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Geoprocessing as a Tool for Predicting the Occurrence of Linear Water Erosion, Based on the Pattern of Runoff Concentration, on a Hillslope Scale

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SUMMARY

Erosion in urban areas is influenced by the interaction between different natural factors and anthropogenic activity, such as intense urbanization and uncoordinated occupation of urban space, which can trigger and intensify erosion processes. The aim of this study was to identify runoff patterns using geoprocessing as a tool for predicting the occurrence of linear water erosion on an urban hillslope at the source of the Grama River in Bauru, São Paulo. The characteristics of the terrain (curvature, gradient and slope orientation) and the influence of urban occupation were assessed in order to gain a general understanding of the events occurring on the hillslope. Existing linear erosion feature surveying and the Concentrated Flow map were superimposed to analyze the compatibility between the runoff pattern and the locations where the features occur. Analysis of the results indicated that, in general, the flow lines lead to the points where the recorded erosion features occur.

KEYWORDS: Linear Erosion. Urban. Geoprocessing.

1 INTRODUCTION

Erosion, mainly due to the constant increase in affected areas as a result of new forms of land use, is a serious problem faced today. In addition to causing the loss of arable land, it also leads to the deterioration of civil works and urban and rural infrastructure, the silting up of water bodies and other effects which may cause socio-economic and environmental impacts (KUHN *et al.*, 2023). As a consequence of siltation processes, the quality of surface water is affected and flooding and eco-hydrological alterations occur with greater frequency and intensity (FILHO; GOMES; JÚNIOR, 2021). Erosion processes which occur in physical environments are interrelated with various factors, such as climate, relief, vegetation, use and occupation and the action of rainwater. The balance between geoenvironmental, geotechnical and anthropogenic attributes in such environments is fragile. Any factor that interferes with one or other of these attributes will destabilize the existing condition, leading to a disruption in environmental balance. Runoff can be a key factor in the initiation and development of the erosion processes resulting from this imbalance (WEI *et al.*, 2022). Therefore, identifying the flow routes of runoff on hillslopes susceptible to erosion, characterized by anthropogenic modifications, is a very valuable way of diagnosing the dynamics and evolution of linear erosion processes, especially when combining topographical factors with changes in urbanization (MATHIAS *et al.*, 2020).

According to Coelho (2001, p. 95) “the preferential routes of surface or subsurface flows define the predominant erosive-depositional mechanisms”, so the runoff is an essential component for analyzing geomorphological processes. The analysis of flow direction extends to urbanized environments where small-scale structures such as roads, street gutters, highways, drainage ditches and culverts control surface drainage patterns. Thus, understanding, diagnosing and solving erosion processes in urban areas is essential.

Changes in soil cover, such as the removal of vegetation and installation of impermeable surfaces, interfere with drainage and runoff. As a consequence of waterproofing, there is a decrease in soil permeability, loss of biodiversity, and altered water quality in runoff (SCALENGHE & MARSAM, 2008; MATOS *et al.*, 2015). Changes to physical environments together with rapid unplanned urbanization alter the use and occupation of land, making the problem of soil erosion one of the most frequent in Brazilian urban centers.

In the municipality of Bauru in the state of São Paulo, Cavaguti & Silva (1993) cite the following as precursors of urban erosion processes: the increase and concentration of runoff due to waterproofing, the absence of an adequate drainage system, the unsuitable layout of streets and roads, deforestation, and the lack of infrastructure in housing complexes. These factors, as highlighted by the authors, stem from a lack of territorial management in terms of promoting the sustainable use of spaces during the process of urban expansion.

In the modern conception of land management, all planning, ordering or monitoring of a given environment must incorporate an analysis of the different components of which it is made up, including the physical-biotic environment, human occupation, and the interdependence of both. Due to the complexity of the analysis, geoprocessing computer tools such as Geographic Information System (GIS) software are essential for integrating data.

Therefore, the aim of the research was to evaluate the use of GIS to predict the occurrence of linear water erosion, based on a model of the pattern of runoff concentration (flow routes), on an urban hillslope in the municipality of Bauru, Sao Paulo state, in which relief characteristics (curvature, gradient and slope orientation) and the influence of urban occupation would be integrated.

2 LOCATION AND DESCRIPTION OF THE AREA OF STUDY

Occupying an area of 667 km^2, the municipality of Bauru is located in the interior of the State of São Paulo, on the state’s Sandstone-Basaltic Plateau, within the Paraná Sedimentary Basin. The Paraná Sedimentary Basin was formed from basaltic flows which, in turn, were overlain with sedimentary cover that constitutes the Bauru Basin (ALMEIDA, 1964). Bauru’s soil is mostly made up of fine clayey sand with a low silt content. As a consequence of these and other characteristics (such as a porous structure, low cohesion and soil compaction) it is highly prone to collapse (CORGHI & GIACHETI *et al.*, 2006).

