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Papers

Geomorphological Transformations and Urbanization: Study of the Stages of Anthropogenic Change in the watershed Tiger River (1975-2023)

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Keywords

Urban Geomorphology
Stages of urban intervention
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Methodological guidelines

Abstract

Human activities have modified the relief since the Paleolithic period, intensifying after the Industrial Revolution, especially in urban areas. This study examines the geomorphological and hydrological transformations that occurred in the Tigre River basin in Erechim, Rio Grande do Sul, over nearly five decades of urbanization. The methodological procedures adopted were structured within a multitemporal approach, enabled by the use of Geographic Information Systems (GIS) and geoprocessing techniques. Cartography, remote sensing, and photointerpretation were applied. This analytical strategy made it possible to classify the different stages of human intervention, investigate changes in river dynamics, and understand the effects of urbanization on local geomorphological and hydrological processes. The results reveal that, by 2023, urban coverage of the basin reached 79.48%, with a predominance of the Active Disturbance and Post-Disturbance stages. These transformations impacted surface and subsurface flows, increasing susceptibility to flooding. Intensified waterproofing, reduced infiltration, and modifications to drainage networks were also observed, all of which compromise the hydrogeomorphological balance. The conclusion is that mitigation measures, such as sustainable management and restoration of riparian vegetation, combined with public urban planning policies, are necessary to contain the effects of urbanization and reduce the risks of landslides, floods, and environmental degradation.

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INTRODUCTION

Human activities have impacted relief since the Paleolithic period, intensifying during the Industrial Revolution (Hooke, 2000; Li *et al.*, 2017). In urban areas, these impacts have consolidated humans as geomorphological agents, reshaping natural landscapes and creating anthropogenic landforms (Nir, 1983; Rodrigues, 2005). Urbanization promotes profound changes in geomorphological and hydrological systems, highlighting human action as a transformative agent in environmental dynamics (Nir, 1983; Moura, 2008; Simon; Cunha, 2008; Rodrigues, 2010; Del Monte *et al.*, 2016). Urban geomorphology interprets human activities as landscape reshaping processes, impacting the structure and functionality of natural systems (Cooke, 1976; Cooke *et al.*, 1982; Douglas, 1988; Diao, 1996; Jorge, 2011; Mandarino *et al.*, 2020).

Technological advancement and territorial expansion have consolidated humans as geomorphological agents, intensifying changes in morphogenetic and morphodynamic processes (Nir, 1983; József *et al.*, 2010; Luz; Rodrigues, 2013; 2020; Thornbush, 2015; Li *et al.*, 2017). In urban areas, where transformations are rapid and constant, it is necessary to understand the interaction between natural and anthropogenic forces, which redefine the morphology and functionality of fluvial and terrestrial environments (Paschoal; Simon; Cunha, 2015; Fagundes; Lupinacci, 2017; Rodrigues *et al.*, 2019).

Human interventions in landforms occur in three stages of alteration (Nir, 1983). Several authors highlight three essential moments of urbanization: Pre-urban, Active Disturbance, and Post-Disturbance (Wolman, 1967; Nir, 1983; Douglas, 1983; Toy; Hadley, 1987; Gouveia; Rodrigues, 2017). The Pre-Disturbance stage increases surface runoff, increases streamflow, and reduces erosion. In the Active Disturbance cycle, interventions such as cuts, fills, and sealing modify the relief, alter water and sediment flows, and destabilize morphodynamics (Rodrigues, 2005; Gouveia, 2010). The Post-Disturbance stage reveals a modified morphology, with greater impermeability and intensified surface runoff (Luz; Rodrigues, 2013; 2020). The analysis of these periods allows us to understand the geomorphological changes of anthropogenic origin and their gradual impacts on the balance of natural systems, forming an essential theoretical basis for urban geomorphology.

The representation of landscapes, including urban ones, focuses on anthropogenic geomorphology and technogenic forms (Guerra; Loureiro, 2023; Moura *et al.*, 2023). Retrospective cartography, at detailed scales, is essential for identifying anthropogenic features and understanding urban changes (Rodrigues, 2005; Moura, 2011; Moura *et al.*, 2023). Urbanization impacts river and slope systems, modifying surface and subsurface flows (Rodrigues, 2010; Gouveia; Rodrigues, 2017; Chirico *et al.*, 2021). Despite advances in geomorphological cartography, it is necessary to further analyze the transformations in the Tigre River basin, in Erechim, Rio Grande do Sul.

The watershed is largely urbanized and highly vulnerable. The intensification of urban use has altered the landscape, river dynamics, and hydromorphology. The risk of flooding in some areas reinforces the need to understand urban occupation and plan for sustainable development.

This study's overall objective is to demonstrate the landscape transformations over nearly five decades in the watershed. Specifically, it seeks to: a) investigate the urban actions carried out during the analyzed period; b) examine the evolution of anthropogenic interventions on the surface structure, considering the stages of urban intervention and the suppression of river channels; and c) understand how interactions between natural processes and human actions have altered the basin's hydromorphology.

The article is divided into four parts: an introduction with the theme and literature review; materials and methods, with area characterization and analytical procedures; results and discussion of urban occupation, morphological impacts, and changes in river channels; and final considerations, highlighting the need for sustainable urban planning in the face of anthropogenic transformations.

