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EROSIVE VULNERABILITY IN A SCHOOL ENVIRONMENT: AN APPLICATION OF GEOPROCESSING IN PARAGUAÇU PAULISTA-SP

VULNERABILIDADE EROSIVA EM AMBIENTE ESCOLAR: UMA APLICAÇÃO DO GEOPROCESSAMENTO EM PARAGUAÇU PAULISTA-SP

VULNERABILIDAD EROSIVA EN AMBIENTE ESCOLAR: UNA APLICACIÓN DEL GEOPROCESAMIENTO EN PARAGUAÇU PAULISTA-SP

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ABSTRACT: Erosive processes are characterized as natural phenomena, being the main element in the process of terrain sculpting. However, human interventions in the environment break with dynamic equilibrium, which may influence the greater or lesser environmental vulnerability to erosion processes in each area. This article proposes an analysis of how the use of geoprocessing techniques can help in the identification of areas susceptible to erosion processes, as well as identify the patterns that justify the appearance of cores, from the analysis of the environmental vulnerability map of the Escola Técnica Estadual Augusto Tortolero Araújo (ETEC), located in the municipality of Paraguaçu Paulista - SP. The conclusions are that social and environmental aspects are inseparable, given that, through the mapping, the origins of the erosive processes in the school environment were verified, as well as guiding managers to seek measures aimed at preventing such processes.

KEYWORDS: Geoprocessing. Environmental vulnerability. Erosive processes. Escola Técnica Estadual Augusto Tortolero Araújo.

RESUMO*: Os processos erosivos caracterizam-se como um fenômeno natural, sendo o principal elemento no processo de esculturação do relevo. Contudo, as intervenções humanas no ambiente rompem com o equilíbrio dinâmico, que podem influir na maior ou menor vulnerabilidade ambiental aos processos erosivos em determinada área. O presente artigo propõe uma análise de como o uso de técnicas de geoprocessamento podem auxiliar na identificação de áreas suscetíveis à processos erosivos, bem como identificar os padrões que justifiquem o aparecimento dos focos, a partir da análise do mapa de vulnerabilidade ambiental da Escola Técnica Estadual Augusto Tortolero Araújo (ETEC), localizada no município de Paraguaçu Paulista – SP. Concluiu-se que aspectos sociais e ambientais são indissociáveis, dado que, por meio do mapeamento constatou-se as origens dos processos erosivos no ambiente da escola, bem como orientou os gestores a buscarem por medidas que visam prevenir tais processos.*

PALAVRAS-CHAVE*: Geoprocessamento. Vulnerabilidade ambiental. Processos erosivos. Escola Técnica Estadual Augusto Tortolero Araújo.*

RESUMEN*: Los procesos erosivos se caracterizan como un fenómeno natural, siendo el principal elemento en el proceso de esculpiendo del relieve. Sin embargo, las intervenciones humanas en el medio ambiente rompen con el equilibrio dinámico, que puede influir en la mayor o menor vulnerabilidad ambiental a los procesos erosivos en determinada zona. Este artículo propone un análisis de cómo el uso de técnicas de geoprocesamiento puede ayudar en la identificación de áreas susceptibles a procesos erosivos, así como identificar los patrones que justifican la aparición de focos, a partir del análisis del mapa de vulnerabilidad ambiental de la Escuela Técnica Estatal Augusto Tortolero Araújo (ETEC), ubicada en el municipio de Paraguaçu Paulista – SP. Se concluyó que los aspectos sociales y ambientales son indisociables, dado que, por medio del mapeo se constataron los orígenes de los procesos erosivos en el entorno escolar, así como se orientó a los gestores a buscar medidas para prevenir tales procesos.*

PALABRAS CLAVE*: Geoprocesamiento. Vulnerabilidad ambiental. Procesos erosivos. Escola Técnica Estadual Augusto Tortolero Araújo.*

Introduction

Different human groups occupy the terrestrial landscape and appropriate it in unequal ways, shaping it through their actions on the Earth's surface. Nunes *et al*. (2022) point out that when this process occurs in an uncontrolled manner, it leads to environmental degradation, especially in rural areas, through soil loss resulting from the intensification of sheet and linear erosive processes. It is essential to emphasize that erosive processes occur naturally on the Earth's surface, modeling and forming relief, rocks, and soils through detachment, as well as the transport and deposition of particles through hydric and aeolian action (Bertoni; Lombardi Neto, 1999). Therefore, the worsening of environmental conditions occurs through the intensification of these processes, which may be further accentuated by human activity.

Beyond human action, controlling factors such as land use and occupation, slope gradient, rainfall erosivity, soil erodibility, and soil management practices are elements that, together, may directly or indirectly affect the emergence and development of erosive processes. According to Guerra (1994), erosive processes can be classified into three typologies: sheet erosion, rill and gully erosion, and ravines.