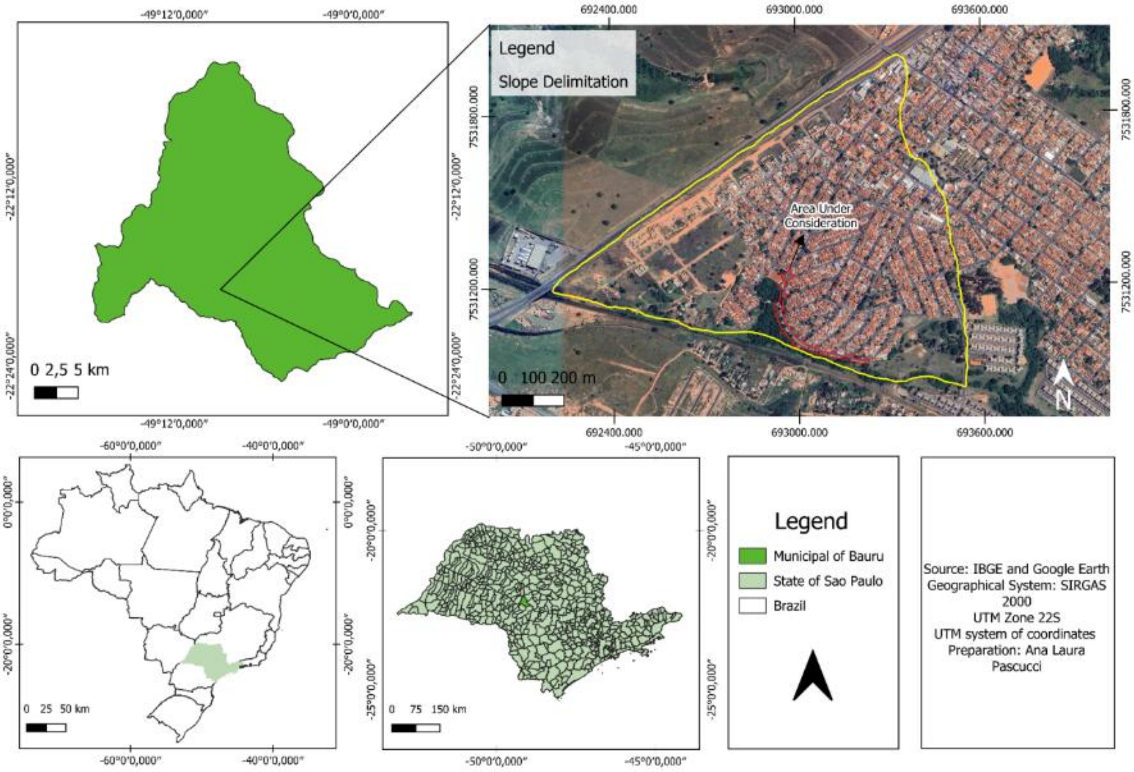
The relief of the region is slightly undulating, with a predominance of broad hills and slopes (DAEE, 2008). Terrain forms in the region often feature watercourses that originate from drainage headwaters and preferential channels, which indicate possible surface flow routes (ALMEIDA FILHO, 2000). The area under investigation is located between the UTM longitude coordinates: 693423.71 E and 692911.79 E; and between the latitude coordinates 7530913.08 S and 7531789.50 S, within the municipality of Bauru (Figure 1).

A number of studies related to erosion processes and runoff have been carried out in the region. Oliveira et al. (2022) analyzed the temporal evolution of the features adjacent to the drainage channel and Souza et al. (2022) evaluated the factors influencing erosion processes in the area. Considering erosion potentially caused by the accumulation of runoff in an urban area at the drainage headwaters, the study area was defined as the slope to the left of the Edson Francisco da Silva Housing Nucleus - COHAB 16 (Figure 1).

The hillslope is densely urbanized, with paved streets and few permeable lots, an established drainage network and a relief comprising broad hills characterized by extensive, flattened tops, and slopes with rectilinear to convex profiles, which allow rapid infiltration

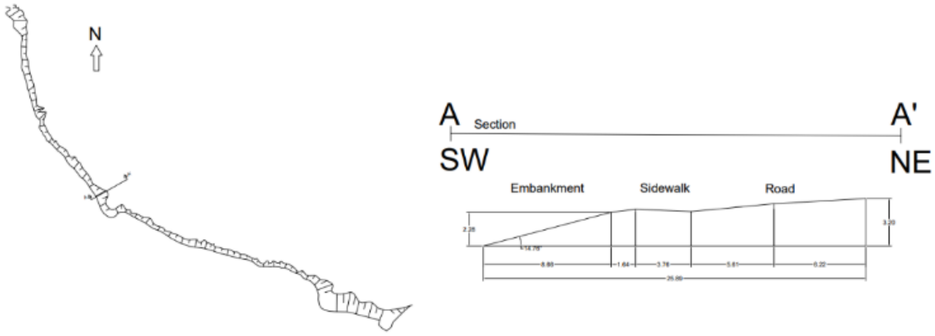
(SHS, 2008). In the lower part of the slope there is an embankment (Figure 2), where erosion is developing on the level ridge, near Sebastião Joaquim Sampaio Street.

Figure 1: Location of the study area in the Edson Francisco da Silva Housing Nucleus in Bauru City in São Paulo State countryside - Brazil, highlighting slope delimitation and detailing the area under consideration.



Source: Own authorship (2022).

