

Technogenic Modifications in River Channels Associated with Urbanization—Ribeirão Brandão Basin, Middle Paraíba Do Sul River Valley, Southeastern Brazil



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Abstract The study presented in this chapter aimed to identify and map technogenic modifications in the margins of river channels that compose the hydrographic network of the Paraíba do Sul River, one of the most important drainage basins of the Brazilian Southeast, seeking to relate them with the regional urbanization process. We used it as analysis cutout of the watershed of Ribeirão Brandão, which encompasses some of the growth axes of the industrial city of Volta Redonda (RJ), and, as a basis for identifying the types of margins of the main collecting river channels of this watershed, the classification of (Wheaton et al., *Geomorphology* 248:273–295, 2015), employing Google Street View and Google Earth Pro images for recognition of natural and built features that exert confinement of rivers. The results obtained show that: (i) in urbanized areas the main confining elements are landfills and buildings, often implemented in floodplains, plains, and terraces, modifying them significantly; (ii) in rural areas or areas with low densification of the urban network, slopes are the predominant confining features; (iii) the classification was effective in the spatialization of technogenic modifications on the banks of the channels, when combined with the recognition of Quaternary depositional features, contributing to the mapping of the technogenic relief.

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1 Introduction

The evolution of drainage systems during the last thousands of years in the columnous geomorphological compartments of the Atlantic Plateau of southeastern Brazil has been investigated by means of stratigraphic and geomorphological studies conducted by the Center for Quaternary and Technogenic Studies (NEQUAT) of the Federal University of Rio de Janeiro (UFRJ). Tecnogeno (NEQUAT) of the Federal University of Rio de Janeiro (UFRJ), using and developing and applying methodologies for reconstructing the sequences of erosional/depositional events, elaborating typologies, and identifying differentiated behaviors in the fluvial systems and drainage headwaters (Moura et al. 1991; Moura e Mello 1991; Mello et al. 2005; Mello 2006; Peixoto et al. 2010; among others). Based on the information produced, the most recent research has been dedicated to identifying and characterizing morphological and functional patterns in river systems, analyzing the role of urban and rural spatial transformations in the geomorphological dynamics of river and slope environments.

The modifications in rivers due to urban expansion and changes in land use in rural areas have been increasing in Brazil since the second half of the twentieth century, associated with the great change that occurred in the spatial concentration of the population, as pointed out by Pelech and Peixoto (2020), which made the country leave a markedly rural occupation pattern for a predominantly urban one. The urban expansion was mostly detached from environmental concerns in the various Brazilian regions, producing intense transformations both in the hydrological system (through soil sealing and construction of new drainage networks) and in the morphology and structure of the banks and beds, affecting the longitudinal profile and the shape in plan of the rivers, the hydrological connectivity between channel and plain and the riparian vegetation (Pelech and Peixoto 2020). The city of Volta Redonda (RJ), as a *company-town* founded in the 1940s with the installation of the Companhia Siderúrgica Nacional (CSN), experienced an accelerated urban growth marked, in a special way, by the different phases of the structuring of the productive networks of the base industry in southeastern Brazil, which allows identifying determining relations with technogenesis (Castro and Peixoto 2015; Mello, unpublished).

In this context, the previous studies carried out in Volta Redonda sought to elaborate a typology of rivers that would allow the identification of different morphological and evolutionary patterns and anthropogenic interventions, using as bases the River Styles® methodology proposed by Brierley and Fryirs (2000; 2005) and Brierley et al. (2002) integrated with the morphostratigraphic approach developed in the NEQUAT researches (Mello 2006; Peixoto et al. 2010). Subsequently, with the works of Del Pozo (2011), Ribeiro (2016), Oliveira (2017), Almeida (2021), and Mello (unpublished), new approaches for mapping and treatment of technogenic information have been applied and analyzed, and it is in this line of research that the present work is inserted. These authors identified, from cartographic bases and digital images, several types of alterations in the river channels by means of technical actions—such as concreting the gutters or banks and straightening the course of

ivers, or even works that made the channels underground—which express the close relationship between geotechnogenesis in river environments and the metabolism of the city.

Thus, this study aims to contribute to the development of procedures for mapping and analysis of the interventions operated on the banks of river channels in urban and rural areas in an integrated way to the recognition of features linked to the geomorphological structure of river systems, from the application of the taxonomy of river features presented by Wheaton et al. (2015), aiming to contribute to investigations on the technogenic relief in the region and in the country.

