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TYPOLOGY OF FLUVIAL CHANNELS AS A MECHANISM FOR THE IDENTIFICATION OF SENSITIVITY AND POTENTIAL FOR RECOVERY IN A DRAINAGE BASIN IN THE SEMIARID OF PARAÍBA – MUNICIPALITY OF SÃO JOÃO DO TIGRE (PB)

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Abstract

The objective of this work was to establish sensitivity levels and recovery potentials for different types of channels in the 3 main rivers of the Tigre river hydrographic basin, in the municipality of São João do Tigre, a semi-arid region in Paraíba. For this purpose, the classification proposed by Rosgen (1994) was used, which at level I of analysis defines 9 general types of river channels through their location in the longitudinal profile, cross profile and plan shape of the channel. The second level of analysis proposes 94 subtypes of channels after the insertion of the analysis variables entrenchment, sinuosity, width / depth and texture of bed material. Thus, after the analysis at 6 points in the basin, it was possible to define 4 subtypes of channels and define which level of sensitivity and potential for recovery according to pre-established criteria in the methodology.

Keywords: Drainage basin; Semiarid; Channel rating.

TIPOLOGIA DE CANAIS FLUVIAIS COMO MECANISMO DE IDENTIFICAÇÃO DA SENSITIVIDADE E POTENCIAL DE RECUPERAÇÃO EM UMA BACIA DE DRENAGEM NO SEMIÁRIDO PARAIBANO – MUNICÍPIO DE SÃO JOÃO DO TIGRE (PB)

Resumo

O objetivo deste trabalho foi estabelecer níveis de sensitividade e potenciais de recuperação para diferentes tipos de canais nos 3 principais rios da bacia hidrográfica do rio do Tigre, no Município de São João do Tigre, semiárido paraibano. Para tal, foi utilizada a classificação proposta por Rosgen (1994), que no nível I de análise define 9 tipos gerais de canais fluviais através da localização no perfil longitudinal, perfil transversal e forma em planta do canal. O segundo nível de análise propõe 94 subtipos de canais após a inserção das variáveis de análise entrincheiramento, sinuosidade, largura/profundidade e textura de material de leito. Sendo assim, após a análise em 6 pontos na bacia, foi possível definir 4 subtipos de canais e definir qual nível de sensitividade e potencial de recuperação de acordo com critérios pré-estabelecidos na metodologia.

Palavras-chave: Bacia de drenagem; Semiárido; Classificação de canais.

TIPOLOGÍA DE CANALES DE RÍO COMO MECANISMO DE IDENTIFICACIÓN DE SENSIBILIDAD Y POTENCIAL DE RECUPERACIÓN EN UNA CUENCA DE DRENAJE EN LA SEMIÁRIDA DE PARAÍBA - MUNICIPIO DE SÃO JOÃO DO TIGRE (PB)

Resumen

El objetivo de este trabajo fue establecer niveles de sensibilidad y potenciales de recuperación para diferentes tipos de canales en los 3 ríos principales de la cuenca hidrográfica del río Tigre, en el municipio de São João do Tigre, una región semiárida de Paraíba. Para ello se utilizó la clasificación propuesta por Rosgen (1994), que en el nivel I de análisis define 9 tipos generales de cauces fluviales a través de su ubicación en el perfil longitudinal, perfil transversal y forma en planta del cauce. El segundo nivel de análisis propone 94 subtipos de canales luego de la inserción de las variables de análisis atrincheramiento, sinuosidad, ancho / profundidad y textura del material del lecho. Así, luego del análisis en 6 puntos de la cuenca, fue posible definir 4 subtipos de canales y definir qué nivel de sensibilidad y potencial de recuperación según criterios preestablecidos en la metodología.

Palabras-clave: Cuenca de drenaje; Semi árido; Clasificación de canales.

1. INTRODUCTION

Searches for understanding river systems through scientific investigations can occur through the ordering or classification of river channels (ROSGEN, 1994), in view of the search for stretches that present homogeneous river morphology and processes, which depend on interrelated variables , which can be easily identified from zoning, such as: relief, geology, soil, climate, vegetation, anthropic interventions, among others.

Classifications of river channels can be defined as an ordering or organization of elements in sets or groups according to their relationship and similarity (ROSGEN, 1994). In fluvial geomorphology, classifications of river types aim to reduce complex units of study into discrete units, that is, that facilitate understanding (FERNANDEZ, 2016). The ideal is that the classification is within a systemic perspective, and can be understood as a complex of variables in interaction (VICENTE; PEREZ FILHO, 2003).

