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FLUVIAL TYPOLOGIES IN THE BRAZILIAN DRYLANDS:
A STUDY ON THE APPLICATION OF THE METHODOLOGICAL PROPOSAL OF RIVER STYLES

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ABSTRACT – In light of the increasing demand for methodological frameworks that underpin the conservation of landscape diversity, particularly within physiographic contexts that have been historically undervalued, such as tropical drylands, the River Styles methodology emerges as a significant approach. This methodology aims to generate a comprehensive set of spatialized information that addresses the systemic interplay of regional and local controls in shaping processual and morphological responses across drainage systems. Furthermore, it facilitates a deeper understanding of the functionality, maintenance, preservation, and sustainable management of fluvial environments. This study applies the River Styles methodology to a semi-arid basin in Northeastern Brazil, where the relationships between channel patterns and the formation of aggradation landforms is still poorly explored by the geomorphological literature. Seven distinct fluvial typologies were identified, grounded in the predominant physiographical, environmental, and processual characteristics of the area. The river styles delineated herein can serve as a valuable reference for the assessment and classification of other basins within the Brazilian semi-arid domain, as well as for comparative analysis with other semi-arid tropical regions situated in similar passive continental margin contexts.

Keywords: River compartmentation; river styles; drylands; landscape units; hydrographic basin.

RESUMO – TIPOLOGIAS FLUVIAIS NAS TERRAS SECAS BRASILEIRAS: UM ESTUDO SOBRE A APLICAÇÃO DA PROPOSTA METODOLÓGICA DE ESTILOS FLUVIAIS. Considerando a crescente demanda por propostas metodológicas que forneçam bases para a conservação da diversidade paisagística, sobretudo em contextos fisiográficos subestimados para esses fins como as terras secas tropicais, destaca-se a dos Estilos Fluviais, voltada à produção de um conjunto de informações espacializadas de caráter sistêmico acerca dos controles regionais e locais responsáveis por produzir características morfológicas e processuais ao longo das drenagens. Ademais, a metodologia aporta informações fundamentais para o reconhecimento da funcionalidade, manutenção, preservação e gestão sustentável dos ambientes fluviais. O presente trabalho aplicou a proposta metodológica de Estilos Fluviais a uma bacia semiárida do Nordeste do Brasil, onde as relações entre os padrões de canal e a criação de formas de agradação são ainda pouco enfocadas pela literatura geomorfológica. Foram identificadas sete tipologias fluviais com base nas características físicas, ambientais e processuais predominantes. Os estilos fluviais estabelecidos para a área podem servir de referência para o levantamento e classificação de outras bacias no domínio semiárido brasileiro, bem como para comparação com outras áreas tropicais semiáridas em contextos plataformais e de margem continental passiva.

Palavras-chave: Compartimentação fluvial; estilos fluviais; terras secas; unidades de paisagem; bacia hidrográfica.

HIGHLIGHTS

- The compatibility of application of river styles to Brazilian drylands.
- To understand river typologies for environmental conservation and water resources in a semi-arid context.
- River Styles in Brazilian drylands are constantly associated with structural and landscape controls.

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1. INTRODUCTION

Irregular and concentrated precipitation, year-round high temperatures, and high evapotranspiration rates characterize the drylands of the Brazilian Northeast. The irregularity of rainfall produces long periods of drought interspersed with occasional peaks of significant rainfall, resulting in a particular geomorphological dynamic associated with the semi-arid river environment (Almeida, 2021; Bracken & Wainright, 2008; Souza *et al*., 2016). In addition to the surface processes peculiar to this type of environment, in its tropical variety, there are impacts on land use since European colonization, with more than 400 years of pastoral activities and traditional dry farming. These transformations have been producing complex responses in the landscape, especially regarding the fluvial morphological units, altering channel character and stability, and creating particular sets of morphologies (Almeida, 2021; Lima *et al*., 2021; Souza *et al*., 2016).

Considering the diversity of river environments, proposals aimed at understanding these geomorphological systems in their varied spatial arrangements are necessary to obtain effective responses to water resource planning and management programs. In this sense, studies focused on the classification of river morphology have been widely disseminated in geomorphology. Many authors have suggested geomorphological schemes for classifying rivers, whether considering their landscape, morphological, or hydrosedimentological aspects, such as those of Miall (1996), Nanson and Croke (1992), Whiting and Bradley (1993) and Woolfe and Balzary (1996). Nonetheless, most studies dealing with river style classification have bypassed the drainage systems of the semi-arid Northeast of Brazil, remaining among the least known regions regarding their fluvial characteristics among the drylands of the world.

In recent decades, innovative methodologies have emerged to develop river typologies that are grounded in realistic ecological and geomorphological settings. These approaches prioritize areal requalification and the comprehensive management of river environments.

Within this framework, the River Styles theoretical-methodological model offers a nuanced geomorphological framework aimed at elucidating the behavior and evolution of rivers on a localized scale. This model places particular emphasis on channel dynamics and the structural characteristics of valley bottoms (Brierley *et al*., 2002; Fryirs & Brierley, 2009; Souza, 2014). Its primary objective is to systematically classify river segments by characterizing them based on a standardized set of geomorphological and hydrodynamic attributes. This classification allows for a clear differentiation of the behaviors and characteristics inherent to various river types (Brierley & Fryirs, 2005; Lima & Marçal, 2013).

The River Styles proposal allows us to identify the relationships between processes and forms along rivers, in their different segments, based on the perspective that these occupy a place within the landscape context of the watershed, in such a way that a river can present different styles, according to the particular interaction of each segment with the landscape in its surroundings (Brierley & Fryirs, 2005).

In this way, the methodology offers a comprehensive overview of the river landscape's structure, which can record the character and behavior of a river and offer a geomorphic assessment of its spatial and evolutionary patterns. The proposed analysis focuses on the drainage basin, considered as a set of attributes, which includes the morphostructural compartmentalization of the relief, the characteristics of the valley, the plan shape and geometry of the channel, the geomorphic units of the basin and the texture of the river bed (Brierley & Fryirs, 2005; Corrêa *et al*., 2009; Lima & Marçal, 2013).

In the drylands of Northeastern Brazil, the methodology was applied by Almeida *et al*. (2016), Corrêa *et al*. (2009), Franco *et al.* (2022), Lima *et al*. (2021), Rodrigues and Souza (2020b), Rodrigues *et al*. (2023), Santos *et al.* (2023), Souza *et al*. (2016). The authors focused on a morphoclimatic context, whose fluvial landscapes have been largely overlooked. They pioneered addressing the existence of ephemeral basins characterized by *sui generis* aggradational forms in this Brazilian region, differentiated from intermittent rivers.

The concept of River Styles offers a versatile framework for understanding the dynamics of rivers and landscapes, yet its application in semi-arid basins remains underexplored. This is notable given the potential benefits that its outcomes could yield for territorial planning. In this context, the present study seeks to apply the River Styles methodology within a semi-arid basin in the Brazilian Northeast.

The primary objective is to establish a new typological framework for the identification of aggradational units. This framework aims to provide a more robust characterization that could serve as a foundation for the conservation and rehabilitation of ephemeral river channels. Such an approach is crucial, considering the diverse uses and environmental services these river systems offer to the region.

2. METHODOLOGY

The application of the River Styles methodology requires the creation of a database composed of a list of integrated geospatial attributes concerning the river forms, processes, and connections established between channels. This spatialized information on the morphological and structural aspects of the channels and their segments constitutes the basis for the four-tiered River Styles analysis and provides a basis for predictions on river behavior (Brierley & Fryirs, 2005).

The first stage of the method involves the identification, interpretation, and mapping of river styles in a river basin. These procedures are the basis for characterizing the river behavior. The second stage consists of conducting assessments of river character and behavior from a dynamic perspective, where forms and processes are evaluated from an evolutionary standpoint. The third stage corresponds to evaluating the future trajectory of changes and the recovery potential of the river channel. Finally, the fourth stage focuses on river management applications by constructing qualitative and prognostic scenarios (Almeida, 2017; Brierley & Fryirs, 2005).

In this work, the methodology proposed by Brierley and Fryirs (2005) was adapted, based on its first two stages, to provide a detailed geomorphological model to understand the behavior and evolution of the river system up to its current spatial arrangement. This work adapted the River Styles methodology with emphasis on the interaction between structural and anthropogenic conditions, in order to complete the definitions for the semi-arid region proposed by Lima *et al.* (2021), Souza (2014) and Souza *et al*. (2016).

The identification of River Styles is based on the analysis of river sections, for which the degree of valley confinement, the number of channels, and the condition of channels' lateral stability are defined. The confinement classification aims to establish whether or not the flow overflows beyond the limits of the channel, and it is possible to identify three classes. The confined valley corresponds to the sectors that present floodplains in less than 10% of the river section; the partially confined valley occurs when 10 to 90% of the analyzed segment presents a discontinuous alluvial plain; while in the unconfined pattern, more than 90% of the section presents a continuous floodplain (Brierley & Fryirs, 2005; Souza, 2014).

In this stage, orthophotomaps from the *Pernambuco 3D Project*, at a scale of 1:5 000, were used to identify current drainage patterns and fluvial deposits. As a result, the approach sought to build an information framework presenting the river's characteristics, behavior, and controls. At this stage, representative channel sections were identified. Next, the adjustment capacity of each section was analyzed.

To assess the processual state of a river in relation to its surrounding landscape, it is essential to determine the adjustment capacity of each river segment and establish its specific morphology. The evolutionary trajectory of each segment must be analyzed to identify any irreversible changes and to pinpoint reference sections that facilitate a more in-depth interpretation of the prevailing geomorphological conditions (Almeida, 2017; Brierley & Fryirs, 2005). Fieldwork was conducted to substantiate the typologies identified, following a comprehensive geomorphological mapping of representative areas.