According to Guerra (1994), sheet erosion results from surface runoff, during which soil sediments are removed and transported. When combined with the splash effect, water flow during runoff becomes more turbulent, thus increasing erosive capacity. Rill and gully erosions also originate from surface runoff, in which the main water flow becomes concentrated in terrain incisions, carving them from upstream to downstream. Finally, the author classifies ravine erosion as the development of gully erosion, characterized by wide, extensive, and deep walls, with the presence of water flow inside them, originating from groundwater outcrops and/or water accumulation during precipitation events. As noted by Oliveira (2023), due to the formation characteristics of this type of erosion, they tend to persist longer in the landscape compared to other processes, thus requiring human intervention for their containment.

Although erosion is a naturally occurring phenomenon, land exploitation and use guided by the capitalist mode of production promote the advancement of these processes, degrade landscapes, and consequently intensify environmental vulnerability.

Environmental vulnerability, according to Aquino (2017), is associated with the level of risk to which the environment is exposed due to natural or external factors. It can be understood through the physical characteristics that compose the landscape, as well as through the risk of degradation of the natural environment. It is related to soil erosion, biodiversity loss, silting, contamination of water bodies, among other factors (Nunes *et al.* 2022).

Fushimi (2016) and Nishizima (2021) reiterate that environmental vulnerability is the set of characteristics of an environment that determine its capacity to resist, respond to, and recover from an aggression. This aggression may be of natural origin—such as drought—or of social origin—such as pesticide pollution or changes in land use. Often, these actions are considered mixed, involving both natural and social factors.

In this context, the present article[3] aims to analyze the use of geoprocessing techniques to support the identification of degraded areas based on an environmental vulnerability map. Clinographic and land cover and land use maps (Oliveira, 2023) are also employed in order to identify patterns that justify the erosive hotspots occurring in the study area. The containment and monitoring of linear erosive features are justified by the need to reduce risks posed to the local academic community, since practical activities of technical courses take place near areas affected by erosion.

With growing global concern regarding environmental issues, geoprocessing emerges as an important tool, as the use of geoprocessing techniques for environmental impact analysis, for example, can contribute to environmental protection (Lima, 2023). Geoprocessing can be understood as a set of mathematical and computational techniques—provided by Geographic Information Systems (GIS)—for processing information that occurs in geographic space (D'Alge, 2001), thus establishing a relationship with cartography. Fushimi and Nunes (2016) highlight that advances in computational techniques have enabled their use as cartographic instruments, which are essential for conducting environmental studies in both urban and rural landscapes.

According to Souza (2022), throughout the national territory, geoprocessing has been used for environmental monitoring due to pressures from human activities on different regions, leading to landscape degradation. Thus, the application of geoprocessing is fundamental, as it allows for the analysis of natural dynamics in space and time. Environmental diagnosis, when supported by thematic maps, enables the understanding and identification of recurring territorial problems, such as hillside occupation, degradation of permanent preservation areas, erosive risks, and pressures on natural resources.

[3]This work is an excerpt from Oliveira's (2023) final course project.

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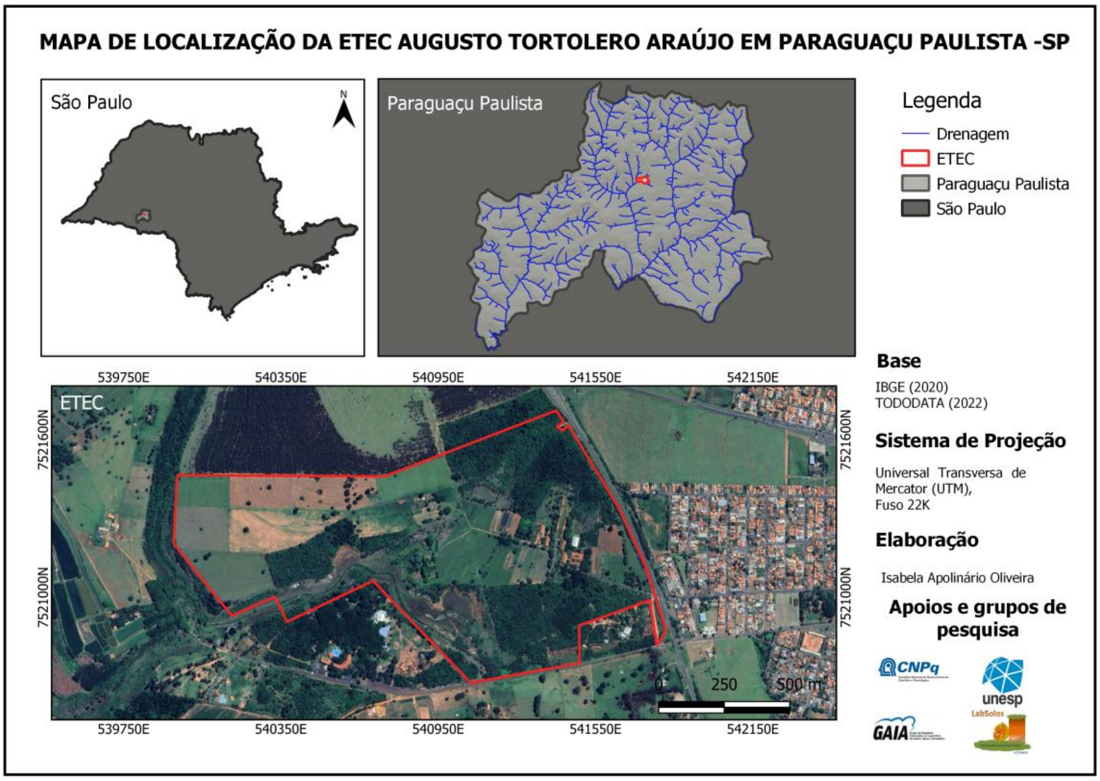
Therefore, cartographic representations can be used as tools to identify the environmental vulnerability of a given area, as well as to analyze the factors that generate such conditions, with the aim of implementing prevention and recovery practices.

