Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / *Online Support*

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

Analysis of risks to water contamination in Lajeado Stream as a mechanism to prevent water security in Dois Córregos (SP)

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ABSTRACT

Urbanization accompanied by population growth has brought with it environmental impacts such as soil impermeability and the occupation of permanent preservation areas. In addition, it has intensified urban flooding, soil erosion and river silting. The objective of this study was to analyze the risks of water contamination in the Lajeado Stream as a subsidy for water security in Dois Córregos (SP). To this end, the methodology was based on the identification of risks in loco and documentary analysis. The risk prioritization matrix tool was applied, according to severity and probability of occurrence and cataloged into constructed, natural, social and productive risks (matrix from 0 to 20). The risks were classified as serious (risk 16) and very serious (risk 20) and refer to changes in the watercourse, soil impermeability, disposal and accumulation of solid waste, presence of irregular occupation/constructions in the surroundings and specific points with erosion processes along the watercourse. The study shows that urban expansion in Dois Córregos changed the Lajeado Stream and caused environmental impacts in several points, such as erosion processes on the banks, silting of the bed, absence of Permanent Preservation Areas (APPs), accumulation of solid waste along the analyzed stretch, in addition to the lack of urban planning. The priority recommendations are socio-environmental awareness, environmental monitoring, improvement of the drainage system and urban cleaning services, preparation of projects aimed at implementing green infrastructure and raising financial resources.

KEYWORDS: Water security. Risk management. Urban rivers.

1 INTRODUCTION

Intense urbanization in recent years has greatly aggravated the problems of urban drainage and water resources management. In this context, environmental changes induced by human action resulting from the lack of urban planning lead to a climate emergency scenario, compromising ecosystems (YANG et al., 2020).

Most Brazilian municipalities emerged on the banks of rivers (Morsch *et al.* 2017). Rivers are essential elements in the city, performing important ecosystem services, however, the lack of permeable areas and interventions in the urban environment is increasingly visible.

The authors state that the waterproofing of urban soil, resulting from population growth and occupation of vulnerable areas in cities, has led to direct interventions in urban rivers, making them targets for waste dumping and irregular occupation, disconnected from the landscape. These interventions are often accompanied by the design of inadequate, inefficient and unplanned drainage systems, altering the natural flow of water resources and surface runoff, mitigating urban flooding (Tucci, 2008; Delcol, 2019).

Apaza *et al.* (2024) illustrated in their study on environmental risks in urban sectors of the Monjolinho River in the municipality of São Carlos/SP that environmental sustainability and urban resilience are aligned with the Sustainable Development Goals (SDGs) due to issues related to the management of urban rivers , due to the need to integrate water resources with comprehensive urban policies, specifically SDG 11 - Sustainable Cities and Communities and SDG 6 - Ensure the availability and sustainable management of water and sanitation for all.

The study area includes the Lajeado Stream, which runs through the urban area of the municipality of Dois Córregos, flowing into the Rio do Peixe, a tributary of the Rio Jaú. In particular, urbanization in Lajeado Stream occurred in a disorderly and unplanned manner, altering its natural dynamics, with stretches of river slope erosion, silting of the bed, occupation of permanent preservation areas – APP and waste discarded on the banks.

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Therefore, the study of urban resilience in this location is essential to establish priority topics for the municipality and public policies in the sector.

As existing sources of contamination in the basin accompany the intensification of human presence and activity, water security enables future planning of water resources and aims to minimize the risks of contamination of rivers (Ventura *et. al*. 2019).

The main objective was to analyze the risks of contamination of the Lajeado stream in Dois Córregos (SP) as a way of supporting local water security.

1.1 WATER SECURITY

Some authors bring similar concepts regarding water security, such as the adequate availability of quantity and quality of water to meet human, environmental and economic needs in addition to the conservation of aquatic ecosystems, with an acceptable level of risk related to extreme events. (Dinar, 2002; Lundqvist *et al*., 2003; Ratnaweera *et al*., 2006; Allouche, 2011; Melo, 2016; Pereira and Rodrigues, 2022).

