Classification of urban erosive features: contribution area evaluation, at Jardim Marilu, Bauru/SP

Classificação das características erosivas urbanas: avaliação da área de contribuição, no Jardim Marilu, Bauru/SP

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ABSTRACT
In urban areas, the development of erosive processes can cause damage such as siltation of water sources, contamination of rivers, destruction of homes, undermining of foundations, silting of pipes, floods, reduced rural productivity and often loss of human lives. For any erosive feature, whether in an urban or rural area, when it is possible promote its recovery, a comprehensive analysis of the installed process must be carried out, observing the local conditions of the area that contributes to the appearance and development of the feature and the surrounding area. In this way, it presents at this article a broad study of the conditions that led to the formation and development of an urban erosive feature in Bauru City, enabling improved decision-making processes regarding solutions that should be adopted. The data were organized using the form for surveying conditioning factors and identifying erosive features, prepared by Mercaldi and Furegatti (2020). The erosive feature was classified based on the table developed by Mercaldi and Furegatti (2019) which identified it as a gully erosion.

Keywords: Erosive processes. Gully. Anthropic action.

RESUMO
Em áreas urbanas, o desenvolvimento de processos erosivos pode causar danos como assoreamento de fontes de água, contaminação de rios, destruição de residências, minagem de fundações, assoreamento de tubulações, enchentes, redução da produtividade rural e muitas vezes perda de vidas humanas. Para qualquer característica erosiva, seja em uma área urbana ou rural, quando for possível promover sua recuperação, deve ser realizada uma análise abrangente do processo instalado, observando as condições locais da área que contribui para o aparecimento e desenvolvimento da característica e da área circundante. Desta forma, apresenta-se neste artigo um amplo estudo das condições que
levaram à formação e desenvolvimento de um recurso erosivo urbano na cidade de Bauru, possibilitando melhores processos de tomada de decisão quanto às soluções que devem ser adotadas. Os dados foram organizados utilizando o formulário de levantamento de fatores condicionantes e identificação de características erosivas, preparado por Mercaldi e Furegatti (2020). A característica erosiva foi classificada com base na tabela desenvolvida por Mercaldi e Furegatti (2019), que a identificou como uma erosão do barranco.


### 1 INTRODUCTION

For many centuries, erosive processes were largely caused by the misuse of the soil in agriculture and by the destruction of wars between civilizations. With urbanization, the industrial revolution, the migration of people from rural areas to urban centers, it is necessary to take into account the changes that this generated and how this affected the soil. According to Santos et al. (2017a), some factors that accelerate erosive processes in urban areas as large migration of people resulting in disorderly growth in cities, causing many environmental impacts, such as allotments, surface waterproofing, runoff concentration, avenues built on the bottom of valleys, precarious urban agglomerations without infrastructure, etc..

In large urban centers, erosive processes are quite common. The sediments transported by the runoff come from permeable areas, pavements and in civil construction, whose soil interventions are severe, from which cuts and embankments can be related. The impact resulting from urban erosion is evidenced by the clogging of manholes, usually causing small floods, whose consequences are manifested in traffic and, mainly, in the material losses of local residents (ANDREOLI, et al., 2014).

The erosive process results from a combination of various factors that must be taken into account. These include the action of erosive agents, the type and texture of the soil, whether there is and which type is the vegetation cover, the slope of the land, the length of the slope, and if there is anthropic action and how it affects the environment (SANTOS, 2017). Anthropogenic action can occur in different ways including deforestation, exploitation of natural resources, urban occupation without planning, construction of roads and dams, and agricultural production that damages the topsoil (OLIVEIRA, et al., 2018). These actions can promote the weakening of the soil and, if added to the waterproofing of the surface, result in a decrease in the capacity of water infiltration into the soil, causing an increase in the speed of surface runoff.
The damage produced by erosive processes in urban areas can be various, such as siltation of water sources, contamination of rivers, destruction of homes, undermining of foundations, silting of pipes, floods, reduced rural productivity, and often loss of human lives (OLIVEIRA, et al., 2018; GUERRA E BOTELHO, 1996; GIFFONI, 2010). A large portion of Brazilian municipalities suffer from the degradation of urban areas by erosive processes, such as laminar erosion in furrows, ravines, and gullies. Erosive processes have a destructive power that results in situations of risk to the population and becomes a restrictive condition for urban expansion (IWASA, et al., 2018).