2 Study Area

Volta Redonda is located in the Tectonic Depression of the Paraíba do Sul River, a compartment inserted in domains of crystalline plateaus that border the southeastern coast of Brazil and limited to the south by the Serra do Mar, and to the north by the Serra da Mantiqueira (Fig. 1). The hydrographic basin of Ribeirão Brandão, chosen as study section, is one of the main tributaries of the Paraíba do Sul River in its Middle Valley, covering an extensive area of the southern portion of Volta Redonda and part of the neighboring municipalities (Barra Mansa and Pinheiral—RJ).

The hydrographic basin of Ribeirão Brandão river comprises geomorphological compartments of hills and hills developed, in the upper and middle courses, over gneisses and granitoids of the Precambrian crystalline basement and, in its middle and lower courses, also over Neogene sedimentary sequences that fill the Casa de Pedra Graben and the Volta Redonda Sedimentary Basin (units 6 and 7, respectively, in the geological framework of Fig. 1), limited by normal faults (Silva 2001). The variation in the dissection and morphology of the slopes and river valleys and in the orientation of the hydrographic networks express the structural controls of the Precambrian substratum and Cenozoic tectonics.

The hill domain where the Ribeirão Brandão basin is located has been remodeled by erosive and depositional processes during the late Quaternary, which is associated with the evolution of fluvial systems and drainage headwaters in amphitheater (the regional drainage networks) as well as the long-term evolution of the relief in southeastern Brazil, marked by neotectonic, lithostructural, and climatic controls. It has as characteristic Quaternary depositional features the different levels of fluvial terraces, the complexes of colluvium ramps, alluvium-colluvium ramps, and the present floodplains, sheltering distinct depositional materials and soils that have direct relation with the landscape development along the last thousands of years (Moura and Mello 1991; Moura et al. 1991). In this context, the main geomorphological and stratigraphic landmark corresponds to the Holocene entrenchment of the valleys and recesses of the drainage headwaters in amphitheater by the Manso Alloformation, associated with the formation of alluvium-colluvium ramps in topographic continuity with the highest regionally recognized terrace level. Subsequent phases of