Study Area

The Augusto Tortolero Araújo State Technical School (ETEC) is located in the municipality of Paraguaçu Paulista, São Paulo (Figure 1), along highway SP-248, km 477/478, in the Sapé neighborhood. The school is part of the Paula Souza State Center for Technological Education, which provides secondary and technical education to the community.

Figure 1 – Location map of ETEC Augusto Tortolero Araújo



Source: Oliveira (2023).

Due to the inclusion of technical courses in its curriculum, the school requires adequate areas for the development of practical classes. However, part of these practical activities is carried out in an agricultural area near the gully identified in Figure 2—the main erosive feature in the area—which, although currently undergoing containment measures, cannot yet be considered stable.

Figure 2 – Farm and gully

Source: ETEC (2017), adapted by the authors.

From a geomorphological perspective (Figure 3), Oliveira (2023) indicates that the ETEC area is divided into three relief compartments: gently undulating hilltops with convex forms; the domain of concave, convex, and rectilinear slopes; and alluvial plains. Furthermore, Oliveira (2023) adds that the highest occurrence of erosive processes is found near slopes with steep topographic gradients and in pasture areas and exposed soils.

As it is located in the municipality of Paraguaçu Paulista, the school is also situated on lithostratigraphic units composed of sedimentary and igneous rocks of the Paraná Sedimentary Basin (Perrotta, 2006). According to Boin (2000, p. 18, our translation), "[...] the relief of western São Paulo presents four subdivisions, namely: aggradational relief; degradational relief in dissected plateaus; residual relief supported by particular lithologies; and transitional relief," with elevations ranging between 300 and 500 meters and low altimetric amplitude.

Regarding hydrography, the ETEC belongs to the 17th Water Resources Management Unit (UGRHI) of the State of São Paulo—known as Médio Paranapanema—located within the Paraná River Basin (State Water Resources Plan, 2006). According to Oliveira (2023), the watercourses within the school perimeter are right-bank tributaries of the Sapê River, which in turn is one of the tributaries of the Capivara River.

Methodological Procedures

For the execution of this research, geomorphological maps of environmental vulnerability, clinographic maps, and land use and land cover maps of the ETEC Augusto Tortolero Araújo were produced. In addition, fieldwork was carried out in the study area in order to verify and confirm the mapped features.

Sketch of Relief Compartments

The sketch map of relief compartments of the ETEC in Paraguaçu Paulista (Oliveira, 2023) was produced based on the interpretation of Google Earth Pro satellite images at a 1:25,000 scale. All geomorphological features were extracted using the digital stereoscopy technique to generate three-dimensional anaglyphs with the StereoPhoto Maker 6.02 software.

The digital stereoscopy technique consists of recording two views of a scene to produce a stereoscopic pair. An anaglyph is an image created by overlaying two images that produce a three-dimensional stereoscopic effect when viewed with two-color glasses—usually red and blue or red and cyan. The three-dimensional effect is caused by the superposition of images with a slight displacement between them, thus creating the illusion of depth when viewed through appropriate glasses.

In QGIS, the anaglyphs were georeferenced, allowing the delimitation of geomorphological compartments and features. The features were obtained in the following order:

1. Extraction of watercourses;
2. Delimitation of alluvial plains, hilltops, watershed divides, and amphitheater-shaped drainage headwaters;
3. Characterization of valley bottoms (flat or V-shaped).

