https://rbgeomorfologia.org.br/
ISSN 2236-5664

Revista Brasileira de Geomorfologia

v. 26, nº 4 (2025)

https://dx.doi.org/10.20502/rbg.v26i4.2679

Research Paper

Large-Scale Segmentation of the Paraguay River Based on Morphological and Hydro-Sedimentary Criteria

Segmentação em Grande Escala do Rio Paraguai com Base em Critérios Morfológicos e Hidrossedimentares

Edson Rodrigo dos Santos da Silva [1], Aguinaldo Silva [2], Hudson de Azevedo Macedo [3], Sidney Kuerten [4], and Leandro Domingos-Luz [5]

[1] Federal University of Mato Grosso do Sul (UFMS), Post-Graduation Program in Geography, Três Lagoas, Brasil. E-mail: edson.r.silva@ufms.br
ORCID: https://orcid.org/0000-0001-6655-5269

[2] Federal University of Mato Grosso do Sul (UFMS), Faculty of Engineering, Architecture, Urbanism and Geography, Campo Grande, Brasil. E-mail: aguinaldo.silva@ufms.br
ORCID: https://orcid.org/0000-0002-0630-9768

[3] Federal University of Mato Grosso do Sul (UFMS), Faculty of Engineering, Architecture, Urbanism and Geography, Campo Grande, Brasil. E-mail: hudson.macedo@ufms.br
ORCID: https://orcid.org/0000-0003-1104-7106

[4] State University of Mato Grosso do Sul (UEMS), Professional Master's in Water Resources Management and Regulation (PROFÁGUA), Campo Grande, Brasil. E-mail: sidneykuerten@uems.br
ORCID: https://orcid.org/0000-0002-1714-0929

[5] University of Minnesota - Twin Cities, Continental Scientific Drilling Facility, Minneapolis, MN USA. E-mail: domin467@umn.edu
ORCID: https://orcid.org/0000-0001-8477-1010

Received: 18/02/2025; Accepted: 15/11/2025; Published: 01/12/2025

Abstract: Hydro-geomorphological dynamics in the Pantanal wetlands remain poorly understood, requiring more comprehensive investigations. Geomorphological compartmentalization has been particularly useful in this endeavor, although such approach presents limitations in terms of analytical scale. Here, we proposed the geomorphological segmentation of a reach of Upper Paraguay River, between Porto da Manga and Porto Murtinho (Mato Grosso do Sul, Brazil) as a framework to better understand the hydro-geomorphological processes in the Pantanal wetlands. Our study integrates multiple geomorphological, hydrological, and geological criteria to define six geomorphological segments in the Paraguay River meander belt, named after local toponym, i) Porto Esperança, ii) Forte Coimbra, iii) Bahia Negra, iv) Barranco Branco, v) Fecho dos Morros, and vi) Porto Murtinho. Remote sensing data, digital elevation models (DEMs), and previous geomorphological mappings were combined here through geoprocessing and manual vectorization techniques. The results reveal that fluvial dynamics along the Upper Paraguay River are highly heterogeneous and influenced by structural controls, geomorphological variability, and channel–floodplain interactions. Hydraulic bottlenecks exert a strong influence on flow regulation and discharge redistribution as the abrupt shifts in channel orientation, sinuosity, and meander-belt width reflect the interplay among hydro-sedimentary processes and tectonic lineaments. This segmentation framework enhances our understanding of the Paraguay River morpho-hydrodynamics and provides a valuable contribution for improving environmental and water resources management in the Pantanal basin, home of the world's largest tropical wetland.

Keywords: Fluvial Geomorphology; Geomorphological Compartmentalization; Hydraulic Bottleneck; Fluvial System; Pantanal Basin.

Resumo: A dinâmica hidrogeomorfológica do Pantanal ainda é pouco compreendida, exigindo investigações mais aprofundadas. Compartimentação geomorfológica destaca-se nesse sentido, embora essa abordagem apresente limitações em termos de escala analítica. Neste trabalho é proposto a segmentação geomorfológica de um trecho do Alto rio Paraguai, no entre Porto da Manga e Porto Murtinho (Mato Grosso do Sul), como uma alternativa para aprofundar a compreensão local dos processos hidrogeomorfológicos. O estudo integra múltiplos critérios geomorfológicos, hidrológicos e estruturais para a delimitação de seis segmentos do cinturão de meandros: Porto Esperança, Forte Coimbra, Bahia Negra, Barranco Branco, Fecho dos Morros e Porto Murtinho. Para isso, foram utilizados dados de sensoriamento remoto, modelos digitais de elevação e mapeamentos prévios, analisados por meio de técnicas de geoprocessamento e vetorização manual. Os resultados indicam que a dinâmica fluvial não segue um padrão uniforme, sendo influenciada por fatores estruturais, variações morfométricas e interações canal-planície. Destacam-se a influência de gargalos hidráulicos na regulação do escoamento e na redistribuição dos fluxos. Além disso, mudanças abruptas de orientação, sinuosidade e largura do cinturão de meandros refletem a interação entre processos hidrossedimentares e controle estrutural. Esta proposta de segmentação contribui para o entendimento dos processos geomorfológicos e hidrodinâmica do Rio Paraguai e colabora para o aprimoramento da gestão ambiental e dos recursos hídricos do Pantanal, a maior área úmida tropical.

Palavras-chave: Geomorfologia Fluvial; Compartimentação Geomorfológica; Gargalo Hidráulico; Sistema Fluvial; Pantanal.

1. Introduction

Despite the recognized social, environmental, and economic importance of the Pantanal, our understanding of its fluvial processes, flood pulses, and channel–floodplain interactions remains poorly understood (Stevaux et al., 2020). This knowledge gap is amplified by the region's intrinsic complexity for field work, characterized by a vast network of dynamic and heterogeneous environments, as well as the logistical challenges of accessing remote areas (Assine & Silva, 2005). Consequently, field investigations at appropriate spatial scales are limited, hindering a detailed comprehension of flood processes and landscape connectivity. These constraints ultimately compromise the development of effective strategies for conservation and sustainable management of this unique wetland system.

In this context, remote sensing emerges as a powerful tool to overcome the challenges posed by limited accessibility and the vast spatial extent of the Pantanal. Through satellite imagery and airborne data, it possible to efficiently and continuously monitor large areas (Menezes & Almeida, 2012), enabling detailed analyses of fluvial processes, flood pulses, and channel–floodplain interactions (e.g., Kuerten & Assine, 2011). This methodology also facilitates the identification of inundated zones and the tracking of seasonal and interannual variations in the hydrological regime (Carvalho Junior, 2018).

Considering the aforementioned complexities, Assine & Silva (2009) proposed a systematized geomorphological compartmentalization as a crucial framework for understanding the complex and dynamic fluvial processes of the Paraguay River in the northern portion of the Pantanal wetlands. Their approach was grounded in a structured set of criteria encompassing hydrological patterns and the hydro-geomorphological characteristics of channels and alluvial plains and summarized here in Table 1. The authors proposal emphasized the importance of integrating multiple environmental variables to subdivide the floodplain into more homogeneous and explainable units from both geomorphological and hydrological perspectives. When combined with field observations, this framework enabled a more detailed and reliable analysis of fluvial dynamics.

Table 1. Criteria and parameters proposed by Assine and Silva (2009) for the geomorphological compartmentalization

Criteria/Parameters	Features	Spatial Domain
Drainage pattern	Tributary or distributary	Basin
Channel patterns	Meandering or multichannel	Channel
Adjacent morphologies	Abandoned meanders, fluvial lakes, levees, paleochannels, sand bars, among others	Floodplain
Morphometric parameters	Width, sinuosity, slope	Channel
Geographic orientation	-	Channel and floodplain
River valley confinement	-	-

As a result of this geomorphological compartmentalization framework, several studies have been developed using this approach as a tool for environmental analysis in the Pantanal, addressing both spatial and temporal realms. For example, Assine (2003) investigated the depositional systems of the Pantanal basin and identified two major geomorphological forms: alluvial fans and fluvial plains. Another notable study is that of Assine & Silva (2009), which, in investigating the geomorphology of the Paraguay River megafan, conducted a more detailed mapping at an intermediate scale. Collectively, these studies demonstrated how geomorphological compartmentalization serves as a valuable methodological basis for understanding landscape evolution and hydro-sedimentary dynamics across the Pantanal system.

The understanding of the geomorphology and hydro-sedimentary dynamics of the Pantanal was advanced in Macedo (2013, 2017) and Assine et al. (2015a, b). Macedo (2013), followed by Macedo (2017), conducted detailed mapping and analysis of the geomorphological features of the Paraguay–Corumbá floodplain, near the municipality of Corumbá (Mato Grosso do Sul). Additionally, Assine et al. (2015a) and further supported by Assine et al. (2015b), proposed a new and comprehensive compartmentalization of the Pantanal floodplain. This work systematized the geomorphology, hydrological regime, and sedimentary dynamics of the Pantanal's fluvial systems, establishing a direct connection with the geology and geomorphology of their source areas.

With a higher level of detail, Kuerten (2010) analyzed the environmental characteristics of the Nabileque megafan, located in the southern portion of the Pantanal basin, applying geomorphological compartmentalization criteria to categorize the regional geomorphology. Within this framework, the author identified several geomorphological features, particularly the modern meander belt of the Paraguay River, which is our object of study (Figure 1).

Another important contribution to the fluvial geomorphology of the Pantanal wetlands was made by Stevaux et al. (2020), who systematized previous studies and proposed a new geomorphological compartmentalization of the Upper Paraguay River, identifying eight distinct compartments along the alluvial plain. Collectively, these studies, both spatially and temporally, have greatly advanced the understanding of the geomorphology of the Pantanal floodplain, particularly contributing to the comprehension of the hydro-geomorphological processes shaping the Paraguay River floodplain.

It is also important to clarify the distinction between geomorphological compartmentalization and geomorphological segmentation in the scientific literature. Geomorphological compartmentalization refers to the subdivision of a landscape into relatively homogeneous units based on broader criteria (Trentim et al., 2012), such as predominant geomorphological characteristics, hydrological patterns, and regional geological contexts, as applied by Assine & Silva (2009). Such approach seeks to identify large compartments that share similar dynamics, such as fluvial plains, alluvial fans, and interfan plains, typically analyzed at medium to small spatial scales, thereby providing an integrated view of fluvial, sedimentary, and tectonic processes.

In contrast, the geomorphological segmentation, proposed in this study, involves a more detailed analysis within a given compartment, focusing on specific river stretches based on local variations in relief, sedimentary processes, and hydrological dynamics. This approach is essential for identifying and mapping smaller geomorphological features, which require larger-scale analyses and more precise tools. Both methods share a common foundation in multi-level landform analysis, integrating topographic compartmentalization, landform morphology, and surface structure analysis, following the conceptual frameworks of Ross (1990; 1992). Assine (2003) further contextualized these principles for geomorphological analysis within the Pantanal floodplain. In this study, we propose a novel geomorphological segmentation of the modern meander belt of the Paraguay River between Porto da Manga and Porto Murtinho, Mato Grosso do Sul. Here, we integrate previous mappings performed by Kuerten (2010), Padovani (2010), and Stevaux et al. (2020), particularly on the large-scale segmentation of the different internal sectors within the modern meander belt of the Paraguay River.