To construct the river typologies, it was necessary to compartmentalize the landscape units that make up the watershed. To this end, primary data, such as the Digital Terrain Model (MDT) from the *Pernambuco 3D Project* (Pernambuco, 2013), were used on a scale of 1:5 000 with an altimetric precision of 25cm. These data served as a basis for updating the landscape compartmentalization map proposed in Almeida (2021) for the basin and generating topographic profiles.

Secondary data from other cartographic bases were also used, including geology (Serviço Geológico do Brasil [SGB], 2005a, 2005b, 2005c), geomorphology (Almeida, 2017), and pedology (Oliveira, 2016). Land cover and land use data were obtained from Almeida *et al.* (2016), which generated a mapping based on the legend proposed by Food and Agriculture Organization of the United Nations [FAO], (2014).

2.1. Study area

The Riacho Grande Basin (fig. 1), with an area of 316km², is located in the center of the state of Pernambuco, encompassing parts of the municipalities of Serra Talhada, Calumbi, and Flores, delimited by the geographic coordinates of 7°55' S / 37°55' W and 8°08' S / 38°12' W (Almeida, 2017; Almeida *et al*., 2016). The watershed constitutes a sub-basin of the Pajeú River, a tributary of the São Francisco River, the largest exotic river in South America, and the only perennial course to cross the semi-arid Northeast of Brazil.

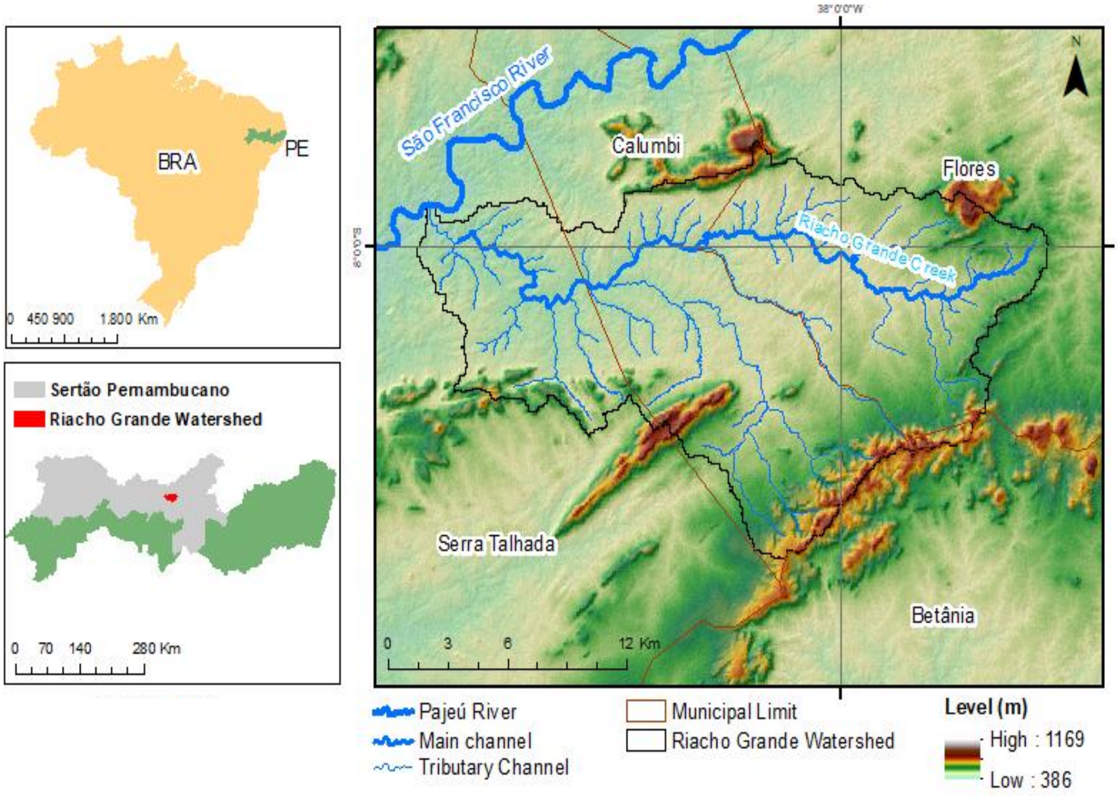

Fig. 1 – Location and hypsometry of the Riacho Grande basin.

Fig. 1 – Localização e hipsometria da bacia do Riacho Grande.

Source: Almeida (2021) and Almeida *et al*. (2025)

Regarding the climatic context, the Riacho Grande basin is located in the semi-arid tropical domain of the interior of the Brazilian Northeast, with average monthly temperatures ranging from 22 to 26°C, total annual precipitation of less than 800mm, and an irregular interannual regime controlled by global-scale phenomena. The area is prone to prolonged droughts or torrential rains concentrated over short periods, even in unlikely times, which favors the occurrence of floods and inundations (Almeida *et al*., 2012; Alves *et al.,* 2017; Aragão, 1998; Barros, 2018; Freire *et al*., 2011).

Identifying landscape physiographic elements allowed the definition of the spatial controls operating over the fluvial domain. Relief morphostructural units were identified by analyzing the different classes of terrain roughness, which led to the basin's subdivision into three larger sectors (table 1 and fig. 2): the Pajeú Interplanaltic Depression, Structural Ridge Massifs, and the Betânia Sedimentary Plateau.

Table I – Summary of the lithological framework of the study area.

Quadro I – Síntese dos dados litológicos da área de estudo.

Morphostructural Unit	**Lithological Framework**	**Landscape setting**
Pajeú intermontane depression	São Caetano Complex Afogados da Ingazeira Complex Floresta Complex Indiscriminated granitoids Recanto - Riacho do Forno Suite	Vegetated or unvegetated dissected pediments
	Alluvial deposits	Alluvial plains
Structural ridge massifs	Prata Intrusive Suite Terra Nova Intrusive Itaporanga Intrusive Suite	NE-SW / E-W trending elongated ridges
Betânia sedimentary plateau	Tacaratu Formation	Homoclinal sedimentary plateau

Source: Serviço Geológico do Brasil (2014)

The Pajeú Intermontane Depression corresponds to a strip of NE-SW elongated lowlands, confined between the Remobilized Massifs of the Transversal Zone Domain and the Western Escarpment of the Borborema Highlands (Corrêa *et al*., 2010). The Riacho Grande basin is installed on this low-lying flat compartment, structured in metamorphic complexes and Neoproterozoic granite plutons, mostly covered by the xerophytic thorn-scrub vegetation of the caatinga. The lowlands are transversed by mylonitic ridges subordinated to the structural controls of the NE-SW and E-W trending Neoproterozoic Shear Zones, where some sections of the larger channels are superimposed (Almeida *et al*., 1967; Sial, 1984; Silva Filho *et al*., 1987; Silva Filho e Guimarães, 1990).

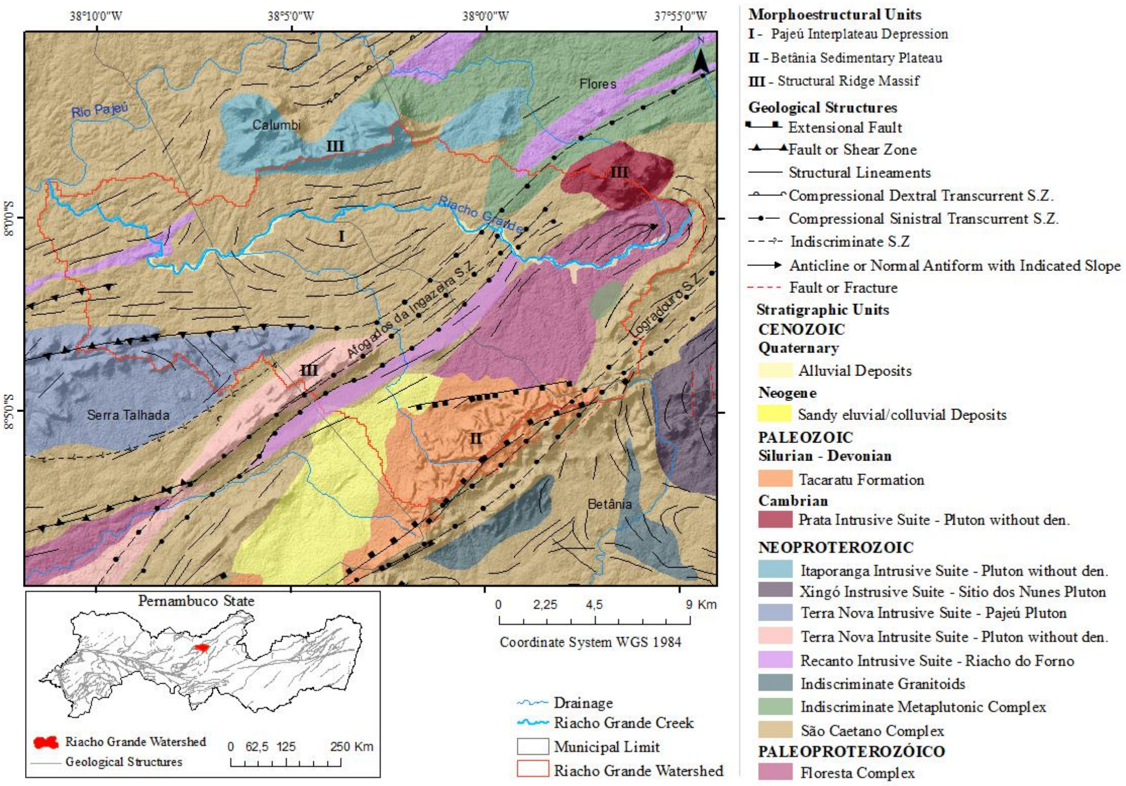

Fig. 2 – Geology of the Riacho Grande basin and its surroundings.