Using the technique proposed by Savigear (1965), it was possible to delimit undulating slope surfaces. Finally, the final composition of the map and its legend were prepared in CorelDRAW software, based on Tricart (1965) and Verstappen and Zuidam (1975).

Clinographic Map

The clinographic map (Figure 5) was developed by extracting altimetric values from the Digital Elevation Model (DEM) provided by TOPODATA. Using the "Slope" tool in QGIS software and subsequently the "r.reclass" tool, clinographic classes were established for the study area (Table 1), based on the proposals of Cunha (2001).

Table 1 – Slope classes

Slope classes proposed by Cunha (2001)	**Slope classes adapted for the study area**
< 5%	≤ 5%
5 ⊢ 10%	5 ⊢ 10%
10 ⊢ 20	10 ⊢ 15% 15 ⊢ 20%
20 ⊢ 30% 30 ⊢ 40% ≥ 40%	> 20%

Source: Adapted from Moreira *et al.* (2020).

Thus, four slope classes were defined for the study area: ≤ 5%, 5–10%, 10–15%, and 15–20%, which were adapted according to the characteristics of the area. Consequently, the 20–40% classes proposed by Cunha (2001) were generalized into a single class (> 20%), since the municipality of Paraguaçu Paulista presents its most pronounced slopes around 20%.

Land Use and Land Cover Map

The construction of the land use and land cover map was based on the extraction of information from CBERS-4A satellite imagery obtained from the Image Generation Division of the National Institute for Space Research. The image used to prepare the land use and land cover map of the ETEC Augusto Tortolero Araújo, developed by Oliveira (2023), was acquired between January 1, 2022, and June 22, 2022.

Because the image was provided in grayscale bands, it was necessary to perform a color composition using the additive color system in order to obtain a natural-color image in the QGIS® software. After completing the image processing steps, the Semi-Automatic Classification Plugin (SCP) was used, which enables supervised classification of remotely sensed images for the preparation of thematic maps.

The classification of land cover and land use classes was based on the Technical Manual of Land Use (Brazilian Institute of Geography and Statistics [IBGE], 2013), resulting in four typologies: Built-up Areas, Vegetation, Pasture, and Exposed Soil. All results obtained through SCP classification were validated through field visits, ensuring a high level of reliability. Finally, the "Band Processing" tool was used to generate and distribute the different typologies identified within the school perimeter.

Environmental Vulnerability Map

The "Environmental Vulnerability to Erosive Processes" map (Oliveira, 2023) was produced using the "AHP Decision Support" tool (Analytic Hierarchy Process), with the objective of comparing and combining data through the assignment of weights for the evaluation of qualitative criteria and joint comparisons among factors.

According to Saaty (1990), the application of the method consists of three stages:

1. Definition of the criteria that will compose the hierarchical decision matrix;
2. Construction of the set of pairwise comparison matrices; and
3. Assignment of weights to the defined criteria.

After defining the criteria, the second step involved constructing the set of pairwise comparison matrices with the selected attributes. For this purpose, a calculation table[4] based on the variable importance scale of the AHP method (Table 2), proposed by Saaty (1990), was used, which comprises five degrees of importance intensity.

Table 2 – Variable importance scale in the AHP method

Intensity of Importance	Definition	Explanation
1	Equal importance	Both activities contribute equally to the objective.
3	Slight importance of one over another	Experience and judgment slightly favor one activity over another.
5	Strong or essential importance	Experience and judgment strongly favor one activity over another.
7	Very strong or demonstrated importance	One activity is very strongly favored over another; its dominance is demonstrated in practice.
9	Absolute importance	Evidence favors one activity over another with the highest degree of certainty.
2,4,6,8	Intermediate values between adjacent values	Used when a compromise between two definitions is sought.

Source: Saaty (1990).

[4] Link to the calculation table: https://bpmsg.com/ahp/ahp-calc.php.

Within a GIS environment, the reclassification stages were operationalized based on the assignment of weights to each of the maps used. Therefore, the vulnerability to erosive processes map results from the comparison and correlation of data collected from the maps produced by Oliveira (2023)—geomorphological sketch, slope, and land use and land cover—through the assignment of weights to each individual class of the maps (Table 3).