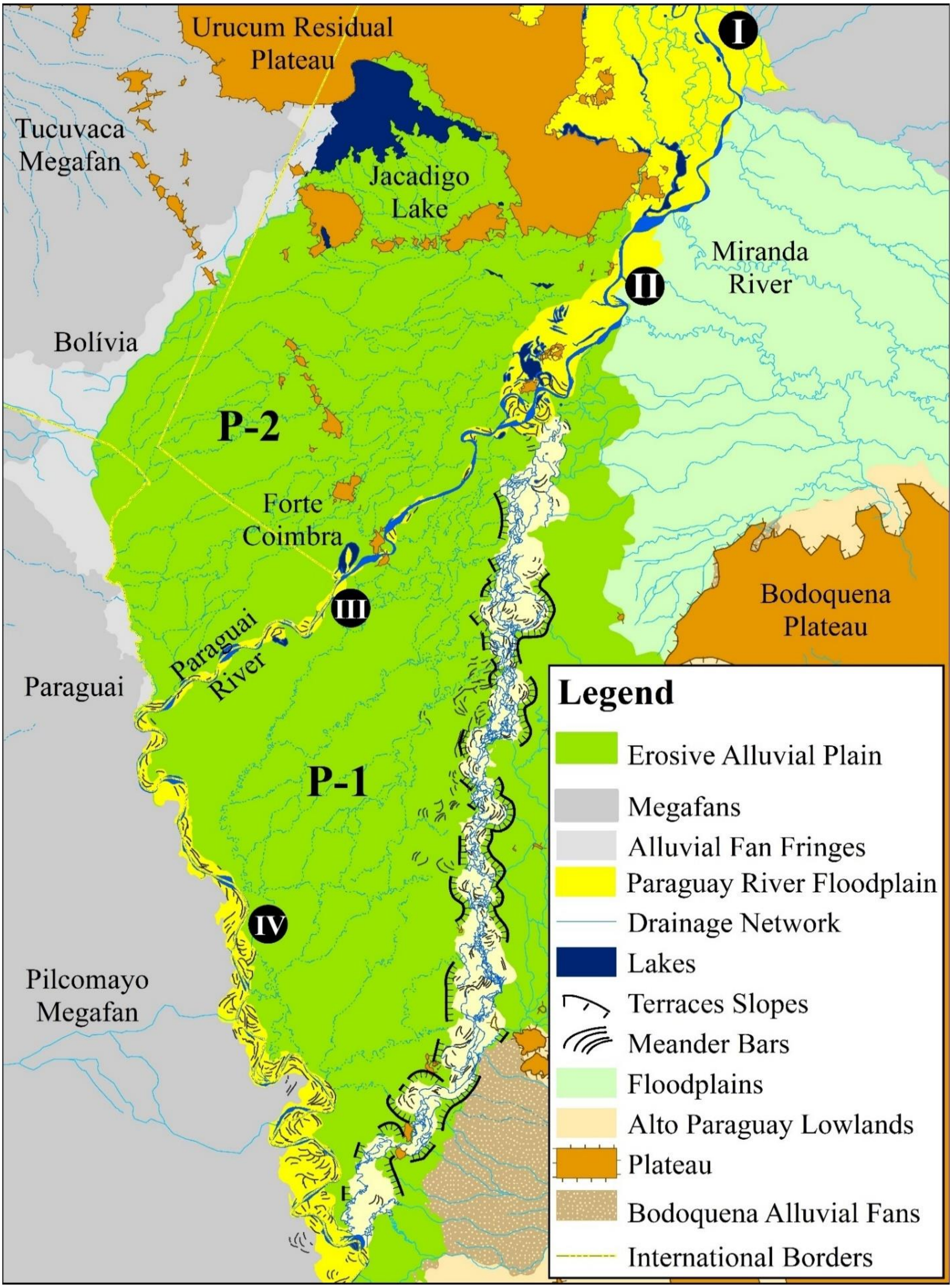

Figure 1. Geomorphological compartmentalization of the Nabileque Megafan proposed by Kuerten (2010). Among the compartments identified in the study area, the modern meander belt, referred to in this map as the “Paraguay River floodplain” (in yellow), stands out. The mapping of this meander belt serves as the basis for the geomorphological segmentation proposed in this study. Also highlighted are the degradational alluvial plain (in green) and the compartments P-1 and P-2.

2. Study Area

The study area is located along the Paraguay River, within the Pantanal region, extending from the vicinity of Porto da Manga locality, in the municipality of Corumbá, to the urban area of Porto Murtinho (Mato Grosso do Sul). This extensive area lies entirely within the Pantanal floodplain (Figure 2).

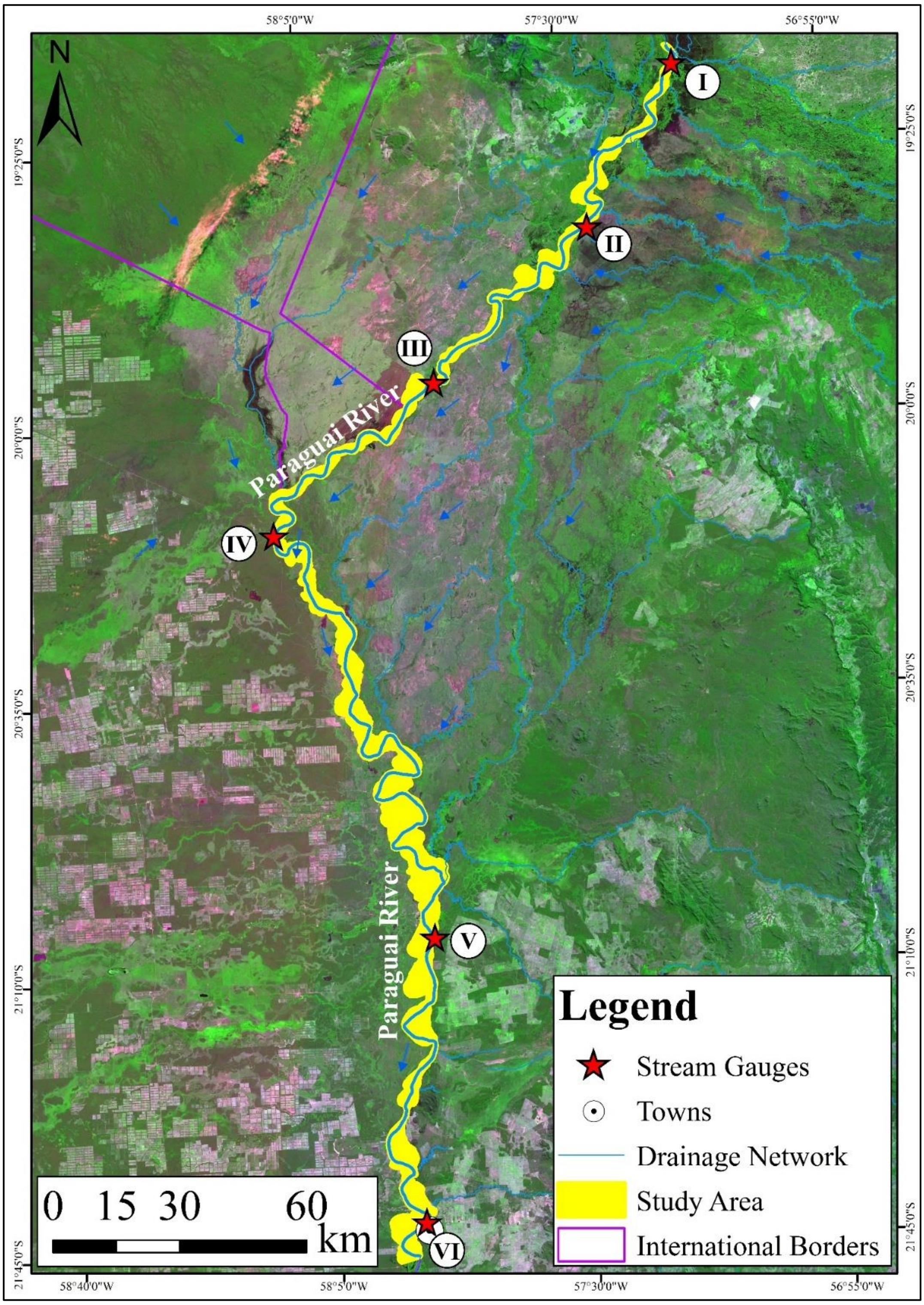

Figure 2. Map of the study area (southern Pantanal). Mosaic of CBERS-4 scenes, WFI sensor. The Roman numerals indicate monitoring stream gauges. Porto da Manga (I); Porto Esperança (II); Forte Coimbra (III); Bahia Negra (IV); Barranco Branco (V); Porto Murtinho (VI).

The Pantanal basin is characterized by a humid tropical climate, with a mean annual air temperature of approximately 24°C, although thermal extremes can range from –1°C to 41°C (Marengo et al., 2015). Precipitation exhibits marked interannual variability, leading to alternating periods of strong flooding and intense droughts that directly influence the flood regime. Spatial variability is also evident, with higher rainfall in the north–northeastern region (~1,350 mm annually) and lower precipitation in the south–southwestern (~710 mm annually) and central regions (~700 mm annually; Stevaux et al., 2020).

Throughout the floodplain, there is a predominance of sedimentary deposits from different geological ages, mainly Neogene and Pleistocene sediments, as well as Holocene alluvium associated with modern sediment deposition. These deposits reflect the complexity of the Pantanal's sedimentary system, which includes the development of modern alluvial fans such as those formed by the Paraguay, Cuiabá, and Taquari rivers (IBGE, 2018). According to Alho et al. (1988), the Pantanal's topography is nearly continuous, characterized by a very gentle gradient—ranging from 2 to 3 cm/km in the north–south direction and 5 to 25 cm/km in the east–west direction. This low gradient results in pronounced variations in flood timing and duration across different sectors of the Pantanal floodplain.

According to Alvarenga et al. (1984), temporal variation in the flood periods across different regions of the Pantanal floodplain can reach an average interval of three to four months between areas adjacent to the surrounding plateaus and the lower-lying zones within the basin interior. Consequently, while in the northern Pantanal the flood pulse is synchronized with the rainy season, in the southern portion it may occur with a delay of up to three months after the end of the wet season (Junk et al., 2006).

3. Materials and Methods

The geomorphological segmentation of the study area was performed using a comprehensive database, established by integrating multiple datasets, including: (1) high and medium resolution satellite imagery (Table 2), used to identify geomorphological features, delineate flood-prone areas, and analyze fluvial and sedimentary dynamics; (2) secondary datasets published by governmental agencies such as Brazilian Institute of Geography and Statistics (IBGE), National Water and Sanitation Agency (ANA), and National Institute for Space Research (INPE), encompassing topographic, hydrological, and geological maps, as well as historical climatic and hydrometric records; and (3) primary data derived from geoprocessing techniques, including digital elevation models (DEMs), terrain curvature analyses, and image processing outputs.

Table 2. Satellite scenes employed in the geomorphological segmentation of the study area.

Satellite	Sensor	Scene ID	Date	Spectral bands used	Spatial resolution (m)
Landsat-5	TM	227/73; 227/74; 227/75	June 1988	1, 2, 3, 4 e 5	30
Landsat-8	OLI	227/73; 227/74; 227/75	August 2014	2, 3, 4, 5 e 6	30
Landsat-8	OLI	227/73; 227/74; 227/75	August 2023	2, 3, 4, 5 e 6	30
CBERS-4A	WFI	218/140	August 2023	13, 14, 15 e 16	55
CBERS-4A	WPM	217/137; 217/138; 217/139 217/140; 218/137; 218/138 218/139; 218/140	August 2023	0, 1, 2, 3 e 4	8 - multispectral 2 - panchromatic
Sentinel 2A	MSI	21KVU; 21KUT; 21KVT 21KUS; 21KVS	September 2023	2, 3, 4 e 8	20

The delimitation of geomorphological segments was determined based on the data from the Natural Resources Mapping of Brazil (IBGE, 2018), including geological, geomorphological, and pedological maps (SD-21, SE-21, and SF-21), produced at 1:250,000 scale. To ensure precision and detailed understanding, the files were organized to represent information down to the lowest available taxonomic level in each dataset. Processing and analysis of these datasets were performed using ArcGIS 10.8® (ESRI, 2021), enabling efficient integration and visualization of the spatial information.

Similar to the vector datasets, the orbital scenes were processed using ArcGIS 10.8® (ESRI, 2021). All images underwent enhancement techniques aimed at improving visualization, as described by Florenzano (2008). Subsequently, band composition was performed. The integration of these spectral bands enabled the generation of different color composites, allowing for a more detailed and efficient analysis of the elements within each area, thereby optimizing the identification of geomorphological features, vegetation cover, and hydrological patterns.

For the delineation of geomorphological segments, the manual vectorization method was employed—a technique widely recognized in geomorphological mapping (Florenzano, 2008), particularly when high precision between feature and compartment boundaries is required. This method involved manually tracing the contours of geomorphological units directly over orbital imagery, digital elevation models (DEMs), and/or other geospatial datasets using GIS software tools. Manual vectorization enabled to integrate ground truth with the visual interpretation of data, allowing for the identification of subtle details that are often overlooked by automated methods, an especially valuable advantage in highly complex environments such as the Pantanal.

Accordingly, the vectorization process was performed in ArcGIS 10.8® (ESRI, 2021), where a new vector layer was created. The analysis scale was standardized at 1:30,000 scale, which allowed for the visualization and identification of geomorphological units directly over the orbital imagery. Subsequently, the geomorphological features were delineated. A synthesis of the steps involved in the geomorphological segmentation process is presented in Figure 3.