Fluvial classification models have existed since the middle of the 20th century (CUNHA and GUERRA, 1998), and Rosgen (1994), in an analysis of 450 rivers in 5 different countries, states that a classification of channels is an organization of data on the characteristics of the channel , the fluvial classification system being a goal for individuals who work with rivers, serving to understand their processes that have a high degree of complexity over a set of interrelated variables that determine the morphology (dimension, pattern and profile) of a channel. This morphology is directly influenced by eight important variables, which are: width, depth, speed, flow, slope, roughness, sediment load and sediment size. A change in any of the variables causes a series of adjustments to the channel, changing its pattern.

In a more recent classification, Brierley and Fryirs (2000), claim that historically the differentiation of river types has been based on the plan shape of the channel, and this perspective minimizes the importance of morphological relationships and types of floodplain. Thus, they use four interconnected scales in their classification: river basins, landscape units, river fluvial styles and geomorphic units. This approach effectively dissects a basin, characterizing river styles for different landscape units, and these units comprise characteristic formation patterns and are differentiated based on physiographic configuration.

However, commonly the fluvial classifications are generated for environments with perennial channels of humid environments and only later applied and / or adapted in channels of semiarid regions, where the functioning of the water and fluvial systems are completely different, as is the example of work carried out by Souza, (2014) who adapted the nomenclature proposed in the fluvial styles methodology, emphasizing the different morphologies and functional characteristics of the semiarid fluvial system. In the same perspective, Maia (2016) found it necessary to adapt to the semi-arid zone due to differences in flows and recurrences of ephemeral and intermittent flows.

Bearing in mind that the normal behavior of semi-arid river channels is when they are dry (SOUZA and ALMEIDA, 2015), rivers in the semi-arid region are irregular and their flows disappear during the dry season, presenting a characteristic of intermittent or ephemeral character. The intermittent channel only flows during the rainy season. Ephemeral channels provide short-term runoff that varies from hours to a few days during or shortly after the rain event, causing discontinuity (SUTFIN, 2014).

It is important to emphasize that understanding how surface processes behave through changes in energy inputs is vitally important to think about models about the evolution of the geomorphological landscape. With that, the sensitivity study of natural environments was used in order to understand environmental changes, as well as superficial impacts on natural systems. It is essential to understand the possibilities of change in the landscape and to identify the areas that would respond more easily to changes in forces or resistance (BRUNSDEN, 2001).

The objective of this work is to identify the recovery potentials for different levels of sensitivity in different types of fluvial channels in the Tigre river basin, semi-arid region of Paraíba.

2. METHODOLOGY

2.1. Characterization of the Area

The three main channels of a semi-arid hydrographic basin in the municipality of São João do Tigre - PB were evaluated, more precisely in the cariri of Paraíba, bordering the states PB / PE (Figure 1), based on the theoretical-methodological proposal for analysis of river classification by Rosgen (1994).