Figure 2: Sketch and schematic section of the embankment.



Source: Own authorship (2023).

3 METHODOLOGY

The data utilized for the present study comprises the contour lines taken from a dwg file provided by the Bauru City Hall and a Total Station planialtimetric survey carried out along Sebastião Joaquim Sampaio Street. The survey includes details of the plateau between the canal and the public road and notes the linear erosion features, establishing the area of the slope under consideration (highlighted in Figure 1). The specific area selected was the lower slope region, one where the flow which has caused the erosive features is concentrated. The area under consideration does not, therefore, include the street blocks with lot divisions.

Having established the database, a priori, a Digital Elevation Model and, a posteriori, the geomorphometric variable maps and the Surface Water maps (Drainage Direction and Concentrated Flow maps) were prepared.

In order to systematize and guide the study, a survey was carried out of the location and occurrence of the linear erosive features found on the slope. The characteristics of the slope were recorded and analyzed during technical visits in order to understand the appearance of the features and which aspects of the delimited slope influence the dynamics of the erosion processes. The survey was carried out during two field visits, the first in July 2021 and the second in September 2022. On the first visit, 7 linear erosion features were identified on the lower slope alone, while on the second visit, a year later, 4 more features were observed in the vicinity. The survey was restricted to the features adjacent to Sebastião Joaquim Sampaio Street, since it is these that can be directly associated with the urban occupation of the slope.

By superimposing the maps with the survey of existing linear erosion features, it was possible to analyze the relationship between the concentration of flow on the lower slope and the occurrence of current erosions.

3.1 Planialtimetric Survey of the Area Under Consideration

The selection of points and the quantity of data sampled are directly related to the quality of the results generated from an application using the model. For applications requiring a higher degree of realism, the number of points sampled and the quality of the data are decisive. As the number of points as representations of the real surface increases, the greater the computational effort required to store, retrieve and process the points until a superior result is achieved. The detailed representation of the relief in digital models ensures the compatibility of runoff, guaranteeing hydrological consistency and the careful assessment of erosion phenomena (TAROLLI, 2014).

Therefore, in order to guarantee the consistency of the concentration pattern, carrying out a detailed survey of the area was considered necessary. Using a Stonex R25 Total Station, altimetry data was recorded on a grid at approximately two-meter intervals. The survey was carried out over an area of 9,457m^2, being roughly 1% of the total area of the slope studied, which measures 893,315m^2. Due to the need to capture altimetric data on a one-off basis, the planialtimetric survey proved unfeasible (due to the length of the process) for regions beyond the area under consideration.

The surface water maps generated, therefore, disregard the existence of lots with buildings and asphalted roads, which generate different paths for the water, and do not offer the detail obtained in the area under consideration. Although this fact only influences the distribution of water uphill, a general analysis of the behavior of the relief is still possible, as it does not compromise the path of the water further downhill, since the final destination of the flow is determined by the micro relief of the area under consideration.

3.2 Digital Elevation Model (DEM)

Digital models and product maps, being reductionist representations of the real environment in a computer interface with the insertion of databases, depend on the combinations and associations of information through geometric and topological operations. In order to represent the relief using a Digital Elevation Model, the grid must be defined to mathematically describe the terrain, depending on the purpose of the data used and the way in which the data will be employed within the structure of the model (Moore *et al.*, 1991).

In the present work, the Triangulated Irregular Network (TIN) interpolator was used, which presents grids formed by triangulation for areas characterized by changes in relief and use and occupation, resulting from anthropic intervention. The advantages of the triangulation model over others relate to its relevance to gravitational movement and especially to hydrological applications (SZYPULA, 2017).

As a result of the QGIS software interpolation process, two Digital Elevation Models were generated, one using only the contour line data (total slope) and the other combining the contour lines with the planialtimetric survey (total slope, containing the area under consideration). To facilitate visualization and comprehension of the model, a simple false-color band was assigned to the two DEMs generated.

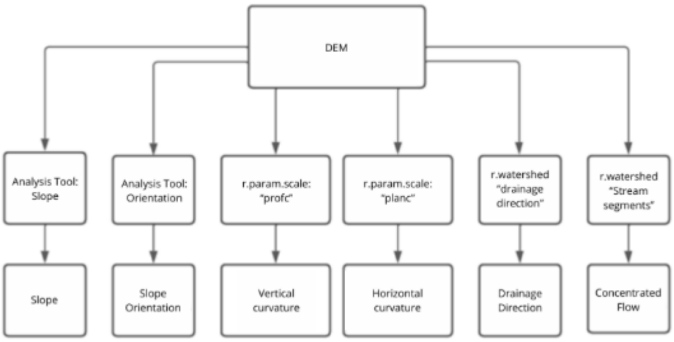
3.3 Generation of Geomorphometric and Surface Water Variables Charts

Having established the stages of acquiring the sample data and choosing the mathematical model (TIN), the maps derived from the DEM can be generated for Geomorphometric Analysis (such as the Gradient, Horizontal Curvature, Vertical Curvature and Slope Orientation maps), as well as for Surface Water (Drainage Direction and Concentrated Flow maps).