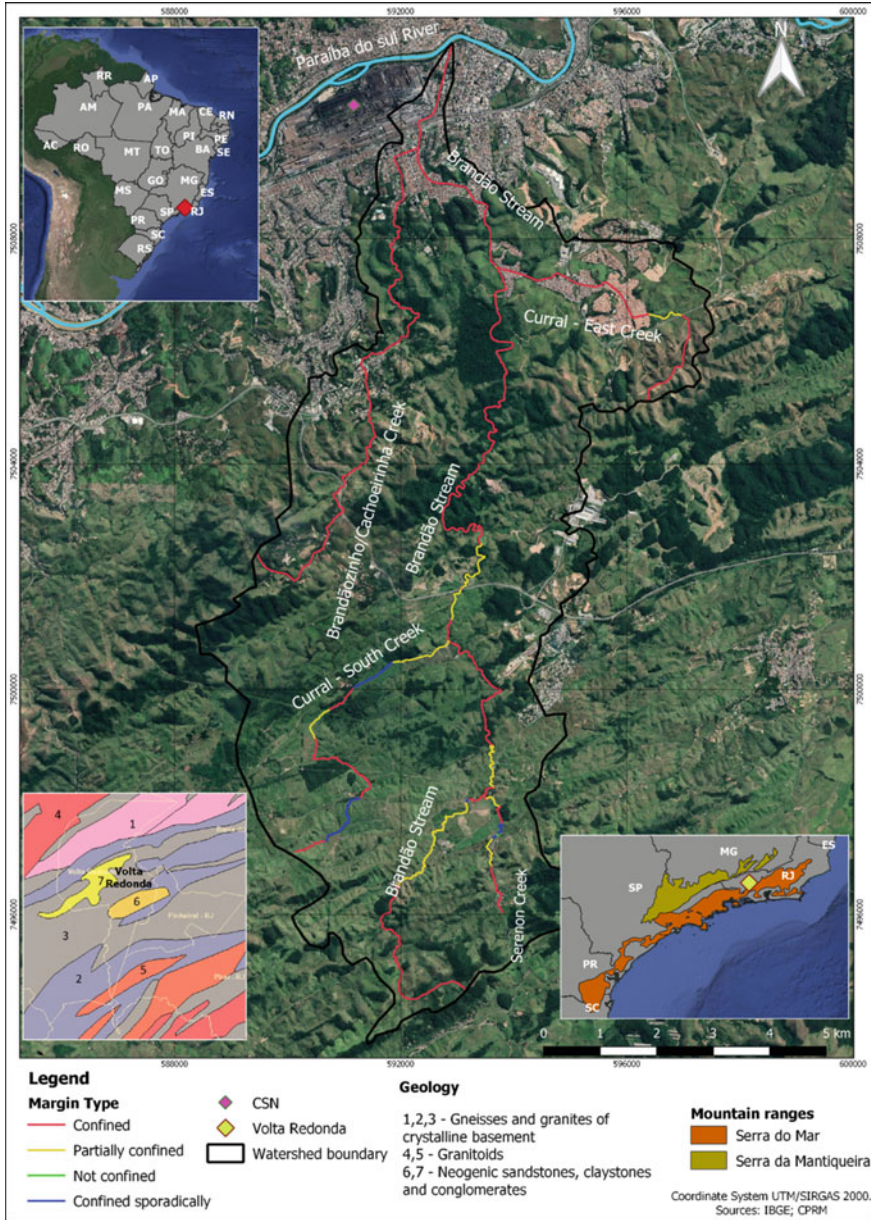


Fig. 1 Localization of Volta Redonda on Rio de Janeiro State (RJ), SE Brazilian Plateau, and Brandão Stream drainage basin showing confinement types of the main river and tributaries

fluvial entrenchment and hydrographic re-hierarchization by accelerated channelized erosive processes (gullies) have affected the watersheds and their tributaries differently, resulting in distinct patterns of preservation of the entrenchment features and generation of low terraces and fluvial plains, as can be identified in the mappings of Del Pozo (2011) and Ribeiro (2016), for example.

The hydrographic basin of Ribeirão Brandão embraces distinct hillside compartments with urban and rural uses, having previous studies of mapping and classification of features indicative of technogenic alterations in the drainage networks, detailed in several stretches of channels (Mello 2006; Peixoto et al. 2010). The Ribeirão Brandão has as main tributaries, from upstream to downstream (Fig. 1):

- the Serenon stream, located in the headwaters of the basin, and the Curral stream, the main tributary in the upstream section of the basin (called “Curral-Sul Stream” in this study);
- the Córrego do Curral tributary in the central stretch of the basin (here called “Córrego do Curral-Leste”, to distinguish it from its homonym) and the Córrego Brandãozinho or Cachoeirinha, the latter an extensive tributary that drains a large part of the western sector of the basin, in its middle and lower courses.

The main collector of the basin has a clear south-north orientation, crossing more dissected and elevated hill and hillside compartments in the headwaters and in its middle-lower course, which contrast with more depressed compartments of gentle hills and plains in the middle course and in the confluence zone with the Paraíba do Sul River (Fig. 1). The tributary sub-basins of Ribeirão Brandão are predominantly elongated, following the design and general orientation of the hill geomorphological compartments, and in several stretches, one can observe lattice drainage patterns, with higher drainage density (Mello 2006). The basin shows clear asymmetry, with the western tributaries more extensive than the eastern ones, observing also the structural control in the organization of the drainage network mainly in the middle and upper courses, by the orientation and sharp inflections of the main collector and the Curral-Sul stream, clearly controlled by the NE-SW regional lineaments. The predominant NW–SE orientation of the 1st and 2nd order channels in narrow and parallel aligned valleys is also evidence of this structural control. As described by Almeida (2021), the main collecting river channels of the Ribeirão Brandão basin present margins predominantly limited by slopes or fluvial terraces, being thus mostly confined (48.34 km) or partially confined (10.13 km), with few unconfined segments (0.1 km) or sporadically confined (3.29 km).

The Middle Valley of the Paraíba do Sul River region where the basin under study is located is characterized by a tropical climate, with average annual precipitation of around 1,300 mm. The largest precipitation volumes and the highest temperatures occur in the summer (December to February) when the average monthly rainfall totals range from 600 to 800 mm, which represents approximately 42.7–46.7% of the total annual precipitation volume. In autumn, the average monthly rainfall varies between 130 and 230 mm (about 10.1–13.4% of the total annual precipitation), and in winter (June to August), this average remains between 100 and 170 mm, (7.7–9.7% of the annual rainfall). Spring corresponds to the second wettest season, with

the average monthly rainfall totals ranging between 450 and 550 mm (31.5–36.1% of the total annual precipitation), according to Costa et al. (2012). In the case of Ribeirão Brandão, the rainfall regime, in association with the effects of changes in land use, has resulted in frequent floods, especially in the summer months, generating significant impacts in urban areas.