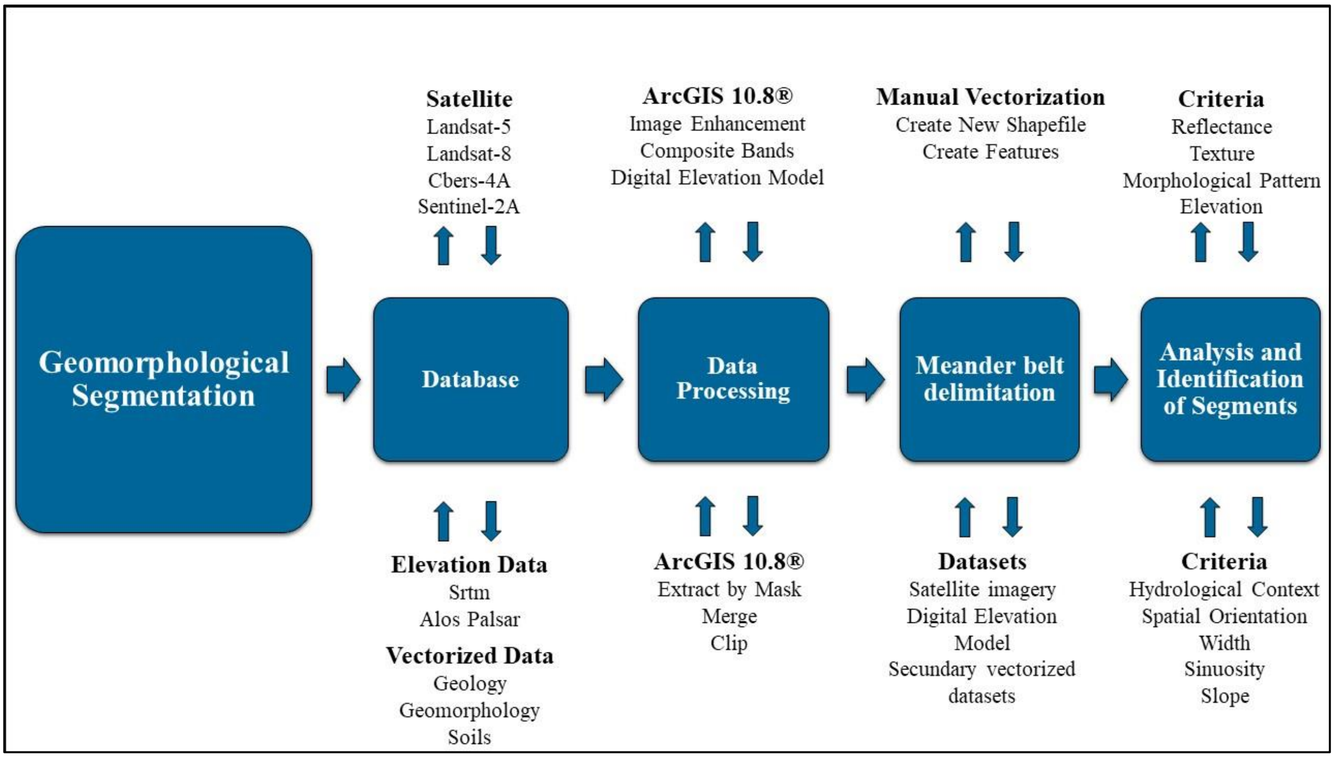

Figure 3. Flowchart of the steps involved in the geomorphological segmentation used in this study.

Geomorphological segment identification and delineation were guided by a set of key parameters, including tone and color (reflectance), texture, morphological patterns, elevation, hydrological context, meander-belt orientation and width, and channel sinuosity and slope. These criteria formed the basis for the construction of an interpretation key outlining the spatial distribution of diagnostic features (Figure 4).

Within the context of geomorphological mapping, the interpretation key plays a crucial methodological role in identifying and classifying morphological features and their associated dynamics, aiding in the recognition of landforms and the determination of their characteristics (Lima & Lupinacci, 2021). The interpretation key is particularly valuable for ensuring analytical consistency and accuracy, allowing the features identified in orbital imagery to be compared and integrated within a coherent classification system (Melo et al., 2017). In geomorphological studies of the Pantanal, this approach represents one of the first efforts to develop an interpretation key specifically for morphological features.

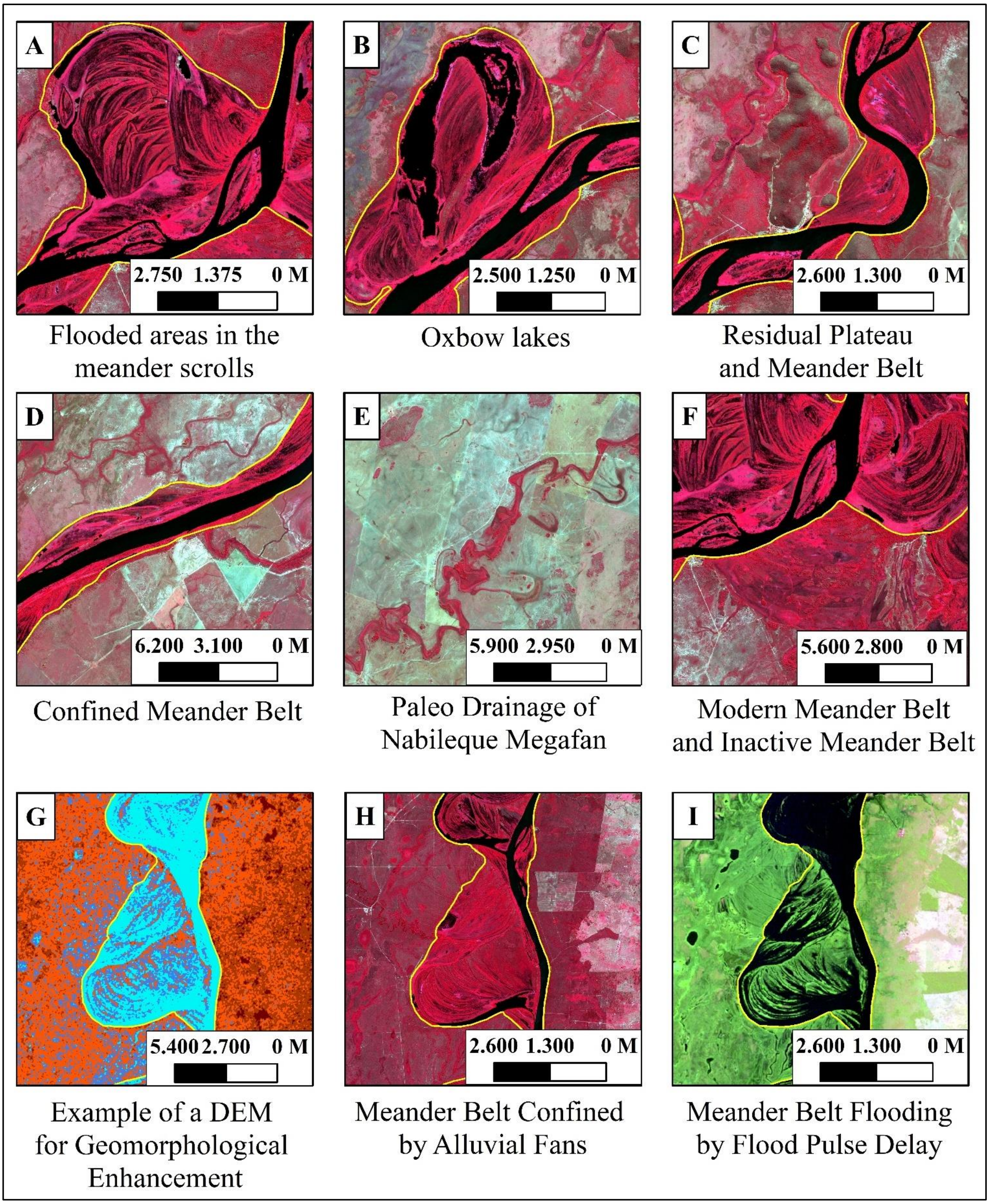

Figure 4. Interpretation key showing representative examples of the criteria used in the geomorphological segmentation.

Figure 4 illustrates distinct areas exemplifying the criteria applied in delineating the geomorphological segments. Figures 4A and 4B highlight morphological and hydrological patterns, emphasizing the relationship between water flow and landform configuration. Figure 4C integrates tone, texture, morphology, and hydrology, allowing the identification of two distinct geomorphological compartments. Figure 4D combines texture, morphology, and topography, which are essential for understanding the three-dimensional configuration of the terrain. Figure 4E emphasizes the orientation and width of the meander belt, providing insights into local fluvial dynamics. Finally, Figure 4F explores the interaction between morphology and topography, consolidating the analysis of geomorphological units.

In Figures 4G to 4I, the same area is analyzed using three different data sources, demonstrating how the integration of these datasets enhances the accuracy of geomorphological segment delineation. Figure 4G presents a Digital Elevation Model (DEM) derived from SRTM data (resampled to 12.5m) made available by the Alaska Satellite Facility (ASF), providing a detailed representation of relief and assisting in the identification of topographic levels. Figure 4H displays an RGB 4-3-2 composite from the WPM sensor onboard the CBERS-4A satellite, emphasizing vegetation cover and hydrological patterns. Figure 4I shows an RGB 5-4-3 composite from the TM sensor of the Landsat 5 satellite, highlighting morphological features and surface cover.

4. Results and Discussion

Our study area extends total length of ~465 km of the Paraguay River, encompassing six geomorphological segments named here after local toponyms, Porto Esperança, Forte Coimbra, Bahia Negra, Barranco Branco, Fecho dos Morros, and Porto Murtinho (Figure 5). These segments are located within one of the lowest portions of the Pantanal, at elevations below 100 m asl, playing a fundamental role in the drainage of the floodplain. The elevation of the meander belt decreases southward, following a topographic gradient of only 2.15 cm/km. This low gradient contributes to the slow surface runoff, promoting the overflow of water onto adjacent floodplains and playing a crucial role in the hydrological and ecological regulation of the fluvial system, as noted by Stevaux et al. (2020).

The differentiation among the geomorphological segments is defined by the interaction of the criteria employed in the geomorphological mapping. For instance, between the Porto Esperança and Forte Coimbra segments, the average width of the meander belt, the sinuosity index, and the slope were key distinguishing factors. In the stretch between Forte Coimbra and Bahia Negra, in addition to a deflection and change in channel orientation, variations in belt width were observed, along with an increase in sinuosity and a reduction in slope.

Downstream, between the Bahia Negra and Barranco Branco segments, a new change in the meander belt orientation was observed, accompanied by an increase in its average width, channel sinuosity, and mean slope. Between the Barranco Branco and Fecho dos Morros segments, however, a reduction in both belt width and channel sinuosity was observed, reaching values characteristic of straight channels, as noted by Stevaux and Latrubesse (2017). Finally, in the reach between Fecho dos Morros and Porto Murtinho, the belt width increases once again, along with a shift in channel orientation and a rise in the sinuosity index. The values of the criteria considered for the geomorphological segmentation are summarized in Table 3.

Table 2. Summary of parameters used in the geomorphological segmentation of the Paraguay River meander belt within the study area. See the segments in Figure 5.