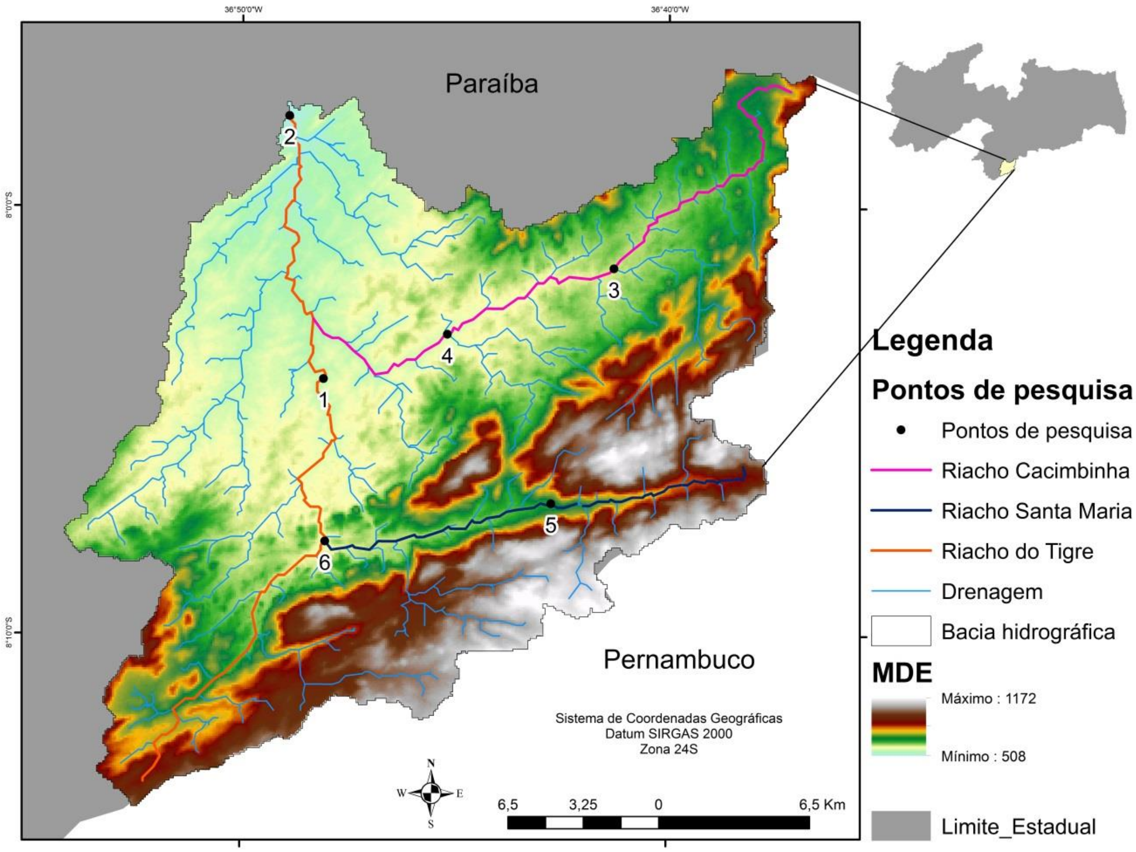

Figure 1 - Location map of the Tigre river watershed. Source: Prepared by the authors (2016).

The basin's geology is totally crystalline, considering that the basin is inserted on the Borborema Plateau, and can be understood as a collisional band involving amalgamation and accretion of microplates and consolidated lands at the end of the Brasilian event in the upper tertiary, or that is, a meso / neoproterozoic orogenic belt that extends over much of the Brazilian Northeast (CAMPELO, 1999). The highest parts of the basin are located to the southeast, showing the drainage headwaters of the Santa Maria River. The Tigre River has steep headwaters, however, most of its course is located between medium and low topographies of the basin. The Cacimbinha River does not exceed 750 m in altitude at the head, distinguishing it from the other main channels as it flows almost entirely over a lower, flattened surface.

2.2. Methodological procedures

For Rosgen (1994), width, depth, slope and size of the sediments are variables that can be used as a classification criterion, that is, the organization of the analysis variables allows to reach different levels of detail appropriate for the classification. Therefore, the first level is to describe the characteristics of the fluvial environment from the channel's morphology and provide a characterization that integrates the relief and the fluvial processes, for this, remote sensing and geoprocessing tools will be used that will allow the interpretation of the surface of the basin .

In general, level I is concerned with geomorphic characterization, while level II refers to a morphological description (Figure 2).

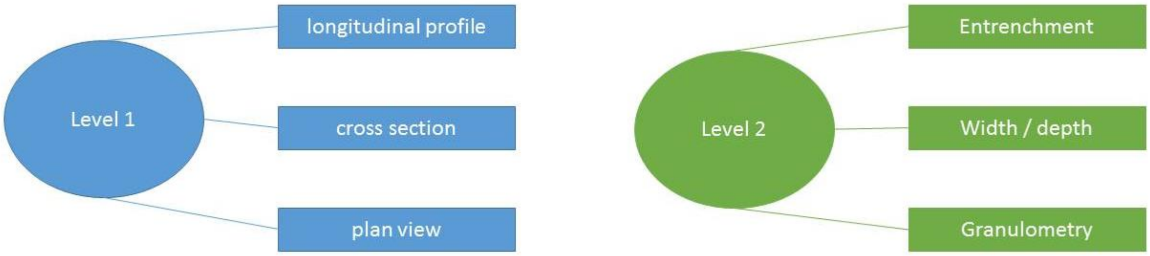

Figure 2 - Steps of the methodological proposal. Source: Adapted from Rosgen (1994).

Level I provides the classification in up to 9 types of channel flows that can be defined through longitudinal profiles, cross sections of the valley and plan view (Figure 3).

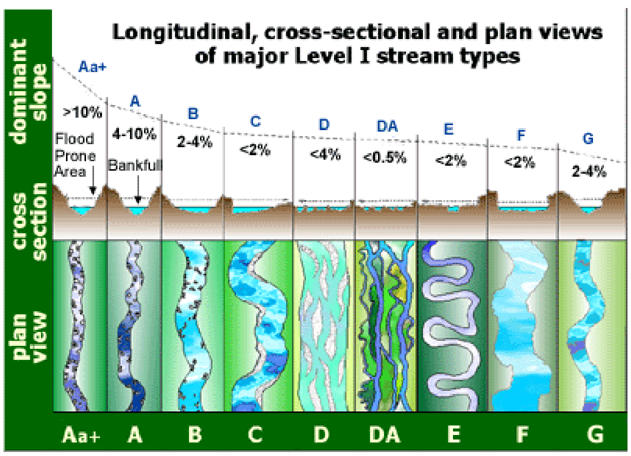

Figure 3 - Parameters used to classify channels at level I: Declivity in the longitudinal profile; Transversal section; Plan shape. Source: Rosgen (1994).

