degrees of fragility would increase, mainly due to the increase in runoff due to soil impermeabilization. However, what happened was the opposite, the areas of low and very low fragility were increased and the medium and strong areas were reduced. The explanation focuses on the fact that waterproofing, in spite of increasing the runoff, they serve to protect the soil. In this context, we found that one of the biggest gaps in the method focuses on the homogenization of complex attributes of interaction between the urban and the environmental.

The loss of soils in these areas has more complex factors than the method can capture, among them: the arrangement and configuration of the installed and not installed drainage system; the interaction between the type of pavement (asphalt, concrete, vegetation cover or mixed) with the exposed soil, preferential zones of accumulation of flow, the time of recurrence of extreme and anomalous rains, among other intervening mechanisms. For a better understanding of erosive processes in the urban environment, complementary studies of hydrological nature and geographic information plans mapped in high detail are necessary.

CONCLUSION

The elaboration of a model adapted and complemented for studies of fragility of the environments, which integrates information of subsurface, mechanical resistance to erosion of the lithostratigraphic units, density of structural lineaments and densities of their intersections, proved to be complementary and efficient in the characterization of zones more unstable to the installation and / or evolution of erosive processes on the ground.

The distinction between the climatic elements of rain, pluviometric intensity and erosivity, verified in the present study, finds that both should be considered in the modeling equations of fragile environments the incidence of erosion, considering that they are important exogenous geoenvironmental variables in the dynamic transformation of the relief. However, these variables, when considered, tended to minimize the fragility of the model, considering that the extreme levels, with greater rainfall volume, are rarer in the Brazilian territory. Given this fact, it is understood that rainfall intensity and erosivity, despite being important, are, at the same time, variables that contribute or should contribute with less weight in the deliberation between the hierarchical themes.

The characterization of the resulting flows, according to the shape of the terrain and the correlation with classes and degrees of fragility, proved efficient in the identification of areas subject to the installation of linear erosive processes, however, it is not indicated for verification of areas susceptible to soil losses due to laminar erosion, given that the performance of this type of erosion is more chaotic and has repercussions even in areas with low slope.

The adaptations implemented by the correlation of the levels of urbanization and degrees of protection and land cover configured more precise elements in the characterization of the PUR's land use, considering that it has attributes of both urban and agrarian areas. The use of medium-high resolution satellite image, CBERS-4 of the current year, was important in distinguishing targets, contributing to the analysis of the fragilities that operate in the field today.

The medium and strong potential fragilities of the PUR are conditioned mainly to the types of soils, specifically to the Neossols and Argisols, as well as, unconsolidated sediments of alluvial deposits existing in the river valley of the Red River. While the emerging fragilities are medium and high, areas with exposed soils are predominantly related to the peripheries of the effectively consolidated urban network, industrial sectors with high circulation of large vehicles and areas south of the perimeter where agro-industrial activities are carried out cultivation of soybeans and corn in the off-season.

The model of environmental fragility of environments to erosive processes, with the complementations proposed in the present case study, can be replicated to other urban environments, considering the specificities of the spatial arrangement of geoenvironmental variables that adjust to their reality, improving environmental zoning and previous studies of environmental impacts required to the Municipal Master Plans.

It is understood that the methodology when using free geographic databases, available on official sites of federal, state and municipal bodies, required little resource to be executed, which will allow agility and economy to the public power in making the most correct decisions in the ordering and management of urban-environmental systems.

For future studies, it is recommended to use other morphological and morphometric variables not used in the present study, such as Geomorphons (JASIEWIC; STEPINSKI, 2013) and the topographic position index (WEISS, 2001) respectively, considering that both are sources of automated mapping of the digital terrain model and have potential use in morphodynamic studies (GOUVEIA; ROSS, 2019; SILVEIRA; SILVEIRA, 2017). In view of the identification of the variables that represented fragility of the urban environment, we suggest the application of the Fuzzy logic and the Kolmogorov-Smirnov test to determine the weights to the different geoenvironmental input variables of the model, as presented by Messias and Ferreira (2017).

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