Geomorphological segment	Spatial orientation	Average Belt Width (m)	Slope (cm/km)	Area of the meander belt (km²)	Channel Length (km)	Sinuosity (m)
Porto Esperança	NE-SW	2242	2.02	195	98.8	1.37
Forte Coimbra	NE-SW	1768	3.6	141	84.6	1.21
Bahia Negra	NW-SE	3080	1.94	244	102.5	1.54
Barranco Branco	N-S	5504	2.69	394	111.7	1.63
Fecho dos Morros	NE-SW	1793	-	33	22.1	1.06
Porto Murtinho	N-S	4465	2.2	152	45.3	1.45

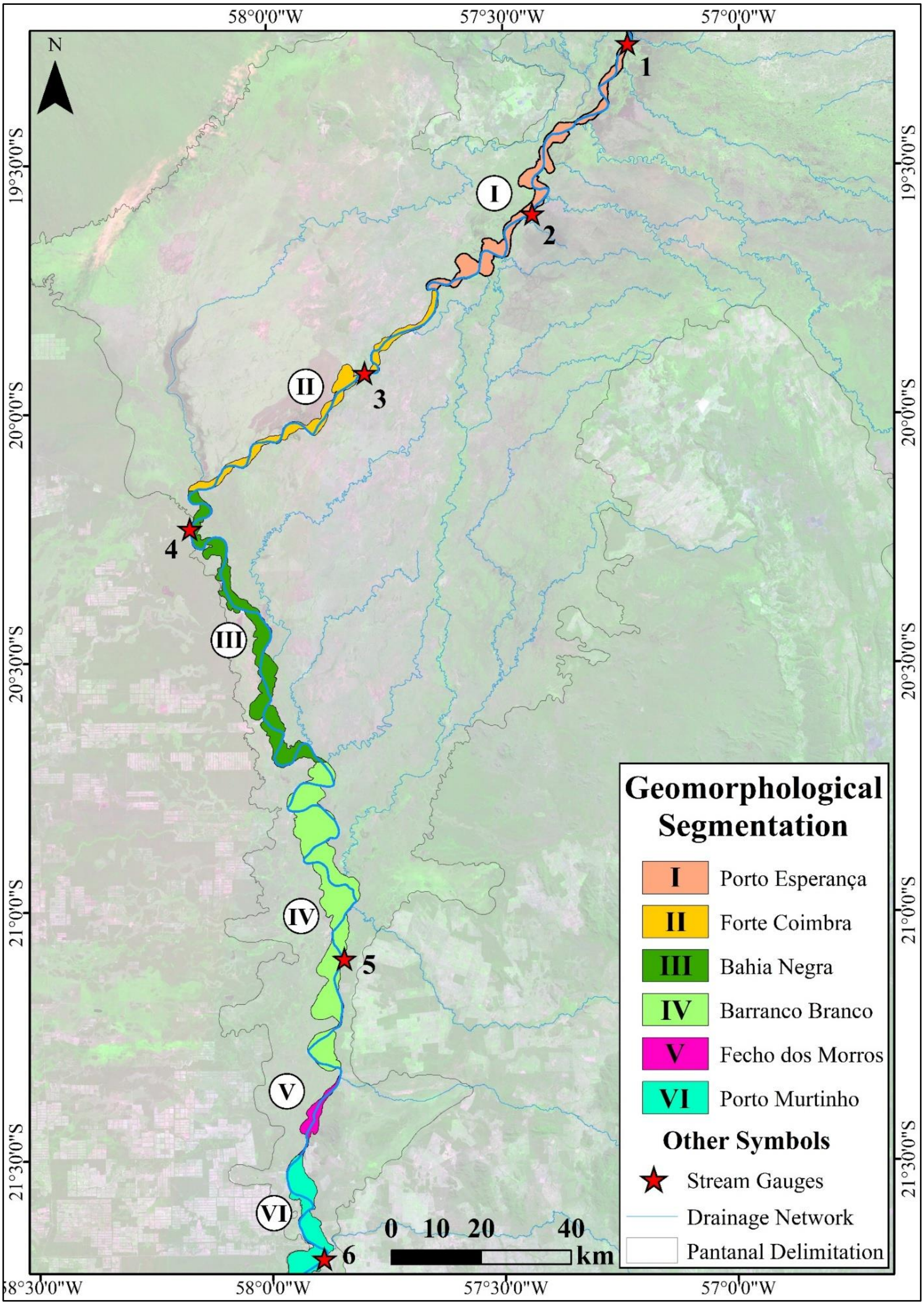

Figure 5. Geomorphological segments along the study area. Red stars denote the monitoring stream gauges: (1) Porto da Manga, (2) Porto Esperança, (3) Forte Coimbra, (4) Bahia Negra, (5) Barranco Branco, and (6) Porto Murtinho.

4.1. Porto Esperança meander belt (CmPE)

The Porto Esperança meander belt has an average width of ~2,240 meters and exhibits a progressive expansion from northeast to southwest, encompassing an area of ~195 km². The narrower section in the northern portion results from the confinement of the meander belt. On its left margin, the meander belt is constrained by Quaternary sedimentary deposits associated with the paleo-depositional lobe of the Miranda River (e.g., Merino, 2011), which currently forms a degradational alluvial plain. This area is characterized by discontinuous drainage networks with a predominantly westward orientation, among which the Mutum creek (*corixo Mutum*) stands out (Figure 6B).

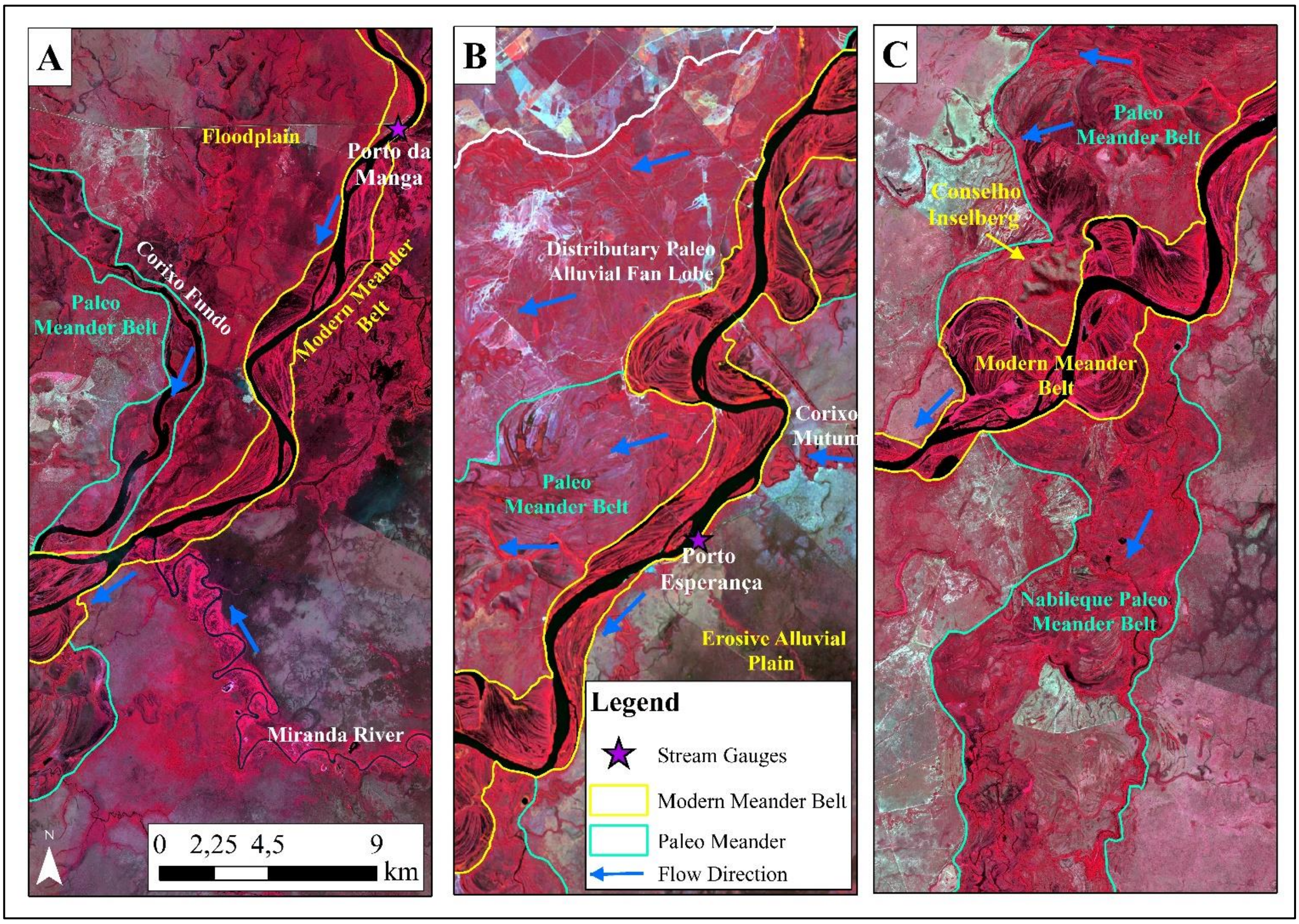

Figure 6. Satellite imagery of the Porto Esperança meander belt, acquired from the CBERS-4A satellite (WPM sensor).

On its right margin, upstream from the confluence with the Miranda River, the meander belt is confined by a flood basin characterized by degraded paleo-drainages formed by Quaternary deposits, as well as by a paleo-meander belt (Figure 6A), a remnant of an ancient course of the Paraguay River (Macedo, 2017). Downstream from the confluence, along the right margin, the belt becomes constrained by Precambrian terrains belonging to the Urucum Residual Plateau (Neoproterozoic) and subsequently by a broad distributary paleo-lobe oriented toward the southwest (Figure 6B).

Farther south, the meander belt widens, particularly near a residual hill locally known as Morro do Conselho and the paleo-meander belt of the Nabileque River (Figure 6C). Based on analyses by Macedo (2017) and Kuerten (2010), it is possible to observe the continuity of an extensive paleo-meander belt that, in the past, represented an ancient course of the Paraguay River. To the north, this paleo meander belt is currently drained by the Paraguay-Mirim River, which drains the northern portion of the floodplain, particularly from the Taquari megafan. In the central region, the paleo meander belt is intersected by the modern meander belt of the Paraguay River near the confluence of the Paraguay-Mirim River. From that point southward, the paleo meander belt is drained by the Fundo creek (corixo Fundo; Figure 6A).

4.2. Forte Coimbra meander belt (CmFC)

The Forte Coimbra meander belt is the narrowest reach among the geomorphological segments identified here, with an average width of only 1,767 meters (Figure 7) and a total area of ~141 km². This meander belt is confined on both margins by older sedimentary deposits associated with the evolution of the Nabileque megafan. The boundary between the meander belt and the surrounding degradational plain is particularly evident during the dry season, when the presence of narrow meander loops containing higher water volumes contrasts sharply with the adjacent vegetation cover, which is composed mainly of grasses and shrubby grasslands (Silva et al., 2011).

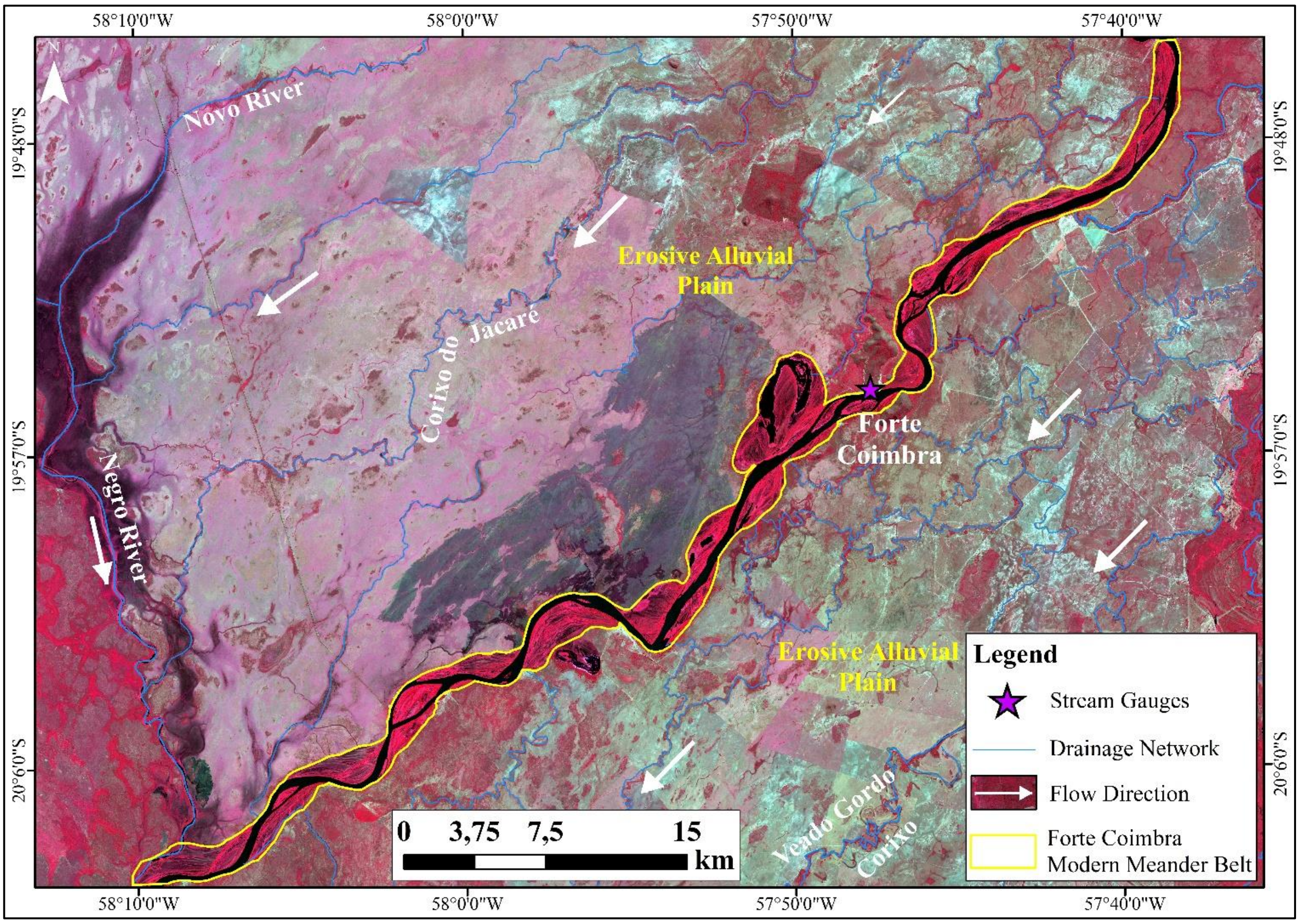

Figure 7. Overview of the Forte Coimbra meander belt. Orbital image acquired by the CBERS-4A satellite, WPM sensor