The longitudinal profile will be generated from topography information, which in turn was generated from SRTM images with a resolution of 30 m obtained from USGS (American Geological Service). Thus, the extraction of topographic information from the river course is done in a GIS environment (ArcMap 10.5) and processed in Excel. This parameter will indicate the slope of the flow and define whether the channel is steep (above 4%) or flat (below 4%). The morphology of the bed can be predicted from the type of flow, using bed slope indexes (ROSGEN, 1994).

The cross section indicated that the flows are narrow and deep or wide and shallow, as well as functioning as an index to identify the geomorphic units in the channel, such as bars, islands, plains and river terraces. Thus, the cross section was made using a total station, which served to measure the extension and topography from one margin to the other, which allowed to show the asymmetries of the relief of the river beds.

The plan view serves as a tool to classify sinuosity and thus provide interpretations of its morphology. Regarding the measurement of the degree of sinuosity, there is no unanimity to classify it in a channel. In this work, the classification proposal proposed by Christofoletti (1980) was used, which indicates that a channel has low, medium and high sinuosity, where this measurement was made by the extension of the channel divided by the length of the valley, that is, values < 1.2 are of low sinuosity; > 1.2 are moderate; > 1.4 are high and> 1.5 is very high. This measurement of extensions was made from satellite images available on Google Earth.

Level II deals with the relationship between the types of channel with their gradient and size of the dominant sedimentary particles, degree of entrenchment and width / depth ratio, in view of the search for subtypes of river channels. In this perspective, the degree of entrenchment is defined as the level of vertical incision of a river made at the bottom of the valley (ROSGEN, 1994). When entering the level II analysis variables, the Rosgen classification starts from 9 general types for 94 subtypes, as seen in Figure 4.