Fig. 2 – Geologia da bacia do Riacho Grande e arredores.

Source: Serviço Geológico do Brasil (2014)

The climatic and geological characteristics of the region significantly influence soil development, as highlighted by Corrêa *et al*. (2014). In the semi-arid Northeast of Brazil, the soils demonstrate a denudational balance that tends to prioritize erosion over pedogenesis. This process results in a distribution of soil classes that is primarily governed by lithological controls, geomorphic compartmentalization, and land use types. Within this framework, the Fluvisols present in the Riacho Grande basin are noteworthy; these soils are formed from recent alluvial deposits found in river plains and their associated terraces.

Additionally, the presence of Leptosols, which are shallow soils containing gravel, and Arenosols, characterized by sandy textures that are highly susceptible to erosion, is significant. The Arenosols exhibit a high infiltration capacity and notably low clay content.

Planosols are another class of greater recurrence in the Riacho Grande basin. They exhibit light-colored horizons and abrupt changes in texture, are shallow, have low permeability, and are more susceptible to erosion processes (Almeida, 2015; FAO, 2014; Oliveira, 2016), especially when related to the intensity of human activities in the sectors close to the terraces and riverbeds.

In these regions, Fluvisols and Planosols are the dominant types found at the interface between the alluvial plains and the adjacent rocky pediments, which delineate the lateral boundaries of the alluvial domain. Within this geoenvironmental unit, a range of agricultural practices is undertaken, including cattle ranching and dryland farming, particularly by smallholder farmers.

The pediments cover a large part of the Riacho Grande basin, alternating areas with preserved vegetation cover and areas under agricultural activities closer to the main channel. These are overall level surfaces with a ramp morphology, occurring between 450 and 550 meters (Almeida *et al*., 2016). These compartments are primarily structured in the sequences of metamorphosed metasedimentary rocks of the São Caetano Complex (SGB, 2001) to the north of the Afogados da Ingazeira Shear Zone and in the orthogneisses of the Floresta Complex. Leptosols and Luvisols predominate on the pediment ramps, while Planosols occur in the fluvial plains.

The agricultural activities carried out in the areas of contact between the pediment and the alluvial plains are those aimed at subsistence, carried out on small family properties, which take advantage of areas capable of holding soil moisture even after the short rainy season to grow short-cycle crops.

The semi-arid nature of the region significantly influences agricultural development, necessitating the construction of small-scale dams and the drilling of shallow wells. The prevalence of these rudimentary dams is closely associated with the Fissural Hydrogeological Domain, characterized by crystalline rock formations. In this domain, water storage is primarily dictated by secondary porosity, which is manifested through fractures and fissures. This results in underground reservoirs that are often spatially limited, discontinuous, and unpredictably distributed. Consequently, the wells in this region typically exhibit low flow rates. Furthermore, due to inadequate water circulation, elevated rates of evapotranspiration, and the specific characteristics of the bedrock, the water is frequently prone to salinization (Ministério de Minas e Energia [MME], 2009).

The Betânia homoclinal sedimentary plateau is characterized by a continuous cover of caatinga vegetation, which marks its distinctive landscape unit within the basin. This region is notable for its asymmetric ridges, featuring slopes exceeding 15°, and is further defined by dip-slip slopes that are dissected by canyons and steep valleys. The morphological characteristics observed in the area are largely attributed to the adaptation of the drainage network to the predominant psammite-psephitic lithotypes, which exhibit significant diagenesis and sub-vertical fracturing.

In this landscape unit (fig. 3), aggradational areas are characterized by alluvial plains presenting sediments of sandy, clayey, and gravelly textures. In contrast, sandy eluvial-colluvial sediments occur at the foot of the elevations. Prevailing soil classes in this landscape unit are Leptosols, rocky outcrops on the higher hillslopes, and Arenosols at the foot of the slopes. Associations with Acrisols were also observed to a lesser extent.

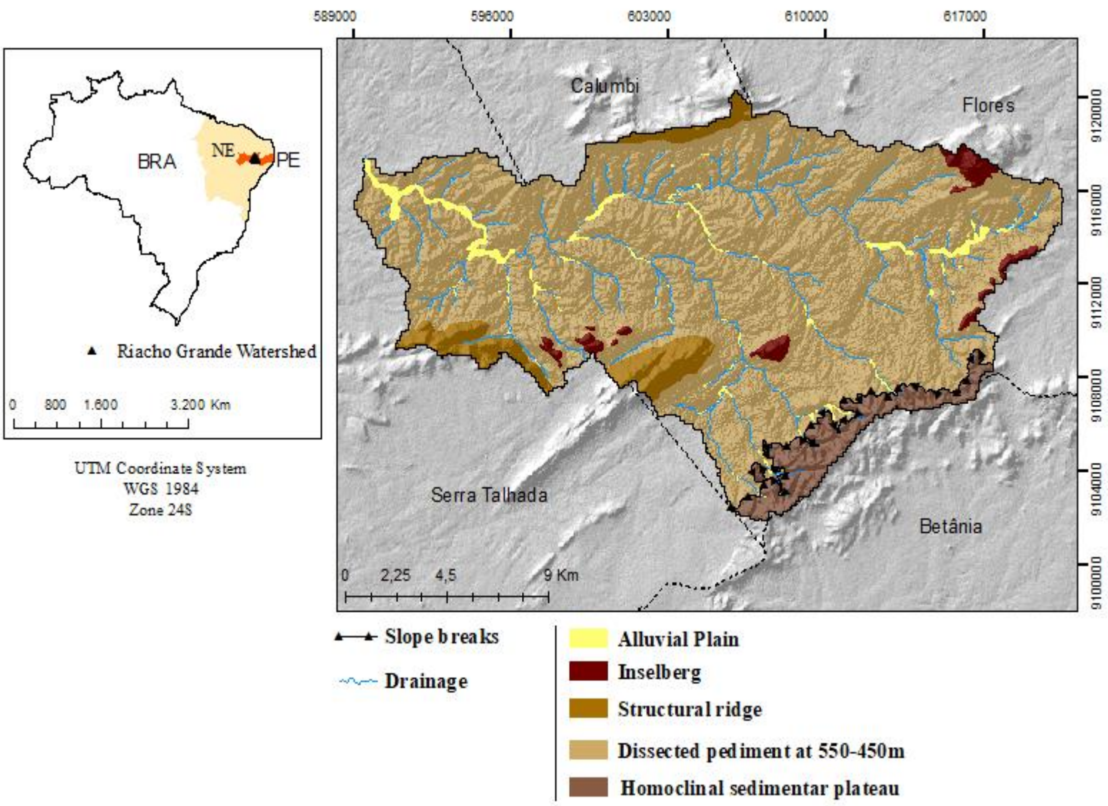

Fig. 3 – Landscape units of Riacho Grande basin

Fig. 3 – Unidades de Paisagem da bacia do Riacho Grande.

Source: Almeida *et al.* (2025)

3. FLUVIAL COMPARTIMENTS AND TYPOLOGIES

To comprehend the fluvial dynamics within a semi-arid environment, a detailed analysis of the channels in the Riacho Grande basin was conducted, employing the River Styles framework established by Brierley and Fryirs (2005). The analysis commenced with an exploration of fluvial compartmentalization, a concept that reflects the regional influences on channel morphology and highlights the prevailing surface processes within the landscape framework.

This approach categorizes the channels based on the degree of valley confinement, further subdividing them according to shared characteristics regarding the distribution of floodplain deposits along their lengths. Specifically, confined valleys are identified as those that either lack floodplains entirely or exhibit them sporadically, characterized by unilateral overflow. In contrast, partially confined valleys display discontinuous floodplains throughout the majority of their stretches. Finally, laterally unconfined valleys are distinguished by the presence of bilateral overflow deposits and the continuous development of alluvial plains.

A longitudinal profile of the main channel has been constructed (fig. 4), delineating the various river compartments within the Riacho Grande Basin. In the section of the profile up to an elevation of 530 meters, a predominantly erosive behavior is observed, which is characteristic of confined valley systems.

Conversely, downstream of this elevation, the profile becomes increasingly smoother, indicating a transition to depositional processes. This shift is reflected in the landscape through laterally unconfined valleys, which are influenced by features that disrupt sediment transfer within the channel. These disruptions may be attributed to both geological structures and anthropogenic interventions, leading to the formation of zones of sediment storage.

Between 500 and 450 meters, the river dynamics combine erosive and depositional processes. In this section, the channel is partially confined and is characterized as a sediment transfer zone. In this segment, the knickpoints record the existence of structural controls on the geometry of the channel, characterized by a sequence of rocky sills along the riverbed. Then, the profile becomes smoother again, evidencing a resumption of depositional processes close to its mouth.