3 Methodology

3.1 *The Study of Rivers in the Technogenic Approach*

The basis of the studies on the processes and products related to the human agency in the region under study is the geotechnogenic approach, executed through the identification of the sets of technogenic processes in their specific geographic, territorial and historical contexts—the technogenic systems. The geotechnogenesis comprises: the modifications in the relief, resulting in the creation or remodeling of technogenic reliefs; the changes in the physiology of landscapes, with the creation, induction, intensification, or modification of the behavior of the processes of external dynamics; the generation of technogenic surface deposits (Oliveira et al. 2005, 2018; Pelech and Peixoto 2020).

In this approach, human technical action constitutes a modifying agent of geomorphological landscapes, being associated with changes in land use and land cover. The individualization of geotechnical processes and forms, as well as their correlated deposits and sedimentary facies that record the processes and stages of land use, allow the sequencing of anthropogenic environmental transformations (Peloggia et al. 2014; Oliveira et al. 2018). For the study of river systems, identifying the modifications in relief forms and spatializing them in drainage basins are fundamental steps of analysis, especially considering that rivers, due to their high geomorphological sensitivity, are important archives of recent environmental history.

In this sense, the methodology adopted for the identification of types of river channel margins and technogenic interventions was the taxonomy of fluvial geomorphological features developed by Wheaton et al. (2015). This methodology takes into consideration, the classification and taxonomy of fluvial forms, the river banks, structural elements, and geomorphic units, which requires, at first, a high level of detail analysis with high-resolution images. Wheaton et al. (2015) recommend, for the channel scale, that cartographic scales from 1:100–1:2000 be employed in the identification and representation of these components, and that structural elements, margins, and geomorphic units be discrete and represented by means of symbols.

The use of the taxonomy of river forms elaborated by Wheaton and collaborators in the present study is also based on the methodological framework of River Styles®, defined by a set of geomorphological units in a river section that establishes an integrated framework of the biophysical processes along the hydrographic basin, being identified by the character and behavior of the channel (Brierley and Fryirs

2000). The character—defined by the channel planform, geometry, the assembly of geomorphological units, the type of vegetation cover and detrital material—and the behavior—comprising the hydraulic characteristics, the channel-plain connections, the sediment regime and the propensity to geomorphological transformations—allow identifying discontinuities and local controls that result in the diversity of behaviors of rivers and river networks (Brierley et al. 2002; Fryirs 2003). The use of this framework in conjunction with the morphostratigraphic approach allows the identification and mapping of Quaternary depositional features of regional expression and individualizes different patterns of fluvial behavior (Peixoto et al. 2010; Del Pozo 2011).

Technological advances, especially in the last decade, have allowed the use of new remote sensing imaging techniques in geomorphological studies and mapping of fluvial environments in different climatic and tectonic contexts. In this scenario, the taxonomy proposed by Wheaton et al. (2015) stands out for providing a multilevel classification that can be applied in a wide diversity of environments and with the available inputs, based on principles of natural fluvial dynamics and allowing the incorporation of the diversity of technogenic features.

3.2 *Methods and Materials*

The taxonomy of Wheaton et al. (2015) defines different stages of analysis for river channels, which, for the purposes of the present study, were adapted to the purpose and the available inputs. Thus, the first step of the mapping carried out for the Ribeirão Brandão watershed was the identification of the different types of banks (channel, valley bottom, and valley) used to define the configuration of the valley. Within this step it is necessary to identify, firstly, if the river channel bank has characteristics that are indicative of direct technogenic interventions or not, examples of these interventions being the different types of built features such as embankments, fences, dikes, railways, roads, walls or other structures that limit the channel bank. According to Wheaton et al. (2015), channel banks with these types of intervention are present in many rivers, occupying, fragmenting, and dissecting many valley bottoms. River channel banks that do not contain features directly produced by human agency (termed “natural” by the authors) may also be associated with confining features such as terraces and slopes.

It is important to highlight the distinction between river valley margins and river valley bottom margins, which also differ from river channel margins, according to the authors: the valley margins correspond to the boundary between the slope environment and the valley bottom, while the valley bottom margins delimit the scope of only the active river channels and the contemporaneous floodplains (plains); the river channel margins correspond, in turn, exactly to the limits of the river channel, that is, they are defined by the boundary between the channel flow and the area reached when it overflows into the floodplains or plains during episodes of higher flow.