Currently, GIS programs have specific modules for extracting geomorphometric and surface water variables from the DEM. The advantages of automated algorithms over manual procedures ensure the greater efficiency and credibility of the processes, as well as the reproducibility of the results, and the possibility of storing and sharing digital data.

A summary of the main tools used in QGIS to produce the geomorphometric and surface water maps, based on the Digital Elevation Model, is shown in the flowchart below (Figure 3).

Figure 3: Flowchart of the process for generating geomorphometric and surface water maps.



Source: Prepared by the author (2022).

3.4 Approach adopted for preparing the surface water maps

There are two approaches in the literature for preparing drainage network maps detailing the flow routes of runoff. The first uses a filter applied to the Digital Elevation Model (DEM) raster. The approach involves local evaluation of the elevations of the model and the identification of concave and convex pixels as potential flow, as well as ridge points (PEUCKER; DOUGLAS, 1975). The main disadvantage of this approach is the detection technique, which acts in a localized manner and generates discontinuous network segments, in the form of an approximation of the drainage network that then requires further processing to generate a connected drainage pattern. Whereas the approach is well suited to an initial identification of features in hilly terrain with well-formed watercourses and clear dividers (Band, 1986), it is difficult to apply the approach in urban areas.

The second approach, originally proposed by O'Callaghan and Mark (1984), defines a drainage network based on the automatic derivation of the preferential path of runoff over the DEM. As well as the digital data obtained by the derivation method being generated more quickly and in a less subjective way, the advantage of this approach is that the data can be easily analyzed in GIS. Considering the simulation approach, implementation variations have been developed, such as those proposed by Jenson and Dominique (1988), Garbrecht and Martz (1992) and others that have succeeded them (PELLETIER, 2013; YUANZHI YAO et al., 2022). Although there are differences in the method, essentially similar processing steps take place.

The basic method for determining flow direction uses 3x3 matrices, where each cell has eight neighbors and the flow goes from the central cell towards the cell with the lowest altitude value; in the case of two neighboring cells with the same altitude, the algorithm gives preference to the cells that are not on the diagonal, thus generating a single direction flow (O'CALLAGHAN; MARK, 1984). If more than two adjacent cells have the same altitude, the direction will be towards the central cell (JENSON; DOMINGUE, 1988).

Therefore, in opting for the second approach, this study used the r.watershed tool from the GRASS catalog in QGIS (Figure 3), taking the information from the Digital Model and the parameters adopted. The tool generated the Drainage Direction and Concentrated Flow maps by identifying the preferential path of runoff between each DEM cell and its neighbors.

3.5 Parameters for preparing Geomorphometric and Surface Water Maps

In the same way that variations occur depending on the choice of grid for modeling, variations can also occur in the choice of parameters for obtaining results derived from the DEM. The parameters used in this study to draw up the geomorphometric, drainage direction and concentrated flow maps are presented in Table 1, based on the variation of the parameters and evaluation of the respective products generated. The following parameters were considered: slope classification according to EMBRAPA (1979); orientation classification according to Rovani and Cassol (2012); processing window size (r.param.scale) equal to 45; and minimum outer watershed size (r.wartershed) equal to 50.

Table 1: Parameters adopted when preparing geomorphometric and surface water maps.

QGIS Tool	**Parameter**	**References or Values Adopted**
Gradient	Classification of the gradients	EMBRAPA (1979)
Orientation	Classification of the slop orientations	Rovani and Cassol (2012)
r.param.scale	Size of the processing window	45
r.watershed	Minimum size of the outer watershed	50

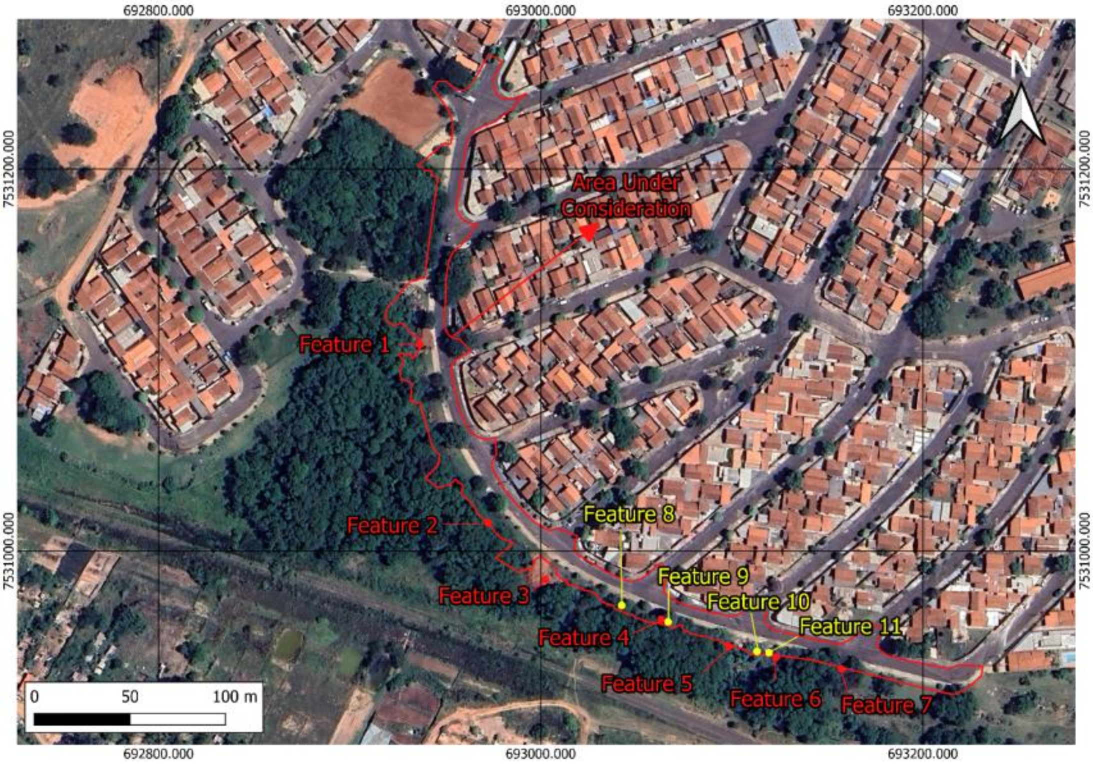
Source: Prepared by the author (2024).