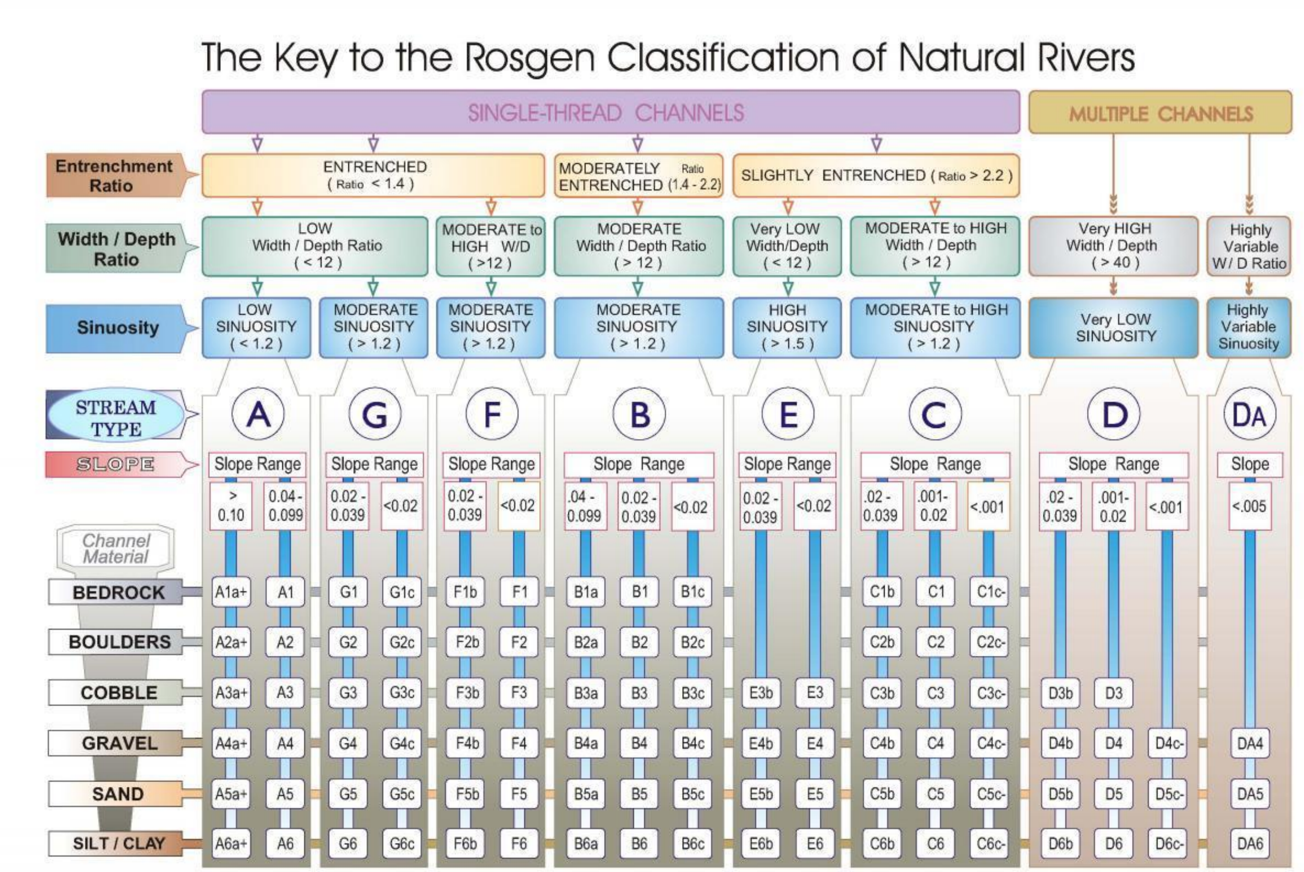

Figure 3 - Classification key at level II. Source: Rosgen, 1994.

To measure the degree of incision of the channel, just observe the relationship between the width of the channel with the usual flow divided by the maximum width of the river environment that can be reached by a flood. This calculation is important to identify the geomorphic unit to the side of the channel, whether it is a plain, terrace or an area that is not susceptible to flooding (bordering valley). The area susceptible to flooding is defined as the average width at an altitude that is determined at twice the maximum flood depth. Thus, values between 1-1.4 represent entrenched flows; 1.41-2.2 have moderately entrenched flows; radii greater than 2.2 are slightly entrenched.

The granulometry was made from the collection of sediments in the river beds and analyzed in the laboratory, where 5 classes were used: Rocky bed; Rock (> 256 mm); Gravel (2 - 256 mm); Sand (0.0625 - 2 mm); Silt and Clay (<0.0625 mm). Finally, after defining the subtypes, it was possible to identify the sensitivity to disturbances and the potential for recovery according to the parameters established in figure 5.

The width / depth ratio was made from the measurement of the flow surface width divided by the depth measurement, knowing that this result is useful during a short temporality due to the intermittent behavior of the channels. As a result, the low ratio values are those less than 12; Values greater than 12 are moderate or high and the average values are the transition between them presented in the summaries of the types of flows.

Management interpretations of various stream types

Stream type	Sensitivity to disturbance [a]	Recovery potential [b]	Sediment supply [c]
A1	very low	excellent	very low
A2	very low	excellent	very low
A3	very high	very poor	very high
A4	extreme	very poor	very high
A5	extreme	very poor	very high
A6	high	poor	high
B1	very low	excellent	very low
B2	very low	excellent	very low
B3	low	excellent	low
B4	moderate	excellent	moderate
B5	moderate	excellent	moderate
B6	moderate	excellent	moderate
C1	low	very good	very low
C2	low	very good	low
C3	moderate	good	moderate
C4	very high	good	high
C5	very high	fair	very high
C6	very high	good	high
D3	very high	poor	very high
D4	very high	poor	very high
D5	very high	poor	very high
D6	high	poor	high
DA4	moderate	good	very low
DA5	moderate	good	low
DA6	moderate	good	very low
E3	high	good	low
E4	very high	good	moderate
E5	very high	good	moderate
E6	very high	good	low
F1	low	fair	low
F2	low	fair	moderate
F3	moderate	poor	very high
F4	extreme	poor	very high
F5	very high	poor	very high
F6	very high	fair	high
G1	low	good	low
G2	moderate	fair	moderate
G3	very high	poor	very high
G4	extreme	very poor	very high
G5	extreme	very poor	very high
G6	very high	poor	high

Figure 5 - Possibilities for sensitivity and recovery of channels according to the sub-types of rivers. Source: Rosgen (1994).

3. RESULTS ANS DISCUSSION

Considering that the level I of detail of the proposed classification of Rosgen (1994) starts from three parameters: slope in the longitudinal profile, transversal profile and plan shape, analyzes were made in the three main channels of the Tigre river hydrographic basin (PB), that is, Tigre river, Cacimbinha and Santa Maria. First, the selected sections were delimited to generate the longitudinal profile of each section. In this perspective, two points in each river were analyzed. Thus, points 1 and 2 were performed on the Tigre river, 3 and 4 were analyzed on the Cacimbinha river and points 5 and 6 were analyzed on the Santa Maria river (Figure 6). Later, the lateral profiles were generated and demonstrate the variability of fluvial relief in each analyzed point (Figure 7). The plan shape indicates the sinuosity that each point has according to the relationship between the valley extension and the thalweg extension (Figure 8). Thus, from these three variables, it was possible to define the types of river channels (Table 1).