Bauru City is intensely degraded by medium and large linear erosions (ravines and gullies), causing destruction of works, siltation of valley bottoms, soil devaluation, among several other damages to the city (CORGHI, 2008; ALMEIDA FILHO, 2000; MOTA AND FUREGATTI, 2021). Many factors contribute to the processes, such as the lack of a drainage collection network, unplanned occupation of valley bottoms and headwater areas, and waterproofing. These factors end up forming erosive features and flooding due to siltation of rivers (CORGHI, 2008). The recoveries of features made in the city are mostly temporary palliative work, carried out without any adequate technical project. Deposition of stones and raw civil construction waste, soil movement without importing the material, and crater filling without compaction control are some of the actions implemented the city hall (BIGHETTI, et al., 2021).

Corghi (2008) also evaluated most of the old and recent erosions in Bauru City arose from inadequate land subdivisions without preventive actions, besides the negligence when building infrastructure works such as adequate paving and lack of energy dissipators.

For any erosive feature, whether in urban or rural areas, when it is possible for it to be recovered, this will be more efficient if done by specialized companies. A comprehensive analysis must be sought, reflecting on the erosive agents, understanding the combination of factors that influence the installed process and the dynamics between them which led to the appearance and development of the feature (OLIVEIRA, et al., 2018). Thus, it presents at this article a broad study of the conditions that led to the formation and development of an urban erosive feature in Bauru City, enabling improved decision-making processes regarding solutions that should be adopted.
2 METHODOLOGIES

An identification form of the studied feature was prepared based on the conditioning factors and identification of erosive features survey form, developed by Mercaldi and Furegatti (2020), which was established to help with local information. Moreover, the methodology used to classify the erosive feature was based on the table developed by Mercaldi and Furegatti (2019). The methodology proposed by the authors was applied through a study of different classifications of erosive features adopted by different Brazilian and foreign authors.

Five visits were carried out to the erosive feature, between January and April 2021, to collect data on the area and surroundings and also to examine its stability. The surroundings encompass the contribution area of the feature and a downstream region, identifying the deposition of sediment generated by the feature.

The dimensions of the feature were obtained in loco and through the Google Earth platform. The estimated length of the feature was obtained through analysis of satellite images from Google Earth, as well as the determination of the slope length and mean slope. Width and depth measurements were taken on site using a flexible measuring tape.

The survey of rainfall data in Bauru was obtained from the Meteorological Research Institute of Unesp Bauru (IPMet/Bauru, 2020) (https://www.ipmetradar.com.br/2estHist.php).

3 LOCATION AND CHARACTERIZATION OF THE STUDY AREA

Bauru City is located in the countryside of the São Paulo State. According to Salomão (1994), the regional relief consists of broad and smooth hills, modeled on sandstones from the Marília and Adamantina Formations, with water courses forming the headwaters of the Bauru River. Rains are concentrated in the period from September to March (IPMet/Bauru, 2020).

The focused erosive feature is in Bairro Jardim Marilu at the Bento Duarte de Souza Street, block 12. According to the Municipal Law of Land Use and Occupation, the part of erosion closest to the headwater is in the service zone and the part closest to Waldemar G. Ferreira Avenue is in a residential area. The head of the feature is located at UTM coordinates: Zone 22 K E 693,620.00 m, S 7,529,832.00 m, altitude 571 m (Figure 1).

The feature of Jardim Marilu is located in the area under consolidation, according to the Municipal Master Plan (Law No. 5.631/2008). Among its characteristics, the
consolidating zone has poor accessibility and infrastructure, low occupation density and investment by private initiative, presence of advanced erosive processes and silted streams, concentration of low-income population, and irregular occupations (Law No. 5.631/2008). Locally, it was observed that the feature is in a peripheral region with little occupation and paved only in some parts.

Figure 1 – Location of the Jardim Marilu erosive feature in Bauru City within São Paulo State in Brazil.

4 DATA COLLECTION

During a visit to the site, it was observed that the feature is between the residential condominium and the sports court. In a certain stretch, the feature is a few meters away from the condominium wall. Based on the feature data collection during the visits and satellite photos a sketch of the erosive feature boundary was drawn, indicating locations of the features observed in the survey (Figure 2). At site 1 (Figure 2) a contour curve was built, with the purpose of diverting water from the surface runoff that went towards the head of the feature (Figure 3a). However, this deviation apparently led the flow to another point, triggering the initial formation of an arm of the feature identified as location 2 in Figure 2. In the last visit made to the site in April 2021, it was identified that the city hall did a new intervention, increasing the length of the existing contour line, with a clear intention to divert the flow of water from the arm (Figure 3b).
In the area identified as location 3, there was a layer of water that covered almost the entire feature. It was identified that part of the water came from a rainwater pipe located at the head of the feature, near location 1 in Figure 2. The identified pipe comes from a water outlet on Elias Miguel Maluf Avenue. This exit receives runoff coming from the drainage network distributed by the area of contribution of the erosive feature itself, in addition to surface runoff coming from the avenue. Thus, the feature ends up receiving influence on the erosive process through surface runoff and the drainage network.