Table 3 – Values assigned to thematic classes of the variables

Geomorphology	**Slope**	**Land Use and Land Cover**
Hilltops - 1	Flat (>5%) - 1	Built-up Areas- 1
Domain of concave, convex, and rectilinear slopes - 5	Gently Undulating (5-10%) - 2	Vegetation - 1
Alluvial plains - 9	Undulating (10-15%) - 7	Pasture - 7
-	Strongly Undulating (15-20%) - 9	Exposed Soil - 9

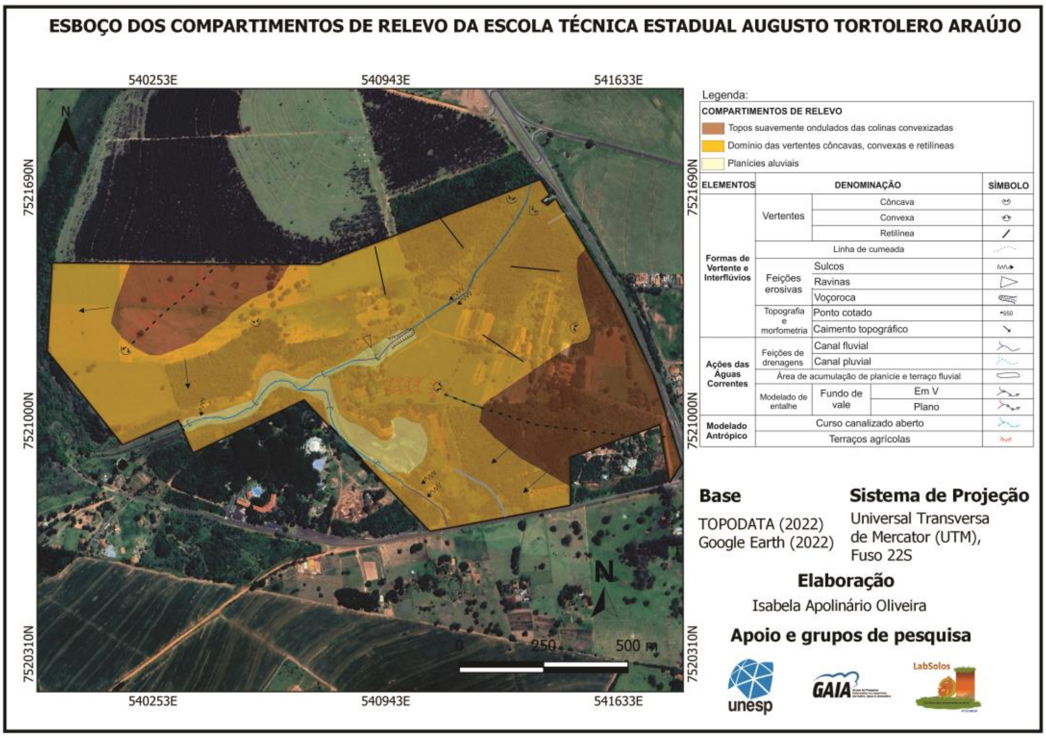
Source: Oliveira (2023).

The process of weight assignment was carried out in the QGIS® software, obtaining reclassification based on the weights attributed to each map. After determining the importance of the criteria and properly assigning the weights, it was necessary to input the generated matrix and select the features and reclassified layers of the geomorphological, slope, and land use and land cover maps.

Results and Discussion

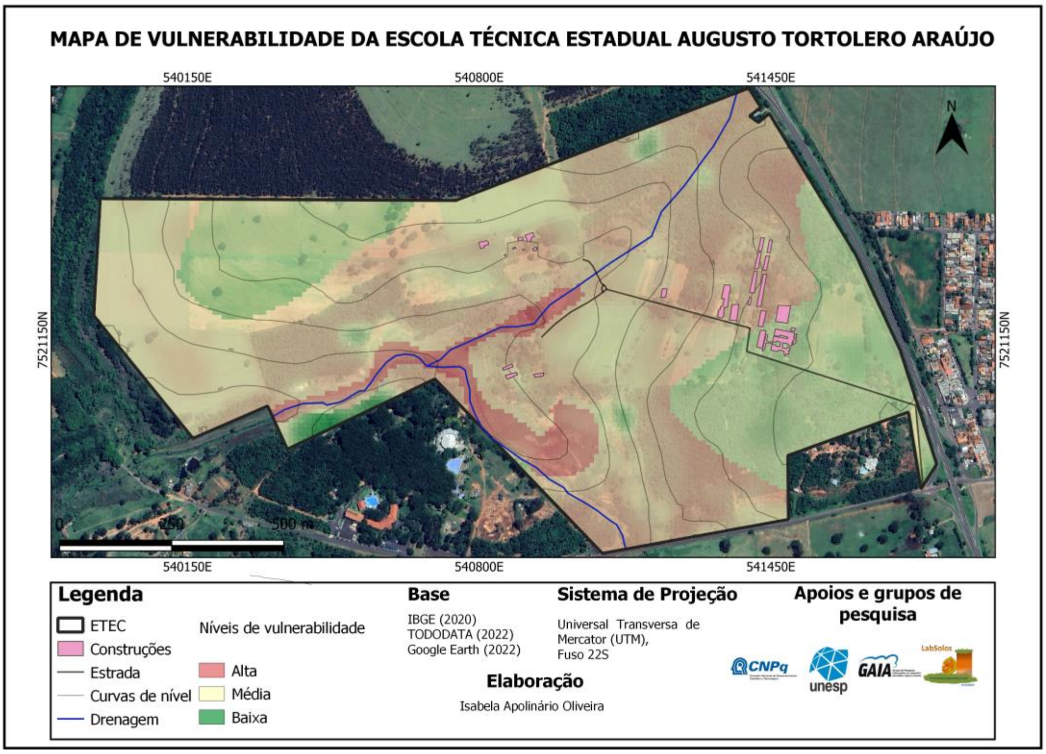
The results obtained from the preparation and analysis of the maps supported the understanding of vulnerability levels, as well as the analysis of clinographic levels and land use and land cover typologies. Relief forms (Figure 3) influence environmental vulnerability to varying degrees. In order to establish a relationship between erosive potential and environmental vulnerability within the school perimeter, the environmental vulnerability map (Figure 4) enabled the identification of the main affected areas at the ETEC.