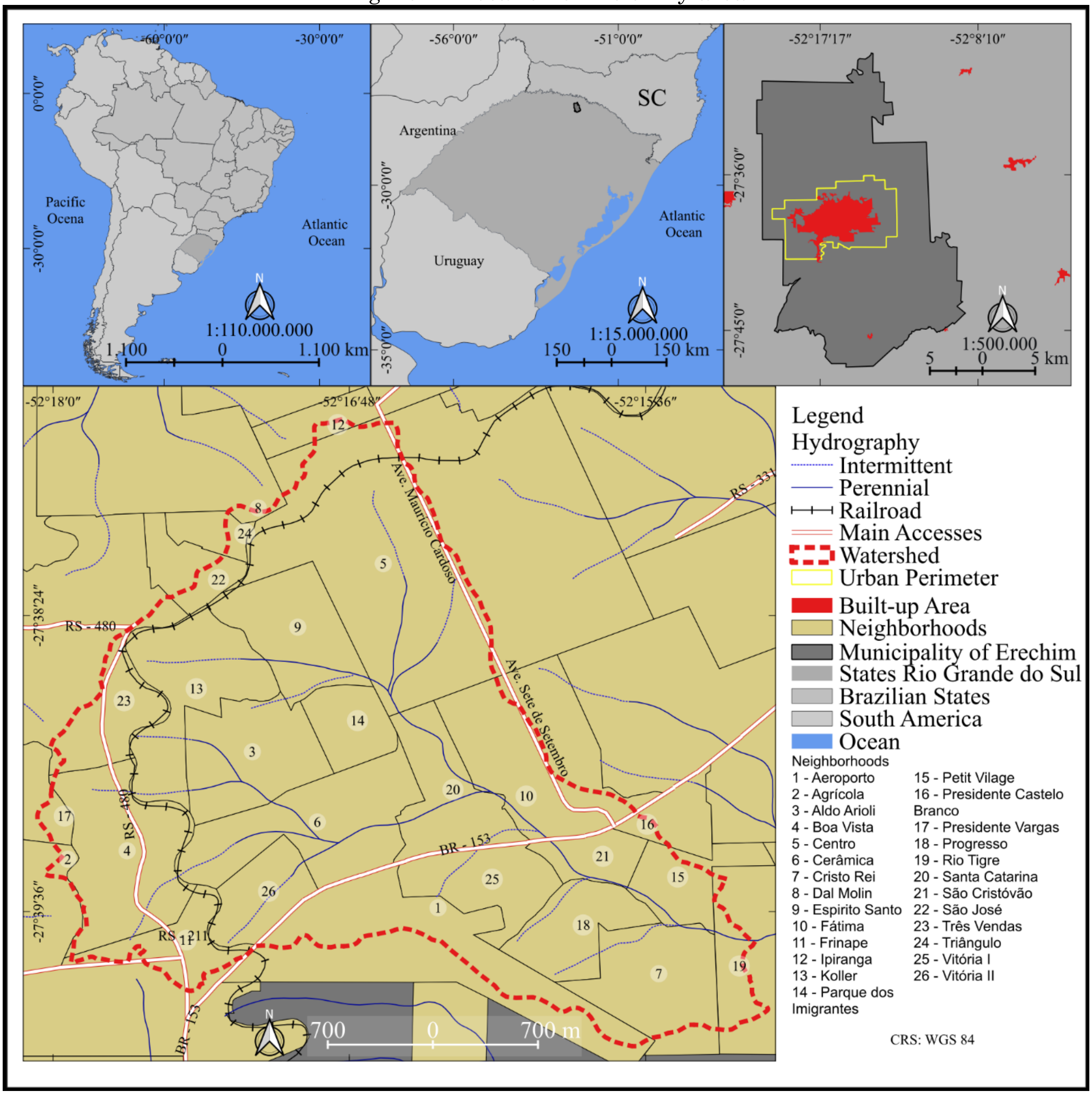
MATERIALS AND METHODS

Characterization of the Study Area

The municipality of Erechim, located in the northern region of Rio Grande do Sul, is located in the Alto Uruguai region and has a total area of 430 km² (IBGE, 2017). Its urban perimeter is concentrated in the central portion, covering approximately 72 km². The analyzed watershed has an area of 11.60 km² (Figure 1). According to the Instituto Brasileiro de Geografia e Estatística (IBGE, 2022), the current population is 105,705 inhabitants. In the 2010 census, the municipality had 96,087 inhabitants, of which 90,552 lived in urban areas and 5,535 in rural areas (IBGE, 2011). Erechim is part of the microregion of the same name and stands out as one of the main urban centers of the Alto Uruguai region.

Erechim's urban structure was shaped by the Itararé/Santa Maria Railway and BR-153, a strategic axis for transportation and economic development. The municipality is served by major highways such as BR-153, BR-477, and RS-135 (Psidonik, 2019). The Tigre River basin comprehends 26 neighborhoods, including Aldo Arioli, Boa Vista, and Progresso, which are entirely within its boundaries. In 2015, urban expansion reached 100% of the urban perimeter.

Figure 1 - Location of the study area



Source: Hasenack; Weber (2010); Erechim (2015); IBGE (2017); SEMA (2018). Elaborate by the authors (2025).

Geomorphologically, the watershed is located in the Morphostructural Domain of Basins and Sedimentary Covers of the Paraná Basin, within the Geomorphological Region of the Missões Plateau. Its Geomorphological Unit is the Santo Ângelo Plateau, with a dissected relief (IBGE, 2008), characterized by wavy hills, flat and convex tops, and slope ruptures caused by faults and geological fractures, which create embedded valleys.

The region's climate features annual precipitation between 1,700 and 1,900 mm, peaking in spring (175 to 215 mm). The altitudes of the Basalt Plateau, combined with the relief morphology and atmospheric systems, favor high rainfall. The location of the Uruguay River valley, in the north of the state, facilitates the rise of moist air from Santa Catarina and southern Rio Grande do Sul, intensifying rainfall (Rossato, 2020).

The analyzed locations have recorded flooding, according to Peretti (2013). Many of these areas, now urbanized and subject to flooding, would be classified as Permanent Preservation Areas (APP), according to Law No. 12,651/2012 (Brasil, 2012), due to the presence of springs, drainage headwaters, and river channels, including in consolidated urban areas.

The basin is home to diverse uses, such as urban areas, pastures, trees, parks, and APPs (Erechim, 2011). Among the basins located within the urban perimeter, the Tigre River basin has the largest urbanized area (Furlan; Spinelli, 2019) and is undergoing morphodynamic transformations that increase the risk of flooding (Furlan; Spinelli, 2020). Urbanization occurred through successive anthropogenic interventions, such as open or capped channels, landfills, and drainage in wetland areas. The replacement of the original morphology by anthropogenic forms was aggravated by the lack of sewage treatment and the direct dumping of waste into river channels (Erechim, 2011).

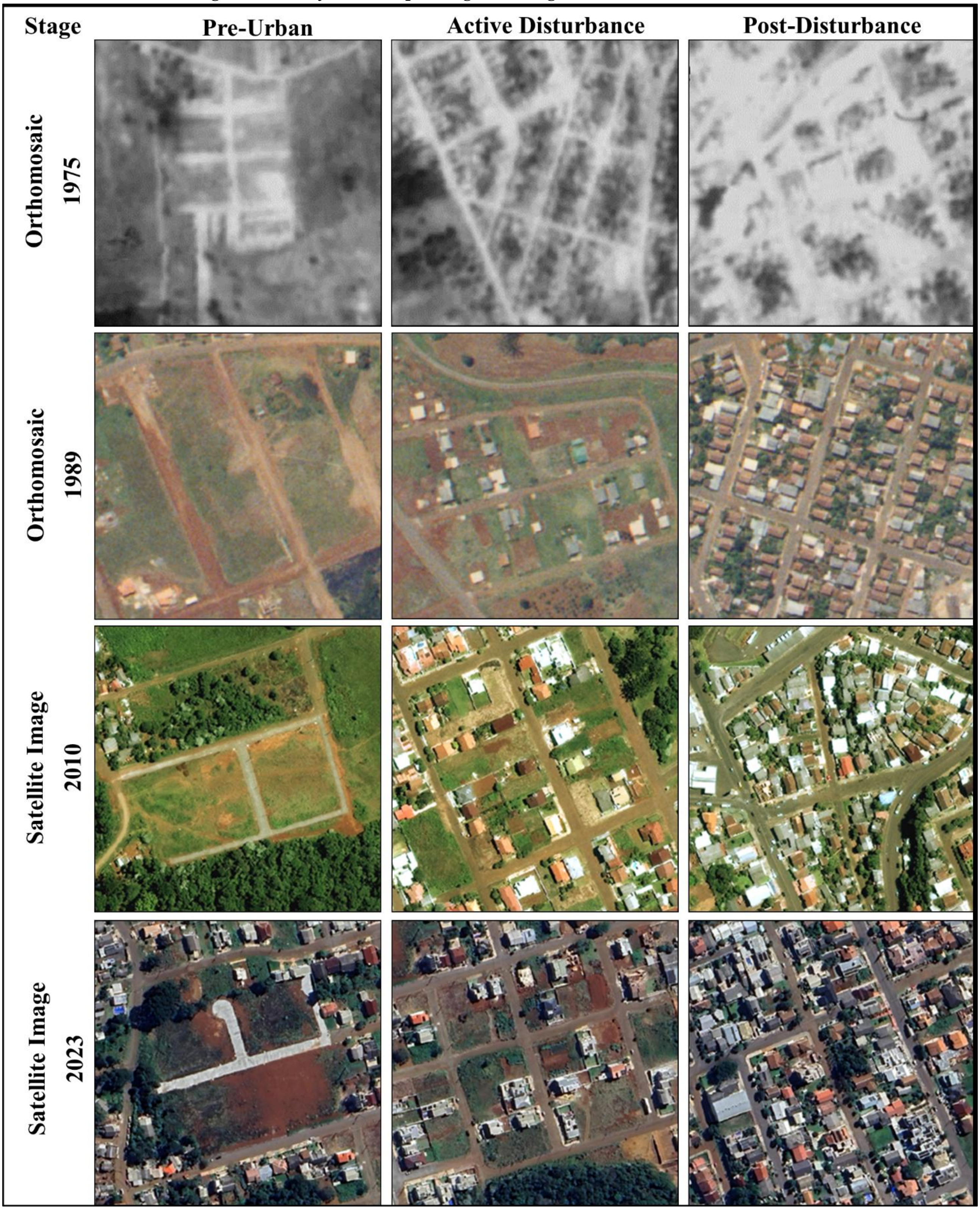
Procedures for Analyzing Urbanization Stages

The analysis of surface coverage and current processes used a historical-geographical and cartographic approach, with interpretation of aerial photographs and remote sensing for surface observation and process monitoring (Roccati *et al.*, 2020). The characterization of Intervention Stages relies on historical studies, in which historiography, iconography, ancient cartography, and toponymy are essential elements. These resources underpin the main methods for analyzing geomorphological processes in urbanized areas (Cooke, 1976; Nir, 1983; Douglas, 1983; Toy; Hadley, 1987; Goudie, 1994; Rodrigues, 2005; 2010; Goudie; Viles, 2010; Gouveia, 2010; Luz; Rodrigues, 2013).