Water security enables future planning of water resources and aims to minimize the risks of river contamination (Ventura *et. al*. 2019). It is about using water in ways that increase economic well-being, improve social equity, advance long-term sustainability or reduce water-related risks (Hoekstra *et al*., 2018).

The management of water resources is an example of the need for interaction between different systems. Cities need to associate urban resilience with environmental planning, aiming to build sustainable, adapted environments with the capacity to respond and reinvent themselves in the face of adverse events (Obraczka et al., 2019; Feagan et al., 2019).

The implementation of intelligent technologies for the sustainable management of water resources, with the use of models, optimization tools and decision support systems in addition to the Geographic Information System (GIS) optimize support for the smart water sector. The adoption of standardized performance measurement systems with relevant indicators and decision support interfaces allows support for decision-making in water management (Ramos et al., 2019; Cramolichi et al., 2023).

It is about using water to increase economic well-being, improve social equity, advance long-term sustainability or reduce water risks (Hoekstra et al., 2018).

1.2 URBAN AND CLIMATE RESILIENCE

In recent years, the term “Resilient Cities” and “Urban Resilience represents urban adaptation to climate change.

River basins have been experiencing pressure due to the demands of the use of their natural resources (Ioris et al., 2008; Almeida and Carvalho, 2010; Asefa *et al*., 2014; Oliveira and Silva, 2014; Tony *et al*., 2015; Godoy and Cruz, 2016).

Resilience refers to the ability to withstand, resist and absorb disturbances, disturbances, changes, which negatively impact people's lives, urban infrastructures and the economy (Tony *et al*., 2015; Ferreira, 2016).

Urban resilience proposes the view of cities as a complex adaptive system, so that pressures exerted continuously, if accumulated, can result in crises in social and environmental systems (Gonçalves, 2017). In this context, proposals that aim to integrate and/or reintegrate nature into urban space can help resolve problems such as pollution and environmental

Periódico Técnico e Científico Cidades Verdes
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contamination (Pauleit *et al.*, 2017). Therefore, it is necessary to understand the causes and extent of the population's vulnerability to water, in order to develop prevention strategies for scenarios that are unsafe in terms of quality and availability.

Planning and management actions for urban resources must take into account the possibilities of the urban environment (Oliveira et al., 2023). Examples of the application of green and blue infrastructure can be observed through nature-based solution projects, such as parks and green corridors, urban green areas, rain gardens, green roofs and urban agriculture, reforestation and vegetation restoration, among others (Dullius and Silva, 2017; Cortinovis and Geneletti, 2018; Guimarães et al., 2018; Valck el al. 2019; Costa and Sakurai, 2021; Fraga; Sayago, 2020, Ximenes and Maglio, 2022).

In the urban context, these solutions can be used to address challenges such as floods, heat waves, water scarcity and pollution, taking advantage of nature's capabilities to provide essential ecosystem services (Oliveira et al., 2023). Therefore, it is essential to incorporate green-blue infrastructures into urban space planning, especially due to the lack of investment and adequate urban planning, absence/insufficiency of municipal supervision, inadequate political influence, awareness and knowledge at different levels that focus on traditional models of engineering to resolve urban conflicts (FRAGA, 2020).

2 CHARACTERIZATION OF THE STUDY AREA

The municipality of Dois Córregos is a Brazilian city located 221 kilometers from the capital city of São Paulo, in the central region of the State and borders the municipalities of Dourado, Mineiros do Tietê, Brotas, Torrinha, Santa Maria da Serra, Botucatu, São Manuel and Jaú. Its official foundation is considered to be on February 4, 1856, with an estimated population of 24,510 inhabitants (IBGE, 2022) and a total area of 63,297.3 hectares (ha), of which 603.62 ha comprise the urban area and 62,654.60 ha in the rural area.

It has approximately 58.81% of the territory inserted in UGRHI 13 (Tietê – Jacaré), 41.15% inserted in UGRHI 5 (Piracicaba – Capivari – Jundiaí) and the remainder in UGRHI 10 (Tietê- Sorocaba), basically having its entire area urban located at UGRHI 13.