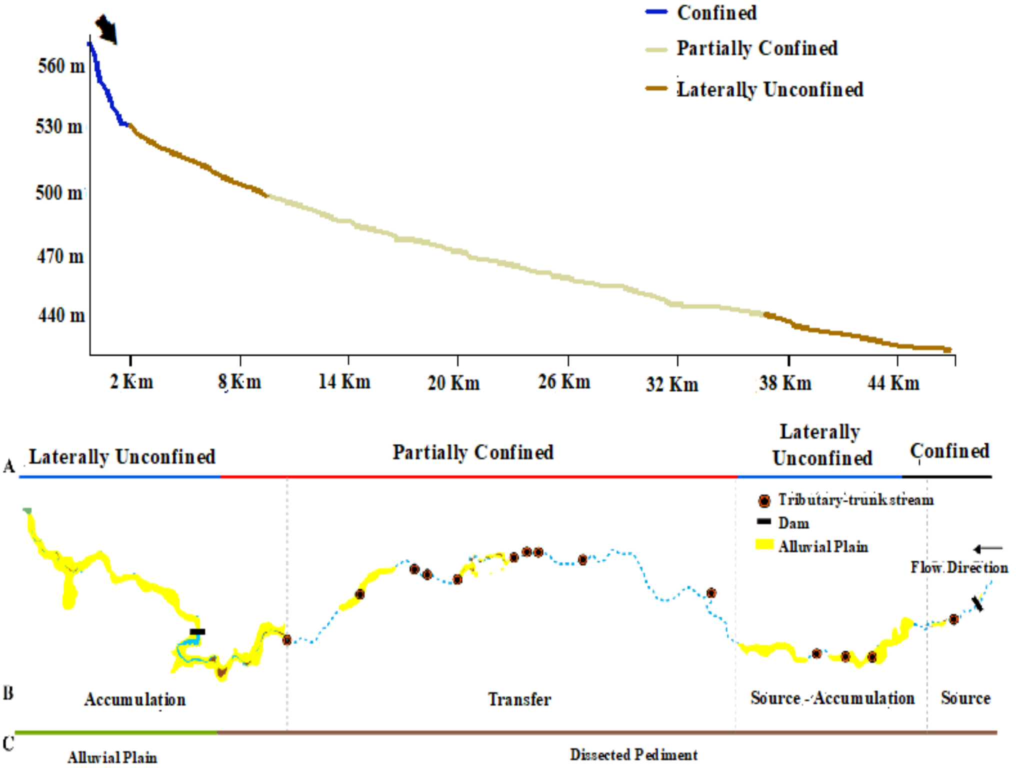

Fig. 4 – Longitudinal profile of the Riacho Grande (A). Main channel of the Riacho Grande and its compartmentalization (B).

Fig. 4 – Perfil longitudinal do Riacho Grande (A). Canal principal do Riacho Grande e a sua compartimentação (B).

Source: Authors

In order to elucidate aspects of the drainage dynamics and behavior, the channels were subdivided into segments, defining typologies that translate the landscape context in which they are inserted on a local scale. Thus, considering the landscape units, the river compartmentalization, and the local geomorphological characteristics, seven channel typologies were defined in the Riacho Grande Basin (fig. 5): rocky confined channels; rocky confined channels with discontinuous floodplains; sandy confined channels with discontinuous floodplains; low sinuosity channels with discontinuous floodplains; channeled valley with filling; filled valleys; and filled valleys in homoclinal morphostructure.

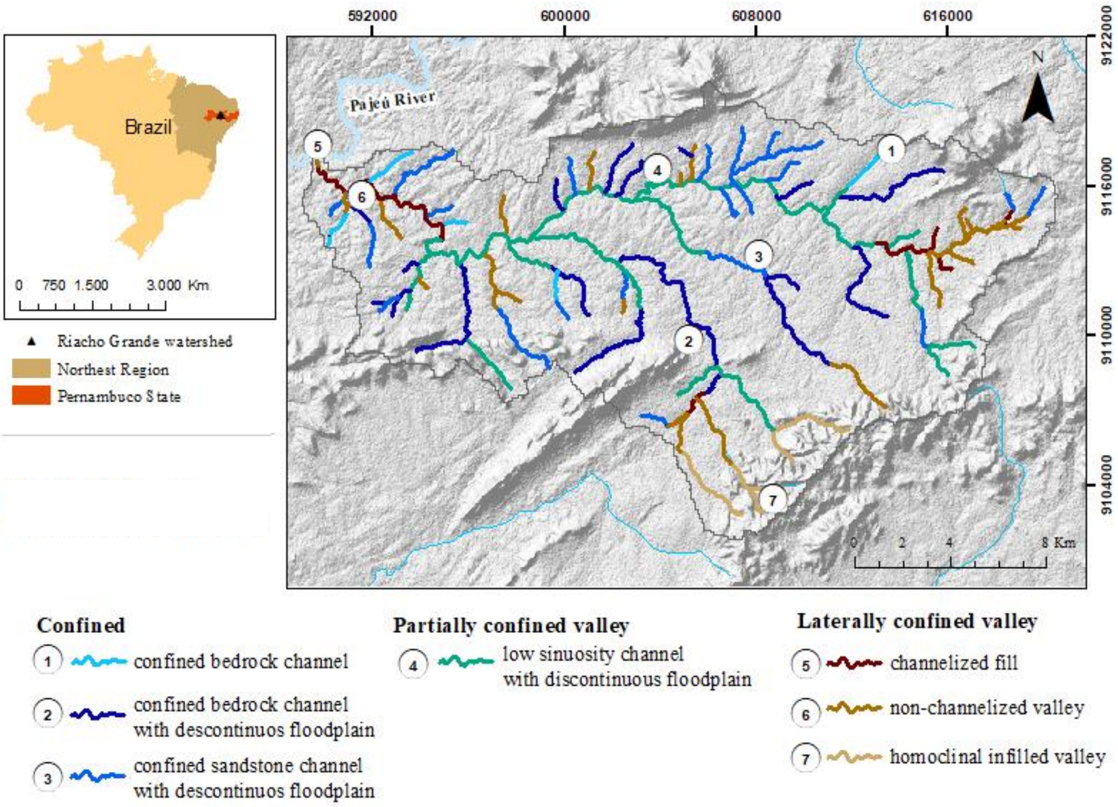

Fig. 5 – Fluvial typologies in the Riacho Grande basin.

Fig. 5 – Tipologias fluviais na bacia do Riacho Grande.

Source: Opentopography, Copernicus (2025)

3.1. Confined pattern

The confined valleys within the Riacho Grande Basin are generally devoid of floodplains, or, when present, these features are limited in both spatial extent and frequency. Lithological and structural controls, including fractures and mylonitic foliation, significantly influence the morphological characteristics of these valleys. The topography leads to the formation of single, continuous, low-order channels predominantly shaped by erosional processes. These channels exhibit low sinuosity and medium to high slopes in longitudinal and lateral profiles. Based on their distinct characteristics and behavior, these channels can be classified into three primary typologies: rocky confined channels, rocky confined channels with discontinuous floodplains, and sandy confined channels with discontinuous floodplains.

With low incidence in the Riacho Grande basin, channels of this type have stable banks and steep slopes, with direct contact between the bed and the rocky substrate (fig. 6). Erosion and transport predominate in their evolution. They are located over sediment source and transfer areas, with punctual deposition characterized by the development of small pockets of sediment retained upstream of rocky sills or at the confluence of tributaries. These deposits are subject to reworking and evacuation during high-magnitude rainfall events. The distribution of artificial dams also contributes to the genesis of these depositional features

During extended drought periods, river channels exhibit a lack of flow, which unveils the presence of gradient disruptions and a sequence of rifles and pools. Upon the resumption of flow, the ensuing torrents exhibit both high capacity and competence, serving as a source area for the downstream segments. This particular typology is characterized by minimal anthropogenic influence along its course, featuring dense shrubby caatinga vegetation. In this context, human interventions are typically localized, manifesting as the construction of rustic dams and the intersection of channels by unpaved roads.

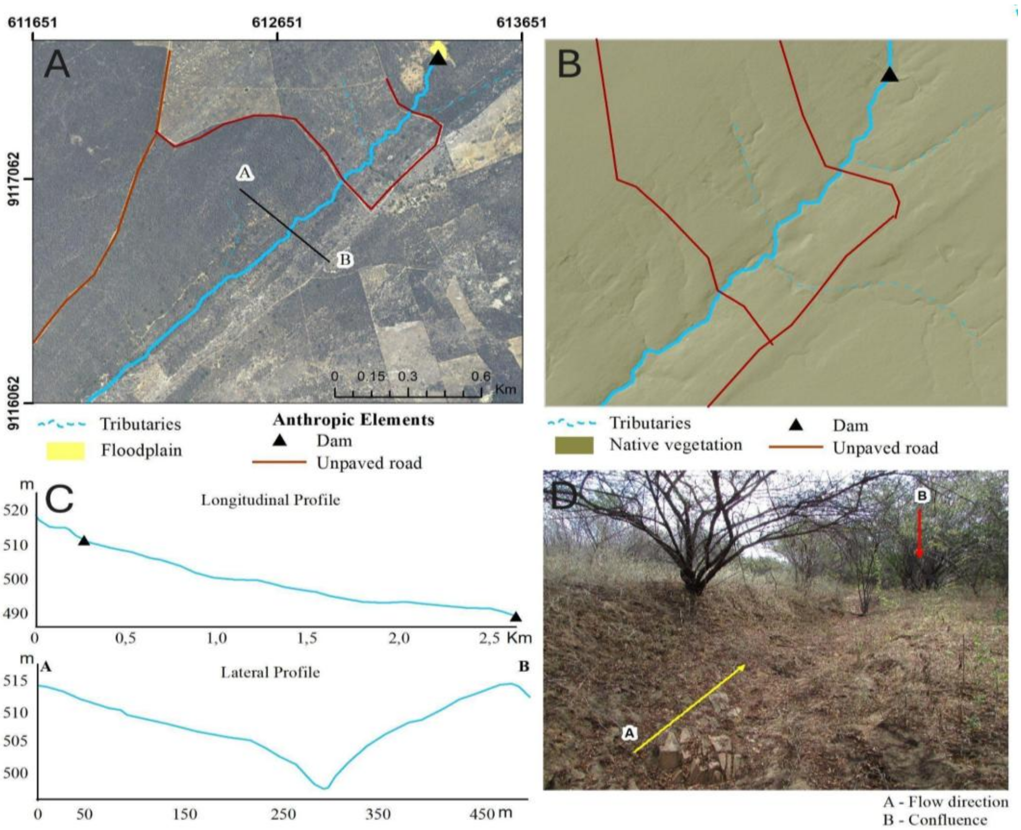

Fig. 6 – (A) Segment of a rocky confined channel, (B) land use, (C) lateral and longitudinal profiles highlighted (point 1), (D) the upper detail on the right refers to sediments trapped near the confluence, where (A) represents the flow direction and (A) the confluence.