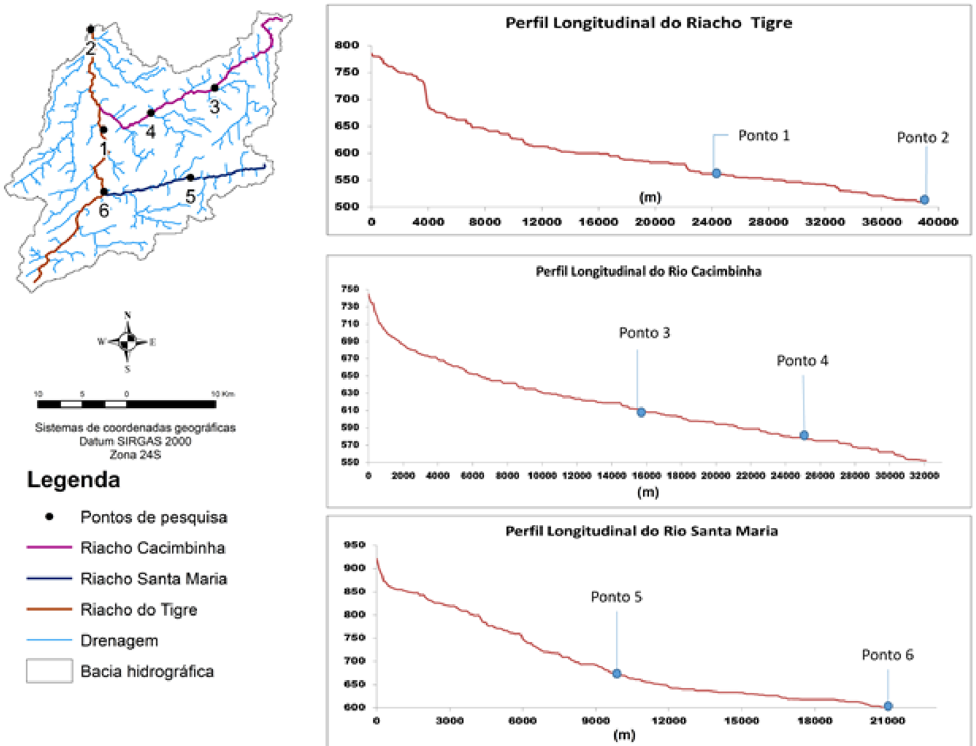

Figure 6 - Location of points in longitudinal profiles. Elaboration: authors (2018).

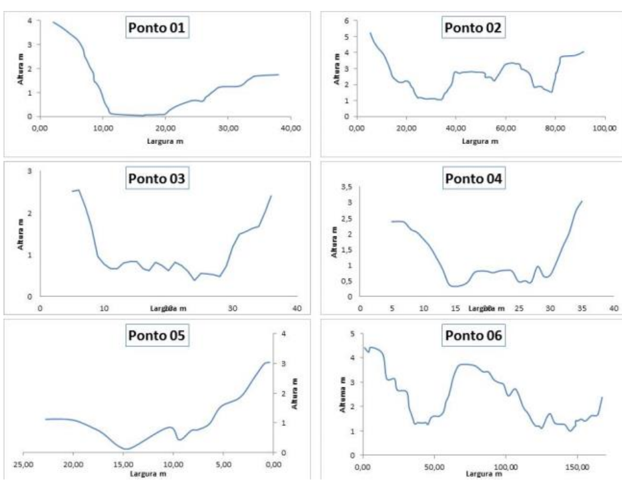

Figure 4 - Side profiles of the analyzed points. Elaboration: authors (2018).

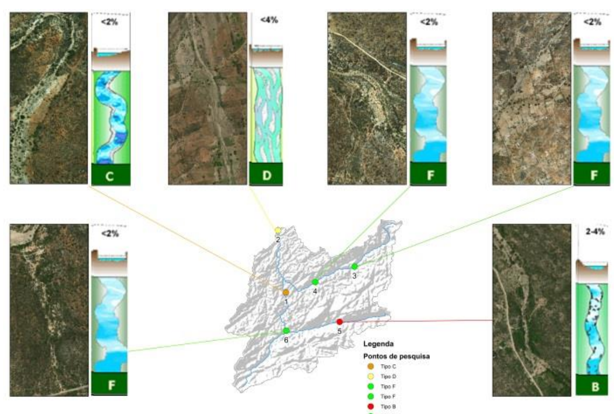

Figure 5 - Plan view and definition of channel types. Elaboration: authors (2018).