It is located in the Sub-Basin of the Jaú River / Ribeirão da Ave Maria / Ribeirão do Sapé and direct tributaries of the Tietê River in UGRHI 13, classified as sub-basin 03, according to the Master Plan for Environmental Education of the Tietê-Jacaré Hydrographic Basin – PDEA-TJ, and inserted in the B7 microbasin of the municipality in accordance with the Plan to Combat Rural Erosion of the TJ Basin in the municipality of Dois Córregos.

It is crossed in its urban area by the Fundo and Lajeado Streams, which flow into the Rio do Peixe, a tributary of the Rio Jaú. Figure 1 demonstrates the coverage area of the proposed project, which is the municipality of Dois Córregos, with emphasis on its urban area, mainly located in the Tietê-Jacaré Hydrographic Basin. The Lajeado Stream is approximately 2.40 km long and is entirely located in an urban area. The study was carried out throughout his bed.

Periódico Técnico e Científico Cidades Verdes
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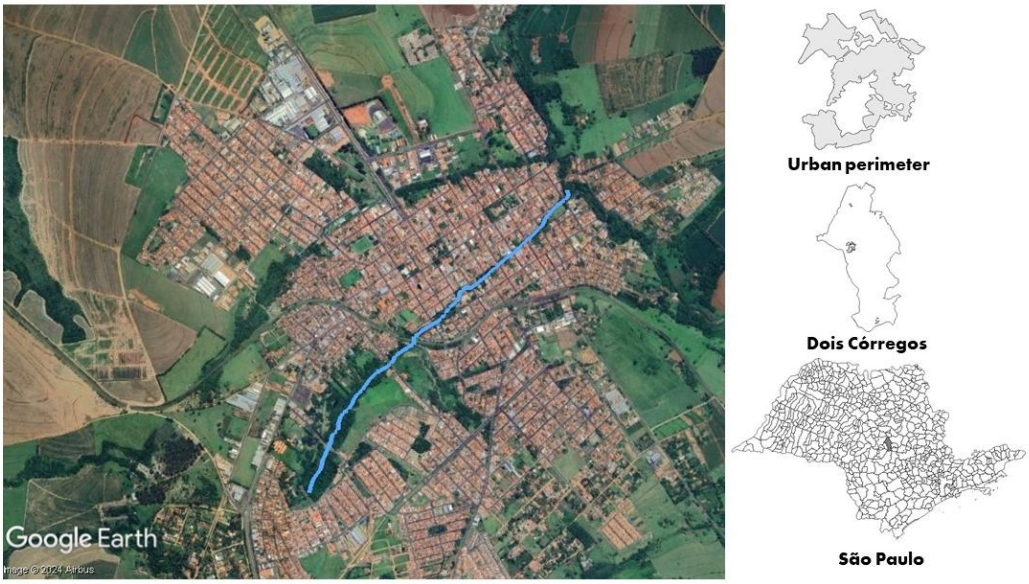
Figure 1 – Delimitation of the Lajeado Stream in the urban area of the municipality of Dois Córregos



Source: Authors (2024).

The municipality of Dois Córregos is in a critical situation in the Continuous Duration Program (PDC) 4.2: Nature-based Solutions (SbNs) – green structure, in PDC 4.1 and 7.1: Rainwater drainage and erosion control according to Annex II – areas criticism of Deliberation CBH-TJ 11/2023 of 12/08/2023 (CBH-TJ, 2023).

The Dois Córregos Urban Drainage Plan governed by Law No. 4,399, of June 18, 2018, presents the need to use techniques to present characteristics to mitigate hydrological impacts or that aim to maintain hydrological functions, encourage infiltration and delay surface runoff, as well as the adoption of integrated solutions using vegetative systems, as they become a landscape attraction.

The Municipal Plan for Integrated Solid Waste Management governed by Law No. 4,308, of June 28, 2017, also includes the aspect of environmental protection through surface drainage to avoid carrying waste into water resources and urban areas.