Fig. 6 – Segmento de canal confinado rochoso, (B) uso da terra, (C) destaque para perfis longitudinal e lateral (ponto 1), (D) o detalhe superior à direita refere-se aos sedimentos aprisionados perto da confluência, onde (A) representa a direção do fluxo e (B) a confluência.

Source: Authors. Photography: Joana Almeida, 2019.

In the Riacho Grande basin, rocky confined channels with discontinuous floodplains are prominent features characterized by single, continuous channels that exhibit rocky beds, with floodplains typically confined to one side. These channels are situated in transitional zones where there is a gradient in sediment transfer capacity, ranging from high to low.

The channels are typically entrenched and possess asymmetric margins, which display varying degrees of resistance that influence their lateral adjustment. This category of confined channels is widespread throughout the Riacho Grande basin, distinguished by an average sinuosity in regions that are predominantly subject to erosion and sediment transport. In certain wider segments, occasional floodplains develop in response to episodic flash floods (fig. 7).

Among the geomorphic units in this typology, lateral bars, floodplains, and riffle-and-pool sequences predominate. Depositional processes occur through flooding on gentle convex banks, while concave and steep banks remain controlled by lithology. In planform, these channels become wider downstream, evidencing a transitional behavior towards a predominance of depositional features. These, in turn, occur as temporary accumulation zones, composed mainly of gravelly- sandy sediments, reworked during high-flow episodes.

In the Riacho Grande basin, this typology is mainly associated with the dissected pediments landscape compartment. In addition to structural controls, human interventions influence river behavior in this sector. Small rural settlements are located directly around the channels, with short- cycle crops and animal husbandry on slopes with eluvial cover. Due to the traditional agricultural activities, the presence and construction of dams and rustic reservoirs temporarily interrupt the longitudinal connection along the channels. The same occurs with the interposition of unpaved rural roads and the Transnordestina railway works, which remobilize sediments from the hillsides to the channels. During the long dry season, sediments remain trapped until the arrival of the first torrential episodes in late summer.

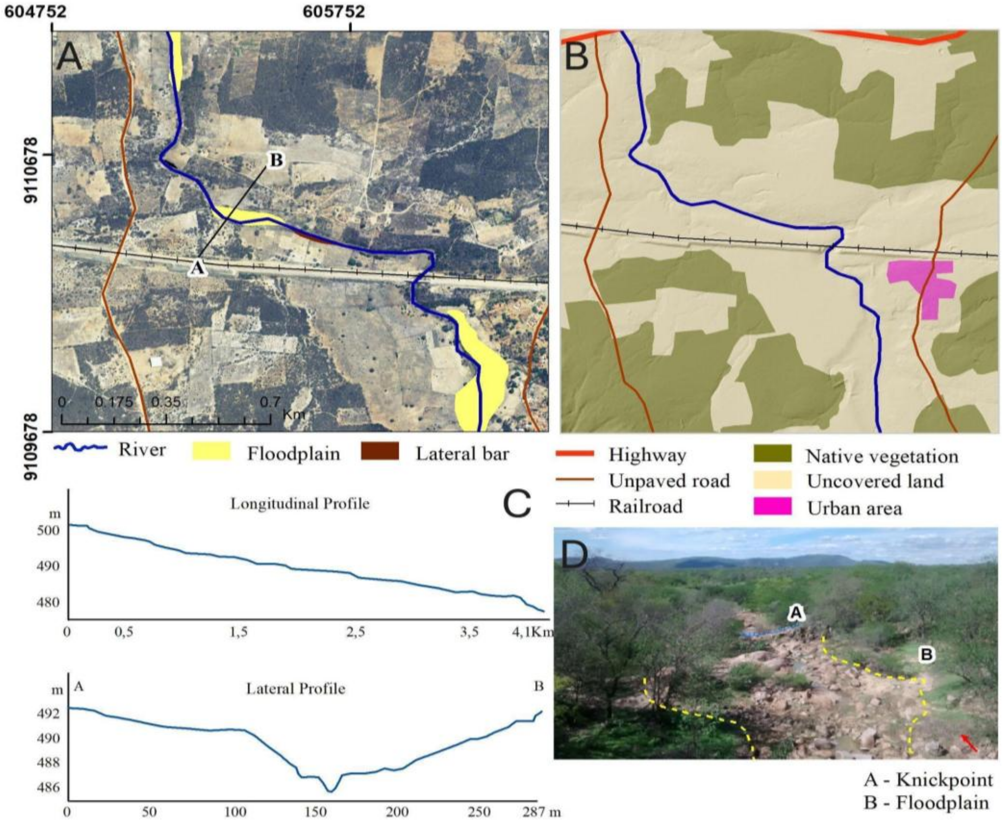

Fig. 7 – (A) Rocky confined channel with discontinuous floodplain, (B) land use, (C) longitudinal and lateral profiles highlighted (Point 2). (D) The image in the upper right corner refers to the deposition of a pocket plain in a bedrock channel, where (A) represents rupture and (B) pocket-plain sediment deposition, while the red arrow indicates flow direction.

Fig. 7 – (A) Canal rochoso confinado com planície de inundação descontínua, (B) uso da terra, (C) perfis longitudinais e laterais destacados (Ponto 2). (D) A imagem no canto superior direito refere-se à deposição de uma planície de inundação em um canal rochoso, onde (A) representa a ruptura e (B) a deposição de sedimentos na planície de inundação, enquanto a seta vermelha indica a direção do fluxo.

Source: Authors. Photography: Joana Almeida, 2014

The sandy confined channels with discontinuous floodplains represent the most prevalent subtype within the confined channels category (fig. 8). These channels are characterized by single, continuous channels, with a substrate formed by alluvial deposits that overlay the dissected surface of rocky pediments. Rocky outcrops are frequently found within the channel, contributing to the banks' structural resistance. These outcrops are linked to more resistant lithologies that influence the flow dynamics.

As a result, sediment deposition occurs upstream of these rocky formations, forming pocket plains embedded within alveoli, which are separated by segments of straight, confined channels. The banks exhibit asymmetry, characterized by the accumulation of lateral bars, shallow floodplains on one side, and steep, more resistant rocky banks on the other.

The segments under analysis stand out due to the predominance of bed incision and thalweg entrenchment over erosion processes on the banks, as observed in the cross-section profiles. The greater resistance of the banks limits the adjustment capacity and lateral migration of the channel, restricting the sediment accommodation spaces to specific sectors of the river where structural controls, such as the intersections of fractures of different directions, allow the widening of the valley (alveoli), as verified in planform through the arrangement of depositional features in sections where the channel presents inflections.

Longitudinally, these segments occur adjacent to partially confined channels, contributing as source and transfer areas for sediments during high-magnitude torrential events. Regarding land use and land cover, the sectors of the Riacho Grande basin under this typology present low levels of human intervention, except for rustic dams and unpaved roads.

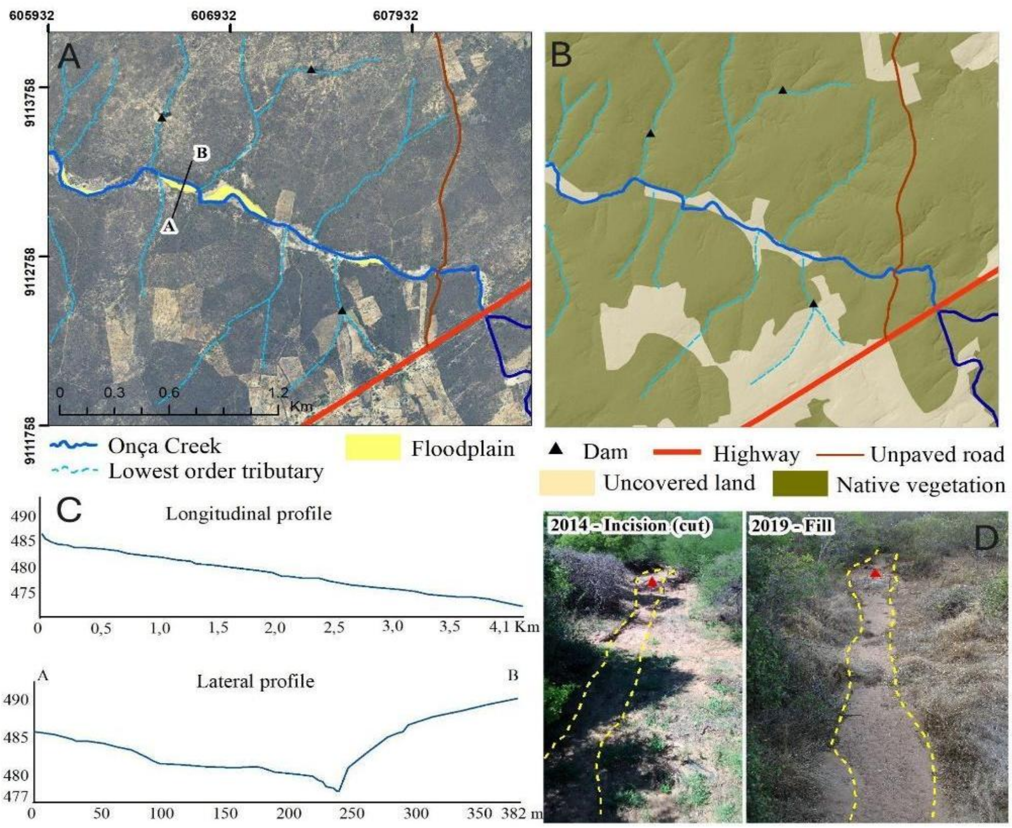

Fig. 8 – (A) Sandy confined channel with discontinuous floodplain, (B) land use, (C) highlighting longitudinal and lateral profiles (Point 3). In the below right corner, an entrenched channel in sandy bed, where (D) represents channel incision in 2014 and channel filling in 2019. The red marker indicates a rocky sill.