4 PRESENTATION AND ANALYSIS OF THE RESULTS

The location of the linear erosion features is shown in

Figure 4. The features numbered 1 to 7 and marked in red are those identified during the first visit in July 2021, while those numbered 8 to 11, marked in yellow, are the most recent (September 2022). The erosions designated as Feature 1, Feature 3, Feature 4, Feature 6 and Feature 7 were observed again in the second survey. The features designated as Feature 2 and Feature 5 previously observed during the first visit no longer existed. For the purposes of analysis, however, the 11 features surveyed were considered.

Figure 4: Location of the features, highlighting the area under consideration.



Source: Prepared by the author (2022).

The model and maps were initially processed using only the contour lines provided by the City Hall (Model 1). Subsequently, the data collected for the area under consideration (Model 2) were added. Compared to Model 1, Model 2 identified higher slope and diversification in terms of the direction and course of the steepest incline of the slope, as shown on the gradient and orientation maps.

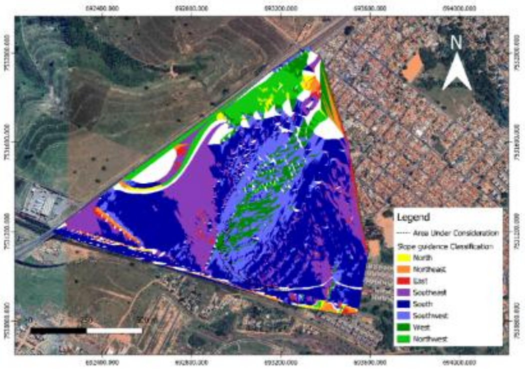
In the concentrated flow chart of Model 1, the flow behaved more diffusely in the area under consideration than in Model 2, in that the exact positions of where features could occur were not shown. Once the detailing is applied, the existence and distribution of the flow lines can be identified, following a centrifugal trajectory along the length of the road. The flow lines generated are directly related to the divergence in direction on the slope orientation map, indicating the importance of such detail for the analysis. In Model 2, Sebastião Joaquim Sampaio Street had begun to act as a receiver and distributor of runoff. This has not been the case in Model 1.

Thus, the analyses carried out for the present study used the maps drawn up from Model 2, because they reveal the importance of detailing the region at the bottom of the slope in order to understand the accumulation of flow and the local erosion processes. In addition, the slop map shows that gradients become steeper the closer they get to the lower slope, being classified as “undulating” (8 to 20%), while on the upper part of the slope there are areas with “smooth undulation” (3 to 8%) and “plateau” areas (0 to 3%) (EMBRAPA, 2006), corresponding to the paved roads (Figure 5). Some areas that have a “strong undulation” (a pumpkin color in Figure 5) represent places with erosive features and the canal itself, close to the highway (which were identified in the City Hall file used). The area under consideration showed regions with a marked gradient, with emphasis on “mountainous” and even “scarpment” regions, according to Embrapa classification (2006).

Figure 5: Slope map with survey data (Embrapa classification, 2006).

Source: Prepared by the author (2022).

Figure 6: Hillslope guidance map with survey data.

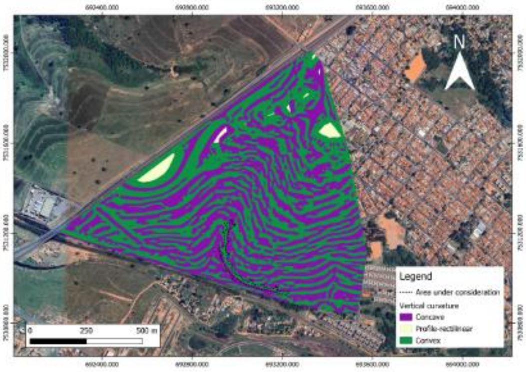


Source: Prepared by the author (2022).

In Figure 6 it can be seen that the lines with the steepest slopes at the bottom of the hill face south, with the flow dispersing directly downhill. The areas with no color on the chart represent the flat regions, i.e. those with no slope orientation, which are from where the flows originate. In the central region of the slope, the gradients are oriented to the southeast on one side and to the west/southwest on the other, in the direction of the area under consideration.