Thus, from the identification of the different margins and their layout, the confining conditions of the fluvial channels are firstly recognized, with the configurations of confined, partially confined and laterally unconfined valleys also referenced in the methodology of fluvial styles (Brierley and Fryirs 2005). According to Wheaton et al. (2015), a confining bank is defined as any channel section that is confined by a valley bank, valley bottom bank, or anthropogenic bank. Confining margins are those that are acting to restrict the lateral setting of a channel, and thus channel margins can be confined by slopes when they are contiguous to them (i.e., by the valley margin) or by other confining features, such as terraces and alluvial fans. In the latter case, these geomorphological features compose the valley, but not the valley bottom, within the conceptualization presented by the authors.

In the analysis carried out, Google Earth Pro images were adopted as the main basis for the mapping of technogenic fluvial features, both for presenting a satisfactory resolution to identify the elements focused on in the classification used, as well as for providing recent and good quality coverage (the one used dates from 23/07/2020). The Google Earth images were processed using the Quantum GIS *software*, defining the cartographic scale 1:1000 as a reference for the mapping, because even though it did not allow for detailed visualization of the interior of the channel, it satisfactorily identified the features present on its banks, as well as on the banks of the valley and valley floor, the focus of this study.

To identify and classify the existence and types of technogenic interventions, we also used the Google Street View tool, obtaining visualizations closer to those seen in the field. Thus, based on the more detailed observation of locations chosen as viewing points on Google Street View, the elements that confine the banks were identified, and with the images from the Google Earth platform, the mapping of their distribution along the main collectors defined for analysis was performed, identifying the degree of confinement. Subsequently, we mapped the confining features of the banks of the channels in the stretches not visualized in Google Street View, based on Google Earth images and using visual records of documents and studies produced previously.

To identify the type of bank confinement and the confining elements, it was necessary to recognize, whenever possible, the Quaternary depositional features present in the channel surroundings and their effect on the arrangement of the valley, valley floor, and channel margins. This identification was made by means of Google Street View, three-dimensional images of the relief by Google Earth Pro, and also by the analysis of contour lines.

4 Technogenic Modifications in River Channels

With an area of approximately 75 km² and a perimeter of approximately 55 km, the hydrographic basin of the Ribeirão Brandão river has its outlet in the Paraíba do Sul River, near the Companhia Siderúrgica Nacional (CSN) plant, encompassing in this area sections of the central neighborhoods of the city (Fig. 1). The Brandão

river is 31.03 km long and its main tributaries are 12.99 km long—Brandãozinho stream/Cachoeirinha stream, which stands out as its largest tributary—and 8.02, 6.41, and 3.39 km long—Curral-Sul stream, Curral-East stream and Serenon stream—the latter, as already mentioned, located in the basin head. The collector and its tributaries go through neighborhoods located in the southeast expansion front of the city of Volta Redonda, in the Gráben Casa de Pedra (case of the Córrego do Curral-Leste), and in the connection axis with the Presidente Dutra highway (case of the Brandãozinho/Cachoeirinha stream, in its lower course). The tributaries of the middle and upper courses run through areas with predominantly rural use, in which pastures dominate with the occurrence of small forest fragments.

The initial identification of river channel bank types, according to the Wheaton et al. (2015) classification, allowed the recognition of three main patterns, named “Anthropogenic” bank, “Partially Anthropogenic” bank, and “Natural” bank. These classes were individualized from the presence or absence of technogenic confining elements, recognized in the visual interpretation of the images. Constructed features and terrain, such as embankments and building walls, for example, define margins classified as “Anthropogenic”, while situations of confinement by hill slope segments or by higher fluvial terrace levels were considered within the “Natural” margin category. It was considered here, as a fundamental criterion, the significant preservation of Quaternary morphology, and therefore, disregarding other aspects acting in the modification of surface coverings by geotechno-genesis. The situations of coexistence of technogenic confining elements in a margin and natural on the opposite margin were classified as “Partially Anthropogenic”. As a result, we identified 44.13 km of channel margins classified as “Natural”, predominant in rural areas; 12.05 km of “Anthropogenic” channel margins, predominating markedly in urban areas; and 5.23 km of “Partially Anthropogenic” margins, generally associated with stretches in which built elements, such as roads, interfere in the natural confinement of rivers (Table 1).