In an informal conversation with residents, they informed that at the site of the feature there was a small drainage channel, before the works that carry water from the drainage network and passing under Elias Miguel Maluf Avenue. Over time, the
concentrated surface runoff added to the concentrated flow from the rain pipe which triggered the erosive process. Residents also told that before the city hall built this pipeline, there was no erosive feature and the channel was less than one meter deep.

With the development of the erosive feature and the risk of compromising the neighboring condominium, the City Hall began to build some containment on the left margin of the feature, where it is closer to the condominium wall. The erosion was almost reaching a sewer pipe that runs parallel to the wall (approximately 2.0 m) of the condominium, located between the wall and the feature. In the last visit made in April 2021, it was observed that residents cemented the region closest to the wall to try to contain the erosive process (Figure 4).

Figure 4 – Containment initiated by the City Hall: (a) situation in January 2021; and (b) when residents cemented the region above the containment in April 2021

The erosive feature extends for approximately 250 m, containing a dense forest in most of its surroundings, starting from approximately one third of its extension. At the other end of the feature (identified as site 7), it was possible to observe that depending on the time of year, the water layer stops in a region deeper into the dense forest (Figure 5). However, during the last visit, it could be noticed that the water layer reaches the dirt road, which crosses with Waldemar G. Ferreira Avenue (Figure 6), where it finds an uneven terrain, forms puddles, and infiltrates the soil. In this location, the amount of deposited sediment stands out (Figure 5).

Nevertheless, according to local residents, on rainy days with the increase in the flow of water, the runoff reaches Waldemar G. Ferreira Avenue, depositing part of the sediment carried on the avenue itself, which contributes to obstructing the manholes along the avenue. As a consequence of the erosive feature, in the region downstream of the feature, the manholes on Waldemar G. Ferreira Avenue were clogged by sediments
coming from erosive processes both from the studied feature and also from the laminar erosion of the upstream area.

When analyzing the relief of the site, it is observed that this region is located at the lowest elevations. So all surface runoff, including sediments from this area goes to the already mentioned manholes. As there are unbuilt sites in this area, the runoff carries a large amount of sediment and debris to the site, in addition to the sediment from the studied feature.

Figure 5 – End of the feature, downstream. Location where the water depth ceased in February 2021.

Figure 6 – Water puddle formed by the drained layer of the erosive feature on the dirt road, located downstream beyond the end of the feature. Situation observed in April 2021.

Source: Elaborated by the authors
Source: Elaborated by the authors

5 DATA COLLECTION AND ANALYSIS

The information collected about the feature is presented in Table 1, which follows the pattern of the form developed by Mercaldi and Furegatti (2019). Data were identified in loco during visits, or with the help of the Google Earth platform and AutoCAD software.

Based on the in loco investigation and analysis employing Google Earth, it was possible to measure the erosive process in the following approximate values: 245 meters in length, the width varies from 5 to 15 meters, and the depth ranges from 7 to 11 meters in the deepest parts depending on the location of the feature (Table 1).
Table 1 – Erosion identification form.

<table>
<thead>
<tr>
<th>Erosive feature identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local: Rua Bento Duarte de Souza, quadra 12</td>
</tr>
<tr>
<td>Date: January to April, 2021</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Naturals Actions</th>
<th>Anthropic actions</th>
<th>Characteristics of the erosive feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related erosion</td>
<td>Erosion by raindrops, rill erosion</td>
<td>Dimensions of erosion</td>
</tr>
<tr>
<td>Trigger process</td>
<td>Rainfall, Anthropogenic Actions and Drainage Network</td>
<td>Width</td>
</tr>
<tr>
<td>Type of flow</td>
<td>Superficial</td>
<td>Ranging from 5 to 15 meters</td>
</tr>
<tr>
<td>Nature of the soil</td>
<td>Dark Red Argisol and Latosol (sandy texture)</td>
<td>Extension</td>
</tr>
<tr>
<td>Existence of river/stream</td>
<td>Unidentified</td>
<td>About 245 meters</td>
</tr>
<tr>
<td>Emergence of groundwater</td>
<td>Unidentified</td>
<td>Depth</td>
</tr>
<tr>
<td>Rainfall</td>
<td>116.28 mm</td>
<td>7 to 11 meters</td>
</tr>
<tr>
<td>Regimen</td>
<td>August is the driest month with 26 mm and January concentrates most of the precipitation, with an average of 215 mm</td>
<td></td>
</tr>
</tbody>
</table>

| Existence of paved streets | It is present in part of the contribution area. |
| Existence/condition of drainage pipes | Region provided with pluvial galleries that contribute to the ordering of surface runoff, leading the pluvial flow to the erosive feature. Most of the manholes in the contribution area are blocked. |
| Plant cover | Forest with erosion, urban constructions in the surroundings |
| Land use | Urban, with part of the subdivision under development |