Fig. 8 – (A) Canal confinado arenoso com planície de inundação descontínua, (B) uso da terra, (C) destacando perfis longitudinais e laterais (Ponto 3). No canto inferior direito, um canal entrincheirado em leito arenoso, onde (D) representa a incisão do canal em 2014 e o preenchimento do canal em 2019. O marcador vermelho indica uma soleira rochosa.

Source: Authors. Photography: Joana Almeida, 2014; 2019.

3.2. Partially confined

Partially confined valleys were identified according to their character and fluvial behavior, with low sinuosity channels and discontinuous floodplains. They are commonly located downstream of confined valleys and stand out as sediment transfer zones. In general, they are quite representative in the study area, especially along the main channel of the Riacho Grande. They constitute transitional typologies characterized by a combination of erosion and depositional processes.

In specific segments, depositional dynamics dominate (fig. 9), leading to pronounced accumulation morphologies, such as point bars and floodplains. The valleys formed in this context tend to be broad and contain discontinuous channels that operate under low energy conditions, displaying reduced competence.

The deposition of silty-sandy materials prevails both in the channel bed and along the banks. This geomorphological section demonstrates a moderate to high capacity for adjustment, as lateral channel migration occurs due to erosional processes impacting the concave banks and sediment accumulation over the convex banks. Additionally, the influence of overflow deposition during flooding events further contributes to accretional physiognomies.

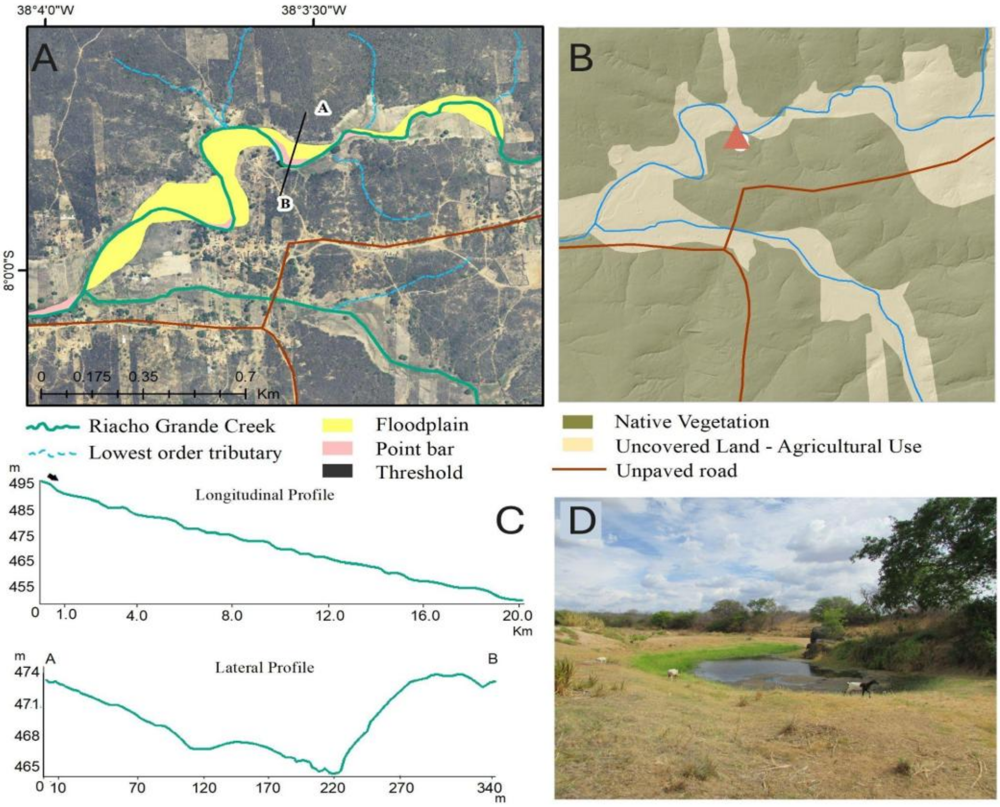

Fig. 9 – (A) Low sinuosity channel with discontinuous floodplain, (B) land use, (C) the longitudinal and lateral profiles of the section (Point 4), (D) in the upper right corner, a low sinuosity channel, where (A) represents the lateral deposition of sediments on the convex bank, with adjacent overflow, while (B) represents a pool adjacent to the rocky sill (indicated by the red marker) and a longitudinal bar downstream.

Fig. 9 – (A) Canal de baixa sinuosidade com planície de inundação descontínua, (B) uso da terra, (C) perfis longitudinal e lateral da seção (Ponto 4), (D) no canto superior direito, um canal de baixa sinuosidade, onde (A) representa a deposição lateral de sedimentos na margem convexa, com transbordamento adjacente, enquanto (B) representa uma poça adjacente à soleira rochosa (indicada pelo marcador vermelho) e uma barra longitudinal a jusante.

Source: Authors. Photography: Joana Almeida, 2015.

The upstream sectors of the laterally unconfined channels are located on hillslopes with eluvial cover, where agricultural activities intensify human interventions in sediment pockets and flat floodplain areas. Agricultural practices also contribute to sediment remobilization from the banks to the channel bed. The most representative stretch of this typology refers to the main channel of the Riacho Grande, which is especially impacted by the construction of dams for water impoundment. Human aggradational morphologies develop upstream of such dams.

3.3. Laterally unconfined

Laterally unconfined valleys are prevalent in the low-slope sectors of the Riacho Grande Basin, characterized by a predominance of aggradational forms. Channels in this typology exhibit significant capacity for both lateral and vertical adjustment, resulting in broad, shallow, and bilaterally symmetrical floodplains.

In many instances, the landscape features discontinuous incisions of single or multiple shallow channels; however, in most scenarios' channels are frequently absent. This cut-and-fill channel pattern is a defining characteristic of the alluvial river segments found in the semi-arid Northeast (Lima *et al*., 2021; Mabesoone, 1981). As a result, the fluvial landscape is dominated by unchanneled depositional sectors, particularly observed in the vicinity of confluences.

These segments have a high incidence of human interventions, mainly focused on agricultural activities, in addition to the implementation of dams for flow containment and water storage. These dams, typical of the drylands of the Northeast, influence the distribution of sediments along the channel, establishing upstream, extensive floodplains. Considering these local particularities of each planform section, the laterally unconfined valleys were subdivided into channeled-filled valleys, filled valleys, and filled valleys in homoclinal morphostructure.

The segment depicted in figure 10 pertains to Varzinha Creek, which exhibits gentle slopes and a longitudinal equilibrium profile. This indicates significant energy dissipation and highlights the prevalence of depositional processes within the creek's dynamics.

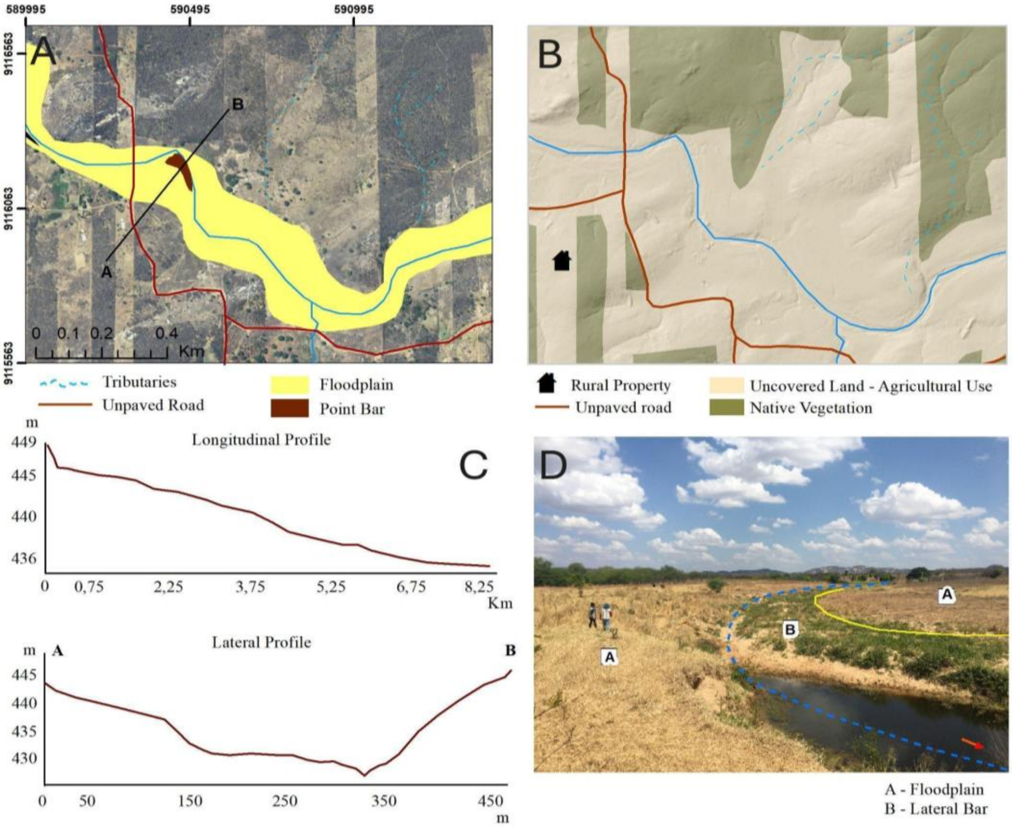

Fig. 10 – (A) Channeled filled valley, (B) land use, (C) lateral and longitudinal profiles of the section (Point 6), (D) in the upper right corner, a section of channeled filling in the Varzinha Creek, where (A) represents the Flood Plain and (B) the Sandy Lateral Bar, while the red arrow represents the flow direction.