The classification was based on photointerpretation of aerial images, considering tone, color, shape, size, and texture to identify drainage networks, land cover and use, as well as active processes (Sampaio, 2007; Nepomuceno; Luchiari, 2014). The database consisted of an overlay of 48 years of records, including orthomosaics generated in PhotoScan from aerial photographs from 1975 and 1989 (DSG, 1975; Erechim, 1989) and satellite images from World View2 from 2010 and Google© (DigitalGlobe, 2010; 2023).

Urbanization, as a geomorphological phenomenon, requires the analysis of human interventions in surface processes and forms, influenced by socioeconomic factors and environmental use techniques (Rodrigues, 2005; Rodrigues *et al.*, 2019). This analysis considers road layout, building density, urban consolidation, and the relocation of surface materials (Douglas; Lawson, 2000; Rodrigues, 2005; Gouveia, 2010). The classification of urban uses occurs in three phases: Pre-Urban, Active Disturbance and Post-Disturbance (Gouveia, 2010; Luz, 2015). Figure 2 presents the key to interpreting the stages of urban intervention over time, highlighting distinct areas in each time frame.

Figure 2 – Key to Interpreting the Stages of Urban Intervention



Source: DSG (1975); Erechim (1989); DigitalGlobe (2010; 2023). Elaborate by the authors (2025).

The Pre-Urban phase is characterized by exposed soil, packed earth, and the absence of paving. Diffuse runoff concentrates in rudimentary channels, reducing infiltration and increasing surface runoff. Vegetation removal increases flow and erodibility, favoring the formation of erosion rills (Moura, 2005; Vieira; Cunha, 2005). Urban intensification alters surface and subsurface flows, modifying hydrogeomorphological dynamics (Rodrigues; Gouveia, 2013; Gouveia; Rodrigues, 2017).

The Active Disturbance cycle covers partially paved areas with incomplete infrastructure. Paving reduces infiltration and intensifies linear erosion, increasing sediment load (Gouveia, 2010; Moura, 2011; Rodrigues; Gouveia, 2013). Cuts, fills, and paving release loosely cohesive materials, modifying slopes and increasing runoff (Moura, 2005; 2008; Gomes; Moura, 2017). The lack of adequate drainage favors erosion and undermining scars, aggravated by changes in slope and vegetation cover (Gouveia, 2010; Rodrigues; Gouveia, 2013; Gouveia; Rodrigues, 2017; Ferreira; Pinton, 2021).

The Post-Disturbance phase is characterized by soil waterproofing and consolidated infrastructure (Nir, 1983; Luz, 2015; Luz; Rodrigues, 2013; 2020; Rodrigues *et al*., 2019). Urbanization intensifies runoff and erosion processes, increasing the risk of flooding and river degradation (Moura, 2008; 2011; Gouveia, 2010; Rodrigues; Gouveia, 2013; Ferreira; Pinton, 2021). Paving raises flood peaks and increases sediment deposition, requiring greater capacity from drainage channels (Vieira; Cunha, 2005; Rodrigues, 2005; Gouveia, 2010; Moura, 2011). Concentrated surface flow aggravates drainage problems, transforming streets into storm channels (Moura, 2008). These changes demonstrate changes in hydrogeomorphological features and water flows.

Semi-Preserved Original Morphology encompasses rural areas with native vegetation and preserved watercourses, which dynamically adjust to natural conditions (Hack; Goodlett, 1960; Nir, 1983; Ahnert, 1994; Luz, 2015). High infiltration reduces surface runoff and maintains hydrological balance. Natural channels transport sediment efficiently, preserving environmental processes (Luz, 2015; Ferreira; Pinton, 2021).

Modifications to River Dynamics

The reconstruction of river channels and the original relief used cartographic bases and geospatial data in Geographic Information Systems (GIS). For the central area, the 1934 map (scale 1:5,000) (CTE, 1934) was used, with 5-m contour lines and hydrological data. The topographic map (scale 1:50,000) (Hasenack; Weber, 2010), based on aerial photographs (1:20,000) (DSG, 1975), contributed to the morphological analysis.

Fifteen topographic maps from 1990 (scale 1:2,000) (Erechim, 1990) were digitized, including contour lines, elevation points, and hydrography data. The Erechim Environmental Plan (Erechim, 2011) supplemented the data. Anthropogenic morphology was analyzed using polygons (dams and reservoirs) (Fujimoto, 2001; Gouveia, 2010; Peloggia; Silva; Nunes, 2014) and lines (buffered and rectified channels) (Gouveia, 2010; Gouveia; Rodrigues, 2017). The street layouts were used to represent streets and bridges (Fujimoto; 2001; Rodrigues, 2005; Peloggia *et al*., 2014).

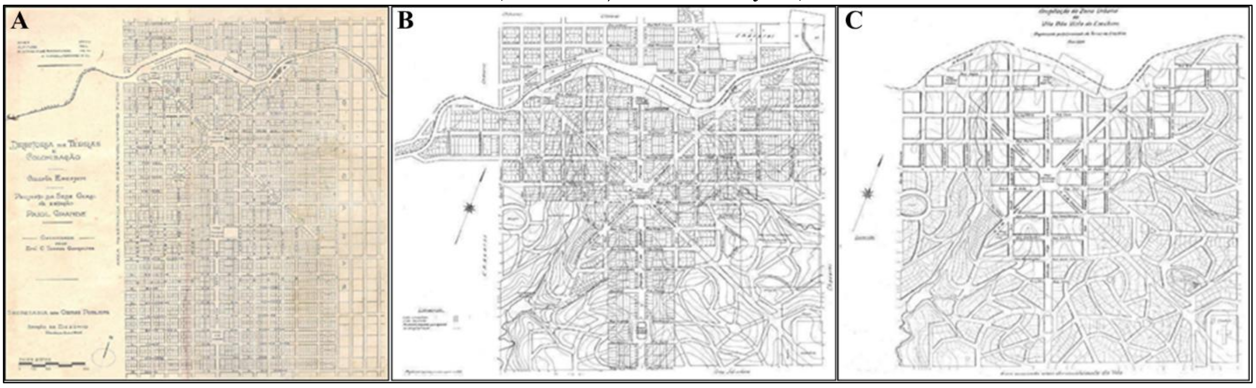
RESULTS AND DISCUSSIONS

Evolution of Urban Occupation

A historical approach is fundamental in urban geomorphological studies, as intense occupation makes it difficult to distinguish natural effects from anthropogenic interventions (Rodrigues, 2005; Moura, 2008). Erechim follows a positivist urban model that follows a grid pattern, with four diagonal streets radiating from the central square and the use of long avenues. The current urban area emerged from a planned central core, expanding east and west along Maurício Cardoso and Sete de Setembro avenues (Aver, 2008).

Figure 3A shows the plan of the Paiol Grande station, the origin of the current municipality of Erechim. Urban expansion followed a grid pattern, suitable for flat terrain but incompatible with the local topography. The 1931 project (Figure 3B) rectangular blocks were adopted and small portions adapted to the topography. In 1934 (Figure 3C), an organic urban layout was proposed that maintained the original layout only in the central blocks, adjusting the rest to the terrain. However, the 1931 design prevailed (Aver, 2008). Figures 3A and 3B highlight changes in the road network, especially in the Tigre river valley. However, the street layout remained linear.