In this segment, channel orientation (NE–SW), narrower meander belt, and low sinuosity (1.21) suggest strong structural control (Kuerten, 2010). According to the author, the main geotectonic element influencing the current channel configuration is the Transbrasiliano lineament, a transcontinental tectonic structure extending for more than 4,000 km across several regions of Brazil. This geological structure is connected to geological features on the African continent, as a result of tectonic events during the Neoproterozoic (Lima, 2015). The structural control imposed by the Transbrasiliano lineament is evident in the straight channel orientation and in its direct influence on fluvial morphology and the dynamics of the meander belt.

The role of the Transbrasiliano lineament in shaping the regional geomorphology of the Pantanal is well recognized and has been documented in several studies, including Soares et al. (1998) and Kuerten (2010), providing a robust hypothesis to explain the morphological pattern observed in the Forte Coimbra segment. Moreover, the influence of structural controls on the definition of the present course of the Paraguay River was previously discussed by Ab'Saber (1988). This interpretation was later reinforced by Paranhos Filho et al. (2017), who synthesized the main structural lineaments coinciding with the current courses of the Paraguay and Nabileque rivers. In addition to the Transbrasiliano lineament (Figure 8A), two other structural lineaments influence the orientation of the Paraguay River (Figure 8B and 8E), as well as two additional structural controls acting on the Nabileque River (Figure 8C and 8D). Collectively, these studies highlight the essential role of tectonic–geomorphological interactions in controlling the configuration of the Pantanal's fluvial system.

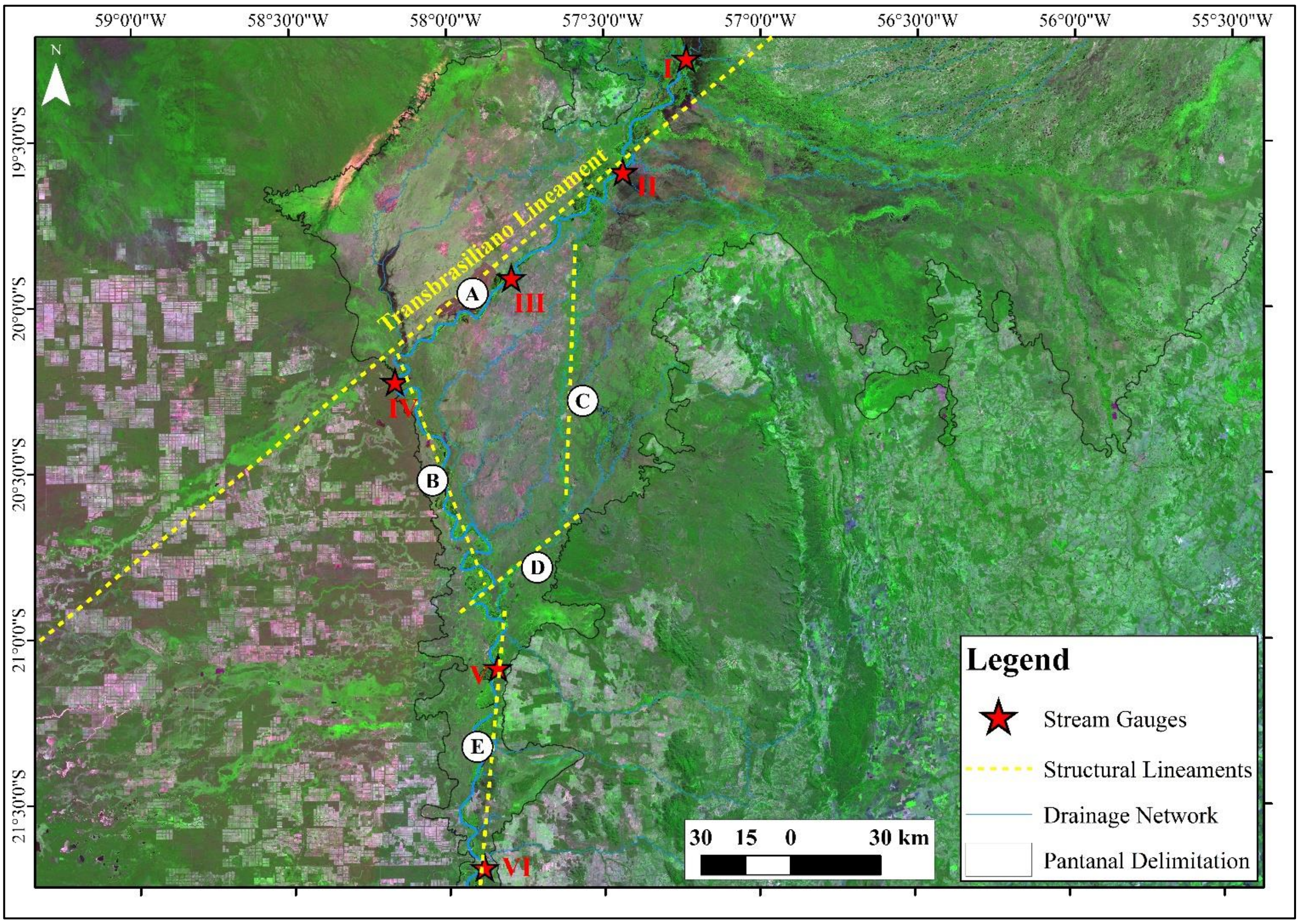

Figure 8. Main structural lineaments coinciding with the modern course of the Paraguay River within the study area. Adapted from Paranhos Filho et al. (2017). Monitoring stream gauges, I – Porto da Manga; II – Porto Esperança; III – Forte Coimbra; IV – Bahia Negra; V – Barranco Branco; VI – Porto Murtinho.

According to Kuerten (2010), however, the development of the current course of the Paraguay River may have resulted from a broad process of avulsion and fluvial capture, influenced by climatic fluctuations that altered environmental conditions and disrupted the hydrological equilibrium of the system. Such changes can significantly modify sedimentation patterns, as suggested by Schumm (1993). Based on this hypothesis, local fluvial reorganization associated with avulsion could have been compounded by a headward erosion process, leading to the upstream migration of a small tributary of the Negro River—an inter alluvial fan channel responsible for draining water from the Nabileque and Pilcomayo megafans (Kuerten et al., 2013).

This process may have culminated in the partial capture of the Paraguay River's flow by a tributary of the Negro River, a channel that was already structurally constrained by the Transbrasiliano lineament. This hypothesis is consistent with the characteristics observed in the present meander belt, including its orientation, the arrangement of adjacent drainages within the Nabileque megafan, and its relatively narrow and uniform width.

Fluvial avulsion processes within the Nabileque megafan may have been decisive in shaping the morphologies observed in the Forte Coimbra segment. Avulsion events often redistribute water and sediment flow across alluvial plains, producing distinctive geomorphological features (Kuerten & Stevaux, 2021; Cordeiro et al., 2010). Within the Nabileque megafan context, avulsion likely generated the morphological contrasts between the Forte Coimbra meander belt and the surrounding degraded alluvial plain. Therefore, the geomorphological features identified within and around the Forte Coimbra meander belt reflect not only hydro-geomorphological changes induced by avulsion but also the structural influence of the Transbrasiliano lineament.

4.3. Bahia Negra meander belt (CmBN)

The Bahia Negra meander belt exhibits one of the most pronounced morphological transitions along the Paraguay River, characterized by an abrupt channel deflection near Cavayú Island (Figure 9A). At this point, the channel orientation shifts from NE–SW, as observed in the Forte Coimbra segment, to NW–SE in the Bahia Negra segment. This directional change likely reflects the structural control exerted by tectonic lineaments in the region, as proposed by Kuerten (2010) and Paranhos Filho et al. (2017). The channel reorientation stands out as one of the most distinctive features of this segment, marking a sharp contrast between the sedimentary deposits of the Nabileque Megafan to the east and the Pilcomayo Megafan to the west.

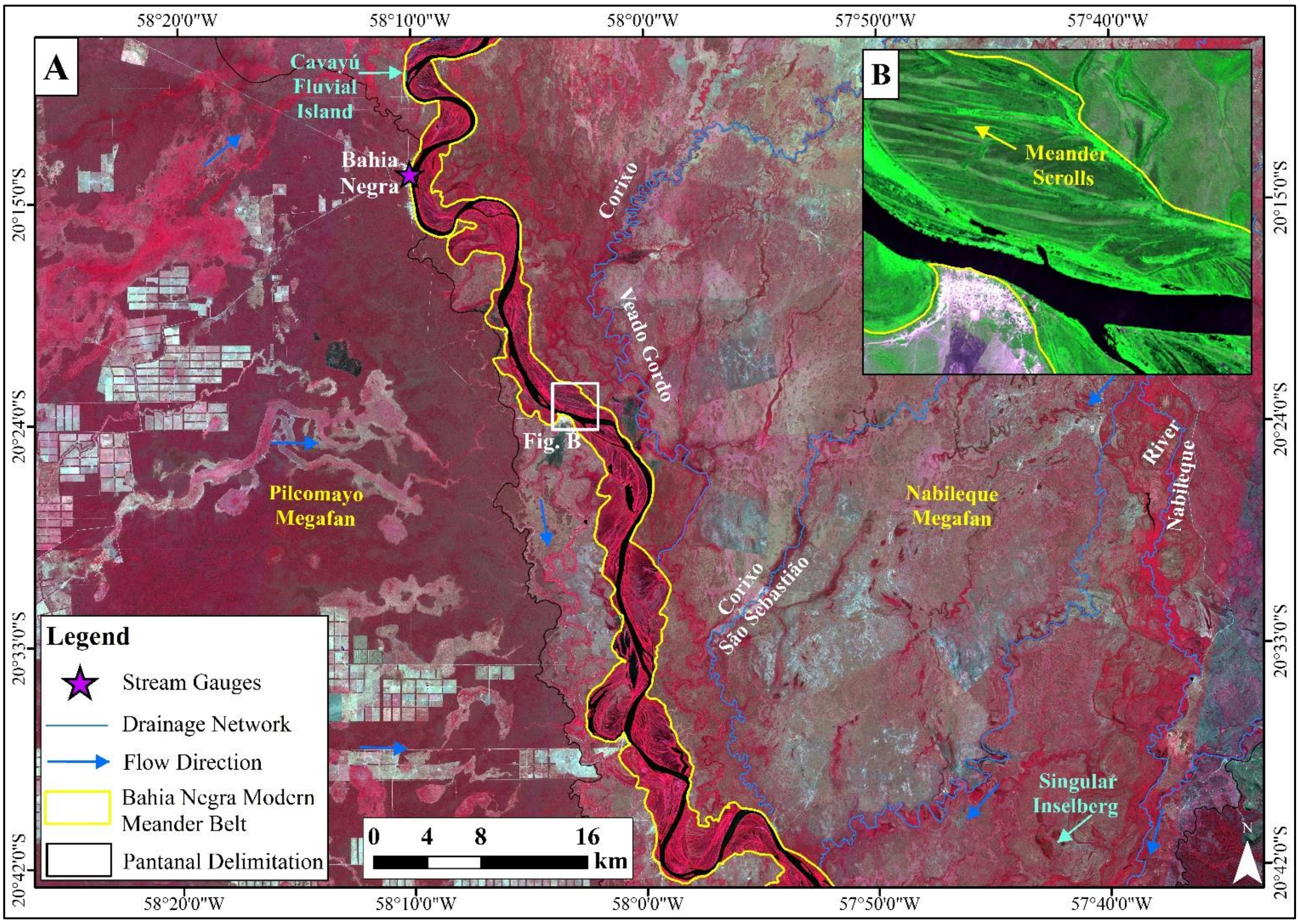

Figure 9. Overview of the Bahia Negra meander belt. Orbital image acquired from CBERS-4A satellite (WPM sensor, August 2023), with drainage network mapped manually. Toponyms sourced from the *Enciclopédia das Águas de Mato Grosso do Sul* (Campestrini et al., 2014).