Fig. 10 – (A) Vale preenchido canalizado, (B) uso da terra, (C) perfis lateral e longitudinal da seção (Ponto 6), (D) no canto superior direito, uma secção de preenchimento canalizado no Riacho Varzinha, onde (A) representa a Planície de Inundação e (B) a Barra Lateral Arenosa, enquanto a seta vermelha representa a direção do fluxo.

Source: Authors. Photography: Joana Almeida, 2019.

As a result, the formation of point bars and adjacent marginal dikes along the alluvial plain is evident. Point bars develop as sandy sediments accumulate on banks that flank rocky outcrops and boulders. These formations are closely associated with litho-structural controls, which are influenced by the intersection of NE-SW and NW-SE lineaments, as illustrated in figure 11.

These controls are manifest in the planform through abrupt inflections in the drainage pattern. Notably, during the dry season, certain areas within this section remain inundated, while in the rainy season, the flow reaches elevations that surpass the level of the alluvial plain, resulting in the reworking and deposition of sediments throughout the valley

This section is approximately 8.5km long, with erosive process predominating up to an elevation of 445km. This behavior is associated with the interposition of an artificial base level resulting from a dam built upstream of the segment. The difference in altitude between the base levels causes the erosive processes to recur and channel dissection to resume. As the flow progress, aggradational morphologies appear in the middle of the channel.

Fig. 11 – Point bar adjacent to a rock outcrop. A – sandy point bar.

Fig. 11 – Barra em pontal adjacente a soleira rochosa. A – barra em pontal arenosa.

Source: Authors. Photography: Joana Almeida, 2019.

The sections classified as filled valleys (fig. 12) are wide, flat, low-sinuosity, sediment-filled, and preserved alluvial valleys with no channeled flow. They are located at the valley bottoms with low lateral and longitudinal slopes, reflected in the flow's low capacity and competence, with a predominance of aggradational processes. They are configured as low-energy fluvial units, with a predominance of depositional morphologies, especially in the middle of the channel, associated with spasmodic overflow events, which, according to Brierley and Fryirs (2005), construct temporary morphologies within the bed materials.

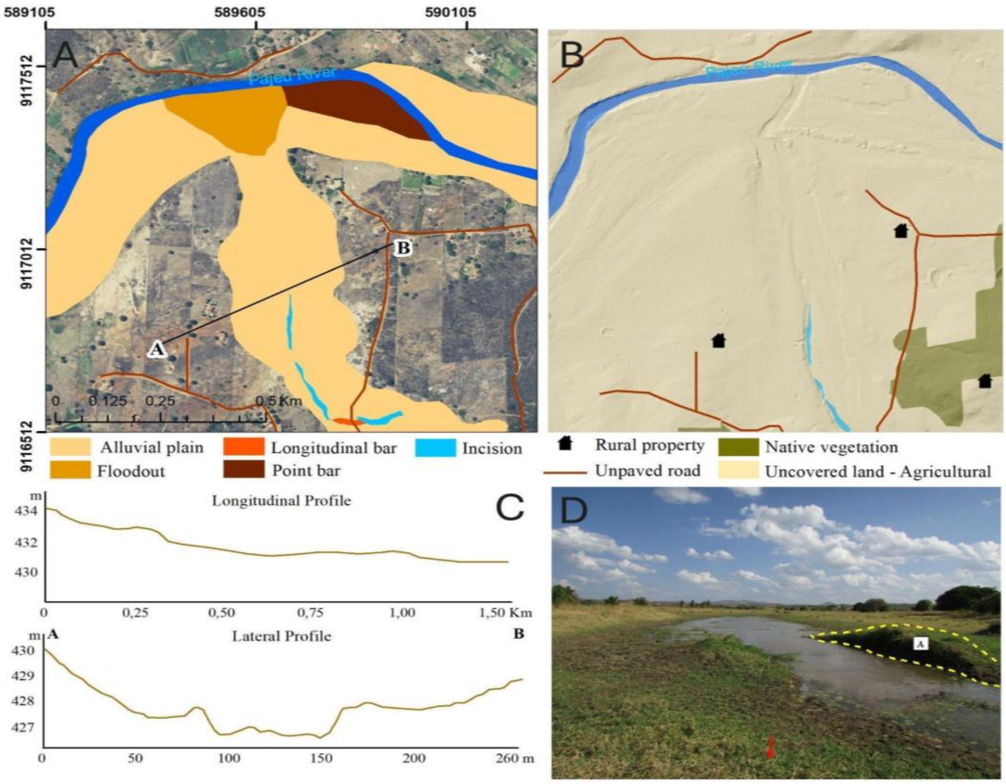

Fig. 12 – (A) Unchanneled filled valley, (B) land use, (C) longitudinal and lateral profiles of the section (Point 5). (D) In the upper right corner is a mid-channel morphology, where (A) refers to the longitudinal bar, and the red arrow indicates the flow direction.

Fig. 12 – (A) Vale preenchido não canalizado, (B) uso da terra, (C) os perfis longitudinal e lateral da seção (Ponto 5). (D) No canto superior direito, há uma morfologia do meio do canal, onde (A) se refere à barra longitudinal e a seta vermelha indica a direção do fluxo.

Source: Authors. Photography: Joana Almeida, 2019.

In this typology, discontinuous ravines and small ponds may be frequent, which are associated with low-flow stages, where the flow is limited to depressions or small incisions in the alluvial surface, with the accumulation of suspended sediments. During periods of higher flow, the valley is entirely covered by a sheet of water. At this time, sediments are remobilized and rapidly deposited as the flow energy is dissipated downstream (fig. 13), resulting in the formation of floodouts.

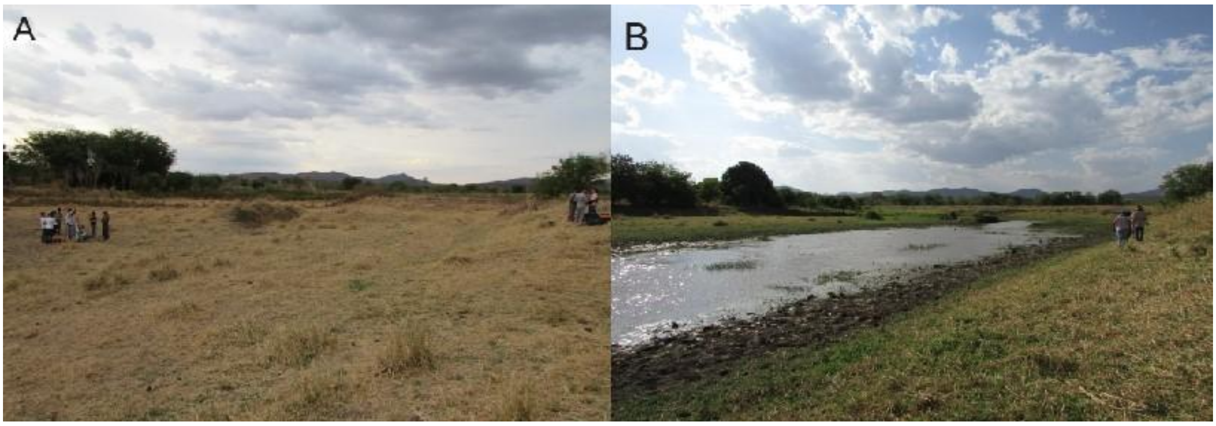

Fig. 13 – Filled valley. A – Dry period (2015). B – Following the rainny season (2019).
Fig. 13 – Vale preenchido. A – Período de seca (2015). B – Após o período chuvoso (2019).
Source: Authors. Photography: Joana Almeida. A) 2015 B) 2019.

Brierley and Fryirs (2013) define floodouts as geomorphic units that are associated with depositional sectors within flood-prone areas. These features arise from the intersection of a discontinuous channel that, influenced by changes in base level, transports sediments downstream into a valley surface that shows little to no incision. The resulting sedimentary deposits typically exhibit a fan-like morphology, primarily composed of bedload materials. However, the low gradient of the channeled flow allows for the deposition of finer materials as well, due to the dissipation of energy.

According to the authors, these sedimentary flood lobes, referred to as floodouts, distribute themselves over a relatively flat surface characterized by slightly convex edges, predominantly filling the lower elevations of the valley bottom.The filled valleys are located in different sectors of the Riacho Grande Basin, usually adjacent to partially confined sections or filled valleys with dominant structural controls.