Furthermore, environmental education is a strategy for the management of water resources, aligned with the Municipal Environmental Education Program, established by Municipal Law No. 5,005, of June 1, 2023, which aims to stimulate environmental education within the community and offer solutions environmentally appropriate for the environment, in addition to working on concepts aimed at conservation/preservation and sustainable use of natural resources (Dois Córregos City Hall, 2023, pg. 16).

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Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

addition to working on concepts aimed at conservation/preservation and sustainable use of natural resources (Dois Córregos City Hall, 2023, pg. 16).

The Municipal Government carries out, through the Secretariats of Infrastructure and Works and Agriculture and Environment, the maintenance and conservation of the municipality's urban drainage systems, as well as being responsible for the analysis and approval of dismemberment and subdivision projects, adding the mandatory implementation of tree space and afforestation of public roads and green areas in accordance with Municipal Law No. 4,402, of June 29, 2018.

In Dois Córregos, several micro and macro drainage works have been carried out at points upstream and downstream of urban streams. In relation to SbNs, the City Hall has two projects approved for the development of the diagnosis of Lajeado stream, Fundo stream and River of the Peixe throughout the urban area and the elaboration of a conceptual project on this topic for the aforementioned water resources. In addition, the elaboration of an executive project for Nature-Based Solutions with Natural Engineering techniques to revitalize a section of the Lajeado stream parallel to the Waters of the Lajeado Ecological Park (Dois Córregos City Hall, 2024).

Finally, preventive, relief, assistance and reconstructive actions are carried out with the creation of the Civil Protection and Defense Coordination, in order to avoid or minimize urban risks and increase urban resilience and adaptation to climate change.

3 MATERIALS AND METHODS

The type of research is characterized by being exploratory and case study (Marconi and Lakatos and 2003). The aforementioned authors understand that exploratory research seeks to increase understanding of the facts studied, helping to identify problems more precisely in an attempt to acquire greater familiarity with the phenomenon being researched. The case study investigates a contemporary phenomenon within its context and reality.

The methodological procedures were based on the collection of secondary data through bibliographical research, census data available on a digital platform, plans, legislation and official documents of the municipality aiming to characterize the study area, as well as deepening the relevant indicators for analysis of risk of Lajeado stream.

A field survey was carried out to collect primary data and support the analysis of existing situations in 6 (six) points of Lajeado stream. The points represent stretches with erosive processes, silting of the bed, human occupation of the Permanent Preservation Area – APP, interventions such as plugging the stretch and preserved APP. Points X and Y represent, respectively, the flow of the Lajeado Stream, from upstream (X) to downstream (Y) (Figure 2).

Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / Online Support

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

Figure 2 – Observation points of the Lajeado Stream

Source: Authors (2024).

The hypothesis assumed in this research is that the municipality of Dois Córregos has SbNs projects, but challenges still exist, especially related to the following issues: silting of the river, erosion of sections along the analyzed section, lack of maintenance of vegetation with vegetation cover surrounding the area visited in addition to the lack of urban planning.

Table 1 illustrates the risk prioritization matrix adapted from NBR 17080 (ABNT, 2023). The data was analyzed based on the risk prioritization matrix, developed by Apaza et al. (2024) based on Vieira's adaptation; Morais (2005) and WHO (2011). To this end, numerical values were assigned to the probabilities of the event occurring (almost certain; very frequent; frequent; infrequent; rare) and the severity or consequence (insignificant; low; moderate; serious; very serious). The variables in Lajeado stream were analyzed based on the dangerous and frequent events that occur in its extension.

Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / Online Support

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

Table 1 – Matrix for prioritizing risks

Provability of the event occurring	Severity or consequence of the event				
	Insignificant	Low	Moderate	Serious	Very serious
Almost certain	5	10	15	20	25
Very frequent	4	8	12	16	20
Frequent	3	6	9	12	15
Infrequent	2	4	6	8	10
Rare	1	2	3	4	5
Risk score		<6	6-9	10-15	>15
Risk classification		Low	Average	High	Very high
	Very high: extreme and unacceptable risk; need for immediate attention.				
	High: high and unacceptable risk; need special attention.				
	Medium: moderate risk; need for attention.				
	Low: low risk and tolerable, controllable through routine procedures.				