Figure 3 – Sketch of the relief compartments of the Augusto Tortolero Araújo State Technical School



Source: Oliveira (2023).

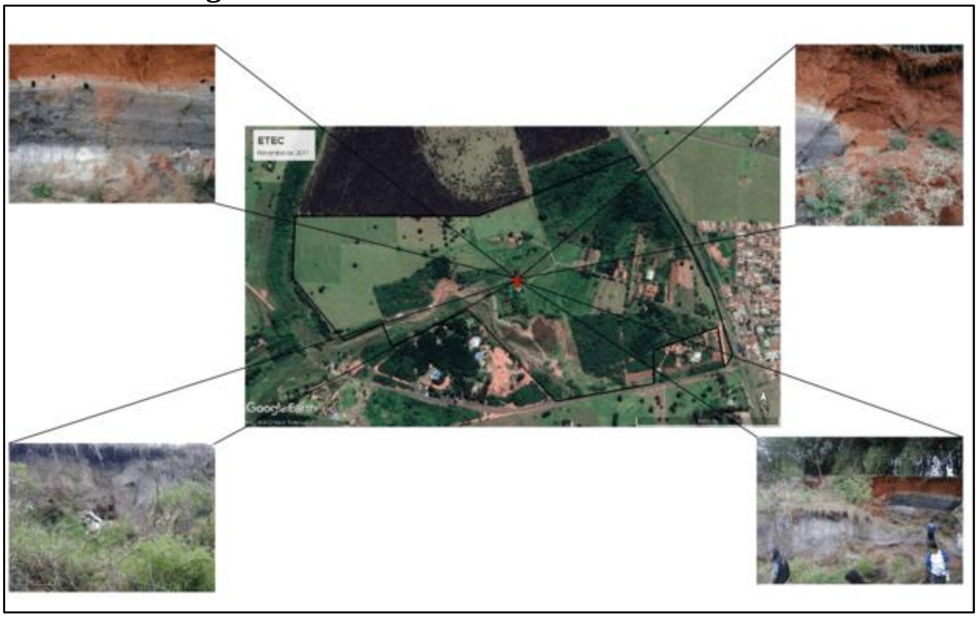
Figure 4 – Environmental vulnerability map of the Augusto Tortolero Araújo State Technical School



Source: Oliveira (2023).

An analysis of Figures 3 and 4 shows that the highest levels of vulnerability are concentrated in valley bottoms within alluvial plains and, subsequently, on slopes with steep topographic gradients in the northeastern and southwestern sectors. These high levels can be explained by the absence of riparian vegetation in valley bottoms, as well as by exposed soil on steeper slopes, as illustrated in Figures 5 and 6.

Figure 5 – Erosive features at the ETEC in 2017



Source: Authors' archive (2017). Adapted from Google Earth (2022).

Figure 6 – Gully advancement in 2017

Source: ETEC (2017).