Another key feature of the Bahia Negra meander belt is the marked increase in its average width (~3,080 m), representing a ~73% expansion compared to the upstream segment. This widening becomes particularly pronounced toward the southern portion of the belt. In addition, the total area of this segment is the second largest among those mapped, encompassing 244 km², which reflects the broadening of the alluvial plain in this reach of the Paraguay River.

In addition, the channel sinuosity index also increases substantially. This higher sinuosity reflects enhanced lateral channel migration, as evidenced by the development of broad meander scrolls and tighter meander curvature. The sinuosity index and meander curvature radius are closely related, as highly sinuous rivers tend to exhibit more pronounced meander bends, and thus greater curvature generally indicates intensified lateral migration (Hickin & Nanson, 1975). Accordingly, in the Bahia Negra meander belt, meander scrolls and oxbow lakes are particularly prominent (Figure 9B).

The orientation of the drainage network adjacent to the Bahia Negra segment indicates that the Paraguay River constitutes the principal drainage axis in this region, particularly during the wet season. This suggests that, in this segment, the Paraguay River exhibits a tributary drainage pattern. On its right margin, the main tributary is the Negro River, a small channel originating in Bolivian territory that drains waters from the distal portions of the Tucavaca megafan, one of the largest in the Pantanal basin, covering an area of approximately 3,800 km² (Kuerten & Stevaux, 2021). In addition, a network of diffuse flow channels and non-channelized drainages derived from the Pilcomayo megafan is also evident.

On the left margin of the Paraguay River within this segment, tributaries originating from the Nabileque megafan, such as the Veado Gordo and São Sebastião creeks, act as important channels for water and sediment redistribution across the alluvial plain. These left-bank tributaries become particularly active during the wet season, when they drain part of the water stored in the Nabileque megafan directly into the Paraguay River's meander belt (Stevaux & Latrubesse, 2017).

These channels correspond to relict fluvial morphologies that are reactivated during flood periods, resembling the secondary channels identified by Souza Filho and Stevaux (2004) in the Upper Paraná River. Such tributaries enhance the hydrological connectivity between the Paraguay River and its adjacent floodplains, serving as examples of paleo-forms that continue to perform active hydrological functions when reactivated during wet seasons. This highlights the importance of investigating relict morphologies to better understand the evolutionary dynamics of fluvial systems (Blum & Tornqvist, 2000).

4.4. Barranco Branco meander belt (CmBB)

The Barranco Branco meander belt is characterized by a distinct change in channel orientation near Cova da Onça Island, where the course of the Paraguay River shifts from a NW–SE orientation in the Bahia Negra segment to a N–S direction in Barranco Branco (Figure 10). This change in alignment may be attributed to structural controls influencing channel direction. The resulting reorganization of the river course suggests an interaction between tectonic and hydro-sedimentary processes, in which regional structural features play a key role in guiding the flow of the Paraguay River (Ab'Saber, 1988).

One of the most distinctive features of this segment is the increase in the meander belt width to ~5,503 m, representing a ~79% expansion relative to the preceding segment, and the largest value among all mapped units, encompassing an area of 394 km². This widening is most pronounced in the northern and central portions of the meander belt, but a significant narrowing occurs downstream of the confluence with the Branco River (Figure 10). The reduction in width can be attributed to increased channel confinement, with well-defined boundaries: to the west, by sedimentary deposits of the Pilcomayo megafan, and to the east, by alluvial terraces composed of Quaternary sediments. This configuration produces a geomorphological transition that delineates the limits of the meander belt within the broader Pantanal alluvial plain.

The Barranco Branco meander belt exhibits the highest sinuosity index in the study area (1.63). The pronounced curvature of the meanders and the presence of extensive meander scrolls adjacent to the active channel indicate intense lateral channel migration throughout the Holocene, as supported by chronological data from multiple geomorphic compartments in the region (Kuerten, 2010). These features are diagnostic of a highly dynamic fluvial system, reflecting in continuous adjustments of channel morphology driven by sedimentary reworking and hydrological variability.

In the Barranco Branco meander belt, the Paraguay River is supplied by major tributaries such as the Nabileque, Aquidabã, and Branco rivers, all located on its left margin, while on the right margin it receives surface runoff from the Pilcomayo megafan (Kuerten & Assine, 2011). The Aquidabã and Branco rivers drain the western slope of the Bodoquena Plateau; however, upon entering the Pantanal, the Aquidabã River develops a small alluvial fan. This fluvial fan extends the geomorphological framework of the Pantanal, as illustrated in Figure 10. Small-scale alluvial fans situated near adjacent escarpments have been identified across several regions of the Pantanal (Lo et al., 2019).

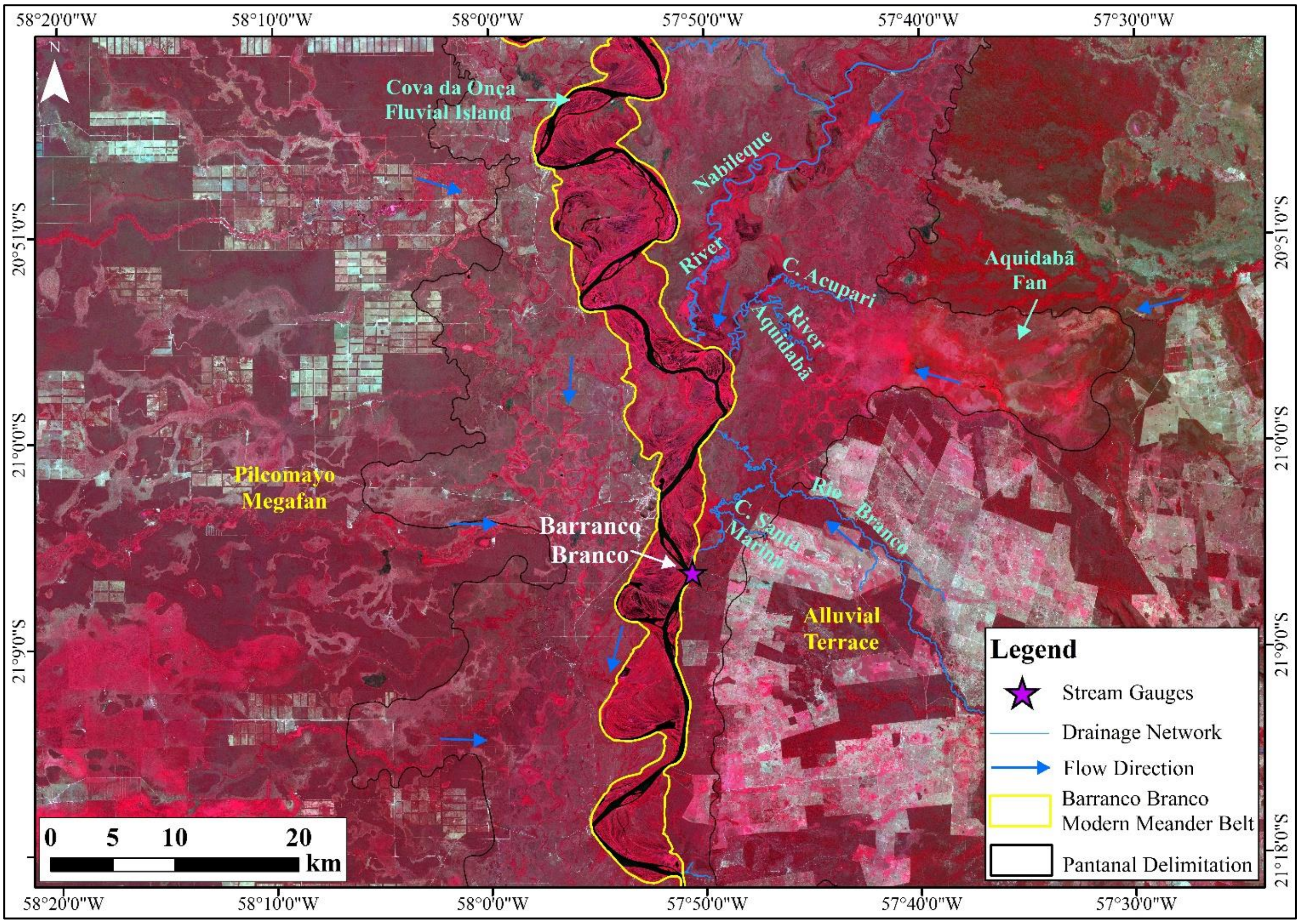

Figure 10. Overview of the Barranco Branco meander belt. Orbital image acquired from CBERS-4A satellite (WPM sensor), with drainage network mapped manually.

4.5. Fecho dos Morros meander belt (CmFM)

The Fecho dos Morros meander belt has the smallest area among the geomorphological segments mapped, encompassing only 33 km² (Figure 11). This meander belt is also the narrowest within the entire study area, with an average width of ~1,700 meters. Such narrowing reflects the geomorphological confinement imposed by sedimentary deposits from the Pilcomayo megafan and the Tererê alluvial fan.

The primary factor controlling this channel confinement is the presence of residual hills known locally as Fecho dos Morros, which play a key structural role in shaping this segment. The Fecho dos Morros represents one of the most important hydraulic bottlenecks in the Pantanal (Stevaux et al., 2020). This term refers to natural constrictions within the fluvial channel or floodplain that restrict water flow, thereby reducing the system's capacity to dissipate flood pulses (Assine et al., 2015a). Within such bottlenecks, water flow tends to accumulate upstream, producing significant effects on floodplain hydrodynamics, including upstream inundation, flow reversal, and decreased velocity within the main channel.

In the case of the Fecho dos Morros, this geomorphological structure generates a backwater effect, in which the flow of water is decelerated or even temporarily halted, leading to the accumulation and water levels rise upstream as a result of flow obstruction, a process also identified in the Paraguay River near the Paraguay–Corumbá alluvial plain (Macedo, 2017; Macedo et al., 2019). This phenomenon attenuates the Paraguay River's flood pulse, an effect quantified at the Porto Murtinho stream gauge by Stevaux et al. (2020), playing a critical role in regulating floods across the Pantanal (Figure 11).

Due to the structural control imposed by the residual hills, the channel orientation shifts markedly to a NE–SW direction within the Fecho dos Morros segment. Moreover, channel sinuosity is considerably reduced, with an index of only 1.06, classifying this reach as straight (Stevaux & Latrubesse, 2017). Consequently, the configuration of the Fecho dos Morros meander belt reflects a unique combination of structural and hydrodynamic controls, influencing not only channel morphology but also flood behavior and sediment dynamics in the region. Its strategic position as a hydraulic bottleneck, and its interaction with adjacent alluvial fans, make this segment a key element for understanding the geomorphology and hydrology of the Pantanal, exerting a direct influence on the downstream Porto Murtinho meander belt.