Source: Apaza *et al.* (2024).

Based on the prioritization matrix, the risks were prioritized into built, natural, social and productive, according to the classification of dangerous events adopted by Dagnino and Junior (2009), built risks (refer to transformations of the environment through buildings and infrastructures urban areas with soil sealing over natural areas), natural risks (those resulting from natural processes and environmental weather), social risks (related to the characteristics and organization of local society) and productive risks (identified by economic and non-economic activities developed on site).

4 RESULTS AND DISCUSSION

4.1 Direct observations during field visits

The Lajeado Stream has several stretches that culminated, in parallel with the construction of the city, in conventional works that generated environmental impacts and liabilities, such as erosion in river embankments, silting of the bed, occupation of APP areas, solid waste discarded on the banks of the river, in addition also has areas with APP. Figure 3 illustrates the risks observed from primary data collection and field visits.

Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / Online Support

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

Figure 3 – Field observations for the points of Lajeado Stream

Description: erosion processes in a section of the Lajeado Stream after its source at Rua: David Monteiro. Attempts to control erosion are observe.

Description: siltation of a section of the Lajeado Stream on Avenue Bahia. The location is subject to flooding and flooding when heavy rain occurs.

Description: human occupation of Permanent Preservation Area - APP on Avenue Padre Domingos Cidad.

Description: human occupation of APP on Avenue May 29.

Description: section of the Lajeado Stream with direct intervention where it is possible to observe bed plugging on Avenue Modesto Carmesini

Description: section of Lajeado Stream with preserved APP on Avenue Fernando Costa, where the stream is an open channel and natural section

Source: Authors (2024).

4.2 Prioritization of risks in Lajeado Stream in the municipality of Dois Córregos (SP)

The risks classified as serious and very serious severity demonstrate the anthropogenic changes in Lajeado stream and were prioritized in the study. “Changes and/or rectifications in the shape of the watercourse (Strangulation, Channelization, galleries, Bridges)” only reinforce that this stream has part of its section buffered/channelized, strangled sections and changes in the natural bed. “Increase in soil waterproofing in the catchment area of the river basin” and “Presence of occupation/irregular constructions in the surrounding area” (Table 2).

Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / Online Support

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

The stream's APP has minimal or non-existent quantities in some stretches in addition to the presence of human occupation. “Disposal and accumulation of solid waste in general (sediments, construction waste, animal excreta, others)”. There is still a portion of the population that uses APP areas to dispose of materials, requiring reinforcement of environmental awareness. “Presence of specific points with erosion processes along the watercourse” (Table 2).

There is an occurrence of erosion processes and silting of sections of the Lajeado Stream that require immediate measures aimed at the renaturalization and revitalization of the stream.

The following flowchart demonstrates urban situations frequently observed in the municipality of Dois Córregos, based on the risk prioritization matrix for Lajeado stream, as well as presenting consequences and strategies for mitigating these risks.

The flowchart in figure 4 demonstrates the common dangerous events in the municipality of Dois Córregos based on observations carried out in the field as well as possible strategies for mitigating these risks, among which the restoration of APP areas and erosion control actions, improvement of infrastructure and drainage systems through sustainable drainage techniques and SbN, monitoring and mapping of points with alteration or rectification of the stream in addition to reinforcing waste management and environmental inspection associated with environmental education actions on climate change.