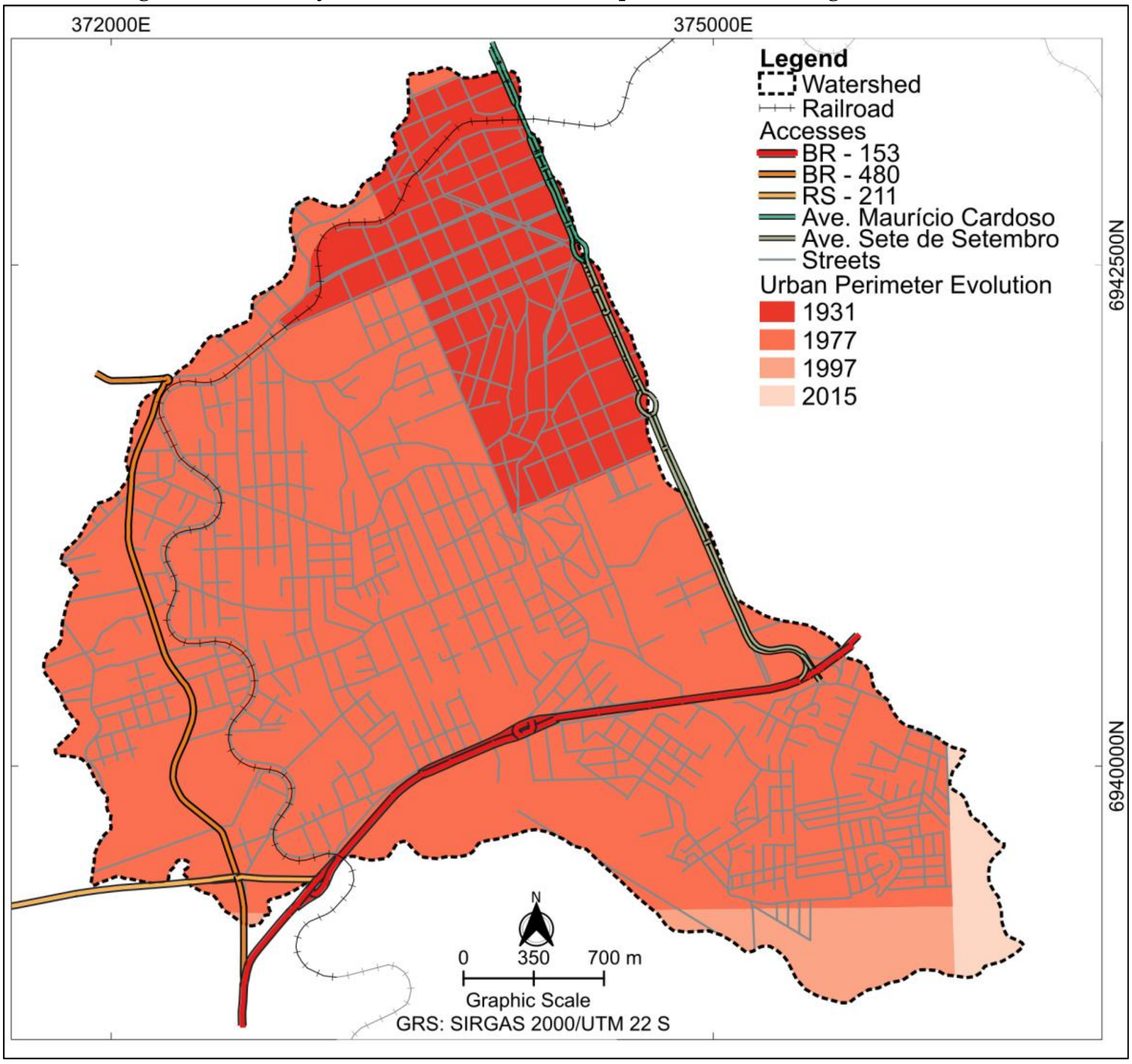
Figure 3 - Urban Projects (1914 – 1951) - A) General Headquarters Project, 1914. B) Urban Perimeter, 1931. C) Urban Project, 1934



Source: DTC (1914); CTE (1931; 1934). Elaborate by the authors (2025).

Figure 4 shows the expansion of the urban perimeter in the watershed, with the northeastern interfluve delimiting the original 1931 perimeter in relation to the areas subsequently included. Initially, the urban perimeter delimited 16.47% of the watershed (1.91 km²). In 1977, the urban perimeter was expanded to 94.65% of the basin area (10.96 km²), with the incorporation of new neighborhoods and industrial zones.

Figure 4 - History of Urban Perimeter Expansion in the Tigre River Basin



Source: Aver (2008); Erechim (2015). Elaborate by the authors (2025).

The increase in the areas included in the urban perimeter demarcation slowed in subsequent years. In 1997, it reached 98.10% (11.38 km²) and reached 100% (11.60 km²) in 2015, with the occupation of the southeastern sector.

Analysis of the Evolution of Urban Intervention Stages

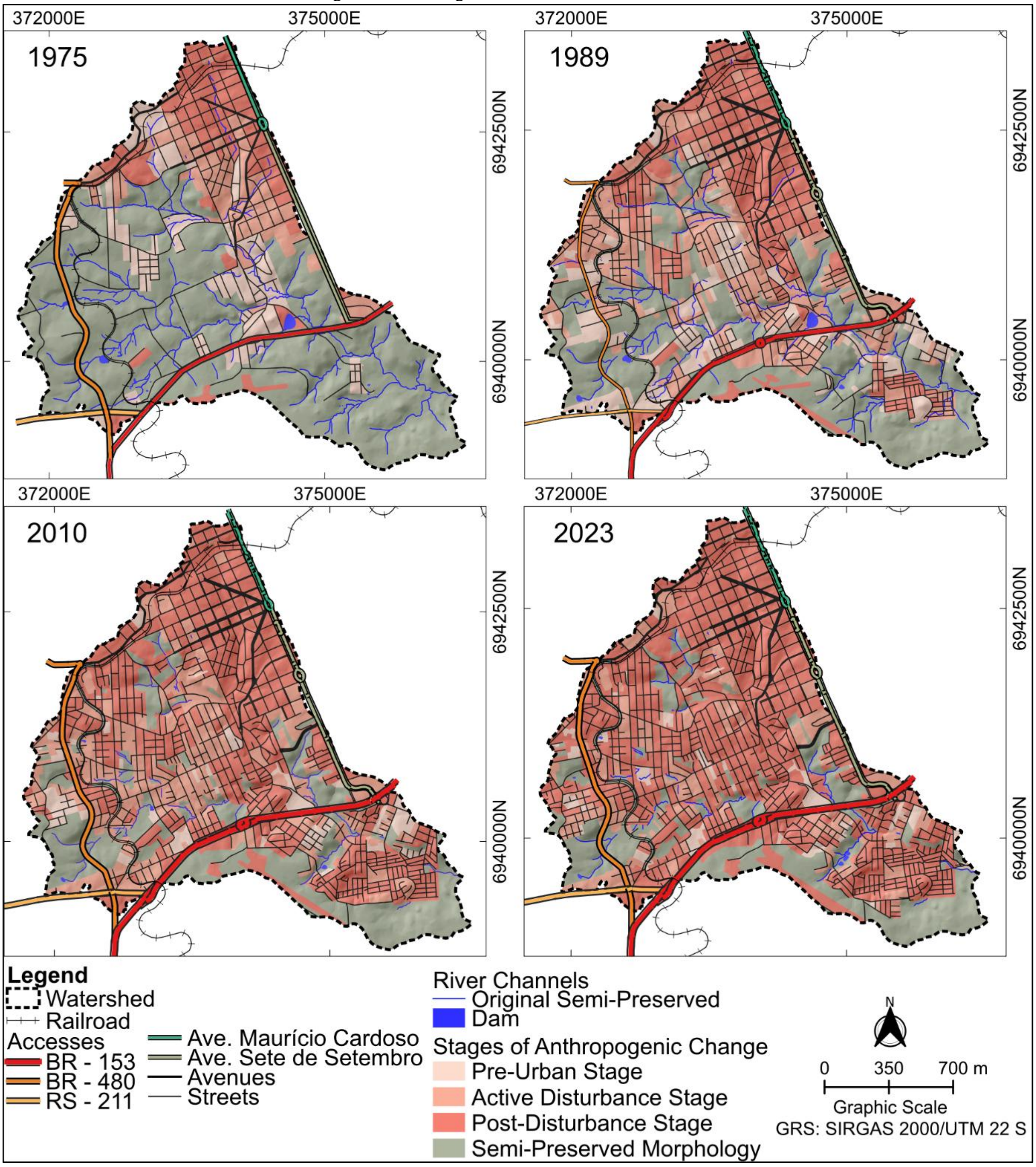
The evolution of the urban intervention cycles in the Tigre River basin, analyzed in the years 1975, 1989, 2010, and 2023, reveals significant territorial transformations and the resulting environmental impacts. This analysis allows us to understand how social, economic, and environmental dynamics shaped urban occupation over the decades (Table 1; Figure 5).