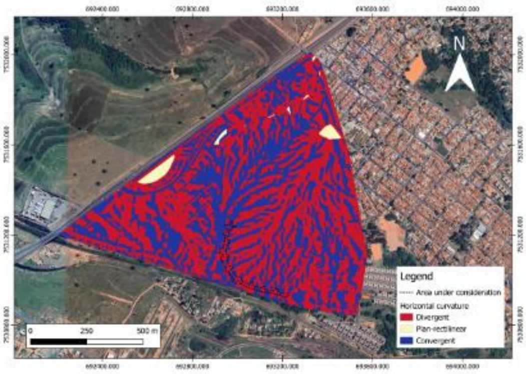
In the vertical curvature map (

Figure 7: Vertical curvature map with survey data.



Source: Prepared by the author (2022).

Figure 8: Horizontal curvature map with survey data.



Source: Prepared by the author (2022).

), classification transitions between convex and concave regions can be seen; these were quantified at approximately 32% concave curvature, 53% convex curvature and 15% rectilinear curvature.

There is also a predominance of convex regions both on the highest part of the slope and in the area under consideration (corresponding to 57% and 60% of the total area, respectively), indicating areas of water divergence. The concave regions, where there is a predisposition to flow convergence, correspond to 40% on the highest part of the slope and 39% within the area under consideration. Areas of rectilinear vertical curvature accounted for approximately 3% of the total area of the upper slope, while in the detail area, flat areas are non-existent.

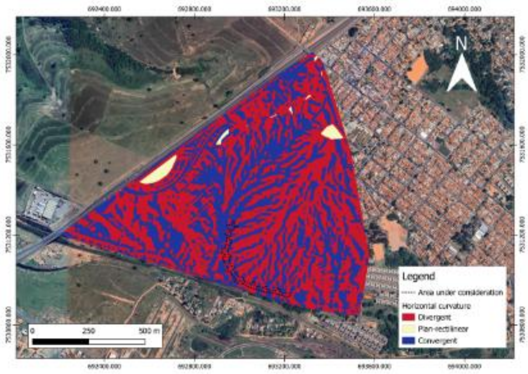
Considering the area under consideration, the main road has a predominantly convex vertical curvature, which suggests a distribution of flow; this, together with regions of convergent horizontal curvature, represents a certain concentration of runoff in specific locations in the region where erosion processes occur.

It is important to note, however, that the data used does not take into account the effect of land development and the region's paved roads, and also describes a feature close to the highway (which has been reclaimed).

Figure 7: Vertical curvature map with survey data.

Source: Prepared by the author (2022).

Figure 8: Horizontal curvature map with survey data.



Source: Prepared by the author (2022).

In the horizontal curvature map (Figure 8) areas of divergent horizontal curvature predominate (representing 56% of the total slope area), while in the high slope region and in the area under consideration convergent horizontal curvature predominate (57% and 62%, respectively). Throughout the latter area it can be seen that the lots with convergence alternate with areas of divergence. In the central portion of the hill, a pre-eminently convergent region can be identified.

The central region of the hill of horizontal curvature, convergent predominantly (Figure 8), together with the orientation of the hillslopes, which on one side faces southeast and the other west/southwest, indicates a convergence of the flow lines towards the drainage channel and Sebastião J. Sampaio Street, which represents the axis of the area under consideration.

The Direction and Drainage maps (Figure 9), which indicate the direction of runoff, and Concentrated Flow maps (Figure 10), which details the drainage network, were essential for analyzing runoff in the area under consideration. The Drainage Direction chart (Figure 9) explicitly shows the places where the flow diverges in different directions and the points at which accumulation occurs, which are delineated on the Concentrated Flow map (Figure 10).

Finally, the location of linear erosion features (

Figure 4) and the Concentrated Flow map (Figure 10) were superimposed to analyze the compatibility between the pattern of runoff and the locations where the features occur (Figure 11).

Figure 9: Drainage Direction Map with survey data.

Source: Prepared by the author (2022).

Figure 10: Concentrated Flow Map with survey data.

Source: Prepared by the author (2022).

Figure 11: Flow concentration lines and locations of erosion.

Source: Prepared by the author (2022).

Superimposing the maps revealed that in Feature 1, Feature 2, Feature 3, Feature 4, Feature 6 and Feature 9, the flow lines lead to the points where the erosion features recorded occur. This indicates the implication of the landforms (geomorphology) and, above all, the characteristics of the paved road in the concentration of runoff in specific places on the lower hillslope.

In terms of Feature 5, Feature 7, Feature 8, Feature 10 and Feature 11, however, the locations did not coincide with the flow lines. One reason for this discrepancy could be the palliative interventions carried out with the aim of restoring the region. As part of these interventions, soil was moved, which changed the roughness of the surface and, consequently, the flow was taken along alternative routes, generally to the sides, generating new preferential flow lines and the possibility of new features occurring in other locations. This justification is clear in relation to Feature 8.