Table 2 - Risk prioritization matrix for Lajeado stream

TYPE	DANGEROUS EVENT	PROBABILITY	SEVERIRITY	RISK
BUILT	Changes and/or rectifications in the shape of the watercourse (Strangulation, Channeling, galleries, Bridges).	Very frequent	Very serious	20
	Presence of occupation/irregular constructions in the surrounding area.	Almost certain	Serious	20
	Increasing soil waterproofing in the river basin’s input area.	Very frequent	Serious	16
	Disposal and accumulation of solid waste in general (sediment, construction waste, animal excreta, others).	Very frequent	Serious	16
	Drainage works (drainage drains, collection networks, canals, reservoirs, etc.) are often inconsistent with the natural flow behavior of the watercourse.	Almost certain	Moderate	15
	Part of the route absent riparian forest.	Very frequent	Moderate	12
	Corrective maintenance works that are poorly dimensioned or carried out in non-conformity/without standards	Frequent	Serious	12
	Presence of gas stations nearby.	Infrequent	Very serious	10
	Destruction of sidewalks along the banks of the stream.	Frequent	Moderate	9
	Soil exposure (bare ground) or without vegetation.	Infrequent	Serious	8
	Presence of excessive noise from motor vehicles.	Frequent	Insignificant	3
	Transport of contaminants by surface runoff.	Rare	Low	2
NATURAL	Presence of specific points with erosion processes along the watercourse	Very frequent	Very serious	20
	Siltation in specific points of the water body.	Frequent	Very serious	15
	Absence of aquatic life (fish, others)	Very frequent	Moderate	12
	Part of the route absent riparian forest	Frequent	Serious	12
	Change in the perceptible characteristics of the water (color, odor, turbidity) and the presence of an unpleasant odor	Infrequent	Moderate	6
	Soil exposure (bare ground) or without vegetation.	Infrequent	Moderate	6
	Occurrence of floods and flooding events.	Infrequent	Moderate	6
	Growth of inappropriate vegetation along the course of the river.	Rare	Low	2

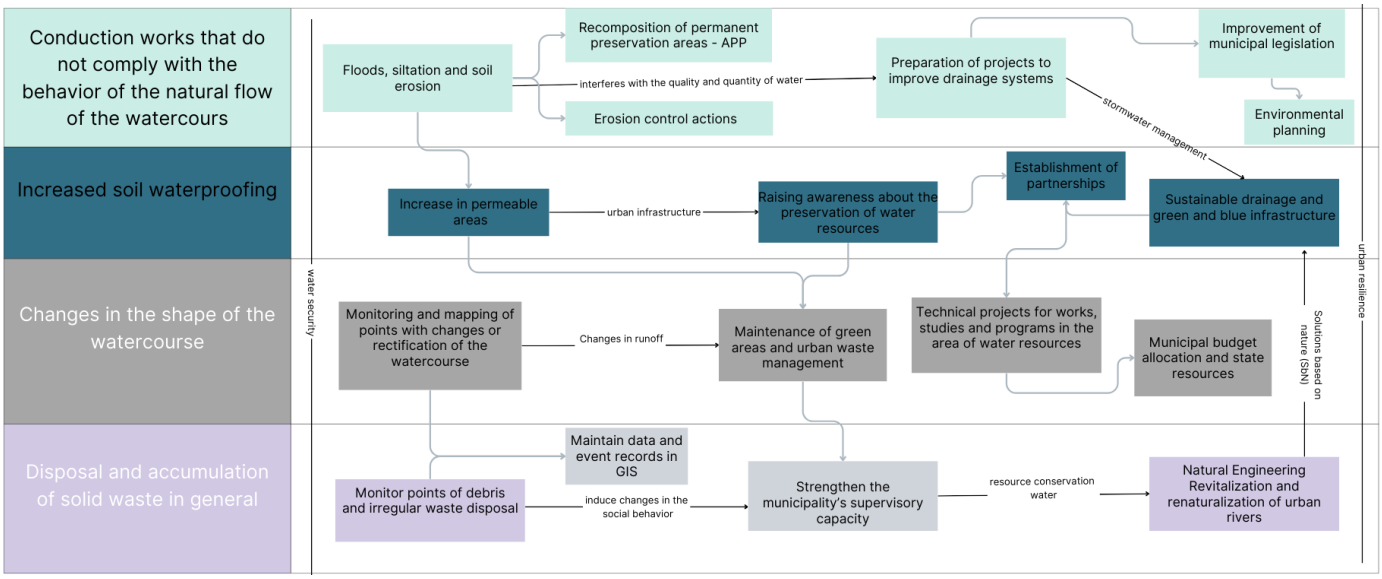
Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / Online Support