Table 1 – Urbanized Area and Urban Intervention Stages

Periods	**1975**	**1989**	**2010**	**2023**
Urban Uses	Km²	Km²	Km²	Km²
Watershed Area	11.60	11.60	11.60	11.60
Urbanized Area	4.11	7.44	8.82	9.22
Pre-Urban Stage	1.38	1.55	0.61	0.50
Active Disturbance Stage	1.19	3.01	2.85	1.61
Post-Disturbance Stage	1.54	2.88	5.36	7.11
Original Semi-Preserved Morphology	7.49	4.16	2.78	2.38

Source: The authors (2025). Elaborate by the authors (2025).

Figure 5 - Stages of Urban Intervention

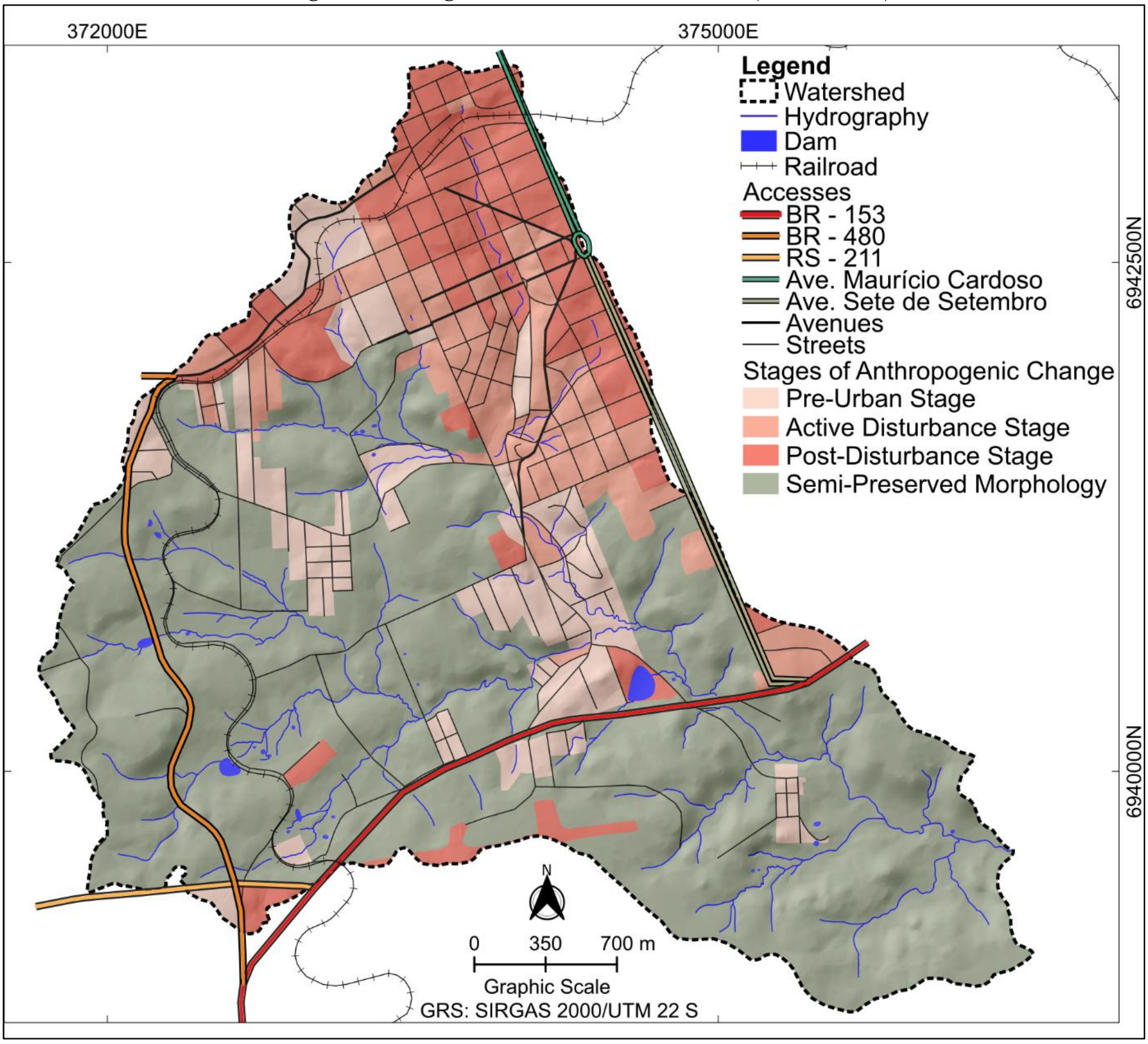


Source: DSG (1975); Erechim (1989; 2011); DigitalGlobe (2010; 2023). Elaborate by the authors (2025).

Urban Transformations and Morphological Impacts (1918–1975)

The map (Figure 6) highlights the Pre-Urban, Active Disturbance, and Post-Disturbance phases. In 1975, urbanization occupied 35.43% of the basin, concentrated within the perimeter of the original project, with structured avenues such as Maurício Cardoso and Sete de Setembro.

Figure 6 - Stages of Urban Intervention (1918–1975)



Source: DSG (1975). Elaborate by the authors (2025).

The Post-Disturbance stage predominated, covering 13.28% of the urban area, expanding along Avenida Sete de Setembro, in the Northwest sector, near the railroad and BR-480, and in the Southwest sector, near BR-153. In 1913, Carlos Torres Gonçalves, then director of Land and Colonization for the state government, reported to the President of the State of Rio Grande do Sul (RS) that in the Paiol Grande Village (present-day Erechim), 1,300 of the 2,500 lots planned to house the Erechim Colony had already been demarcated (Cassol, 2003). These lots were marketed by the State Land Commission, and the initial project included farms, later subdivided into smaller parcels.

The Active Disturbance phase covers 10.26% of the urbanized areas, concentrated around the original core, the railroad, and BR-480. In 1975, the Pre-Urban phase occupied 11.90% of the basin, distributed across various sectors. Vegetation removal increased flow and erodibility, altering sedimentation, particularly on slopes with erosion gullies (Moura, 2005; Vieira; Cunha, 2005). These modifications intensified surface and subsurface flows, affecting hydrological dynamics (Rodrigues; Gouveia, 2013).

Located in the southwest, Vila Operária was one of the first urban centers (Aver, 2008). Other settlements emerged in the central region, with the Aldo Arioli housing complex (Querubin, 1997), and in the southeast, with the Progresso Neighborhood (Psidonik, 2004). Created in 1956, Vila Operária (currently the São Cristóvão Neighborhood) arose from land donated by the state and established by the municipality in the 1960s. Aldo Arioli, developed by the Companhia de Habitação (COHAB) (Housing Company), had 150 250 m² lots. The Legião Brasileira de Assistência (LBA) (Brazilian Assistance Legion) financed housing in various areas, including the Progresso Neighborhood, with no records of exclusive subdivisions (Psidonik, 2019). In 1975, areas of Semi-Preserved Original Morphology occupied 64.57% of the basin and preserved their original form. They were used for agriculture and covered with undergrowth and forest.