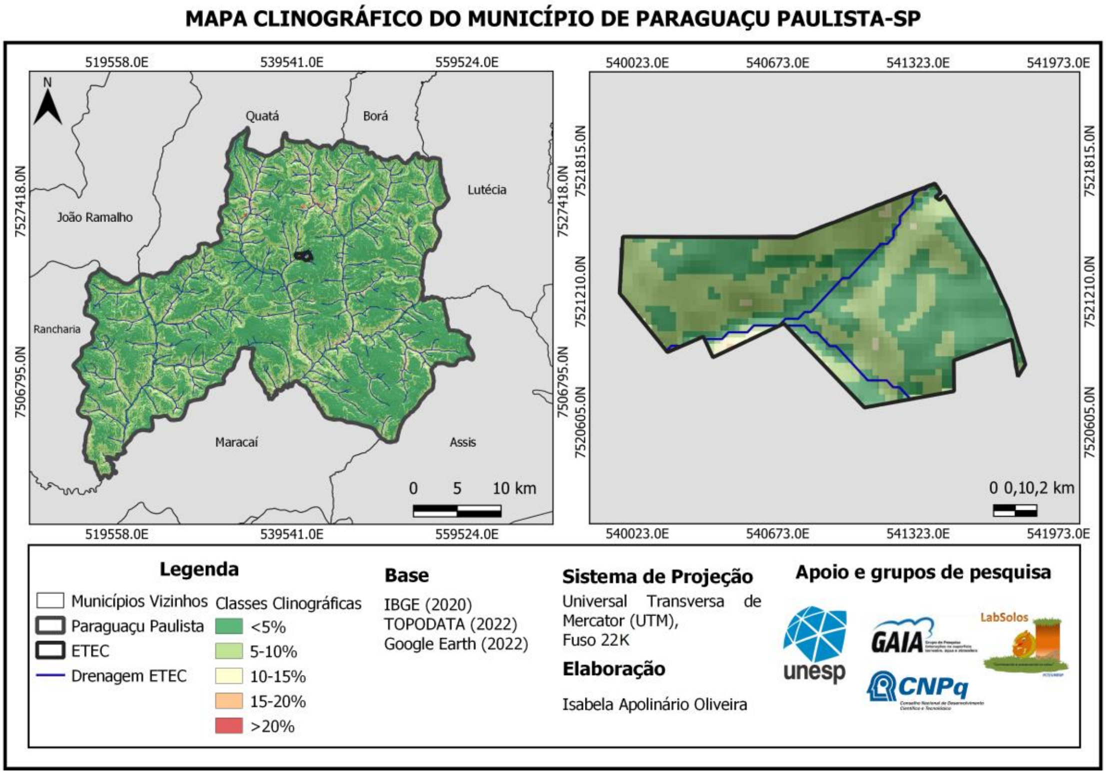
Oliveira (2023) emphasizes that when surface runoff occurs in environments with low vegetation cover or completely exposed soil, rainfall events increase the terrain's predisposition to a significant rise in concentrated surface runoff. When this process is combined with the splash effect, it leads to an increase in water flow energy, resulting in greater erosive capacity. If this process continues without adequate intervention to dissipate runoff energy and without the implementation of conservation and management actions that ensure maximum soil cover, erosion development may accelerate. Under these conditions, the terrain becomes more susceptible to the emergence of new erosive features, particularly in areas with higher levels of environmental vulnerability.

Areas with low vulnerability are mainly those where gently undulating convex hilltops, low slope gradients, and surfaces covered by grasses and forest fragments are found. Locations with low vulnerability are situated on areas used for pasture, where vegetation cover consists of grasses and small fragments of medium- to large-sized vegetation; agricultural terraces act as natural barriers that reduce runoff energy. The area exhibiting the lowest vulnerability coincides with the domain of concave slopes and the predominance of clinographic classes of 10–15% and 15–20%.

Slope is an important factor in understanding increases in erosive processes, since the higher the clinographic class (Figure 7), the greater the surface runoff velocity, a factor that can directly affect the vulnerability of a given location.

When specifically analyzing the school perimeter (Figure 7), the following slope classes are identified: < 5%, 5–10%, and 10–15%, with a predominance of the first two classes. The lowest slopes occur along small watercourses and on convex hilltops, while the 5–10% class is distributed across the domain of concave, convex, and rectilinear slopes. The 10–15% class is concentrated at a single point in the southwestern sector of the school area, where alluvial plains and low altimetry are observed.