In terms of the area under consideration, analyzing Sebastião J. Sampaio Street on a plot scale with the planialtimetric survey was fundamental for determining the paths of least resistance, travelled by the water, which accumulate in small depressions and gain speed as the water level and the gradient of the terrain increase.

Furthermore, the flow distribution in Figure 11 verifies that some lines of concentrated flow lead from the highest part of the hillslope to the lowest, crossing the blocks and running over the lots. In practice, however, part of the volume of rainwater from each lot infiltrates into the land itself, the other part being conducted into the drainage system without traversing individual lots. One possible means of representing the real behavior of water, therefore, would be to consider the lots as impermeable. Another circumstance that would alter the flow line model is the convex shape of the streets, which distributes rainwater to the gutters on each side, thus altering the concentration of flow along the street. For a complete analysis of the flow behavior on the slope, therefore, it would be necessary to correct the model by means of a more detailed survey, such as the planialtimetric survey carried out for the area under consideration, or by adopting a precision GPS system, or by using the surface scanning technique.

5 FINAL CONSIDERATIONS

The specific area studied is highly susceptible to erosion processes, due to its pedological characteristics, related to the type of collapsible sandy soil in the municipality of Bauru and the geomorphological characteristics of the hillslope.

Although the terrain is mostly composed of convex and divergent curvatures, the geomorphology reveals steeper gradients towards the lower slope and an orientation of the hillslopes towards the central region of the hillslope, where there is an area of convergent curvature which concentrates water flow towards the Sebastião Joaquim Sampaio Street.

On the other hand, places with concave-convergent geomorphology, such as the headwaters of the basin, intensify compaction and increase runoff from the area, making these places more susceptible to the formation of linear erosive features.

Urbanization has also proved to be a determining factor in the occurrence of linear erosive features, as it contributes to the concentration of flow in specific locations, depending on the layout and appearance of the streets. Considering that there are still areas on the hillslope that are in the process of being occupied by urban development, expansion is likely to predispose to new erosion processes.

The compatibility between the flow concentration pattern and the occurrence and development of linear water erosion near the drainage channel and along the sidewalk of Sebastião Joaquim Sampaio Street, indicates the possibility of modeling, based on the analysis of flow concentration using the GIS tool, to predict the occurrence of linear erosion features. One way of developing the research study, even without a more detailed survey, would be to reapply the model considering the lots as impermeable and the respective rainwater outlets from the lots to the streets.

The study identified the need to disperse water flow along the paving in order to solve the problem of erosion in the region or, as an alternative, to create specific energy dispersers at the main flow concentration points identified. The palliative interventions carried in the region over time have only moved the concentration of flow to new preferential lines and thus caused new erosive features.

6 REFERENCES

ALMEIDA FILHO, G. Diagnóstico de processos erosivos lineares associados a eventos pluviosos no município de Bauru – SP. In: Simpósio Nacional de Controle de Erosão, Goiânia, 2001. **Anais do VII Simpósio Nacional de Controle de Erosão**, Goiânia, 2001.

ALMEIDA, F. F. M. Fundamentos geológicos do relevo paulista. **Boletim do Instituto de Geográfico e Geológico**, São Paulo, n. 41, p. 169-263, 1964.
BAND, L. E. Analysis and representation of drainage basin structure with digital elevation data. **Proceedings of the Second International Conference on Spatial Data Handling**. Int. Geogr. Union Williamsville, NY, 1986. p. 437-450.

BIGARELLA, J.J.; Becker, R.D.; Santos, G.F. **Estrutura e origem das paisagens tropicais e subtropicais**. Editora da Universidade Federal de Santa Catarina, Florianópolis, 1996.

CASSETI, Valter. **Geomorfologia**. [S.l.]: [2005].

CAVAGUTI, N.; SILVA, M.J.D. Desenvolvimento urbano, erosão e degradação dos recursos hídricos por assoreamento em Bauru – SP. In: I Simpósio de Recursos Hídricos do Cone Sul. **Anais X Simpósio Brasileiro de Recursos Hídricos**, Gramado, 1993.

COELHO, M. C. N. Impactos ambientais em áreas urbanas: teorias, conceitos e métodos de pesquisa. In: GUERRA, Antônio. José. Teixeira. **Impactos ambientais urbanos no Brasil**. Rio de Janeiro: Bertrand Brasil, p. 19-45, 2001.

CORGHI, F.; GIACHETI, H. Processos erosivos na Área Urbana de Bauru-SP. In: VI Simpósio Nacional de Geomorfologia (SINAGEO). **Anais de Trabalhos Completos**, Goiás/Goiânia, v. 1, p. 227, 2006.

DAEE. 2015a. **Diagnóstico hidrogeológico e a elaboração de propostas para a gestão dos recursos hídricos subterrâneos no município de Bauru/SP.** Relatório Final. DAEE/C3 Planejamento Consultoria e Projeto Ltda., São Paulo, 3 volumes.

FILHO, G. S. A.; GOMES, C. L. R.; JÚNIOR, Z. H. EVOLUÇÃO DOS PROCESSOS EROSIVOS URBANOS NO MUNICÍPIO DE CASA BRANCA, SP. In: 9° Congresso Luso-Brasileiro para o Planejamento Urbano, Regional, Integrado e Sustentável 2021. **Anais do Pluris 2021 Digital**. Bauru: UNESP, 2021, ID: 1065.