<table>
<thead>
<tr>
<th>Relief</th>
<th>State of development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headland Contribution Area</td>
<td>Unidentified</td>
</tr>
<tr>
<td>Average slope</td>
<td>3.3 % (max: 4.3 %)</td>
</tr>
<tr>
<td>Ramp length</td>
<td>378 m (max: 931 m)</td>
</tr>
<tr>
<td>Branch existence</td>
<td>Stable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Form</th>
<th>Cross section</th>
<th>floor plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of the erosive feature</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments: Source: Elaborated by the authors

The contribution area of the feature determined from the contour lines by the AutoCAD software is 0.22 km² (Figure 8). By analyzing the shape of the contribution area, it is observed that it has a small stretch with irregular ramp length, between 2 and 3 times longer than the average ramp length of the area. Therefore, an average slope length
of 378 m was obtained, with a corresponding average slope of 3.3% (Figure 8); and, the maximum ramp length of 931 m and its maximum slope of 4.3% (Figure 9).

The type of runoff that was observed in this erosive process is the concentrated surface. There is also runoff through a drainage network that flows into the head of the erosive feature. Thus, anthropogenic action is identified as the main process triggering
the feature. The city hall made a palliative action, building a contour curve probably to protect the headwater region, with the aim of diverting surface runoff causing the emergence of a new branch of the feature. Moreover, there was also the amount of debris found at the site, which may have been thrown directly into that area, or brought in by surface runoff from the rains. All these factors may have contributed to accelerate the development of the erosive feature.

The city hall began to carry out a containment work at the site, as the feature was developing laterally, approaching the wall of the Pinheiros residential condominium. From the analysis of the feature, the erosive process was in progress, as there were signs of slipping of the internal slopes and no evidence of vegetation developing on those slopes. The vegetation is low at the entrance to the region, but as soon as the erosive process begins, the vegetation becomes dense and remains so all around the feature along a narrow strip. There were dwellings at the other end of the feature inside the forest, which may be suffering from the accumulation of runoff and sediment that had been carried up there.

According to the table developed for the classification, it is noted that the erosive process is between a ravine and a gully with linear surface erosion. At the beginning of the feature it has a branch formed by an arm caused by the attempt of the city to divert the water that flowed into the headboard since it did not occur naturally. The shape of the valley on the feature is still undefined due to the degree of development. However, the feature reached the level of the water table, which is a characteristic of a gully. Thus, the characteristics observed, mainly the fact that it reached the water table, led to classifying the feature as a gully.

6 FINAL CONSIDERATIONS

The study carried out allowed classifying the erosive feature as an active gully. The occurrence and activity status of the feature are due, on the one hand, to the high susceptibility of the region, mainly related to the type and characteristics of the soil and slopes, in addition to the waterproofing of the surface by buildings and asphalt. On the other hand, they are due to the conditions of the drainage network, which concentrates the flow of an extensive contribution area, with discharge in an inappropriate location and, also, with the inexistence of adequate energy dissipaters.

There are different types of erosion, erosive agents, and influencing factors. Each erosive process, therefore, behaves in a different way, each one with its specificities.
Furthermore, it is necessary to observe the combinations of factors such as the size and shape of the rainwater contribution area, the occupation of this area, and how the anthropic action took place, if there is asphalt, drainage network, etc., in addition to the characteristics of the soil and surface and, finally, how all these factors influence each erosion process. The more accurate the data collecting, the better it will be for understanding how the erosive process is developing and the analysis of the data collected will enable the option for efficient solutions.

The methodology for surveying the characteristics and organization of the investigated site data, adopted by Mercaldi and Furegatti (2020) was successfully evaluated and validated.

Therefore, a more comprehensive study of the erosive features is necessary, considering all the factors that influence the process, for better decision-making processes regarding the adopted solutions. Despite this need, due to the lack of financial and human resources of city halls in cities with intense occurrence of erosive features, only palliative solutions are adopted, which do not solve the problem and, over time in many of the cases, the erosive process returns.
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