Figure 7 – Clinographic map of the municipality of Paraguaçu Paulista

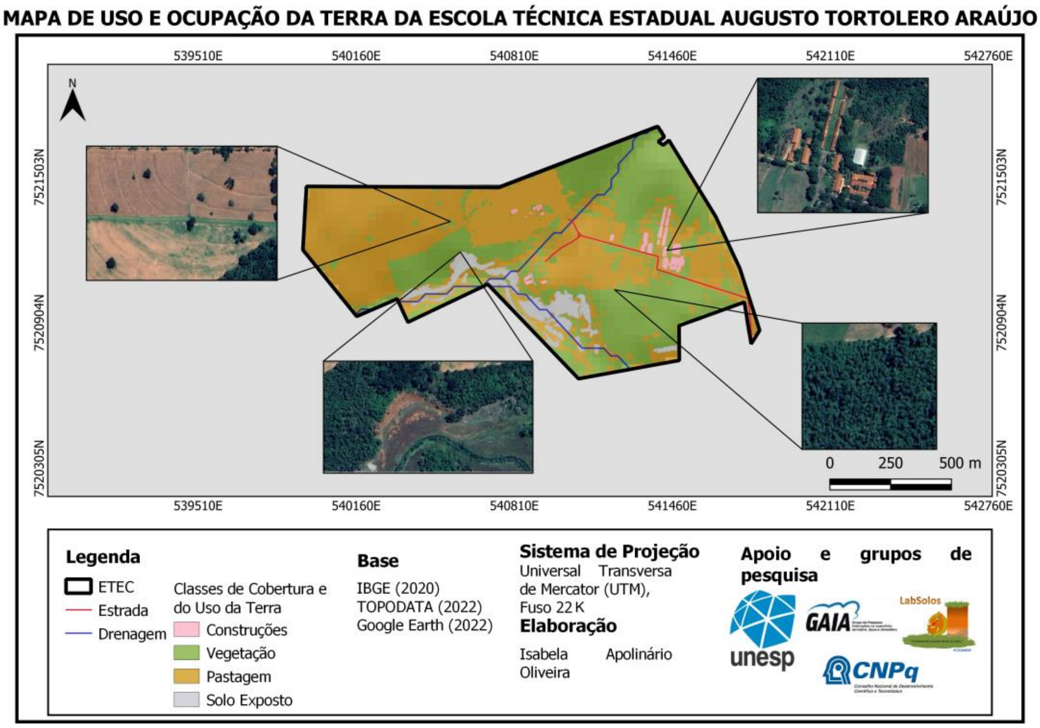


Source: Oliveira (2023).

An analysis of land use and land cover mapping (Figure 8) indicates that the main erosive processes are located on slopes with steep topographic gradients, in pasture areas, and on exposed soils. According to Oliveira (2023), considering the four land cover and land use classes presented, the pasture class covers approximately 85% of the area within the domain of concave, convex, and rectilinear slopes, as well as across the entire hilltop area located to the west.

In the valley bottom of the alluvial plain, the exposed soil class is present within the < 5% and 5–10% slope ranges, corresponding to the area with the highest vulnerability index, where the most advanced stage of erosive processes—the gully—was identified. The built-up areas class is predominantly located in the eastern portion of the site, representing the physical spaces of the school.

Figure 8 – Land use and land cover map of the Augusto Tortolero Araújo State Technical School



Source: Oliveira (2023).

Finally, the vegetation class, indicated in green tones, constitutes the second most extensive class, concentrated in the northeastern and southwestern sectors and part of the central portion of the area. Although the site contains fragments of native vegetation, they are insufficient to contain the volume of surface runoff during months with higher rainfall, due to the lack of implemented technical containment measures.

Land use and land cover, slope gradients, and relief morphology play fundamental roles in identifying different levels of environmental vulnerability at the ETEC. Based on this assessment—combined with the use of geoprocessing techniques and the production of cartographic outputs—it is possible to identify areas environmentally vulnerable to erosive processes, thereby enabling the proposal of mitigation measures.

Conclusions

Based on the analyses of the cartographic products developed during the research, it was found that the Augusto Tortolero Araújo State Technical School (ETEC) presents most of its landscape with low to medium levels of vulnerability to erosive processes. Areas of greater intensity occur on steep slopes with exposed soil and on plains, resulting from the lack of medium- to large-sized vegetation cover. This condition—combined with the absence of containment measures—leads to increased concentrated surface runoff, culminating in the formation of linear erosive processes such as rills, ravines, and gullies.

The current gully erosion process is in a stabilization phase; however, it may become strongly unstable again due to the predominance of morphogenetic processes over pedogenetic ones. The application of techniques for controlling erosive processes and stabilizing unstable areas has contributed to reducing the deepening of rills and has acted as a barrier to decreasing the velocity of pluvial runoff and sediment transport. In this context, the importance of implementing bioengineering techniques in the area is reinforced, in order to contain the volume of water flowing over the relief throughout the year, aiming at slope stability and, consequently, at the gradual restoration of vegetation in erosive features.

The use of geoprocessing—combined with the methodologies applied in this study—enabled the rapid identification of different levels of environmental vulnerability to linear erosive features, as well as an understanding of landscape transformations and the entire historical process of land use and occupation of the school area.

In summary, considering that erosive processes occur mainly in environments altered by human activity—under a predominantly tropical climate, due to high rainfall intensity—it is important to emphasize that the analysis and understanding of this phenomenon through the lens of environmental vulnerability are of great relevance, as they provide an integrated view of the natural and social aspects that interact within geographic space.

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