These areas function as storage basins (sinks) for sediments from the main channel and tributaries, trapping sediments between confluences and promoting river disconnection in the channel-channel and channel-tributary relationship. In these areas, there is an intensification of human activities, both on the banks and in the middle of the channel, with the practice of agriculture, which intensifies erosion processes. Installing open wells (locally known as cacimbas) is common to take advantage of the water storage in the alluvial aquifers.

Also noteworthy in the Riacho Grande Basin are the filled valleys under the morphostructural influence of the Betânia homoclinal plateau (Corrêa *et al.*, 2024), located on the dip-slip slope of the residual landforms, here named "filled valley in homoclinal structure".

These valleys have hollow-shaped headwaters, where surface flows converge, filling the adjacent accommodation spaces with sandy sediments from the weathering of the Tacaratu Formation (Siluro-Devonian), forming extensive alluvial plains (fig. 14). This configuration is evident in the analysis of the longitudinal profile of the highlighted section, where the river presents erosive behavior above 700m under a high gradient, with the gradual smoothing of the longitudinal profile below 650m, indicating the beginning of the accumulation zone.

This typology is characterized by irregular valleys with asymmetrical cross-sectional profiles that widen downstream. Their capacity for lateral adjustment is limited due to the lithostructural controls of the silicified sandstones of the Tacaratu Formation. The alluvial plains differ from the other typologies by the abundance of gravel and coarse sand, which attest to the proximity and control of the source area (fig. 15).

Fig. 14 – Drainage headwaters (Point 7 in Fig. 5). A – Sediment storage in adjacent alluvial plain.

Fig. 14 – Cabeceiras de drenagem (Ponto 7 na Fig. 5). A – Estocagem de sedimentos em planície aluvial adjacente.

Source: Authors. Photography: Joana Almeida, 2019.

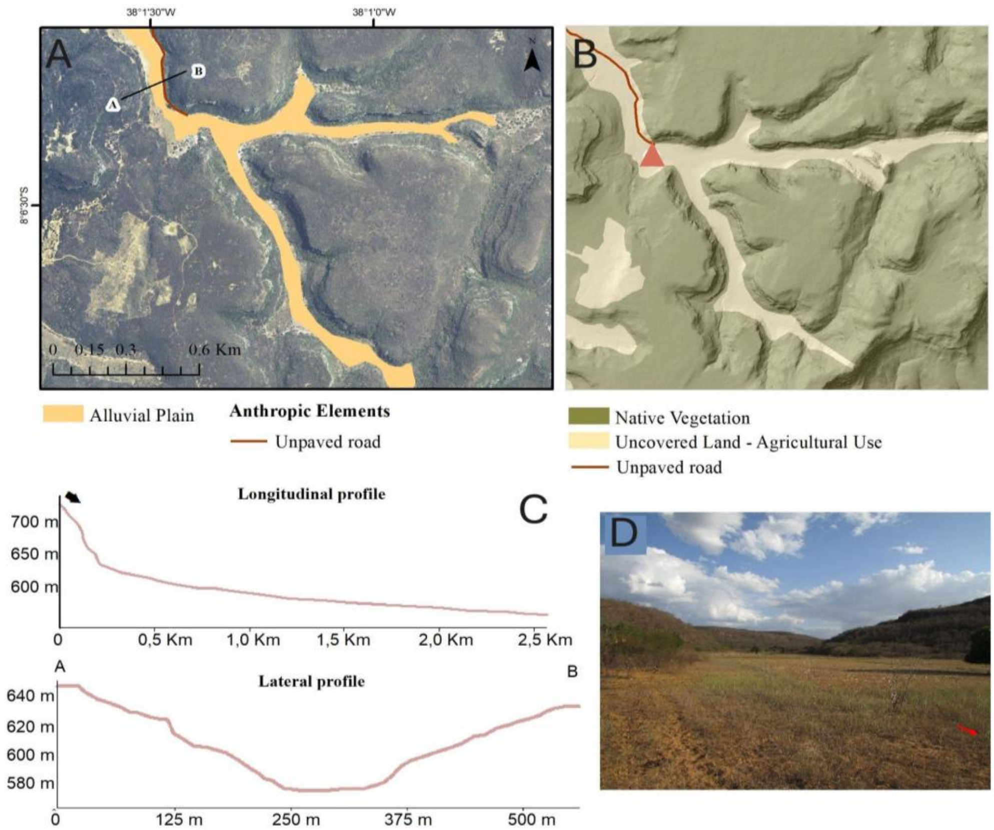

Fig. 15 – (A) Valley filled in Homoclinal Morphostructure, (B) land use, (C) the lateral and longitudinal profiles of the section (Point 7), (D) in the upper right corner, there is an alluvial plain, while the red arrow indicates the flow direction.

Fig. 15 – (A) Vale preenchido em Morfoestrutura Homoclinal, (B) uso da terra, (C) perfis lateral e longitudinal da secção (Ponto 7), (D) no canto superior direito, há uma planície aluvial, enquanto a seta vermelha indica a direção do fluxo.

Source: Authors. Photography: Joana Almeida, 2019.

These segments are characterized, in terms of land use and land cover, by the low incidence of human activities, with interventions restricted to the channel through extensive goat farming. In contrast, the hillslopes are covered by preserved shrubby caatinga. The thick layers of sand that fill the accommodation spaces of the valley bottoms concentrate most of the open wells (*cacimbas*), with depths that vary between 3 and 7 meters, helping to maintain traditional agricultural practices.

The analysis of landscape compartments and river typologies enabled us to establish a preliminary understanding of the river dynamics in the Riacho Grande Basin, resulting in an initial guide to the diversity of semi-arid river systems in Northeastern Brazil and their relationship with the surrounding landscape context. This type of morphological integration approach facilitates the interpretation of sediment production and accumulation processes in the various sectors of a basin. Table II presents a summary of the characteristics and behavior of the river typologies identified in the Riacho Grande Basin.

Table II – Fluvial Typologies in the Riacho Grande basin.
Quadro II – Tipologias Fluviais na bacia do Riacho Grande.

River Style	Characteristics				Adjustment capacity
	Channel in Planform	Geomorphic Units	Bed material	Land use	
Rocky confined	Single, straight, continuous, confined	Gravelly-sandy side bar and pocket floodplain	Rocky	Native vegetation (shrubby caatinga)	Limited. Coarse sediments remobilization during floods
Rocky confined with discontinuous floodplain	Single, continuous, low sinuosity, confined	Side bar, discontinuous pocket floodplain	Rocky	Native vegetation (shrubby caatinga), bare soil and urban aglomerate	Limited to depositional sectors
Sandy confined with discontinuous floodplain	Single, continuous, low sinuosity, confined	Sandy side bar, discontinuous pocket floodplain	Sandy	Native vegetation (shrubby caatinga), bare soil	Channel incision, limited to punctual sectors.
Low sinuosity channel with discontinuous floodplain	Single, continuous, low sinuosity, partly confined	Point bar, sequence of rocky rifles and pools, discontinuous floodplains	Sandy	Native vegetation (shrubby caatinga), bare soil	Moderate to high, overflow.
Filled channelized	Filled valley with continuous channelized flow, laterally unconfined	Continuous floodplain, point bar, marginal dyke	Sandy and silty-sandy	Native vegetation (shrubby caatinga), bare soil	High, cut and fill
Filled Valley	Filled valley, laterally unconfined	Alluvial plain, longitudinal bar, rifle and pool sequences, floodout	Silty-sandy	Native vegetation (shrubby caatinga), bare soil	High, cut and fill
Filled valley in homoclinal morphostructure	Filled unchanneled valley, laterally unconfined	Alluvial plain, side bar	Sandy	Native vegetation (shrubby caatinga), bare soil	Limited by structural controls

Source: Authors

Anthropogenic changes generate direct or indirect impacts on river configuration, altering flow interactions between slopes and the channel itself and tributaries, promoting the development of pleasant features. Thus, areas of preserved native vegetation predominate in the Riacho Grande basin. Areas under dense shrubby caatinga, located on slopes and dissected fronts with detrital cover, occupy the largest area of the basin, playing a significant role in soil stabilization against erosion.

4. FINAL CONSIDERATIONS

The recognition of regional controls affecting the physical characteristics and geomorphological processes in small river basins has led to the development of models that yield efficient and viable systemic products for environmental and territorial planning and management, particularly in the context of the complexity of landscapes in dryland regions. From this perspective, the theoretical-methodological proposal of River Styles provided the basis for the compartmentalization and definition of fluvial typologies, considering the dominant processes and associated morphologies in order to understand their evolution.

To apply the methodology, it was necessary to understand the interactions between water flow, sediments, and vegetation cover, as well as the behavior of the climate and the anthropogenic impacts that shape these interactions. Thus, the study of the fluvial configuration of a low-order ephemeral basin in the semi-arid Northeast of Brazil, the Riacho Grande basin, allowed for the identification of seven typologies, which highlighted the role of structural controls as a fundamental element in establishing the geometry of the channels and the distribution of sediment storage zones. However, the forms of land use, with a predominance of artificial dam construction, intensify the genesis of depositional alluvial features.

Thus, it was possible to determine that in the semi-arid region of Northeast Brazil, as exemplified in the Riacho Grande Basin, compartmentalization and river typologies are direct products of the interaction between primary regional landscape controls (structure and lithology) and anthropic interferences, which, acting in consortium, promote local river diversity.

In short, the application of the established typological model is of great importance, as it offers a valuable reference for the survey, classification, and evaluation of other hydrographic basins in the Brazilian semi-arid domain and for comparison with other semi-arid tropical areas, where the analysis of typologies and their evolutionary trajectory are fundamental for recognizing the functionality of aggradational environments and their sustainable management.

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