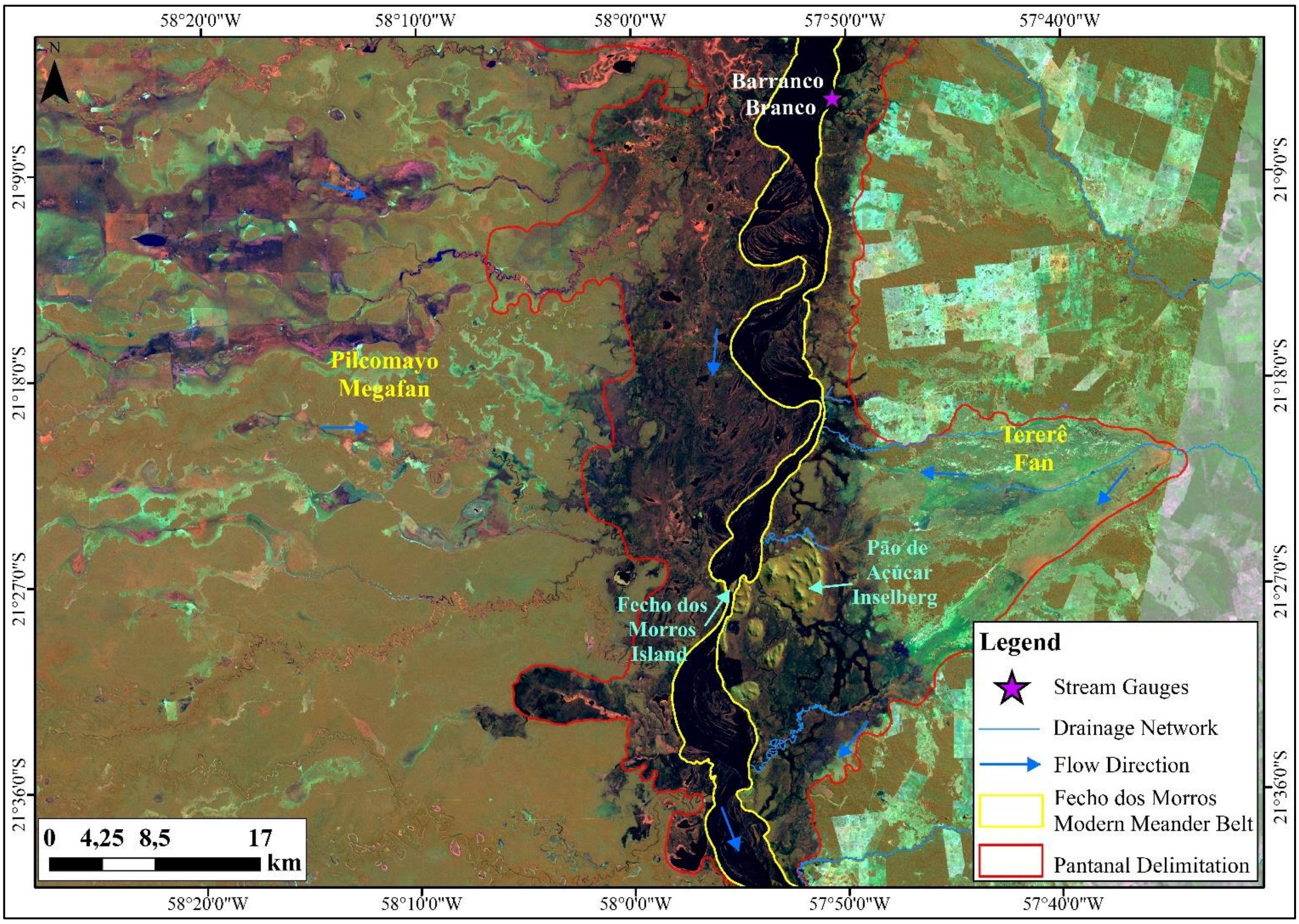

Figure 11. Overview of the Fecho dos Morros meander belt, illustrating its role in impeding the 1988 Paraguay River flood. Landsat 5, TM sensor, July 1988.

4.6. Porto Murtinho meander belt (CmPM)

The Porto Murtinho meander belt exhibits a progressive widening from north to south, with an average width of approximately 4,464 meters, the second largest among the mapped segments. This configuration reflects a geomorphological confinement imposed by sedimentary deposits of the Pilcomayo megafan to the west and by Quaternary alluvial terraces to the east (IBGE, 2018). Consequently, this portion of the Pantanal represents one of its narrowest stretches (Padovani, 2010), with the Porto Murtinho meander belt occupying a substantial portion of this constricted area (Figure 12A).

A distinctive feature of this segment is the change in channel orientation, which shifts from a NE–SW direction in the Fecho dos Morros meander belt to a predominantly N–S orientation in the Porto Murtinho segment (Figure 12A). This directional change, combined with the relatively low sinuosity index (1.45), suggests a high degree of structural control. Although meander curvature is notable, it remains lower than that observed in the Bahia Negra and Barranco Branco meander belts, indicating more subdued lateral migration processes along this reach. The relationship between sinuosity, meander curvature, and structural control reflects the interplay between local and regional geomorphological and hydrodynamic conditions, particularly the influence of consolidated sedimentary deposits and terrains associated with the Paraguay River depression (Alvarenga et al., 1982).

The occurrence of meander scrolls associated with the presence of surface waters gives this segment a striking visual contrast during the dry season. This contrast is further accentuated by land-use modifications in adjacent areas, which have been widely deforested for cattle ranching (Souza Junior et al., 2020). During the flood season, the Porto Murtinho meander belt becomes almost entirely inundated, acting as a large floodplain basin that drains much of the Pantanal's floodwaters (Figure 12B).

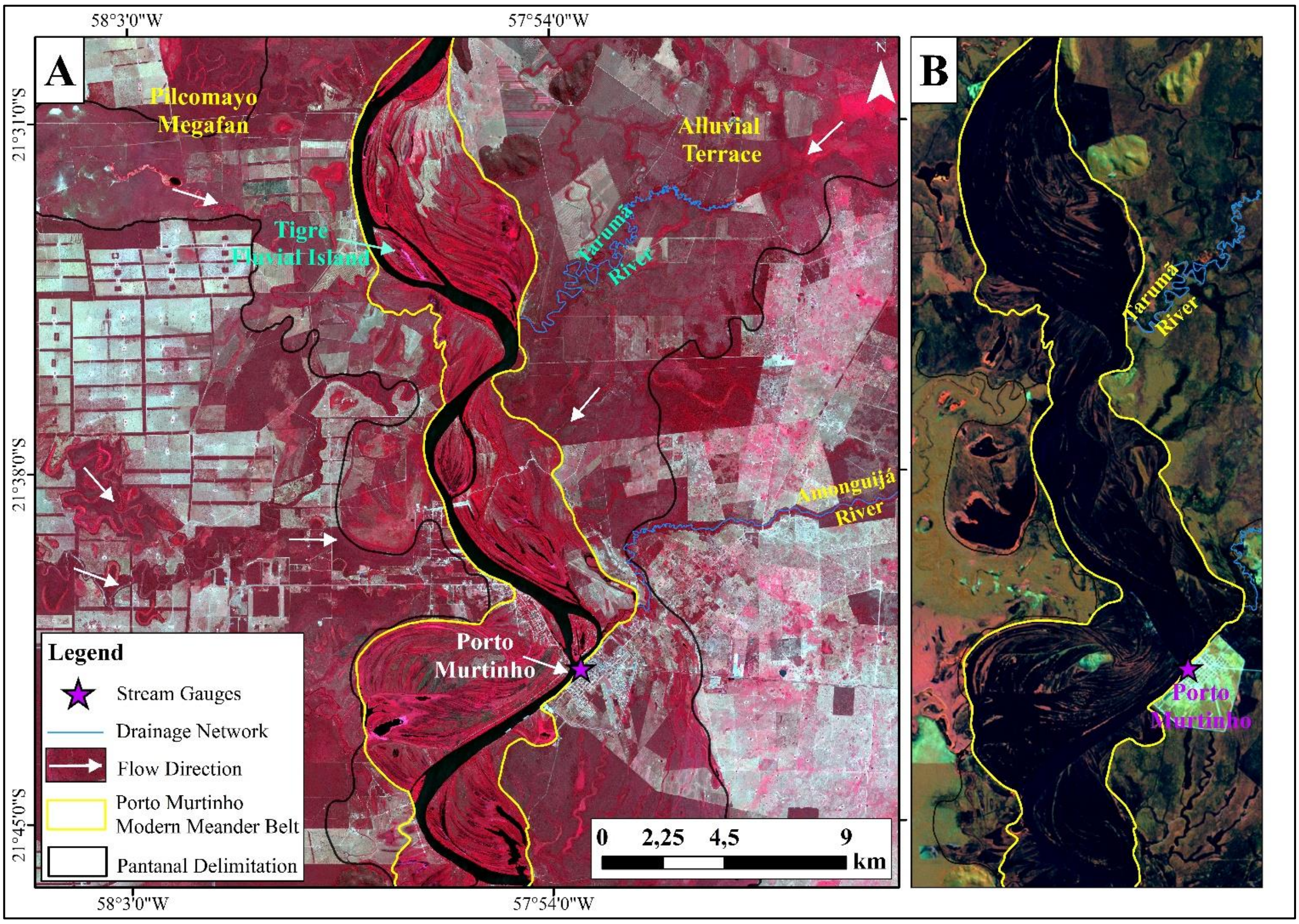

Figure 12. Overview of the Porto Murtinho meander belt. (A) CBERS-4A satellite image (WPM sensor) acquired in August 2023. (B) Landsat-5 satellite image (TM sensor) acquired in July 1988.

5. Conclusions

The geomorphological segmentation presented in this study constitutes a significant contribution to advancing the understanding of hydro-geomorphological processes along the Paraguay River and within the southern Pantanal. The integration of remote sensing data, digital elevation models, previous geomorphological mappings, and the use of manual vectorization techniques provided high resolution and robustness to the proposed geomorphological delineation. The analysis revealed marked spatial variability along the Paraguay River meander belt, including abrupt changes in channel orientation, distinct meander belt widths, and variations in sinuosity indices that reflect not only local hydro-sedimentary dynamics but also regional geological and structural controls influencing the fluvial system.

The mapped segments underscore the complexity of the Pantanal as a highly dynamic sedimentary basin, where past hydrosedimentary processes, such as avulsions and lateral channel migrations, continue to shape the modern landscape. Our findings emphasize the need to consider both temporal and spatial scales when examining the behavior of low-gradient fluvial systems such as the Pantanal. Moreover, the delineation of the six geomorphological segments (Porto Esperança, Forte Coimbra, Bahia Negra, Barranco Branco, Fecho dos Morros, and Porto Murtinho) provides an analytical foundation for monitoring and managing floodplain environments, which play a crucial role in flood attenuation, sediment redistribution, and the regulation of hydrological connectivity, particularly in regions affected by hydraulic bottlenecks and backwater effects.

Hydrological inputs from adjacent drainages and alluvial fans, along with the interactions between the main channel and the surrounding floodplains, are central to understanding the Paraguay River's hydrological and sedimentary dynamics. These interactions are essential not only for maintaining local ecosystems but also for sustaining the broader hydro-sedimentary functioning of the entire Pantanal system. The results presented here strengthen the scientific basis for policy-decision aimed at conservation and sustainable management of the Pantanal wetlands. Furthermore, the detailed identification of geomorphological segmentation and hydrological dynamics along the Paraguay River provides a valuable insight for water resource management, flood and drought risk mitigation, and the establishment of strategic frameworks for ecological resilience within one of the most complex and sensitive wetlands in the world.

Author Contributions: E.R.S.S.: Conceptualization, Methodology, Investigation, Writing – Original Draft, Review and Editing. A.S.: Conceptualization, Methodology, Visualization, Supervision, Funding Acquisition. H.A.: Methodology, Investigation, Data Curation, Writing – Review and Editing. S.K.: Methodology, Resources, Data Curation, Writing – Review and Editing. L.D.L.: Writing – Review and Editing, Visualization.

Funding: This study was funded by the Coordination for the Improvement of Higher Education Personnel (CAPES) – Funding Code 001; Foundation for the Support of the Development of Education, Science and Technology of the State of Mato Grosso do Sul (FUNDECT; Projects 267/2022, 172/2023, 342/2024, and 111/2024); National Council for Scientific and Technological Development (CNPq; Grant 406953/2021-0).

Acknowledgments: The authors thank the the State Board of Education of Mato Grosso do Sul (SED-MS), the Municipal Board of Education and Culture of Três Lagoas (SEMEC) and the Federal University of Mato Grosso do Sul for their facilitating this research.

Conflict of Interest: The authors declare that they have no conflicts of interest.