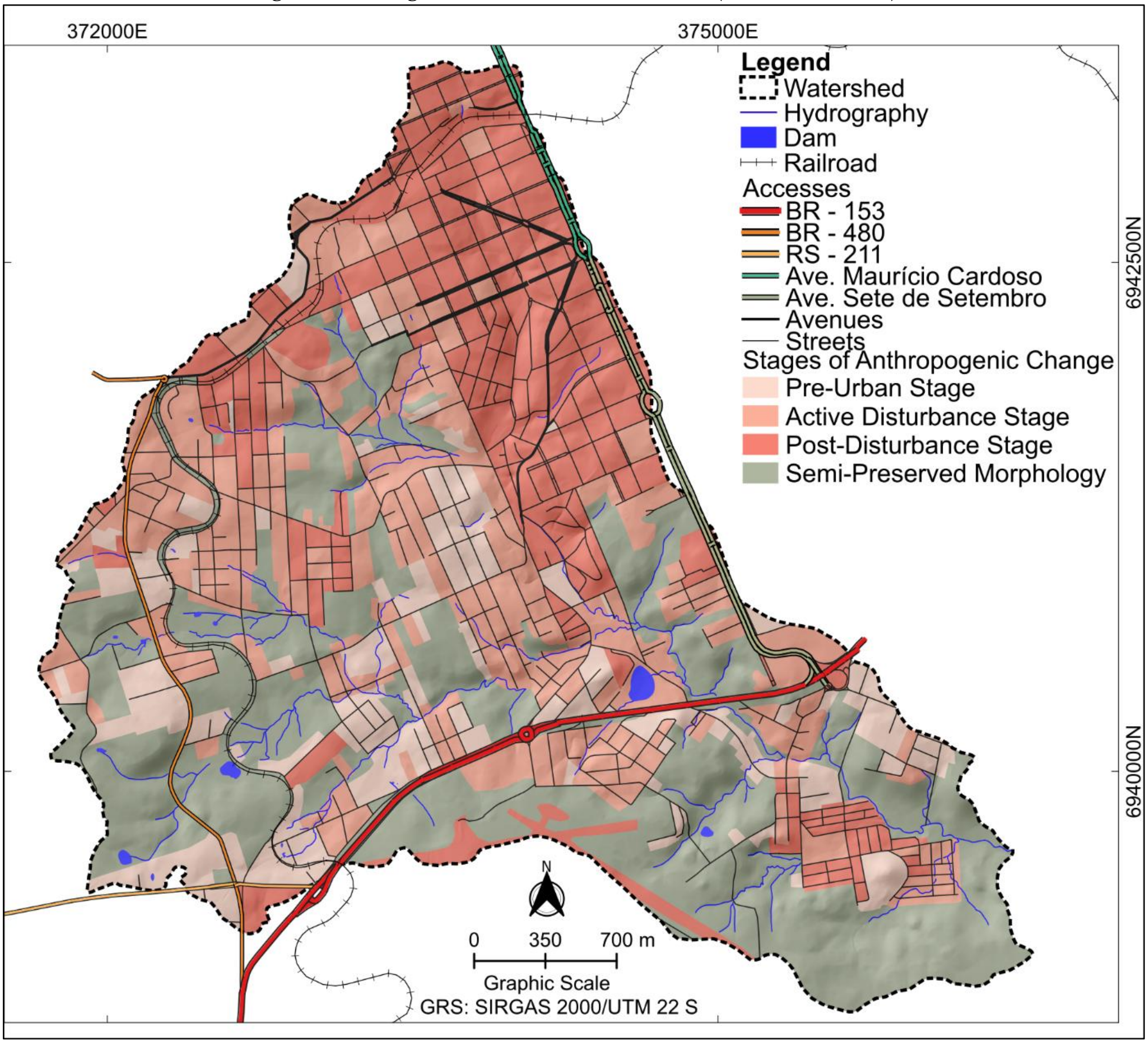
Urban Expansion and Geomorphological Changes (1975 and 1989)

Between 1975 and 1989, urbanization of the basin reached 64.14% of the total area. Subdivisions in the Pre-Urban and Active Disturbance stages evolved into the Post-Disturbance stage, consolidating the urban core, which occupied 24.83% of the urbanized area, with emphasis on the Northwest sector, near the railway and BR-480, and the Aldo Arioli core (Querubin, 1997).

In 1989, Active Disturbance covered 25.95% of the urbanized area, with expansion in the Northwest and Southeast sectors, near BR-153 (Figure 7). During this period, neighborhoods such as Progresso and Cristo Rei grew with the Eradication of Erradicação da Subabitação (Underhousing Program) in 1982, run by the Banco Nacional de Habitação (BNH) (National Housing Bank) in partnership with the Companhia de Habitação do Estado do Rio Grande do Sul (COHAB RS) (Housing Company of the State of Rio Grande do Sul). The program built 593 houses on 160 m² lots and provided basic infrastructure in Vila Progresso, consolidating new urban centers (Psidonik, 2004; 2019).

This period was marked by cuts, fills, paving, and land preparation for construction, creating soil discontinuities, reduced infiltration, and increased water and soil pollution (Gouveia, 2010; Moura, 2011; Rodrigues; Gouveia, 2013). The leveling and paving of streets modified the relief and water flows, intensifying sediment transport. Landfills raised the terrain and increased instability, while vegetation removal exacerbated morphological instability (Moura, 2005; 2008; Gomes; Moura, 2017).

Figure 7 - Stages of Urban Intervention (1975 and 1989)



Source: Erechim (1989). Elaborate by the authors (2025).

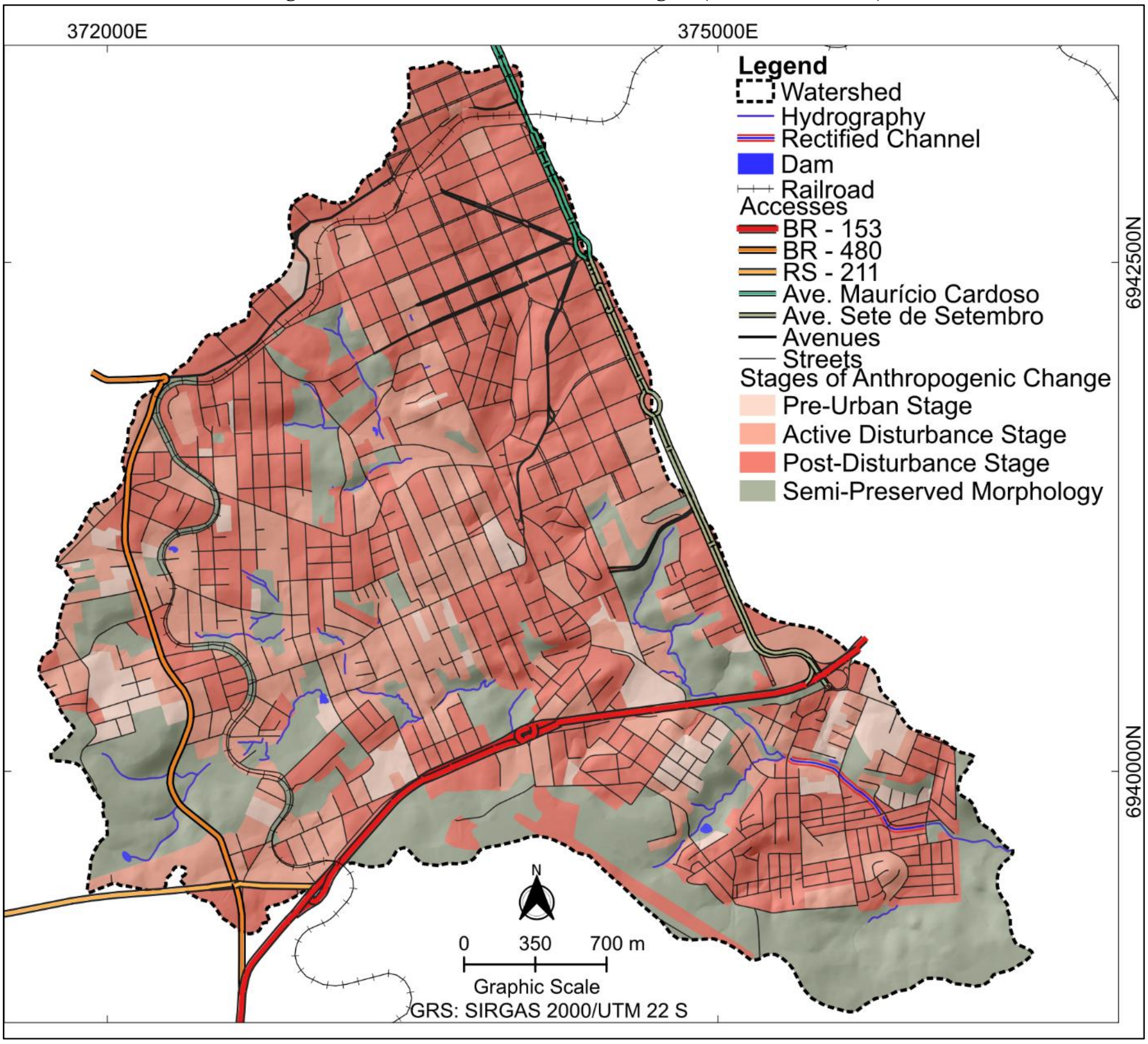
In 1989, the Pre-Urban period occupied 13.36% of the area, with restricted use and partial preservation of the natural relief. The areas of Semi-Preserved Original Morphology, which cover 35.86% of the basin, remained unchanged, with preserved relief. Used for agriculture, they feature low-lying vegetation and trees, essential for the conservation of ecological diversity.