Table 1 - Main types of channels according to the level 1 proposal.

STEP	DESCRITION	Type of flow associated with level I of detail
Step 1	It has an asymmetric valley 30 m wide and 1.5 m deep, with a single channel and floodplain on one of the banks and low gradient valleys, with less than 2%.	Type C.
Step 2	It has an asymmetric valley of 77 m wide and 2.5 m deep. It has multiple channels, bars and islands in the fluvial environment with a slope of less than 4%.	Type D.
Step 3	Symmetrical valley 30 m wide and 2 m deep. It has a single channel, with well-defined margins and small longitudinal bars in the bed. The slope in this section is less than 2%.	Type F.
Step 4	Symmetrical valley 30 m wide and 2 m deep. It has, has a single channel with well-defined margins and small longitudinal bars in the bed. The slope in this section is less than 2%.	Type F.
Step 5	Asymmetrical valley 22 m wide and 1 m deep. It has multiple channels, floodplain on one of the banks and is under a slope between 2 and 4%.	Type B.
Step 6	Asymmetric valley 60 m wide and 1 m deep. It has a single channel with well-defined margins and small longitudinal bars on the bed. The slope in this section is less than 2%.	Type F.

According to Rosgen (1994), flow types C are located in narrow valleys and suffer the effects of fluvial deposition, as seen in the floodplain formed on the right side of the point 1 margin, being relatively sinuous with a slope below 2 %. Flow type D occurs at point 2 and is configured exclusively as a multiple channel system, exhibiting a braided pattern from the geomorphic units existing in the river environment. This type of flow, even though it presents depositional processes generating bars and islands, and valleys with little incision, has confinement on the margins. Flow type F occurs at points 3, 4 and 6. They are entrenched and sinuous channels, and it can be seen that they are relatively incised channels, in relatively low or flat relief. This type of flow, even if it is located in flat areas, has an erosive capacity to widen its margins and deepen its thalweg, abandoning the old floodplains that consequently generate the river's terraces in the basin. Level II allows a greater understanding of each type, breaking them down into subtypes (Table 2).

Table 2 - Main characteristics of the subtypes defined in level 2

STEP	Description	Entrenchment	Width/depth	Sinuosity	Declivity (%)	Bed material	Type	Sub-type
Step 1	It has an asymmetric valley 30 m wide and 1.5 m deep, with a floodplain on one of the banks and low gradient valleys, with less than 2%.	1	> 12	>1,2	0,02	Sand	Type C.	C5
Step 2	It has an asymmetric valley of 77 m wide and 2.5 m deep. It has bars and islands in the fluvial environment with declivity less than 4%.	1,3	>12	<1,2	0,01	Sand	Type D.	D5
Step 3	Symmetrical valley 30 m wide and 2 m deep. It has well-defined margins and small longitudinal bars on the bed. The slope in this section is less than 2%.	1	>12	>1,2	0,13	Sand	Type F.	F5b
Step 4	Symmetrical valley 30 m wide and 2 m deep. It has well-defined margins and small longitudinal bars on the bed. The slope in this section is less than 2%.	1,8	>12	<1,2	0,04	Sand	Type F.	F5b
Step 5	Asymmetrical valley 22 m wide and 1 m deep. It has a floodplain on one of the banks and is under a slope between 2 and 4%.	---	<40	>1,2	0,25	Gravel	Type B.	B4a
Step 6	Asymmetric valley 60 m wide and 1 m deep. It has well-defined margins and small longitudinal bars on the bed. The slope in this section is less than 2%.	---	<40	<1,2	0,06	Sand	Type F.	F5b

According to the sensitivity and recovery potential parameters stipulated by subtype of Figure 5, point 1 was characterized as subtype C5, which according to the sensitivity parameters, indicates that the stretch presents high sensitivity to changes and reasonable recovery potential. In contrast, point 2, characterized as subtype D5, also presents high sensitivity to changes, but low potential for recovery. Points 3, 4 and 6 were characterized as subtypes F5b and defined as sections with high sensitivity to changes and poor recovery potential. Point 5, called subtype B4a, has moderate sensitivity and excellent recovery potential. As for the supply of sediments per stretch, Figure 5 indicates that only point 5 (Subtype B4a) has a moderate supply, while all other points theoretically have very high sediment supply (Figure 9).