References

1. AB'SABER, A. N. O Pantanal Mato-Grossense e a teoria dos refúgios. **Revista Brasileira de Geografia**, v. 50, n. 2 Especial, p.9-57, 1988. Disponível em: <https://www.rbg.ibge.gov.br/index.php/rbg/article/view/1212>.
2. ALHO, C. J. R.; LACHER, T. E.; GONÇALVES, H. C. Environmental degradation in the Pantanal ecosystem. **Bioscience**, v. 38, n. 3, p. 164-171, mar, 1988. DOI: 10.2307/1310449
3. ALVARENGA, S. M., BRASIL, A. E., DEL'ARCO, D. M. **Geomorfologia**. Projeto RadamBrasil. Folha SF-21-Campo Grande. Rio de Janeiro, MME, 28: 125-184, 1982. Escala 1:250.000.
4. ALVARENGA, S. M.; BRASIL, A. E.; PINHEIRO, R.; KUX, H. J. H. **Estudo geomorfológico aplicado à Bacia do alto Rio Paraguai e Pantanais Matogrossenses**. Projeto RADAM/ BRASIL, Boletim Técnico, Série Geomorfologia. Salvador, 187. p. 89-183. 1984.
5. ASSINE, M. L. **Sedimentação na bacia do Pantanal Mato-Grossense, Centro-Oeste do Brasil**. Tese (Livre-Docência) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista Júlio de Mesquita Filho, Rio Claro-SP. 2003. 115p.
6. ASSINE, M. L.; MACEDO, H. A.; STEVAUX, J. C.; BERGIER, I.; PADOVANI, C. R.; SILVA, A. Avulsive Rivers in the Hydrology of the Pantanal Wetland. In: BERGIER, I; ASSINE, M. L (Orgs). **Dynamics of the Pantanal Wetland in South America**. Switzerland: Springer International Publishing, 2015a. p 83-110. DOI: 10.1007/978-3-319-18735-8
7. ASSINE, M. L.; MERINO, E. R.; PUPIM, F. N.; MACEDO, H. A.; SANTOS, M. G. M. The Quaternary alluvial systems tract of the Pantanal Basin, Brazil. **Brazilian Journal of Geology**, v. 45, n. 3, p. 475-489, 2015b. DOI: 10.1590/2317-4889201520150014
8. ASSINE, M. L.; SILVA, A. Contrasting fluvial styles of the Paraguay River in the northwestern border of the Pantanal wetland, Brazil. **Geomorphology**, v. 113, p. 189-199, 2009. DOI: 10.1016/j.geomorph.2009.03.012
9. BLUM, M. D.; TORNQVIST, T. E. Fluvial responses to climate and sea-level change: a review and look forward. **Sedimentology**, v. 47, p. 2-48, 2000. DOI: 10.1046/j.1365-3091.2000.00008.x
10. CAMPESTRINI, H.; MENECOZIM, A. R.; LAURINO, A. A. A.; MINEIRO JÚNIOR, F. J. **Enciclopédia das Águas de Mato Grosso do Sul**. Campo Grande: Instituto Histórico e Geográfico de Mato Grosso do Sul, 2014. 328p.
11. CARVALHO JUNIOR, O. A. Aplicações e perspectivas do Sensoriamento Remoto para o mapeamento de áreas inundáveis. **Revista de Geografia**, v. 35, n. 4, p. 412-431, 2018. DOI: 10.51359/2238-6211.2018.238239
12. CORDEIRO, B. M.; FACINCANI, E. M.; PARANHOS FILHO, A. C.; BACANI, V. M.; ASSINE, M. L. Compartimentação geomorfológica do leque fluvial do rio Negro, borda sudeste da Bacia do Pantanal (MS). **Revista Brasileira de Geociências**, v. 40, n. 2, p. 175-183, 2010. DOI: 10.25249/0375-7536.2010402175183

13. Esri Inc. **ArcMap (versão 10.8)**. Redlands, Estados Unidos-CA, 2021.
14. FLORENZANO, T. G. **Geomorfologia: conceitos e tecnologias atuais**. São Paulo: Oficina de Textos, 2008. 320p.
15. HICKIN, E. J.; NANSON, G. C. The Character of Channel Migration on the Beatton River, Northeast British Columbia, Canada. **Geological Society of America Bulletin**, v. 86, n. 4, p. 487-494, 1975. DOI: 10.1130/0016-7606(1975)86<487:TCOCMO>2.0.CO;2
16. IBGE. **Mapeamento de Recursos Naturais do Brasil**. Rio de Janeiro: IBGE, 2018. Escala: 1:250.000.
17. JUNK, W. J.; CUNHA, C. N. da; WANTZEN, K. M.; PETERMANN, P.; STRÜSSMANN, C.; MARQUES, M. I.; ADIS, J. Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil. **Aquatic Sciences**, v. 68, p. 279-309, 2006. DOI: 10.1007/s00027-006-0851-4
18. KUERTEN, S.; ASSINE, M. L. Rio Paraguai no megaleque do Nabileque, sudoeste do Pantanal Mato-Grossense, MS. **Revista Brasileira de Geociências**, v. 41, n. 1, p. 642-653, 2011. DOI: 10.25249/0375-7536.2011414642653
19. KUERTEN, S. **Evolução geomorfológica e mudanças ambientais no megaleque do Nabileque, Quaternário do Pantanal Mato-Grossense**. Tese (Doutorado em Geociências e Meio Ambiente) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista Júlio de Mesquita Filho, Rio Claro-SP. 2010. 111p.
20. KUERTEN, S.; PAROLIN, M.; ASSINE, M. L.; MCGLUE, M. M. Sponge spicules indicate Holocene environmental changes on the Nabileque River floodplain, southern Pantanal, Brazil. **Journal of Paleolimnology**, 49, n. 2, p. 171-183, 2013. DOI: 10.1007/s10933-012-9652-z
21. KUERTEN, S.; STEVAUX, J. C. Megaleques das bacias sedimentares do Chaco e Pantanal: uma revisão comparada. **Revista Brasileira de Geomorfologia**, v. 22, n. 3, 2021. DOI: 10.20502/rbg.v22i3.1886
22. LIMA, K. C.; LUPINACCI, C. M. Geomorfologia do semiárido: proposta metodológica de representação cartográfica e interpretação do relevo em escala de detalhe. **Revista Brasileira de Geomorfologia**, v. 22, n. 2, p. 217-234, 2021. DOI: 10.20502/rbg.v22i2.1527
23. LIMA, T. P. C. **Expressão geofísica-estrutural do Lineamento Transbrasiliano na porção central da Bacia do Parnaíba (Maranhão-Piauí)**. Dissertação (Mestrado em Geodinâmica e Geofísica) - Universidade Federal do Rio Grande do Norte, Natal-RN. 2015. 92p.
24. LO, E. L.; MCGLUE, M. M.; SILVA, A. BERGIER, I. YAGER, K. M.; MACEDO, H. A.; SWALLOM, M.; ASSINE, M. L. Fluvio-lacustrine sedimentary processes and landforms on the distal Paraguay fluvial megafan (Brazil). **Geomorphology**, v. 342, p. 163-175, 2019. DOI: 10.1016/j.geomorph.2019.06.001
25. MACEDO, H, A. **Geomorfologia e hidrossedimentologia da planície do Rio Paraguai, da Lagoa Vermelha à confluência do Rio Miranda, Pantanal Mato-Grossense**. Dissertação (Mestrado em Geociências e Meio Ambiente) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista Júlio de Mesquita Filho, Rio Claro-SP. 2013. 87p.
26. MACEDO, H. A. **Evolução Geomorfológica e Dinâmica Hidrossedimentar da Planície Fluvial Paraguai-Corumbá, Quaternário do Pantanal**. Tese (Doutorado em Geociências e Meio Ambiente) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista Júlio de Mesquita Filho, Rio Claro-SP. 2017. 195p.
27. MACEDO, H. A.; STEVAUX, J. C.; SILVA, A.; MERINO, E. R.; LO, E. L.; ASSINE, M. L. Hydrosedimentology of the Paraguay River in the Corumbá fluvial reach, Pantanal wetland. **Revista Brasileira de Geomorfologia**, v. 20, n. 2, p. 255-271, 2019. DOI: 10.20502/rbg.v20i2.1500
28. MARENGO, J. A.; OLIVEIRA, G. S.; ALVES, L. M. Climate change scenarios in the Pantanal. In: BERGIER, I., ASSINE, M. L. (Orgs). **Dynamics of the Pantanal Wetland in South America**. Switzerland: Springer International Publishing, 2015. p. 227–238. DOI: 10.1007/978-3-319-18735-8
29. MELO, C. G.; LUZ, I. C.; OSCO, L. P.; RAMOS, A. P. M. Chave de Interpretação para o Mapeamento do Uso e Cobertura da Terra da Bacia Hidrográfica do Alto Curso do Rio Santo Anastácio. **Colloquium Exactarum**, vol. 9, n. Especial, p. 226-233, 2017. DOI: 10.5747/ce.2017.v9.nesp.000147
30. MENEZES, P. R.; ALMEIDA, T. **Introdução ao processamento de imagens de sensoriamento remoto**. Brasília: Universidade de Brasília, 2012, 274 p. Available at: <https://www.researchgate.net/publication/332292728_introducao_ao_processamento_de_imagens_de_sensoriamento_remoto>.
31. MERINO, E. R. **Caracterização geomorfológica do sistema deposicional do rio Miranda (borda sul do Pantanal mato-grossense, MS) com base em dados orbitais**. Dissertação (Mestrado em Geociências e Meio Ambiente) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista Júlio de Mesquita Filho, Rio Claro-SP. 2011. 78p.
32. PADOVANI, C. R. **Dinâmica Espaço-Temporal das Inundações do Pantanal**. Tese (Doutorado em Ecologia Aplicada) – Escola Superior de Agricultura Luís de Queiroz, Universidade de São Paulo, Piracicaba-SP. 2010. 175p.

33. PARANHOS-FILHO, A. C.; MIOTO, C. L.; MACHADO, R.; GONÇALVES, F. V.; RIBEIRO, V. O.; GRIGIO, A. M.; SILVA, N. M. Controle Estrutural da Hidrografia do Pantanal, Brasil. **Anuário do Instituto de Geociências – UFRJ**, v. 40, n. 1, p. 156-170, 2017. Available at: <https://revistas.ufrj.br/index.php/aigeo/article/view/18237>.
34. ROSS, J. L. S. **Geomorfologia ambiente e planejamento**. São Paulo: Contexto, 1990. 98p.
35. ROSS, J. L. S. O registro cartográfico dos fatos geomorfológicos e a questão da taxonomia do relevo. **Revista do Departamento de Geografia**, v. 6, p. 17-29, 1992. DOI: 10.7154/RDG.1992.0006.0002
36. SCHUMM, S. A. River Response to Baselevel Change: Implications for Sequence Stratigraphy. **The Journal of Geology**, 101: 279 – 294. 1993. Available at: <https://www.jstor.org/stable/30081152>.
37. SILVA, J. S. V.; POTT, A.; ABDON, M. M.; POTT, V. J. **Projeto GeoMS: Cobertura vegetal e uso da terra do Estado de Mato Grosso do Sul**. Campinas: Embrapa Informática Agropecuária, 2011.
38. SOARES, P. C., ASSINE, M. L., RABELO, L. The Pantanal Basin: recent tectonics, relationships to the Transbrasiliano Lineament. In: IX Simpósio Brasileiro de Sensoriamento Remoto (SBSR), 9., 1998, Santos. **Anais...** Santos: INPE. 1998. Available at: <https://www.academia.edu/19406820/The_Pantanal_Basin_Recent_Tectonics_Relationships_to_the_Transbrasiliano_Lineament>
39. SOUZA FILHO, E. E.; STEVAUX, J. C. Geology and Geomorphology of the Baia-Curutuba-Ivinhema River complex. In: TOMAZ, S. M.; AGOSTINHO, A. A.; HAHN, N. S. (Eds.) **The Upper Paraná River and its Floodplain: Physical aspects, ecology and Conservation**. Leiden: Backhuys Publishers, p. 1-29, 2004.
40. SOUZA JR, C. M., et al. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. **Remote Sensing**, v. 12, Issue 17, 2020. DOI: 10.3390/rs12172735
41. STEVAUX, J. C.; LATRUBESSE, E. M. **Geomorfologia Fluvial**. São Paulo: Oficina de Textos, 2017. 320p.
42. STEVAUX, J. C.; MACEDO, H. de A.; ASSINE, M. L.; SILVA, A. Changing fluvial styles and backwater flooding along the Upper Paraguay River plains in the Brazilian Pantanal wetland. **Geomorphology**, v. 350, 2020. DOI: 10.1016/j.geomorph.2019.106906
43. TRENTIN, R.; SANTOS, L. J. C.; ROBAINA, L. E. de S. Compartimentação geomorfológica da bacia hidrográfica do Rio Itu: oeste do Rio Grande do Sul-Brasil. **Sociedade & Natureza**, v. 24, p. 127-142, 2012. DOI: 10.1590/S1982-45132012000100011