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

SOCIAL	Presence of occupation/irregular constructions in the surrounding area.	Very frequent	Very serious	20
	Existence of a preserved area and APP does not respect	Frequent	Moderate	9
	Vandalism and Sabotage and perception of insecurity on the margins.	Infrequent	Serious	8
	Area close to or belonging to recreational environments.	Infrequent	Serious	8
	Lack of maintenance of green areas on the banks of the river.	Infrequent	Low	4
	Few initiatives to implement environmental education.	Rare	Moderate	3
	Presence of excessive noise from motor vehicles.	Infrequent	Insignificant	2
PRODUCTIVE	Changes and/or rectifications in the shape of the watercourse (Strangulation, Channeling, galleries, Bridges).	Frequent	Serious	12
	Presence of gas stations nearby.	Infrequent	Serious	8
	Artificial material composing the riverbed (concrete, construction waste, others).	Infrequent	Moderate	6
	Presence of excessive noise from motor vehicles.	Frequent	Insignificant	3
	Presence of bird breeding in the surrounding area.	Rare	Low	2

Source: Authors, 2024.

Figure 4 – Flowchart of understanding common dangerous events in the municipality of Dois Córregos based on field observations



Source: Authors, 2024.

4.3 Sustainable urban occupation of Lajeado stream

To mitigate the environmental impacts of serious and very serious risks in Lajeado stream, strategies were proposed aimed at sustainable urban occupation of the stream and its surroundings:

a. socio-environmental awareness through campaigns and programs covering formal, non-formal and informal environmental education;
b. environmental monitoring by the City Hall in conjunction with the Municipal Civil Defense to identify dangerous events for eventual decision-making;

Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / Online Support

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

c. improvement of the drainage system through works to improve surface runoff of rainwater;
d. supervision of actions that may cause damage to the environment in addition to ensuring the rational use of natural resources and preventing actions that harm the environment;
e. development of projects aimed at implementing infrastructure combined with environmental conservation and focused on green infrastructure, sustainable drainage and nature-based solutions;
f. capture of financial resources by the City Hall to finance programs, studies and works in the area of water resources, promoting the improvement and protection of water bodies and the river basin.

5 CONCLUSION

The study demonstrates that urban expansion in Dois Córregos altered the Lajeado Stream and caused environmental impacts at several points, such as erosive processes on the banks of the stream, silting of the bed, absence of APP in addition to the accumulation of waste, revealing the lack of urban planning in which the city shaped itself.

The most aggressive risks (risk 20) were Changes and/or rectifications in the shape of the watercourse (Strangulation, Channeling, galleries, Bridges), Presence of occupation/irregular constructions in the surrounding area, in construction risks, Presence of occupation and irregular constructions in the surroundings in social risks and Presence of specific points with erosion processes along the watercourse in natural risks.

On the other hand, other dangerous events that draw attention are (risk 16) increasing the waterproofing of the soil in the catchment area of the river basin and disposal and accumulation of solid waste in general (sediments, construction waste, animal excreta, others) at risk built.

In view of these facts, it is observed that incorrect human action was the main element that negatively impacted the object of study and, therefore, there is a need for immediate and preventive actions, adopting an integrative and participatory perspective in planning and interventions in the Stream Lajeado, which involves civil society in line with municipal public management.

In this way, the hypothesis assumed in the research was partially verified, since the silting of the river bed and its erosion were not the only main dangerous events, which highlights the need for attention and prevention on the part of municipal managers to other events of this nature, in order to identify places most exposed to climate risks, based on the combination of social, environmental and existing infrastructure elements, in order to simulate future scenarios and take precautions in the event of extreme climate events.

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Periódico Técnico e Científico Cidades Verdes
Technical and Scientific Journal Green Cities
ISSN 2317-8604 Suporte Online / Online Support

Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 13, N. 40, 2025

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