In general, according to the parameters proposed by Rosgen (1994), only points 1 (Subtype C5) and 5 (Subtype B4a) have greater recovery capacity if there is a change in the landscape, considering that both are prone to change. Conversely, points 2 (subtype D5), 3 (subtype F5b), 4 (subtype F5b) and 6 (subtype F5b) show great propensity to change, but low capacity for natural recovery, showing a greater need for preservation in these stretches.

In relation to bed materials, the basin shows evidence of sandy bed in all stretches, except for point 5 (Subtype B4a), where the diversity of subtypes of river channels provides the landscape with heterogeneity (Figure 9), which arouses the interest in understanding the complexity of river processes and forms, especially in the semiarid region, where studies in river geomorphology are still a challenge for those who decide to do research in the dry perimeter.

In Brazil, classifications applied from the perspective of Rosgen (1994) were developed, as is the case of Fernandez (2016) who, by applying the classification in streams in the western region of the State of Paraná, managed to identify two predominant subtypes of flows that were cataloged as E and G, which can be described as meandering and interlaced channels respectively, occurring in areas mostly flattened and the deposition process predominating. Estiliano (2006), on the other hand, applying the Rosgen classification to the Paraíba do Sul river (SP) managed to identify that the channels called B and C were typically plateau rivers, with high erosive power and sediment transport.

In this research, stretches B and C were categorized as B4a and C5, which indicates that only B4a has an erosive and sediment transport capacity, thanks to the greater slope and rock characteristics in the bed. No studies were found using the Rosgen classification in Brazil that identified the F5b subtype.

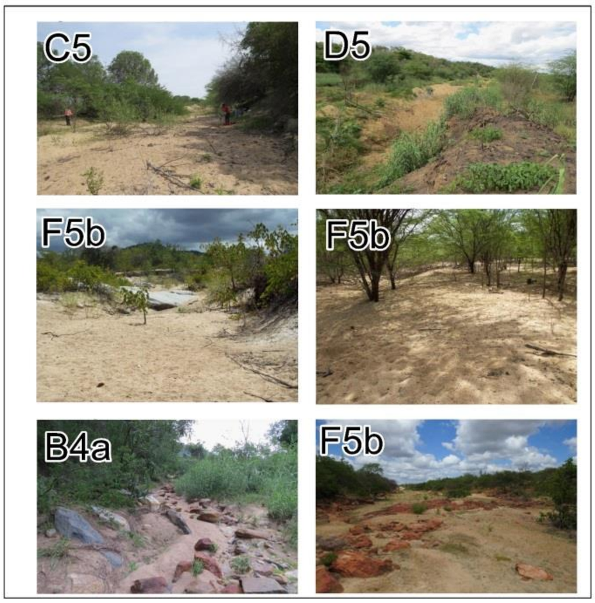

Figure 6 - River landscapes according to the typology of the points analyzed, showing the sandy texture in all sections, except for Subtype B4a. Elaboration: Author (2019).

Thus, the classification of flows provides a means of understanding the diversity and distribution of channels and floodplains that occur in a landscape (Brierley and Friyrs, 2000), identifying the links between geomorphic form and the process. Consequently, the flow classification is frequently used as a planning, management and restoration tool for watersheds, and according to Souza (2015), the identification of sensitivity allows to interpret and infer future scenarios, through the disturbance / resistance relationship. In effect, the sensitivity approach in fluvial systems allows the assessment of channel behavior through active processes, responses / changes and future trajectories. However, the sensitivity assessment proposed by Rosgen is premeditated in established parameters, that is, without directly relating how much would be necessary in an event of magnitude to generate changes in the landscape. Thus, its classification shows rates of change and river recovery.

4. CONSIDERATIONS

River classification provides a means to understand the dynamics and patterns of rivers around the world. In the Brazilian semiarid, this is no different, given that it is necessary to observe the procedural issues inherent in dry lands. The Tigre stream basin presented a variety of river types according to the application of level I of the theoretical methodological proposal of Rosgen (1994), showing different processes and forms that are mainly related to issues such as declivity, sinuosity and characteristics of the valley.

After defining the types of river, 4 channel subtypes were identified, considering issues such as entrenchment, width / depth ratio and granulometry of the bed material. These subtypes showed different levels of resistance and propensity to change, where subtypes D5 and F5b showed the greatest propensity to fluvial modification, and therefore should be preserved.

It is important to highlight that the indicative of sensitivity and recovery potential proposed by Rosgen (1994) is a closed approach, where rivers must be classified in the types and subtypes presented by the referred author. However, there is the possibility of subtypes and even types of rivers that were not proposed by Rosgen in his theoretical methodological proposal, considering that the study of dryland rivers is still a theme that has a wide field of research to be investigated, mainly within the perspective of the evolution of rivers in dry lands, as is the case of the Brazilian semiarid region.

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