Urban Density and Consolidation of Occupation (1989 and 2010)

From 1989 to 2010, urbanization of the watershed reached 76.03% of the total area, with the Post-Disturbance stage accounting for 46.21% of the urbanized areas. Between 1989 and 1995, municipal subdivisions drove urban expansion, such as the Social 1 and 2 subdivisions (27 and 94 lots) in the Petit Village neighborhood (1990); Social 3 (66 lots), in the Progresso neighborhood (1991); and Social 4 and 8 (35 and 32 lots), in the Koller neighborhood (1992). Other projects, such as Social 9 (40 lots), in the Progresso neighborhood (1994), and the Ulysses Guimarães subdivision (82 lots), in the Aldo Arioli neighborhood (1995), consolidated the structuring of the neighborhoods (Psidonik, 2019).

The Pre-Urban stage represented 5.26%, with few areas in the initial process of transformation (Figure 8). In Boa Vista neighborhood, housing cooperatives such as Cooperhabic operate in Pre-Urban areas, the same occurring in the Vitória I neighborhood. In Petit Village, City Hall and cooperative land also falls into this phase (Psidonik, 2019).

Figure 8 - Urban Intervention Stages (1989 and 2010)



Source: DigitalGlobe (2010); Erechim (2011). Elaborate by the authors (2025).

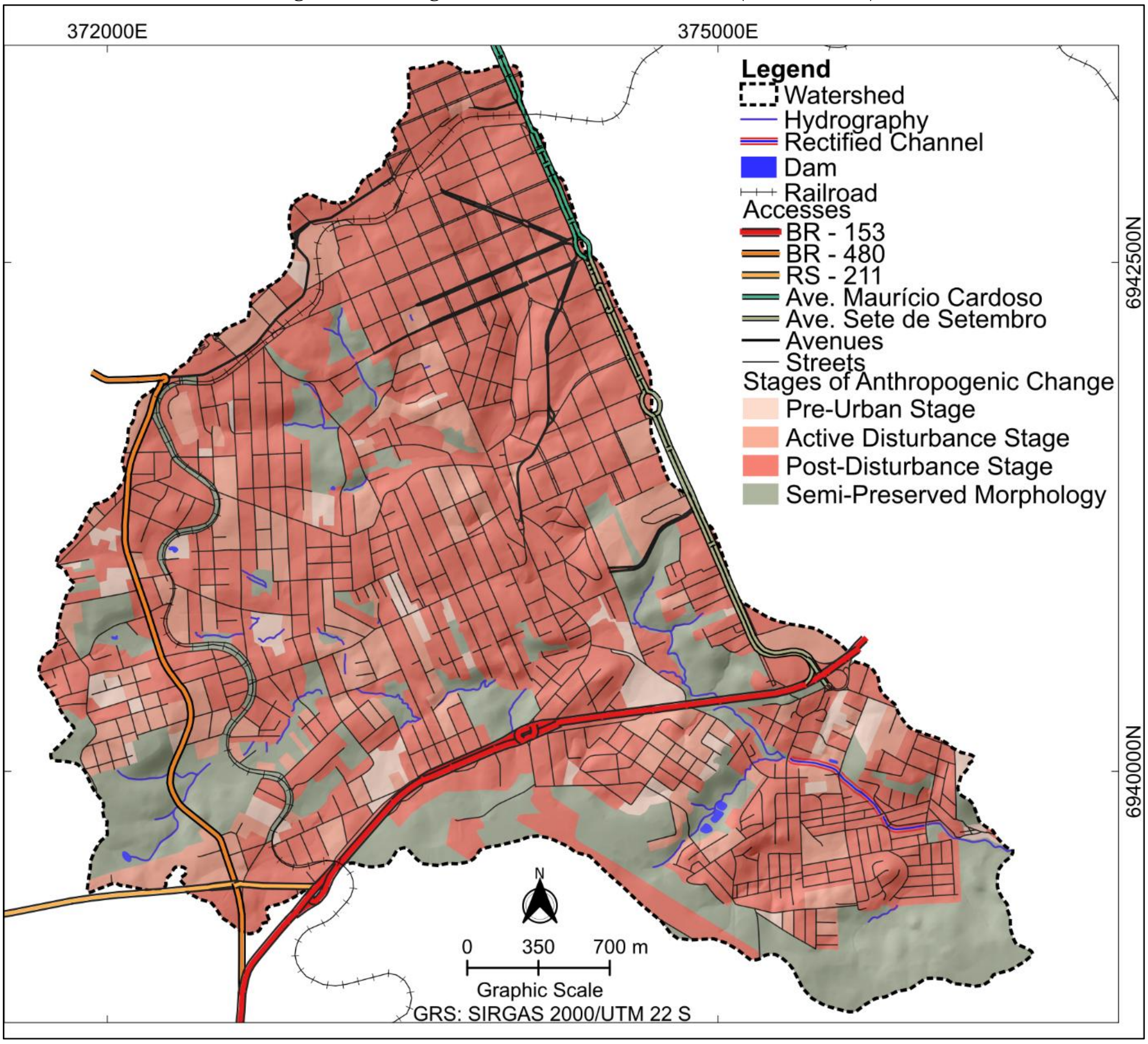
In 2016, Erechim faced irregular occupations in public, vacant, private, and green spaces in the Progresso, Cerâmica, Vitória II, Koller, Boa Vista, Petit Village, and São José neighborhoods. In Progresso, spaces were occupied without legalization, requiring adjustments to urban planning. According to the Department of Public Works, the municipality invested in social housing developments to meet housing demand. In 2013, the largest number of approved developments was registered, expanding urban areas and the housing supply (Psidonik, 2019).

Areas of Semi-Preserved Original Morphology accounted for 23.97%, remaining as undeveloped green spaces. New developments accelerated the transition from areas in Active Disturbance to Post-Disturbance, intensifying hydrogeomorphological changes. Urbanization modified morphological and hydrodynamic patterns, evidencing the impacts of anthropogeomorphological evolution.

Consolidated Urbanization and its Environmental Impact (2010–2023)

Urbanization in the Tigre River basin reached 79.48% in 2023, with 61.29% in the Post-Disturbance stage, signaling urban consolidation (Figure 9). Active Disturbance covers 13.88% of the area, and the Pre-Urban stage, 4.31%, indicating that few areas are still undeveloped.

Figure 9 - Stages of Urban Intervention (2010–2023)



Source: DigitalGlobe (2023). Elaborate by the authors (2025).