GARBRECHT, J.; MARTZ, L. W. Comment on "A Combined Algorithm for Automated Drainage Network Extraction" by Jean Chorowicz et. al**. Water Resources Research**, vol.29, pp. 535-536, 1992.

JENSON, S. AND DOMINGUE, J. Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis. **Photogrammetric Engineering and Remote Sensing**, 54, 1593-1600, 1988.

KUHN, C. E. S. *et al.* The record and trends of natural disasters caused by gullies in Brazil. **Environmental Earth Sciences**, Verlag GmbH/Germany, v. 82, n. 22, p. 524. 2023.

MATHIAS, D. T.; LUPINACCI, C. M.; NUNES, J. O. R. Identificação dos fluxos de escoamento superficial em área de relevo tecnogênico a partir do uso de modelos hidrológicos em SIG. **Sociedade & Natureza**, Uberlândia, v. 32, p. 820–831, 17. 2020.

MATOS, C., BENTO, R., & BENTES, I**.** Urban Land-Cover, Urbanization Type and Implications for Storm Water Quality: Vila Real as a Case Study. **J Hydrogeol Hydrol Eng**, 4(2), 2015.

MOORE, I. D. *et al.* Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. **Hydrological Processes**, Chichester, Sussex,5, 3-30, 1991.

O'CALLAGHAN, J.F. and MARK, D.M. The Extraction of Drainage Networks from Digital Elevation Data. **Computer Vision, Graphics and Image Processing**, Cambridge, Massachusetts, 28, 328-344, 1984.

OLIVEIRA, A. L. P. De; Francisco, M. R.; Furegatti, S. A. Análise Temporal e Evolutiva das Erosões Lineares Hídricas Urbanas em Encosta Localizada na Região de Nascente do Córrego da Grama. **Periódico Técnico e Científico Cidades Verdes**, Tupã, v. 10, p. 98-113, 2022.

PELLETIER, J. D**.** A robust, two-parameter method for the extraction of drainage networks from high-resolution digital elevation models (DEMs): Evaluation using synthetic and real-world DEMs. **Water Resources Research**, Washington, D.C. 49, 1-15p, 2013.

PEUCKER, T. K.; DOUGLAS, D. H. Detection of Surface-Specific Points by Local Parallel Processing of Discrete Terrain Elevation Data. **Computer Graphics and Image Processing**, Cambridge, Massachusetts, v. 4, n. 4, p. 375–387, 1975.

SALOMÃO, F.X.T. **Processos erosivos lineares em Bauru (SP) – regionalização cartográfica aplicada ao controle preventivo urbano e rural** – São Paulo, 1994. Tese (Doutorado em Geografia Física). Faculdade de Filosofia, Letras e Ciências Humanas da Universidade de São Paulo.

SCALENGHE, R., & MARSAN, F. A. The anthropogenic sealing of soils in urban areas. **Landscape and urban planning**, Amsterdã, 90(1-2), 1-10, 2009.

SHS – CONSULTORIA E PROJETOS DE ENGENHARIA S/S LTDA. **Diagnóstico Ambiental e dos Recursos Hídricos do Município de Bauru - SP**. Relatório final. 2008.

SOUZA, D. L. M. de, ROMERO, L. M., & FUREGATTI, S. A. (2022). Analysis of factors that influence the occurrence of erosive branches on the left margin of a urban gully in Bauru/SP: case of COHAB-16 / Análise de fatores que influenciam a ocorrência de ramificações erosivas à margem esquerda de uma boçoroca urbana em Bauru/SP: caso COHAB-16. **Brazilian Journal of Development**, São José dos Pinhais, 8(4), 26519–26535, 2022.

SOUZA, J. O. P.; ALMEIDA, J. D. M. Modelo digital de elevação e extração automática de drenagem: dados, métodos e precisão para estudos hidrológicos e geomorfológicos. **Boletim de Geografia**, UEM, Maringá, v. 32, p. 134-149, 2014.

SZYPUŁA B., 2017. Digital elevation models in geomorphology. [In]: Shukla D.P. (Ed.), **Hydro-Geomorphology – Models and Trends**. InTech, pp. 81-112.

TAROLLI P. High-resolution topography for understanding Earth surface processes: Opportunities and challenges. **Geomorphology**, Illinois, v.216, p.295–312, 2014.

VALERIANO, M. M. Topodata: guia para utilização de dados geomorfológicos locais. ***In:*** **Do Projeto de Produtividade em Pesquisa "Modelagem de dados topográficos SRTM"**, INPE-15318-RPQ/818, São José dos Campos, 75p, 2008.

WEI, Y. *et al.* Analysis of gully erosion susceptibility and spatial modelling using a GIS-based approach. **Geoderma**, Glasgow, Scotland, v. 420, p. 115869, 2022.

YUANZHI, Y.; XUN, S. & ZEKUN, W. An efficient multiple scanning order algorithm for accumulative least-cost surface calculation. **International Journal of Geographical Information Science**, Philadelphia, 36(8), p.1677-1695, 2022.