These stages reflect urban expansion. The Pôr do Sol subdivision (50 lots), in Petit Village, was created by the City Hall in 2011. The Altos da Coxilha subdivision (113 lots), in Cristo Rei, was implemented in 2016 through a Public-Private Partnership (PPP) (Psidonik, 2019). Soil impermeability and dense infrastructure block infiltration, double runoff rates, increase flood peaks, and increase pressure on canals, thus altering drainage and transforming streets into stormwater drains (Rodrigues, 2005, 2010; Gouveia, 2010; Moura, 2008, 2011; Rodrigues; Gouveia, 2013).

The areas of Semi-Preserved Original Morphology, which cover 20.52% of the basin, are crucial to ecological functionality. The analysis of the urbanization phases reinforces the need for environmental planning that reconciles urban development and preservation, reducing socio-environmental impacts and promoting basin resilience.

Anthropogenic Modifications to River Dynamics

The Tigre River basin has undergone alterations to its river channels, classified as Semi-Preserved Original Morphology, buffered, and, since 2010, rectified. Interventions include bridges, pipelines, galleries, and dams. In 1975, 16.57% of the channels were modified; in 1989, 37.26%; in 2010, 75.03%; and, in 2023, 77.47%. The rectifications eliminated meanders and reduced marginal erosion, but worsened hydrological processes. Concrete sealing accelerated flow and increased erosion. Embankments and bridges narrowed the flow sections, favoring obstructions and flooding (Tucci, 2008; Robaina, 2013).

Table 2 - Magnitude of Changes in River Channels

Original Channel		**Magnitude of Change**							
	Period	**1975**		**1989**		**2010**		**2023**	
		m	%	m	%	m	%	m	%
41,050.64	Buffered	6,801.71	16.57	15,295.71	37.26	30,043.51	75.03	31,455.76	77.47
	Rectified	0.00		0.00		757.73		757,73	

Source: The authors (2025). Elaborate by the authors (2025).

Between 1975 and 1989, the area of dams in the basin decreased, with a further decline until 2010. From 2010 to 2023, there was a slight increase, indicating some recovery of the reservoirs (Table 3).

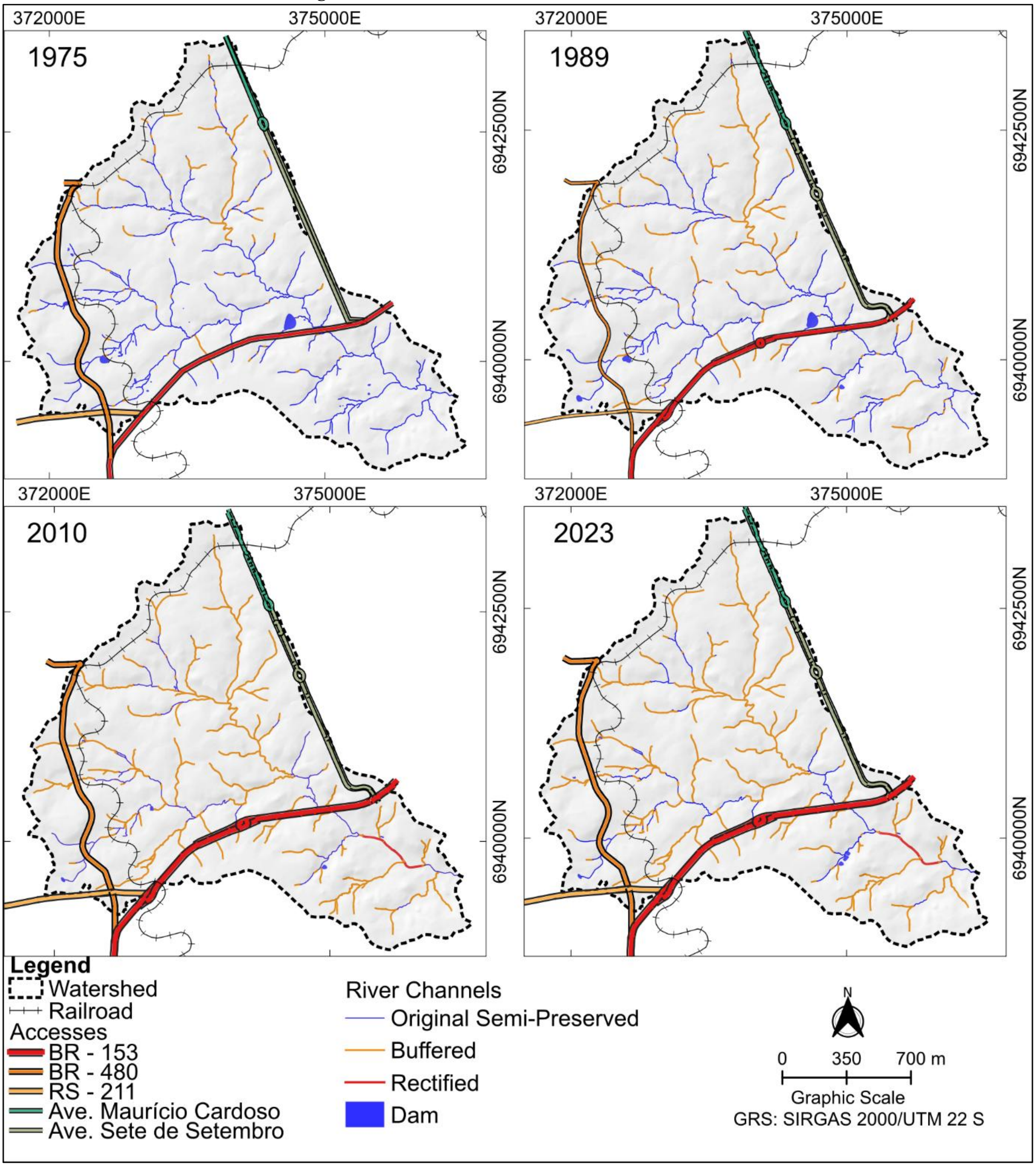
Table 3 – Water Reservoir Dynamics

Período	**1975**	**1989**	**2010**	**2023**
m^2	36,822.93	33,468.87	13,497.32	17,340.14

Source: The authors (2025). Elaborate by the authors (2025).

The anthropogenic morphologies of the river system (Figure 10), such as straightened and buffered channels, were designed to accelerate water flow, influenced by real estate speculation and road transportation. Techniques that altered the channels enabled the occupation of river plains and terraces, but were applied indiscriminately, without considering the complexity of the river basin (Gouveia; Rodrigues, 2017).

Figure 10 - Modifications in river channels



Source: DSG (1975); Erechim (1989; 2011); DigitalGlobe (2010; 2023). Elaborate by the authors (2025).

Figure 11 shows cross-sections of the lower basin in 1989 and 2023, highlighting the rectification and channeling. These interventions reflect urban expansion and the influence of urban dynamics on the basin's configuration.

Figure 11 - Low course cutouts (1989 – 2023)

Source: Erechim (1989); DigitalGlobe (2023). Elaborate by the authors (2025).

Lack of planning has exacerbated flood risk, with bridges, embankments, and embankments obstructing flows, and straightening intensifying downstream effects. Mitigating these impacts requires urban planning, water management, and channel preservation actions to strengthen urban resilience.

FINAL CONSIDERATIONS

This study analyzed landscape transformations and the impacts of urbanization on morphodynamics and hydromorphology over five decades. Since 1911, urban expansion, which reached 79.48% of the area in 2023, has promoted the transition from Semi-Preserved Original Morphology to Anthropogenic Morphology, intensifying flooding episodes and river changes. Initial plans adopted a positivist model, disregarding topography.

Although adjustments have been made over time, practices such as channel straightening and damming still persist, often ineffectively and aggressively affecting the natural system. GIS-integrated cartography allowed us to interpret urban developments and reconstruct the natural conditions of the channels. Since the basin's full inclusion within the urban perimeter in 2015, it has been essential to protect banks and springs, map risk areas, and adopt effective strategies to mitigate socio-environmental and hydrological impacts.

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