Based on the recognition of differentiated structures on the banks of the channels and in the context of the river segments, a typology of channel banks was elaborated, resulting in six types that seek to synthesize the information regarding the elements that border the banks of the collecting channels of the Brandão river basin (Table 2).

It is evident from the data presented in Table 3 and the map is shown in Fig. 3 that the most common type of confinement of the banks of the main collectors of Ribeirão Brandão is produced by the slopes of the hills and hills, a situation that predominates in rural areas or where the urban network has a low degree of densification, and where the floodplain cannot be seen or does not exist.

Table 1 Length of channel margins types of Ribeirão Brandão and main tributaries, Middle Paraíba do Sul River Valley-Brazil

Margin type	Length (km)	Length (%)
Anthropogenic	12.5	20.23
Natural	44.1	71.36
Partially anthropogenic	5.2	8.41

Table 2 Confinement features of river channel margins* in Ribeirão Brandão drainage basin, Middle Paraíba do Sul River Valley-Brazil

<p>1. Landfills and buildings Channel banks confined by landfills with buildings or roads, often making it impossible to view the floodplain. They occur more frequently downstream of the Ribeirão Brandão basin, where the relief is softer, and with a high urban density</p>	
<p>2. Low terraces (sporadic) Channel banks with continuous floodplains bordered by low terraces in a few stretches. Their occurrence is restricted to upstream tributaries, in places where channels still present a meandering pattern</p>	
<p>3. Hillslopes 4. Hillslopes and roads or buildings River channel banks juxtaposed to the edges of the valley, with no floodplains. They occur in stretches with narrow valley bottoms, located mainly in the upper and middle courses of the basin. They may also be confined by highways, roads, or buildings, a situation found throughout the entire hydrographic basin</p>	
<p>5. Low terraces and hillslopes 6. Low terraces, hillslopes, or roads Conditions with a discontinuous floodplain where the channel's sinuosity is controlled by the valley floor margin; control can also be carried out by roads or highways. Its occurrence is restricted to the upper course of the watershed, where rural use predominates</p>	

Table 3 Length of confining features of the fluvial channel margins for Ribeirão Brandão and main tributaries, Middle Paraíba do Sul River Valley-Brazil

Types of confining features	Length (Km)	Length (%)
Landfills and buildings	12.692	20.51
Low terraces (sporadic)	3.2398	5.33
Hillslopes	31.913	51.58
Hillslopes and roads or buildings	3.739	6.04
Low terraces and hillslopes	9.513	15.38
Low terraces, hillslopes, or roads	0.616	1.00
Not identified	0.095	0.15

In the more urbanized stretches, the main element of confinement of the banks is the embankments, which are often made in floodplain and river plain areas, modifying them significantly.

In the map of Fig. 2, sections A and B are highlighted where Google Street View was used to visualize them in greater detail in order to serve as a reference for the areas without photo coverage from roads, where we could only perform a visual analysis in plan. In section A it is observed the predominance of channel margins is limited by embankments and buildings in the urban area, and by slopes or roads in the rural area, situations exemplified in types “1” and “4” of Table 2. The urban density of this area of the city implies a large number of interventions in the drainage networks, and most of the stretches of river channels with banks classified as “Anthropogenic” are inserted in this location. The stretch highlighted in B, upstream of the basin, encompasses rural areas with lower density of direct interventions in the river channels, observing the predominance of “Natural” and “Partially Anthropogenic” banks (types “2,” “4,” and “6” of Table 2).

The channel margin features identified in the present study show strong correspondence with the typology proposed by Mello (2006). Mello (2006) proposed nine types of fluvial channels in the Ribeirão Brandão basin: silted, clogged, erosive, forested, impermeable, incised, non-incised, rectified, rocky, and underground, identified based on the morphostratigraphic approach combined with the fluvial styles methodology. The channels classified by Mello (2006) as Rectified, Impermeabilized, and Underground correspond, in the current mapping, to those that present banks confined by embankments or constructions installed on the floodplain since the rectifications of the rivers are associated with engineering works carried out in various stretches of the basin in order to reduce flooding in urban areas and/or near highways. The channels that suffer the impermeabilization of their gutter and banks, in general, are also rectified, and it is frequent in urban areas with more dense occupation, the confinement in underground galleries, which make the rivers no longer visible.

On the other hand, the channels classified as Incised type by Mello (2006), which result from the Holocene or current fit of the drainage in valley bottoms filled by the Manso Aloformation, present, mostly, margins confined by slopes, terraces, or roads, and the inexistence of significant plains are explained by this behavior of

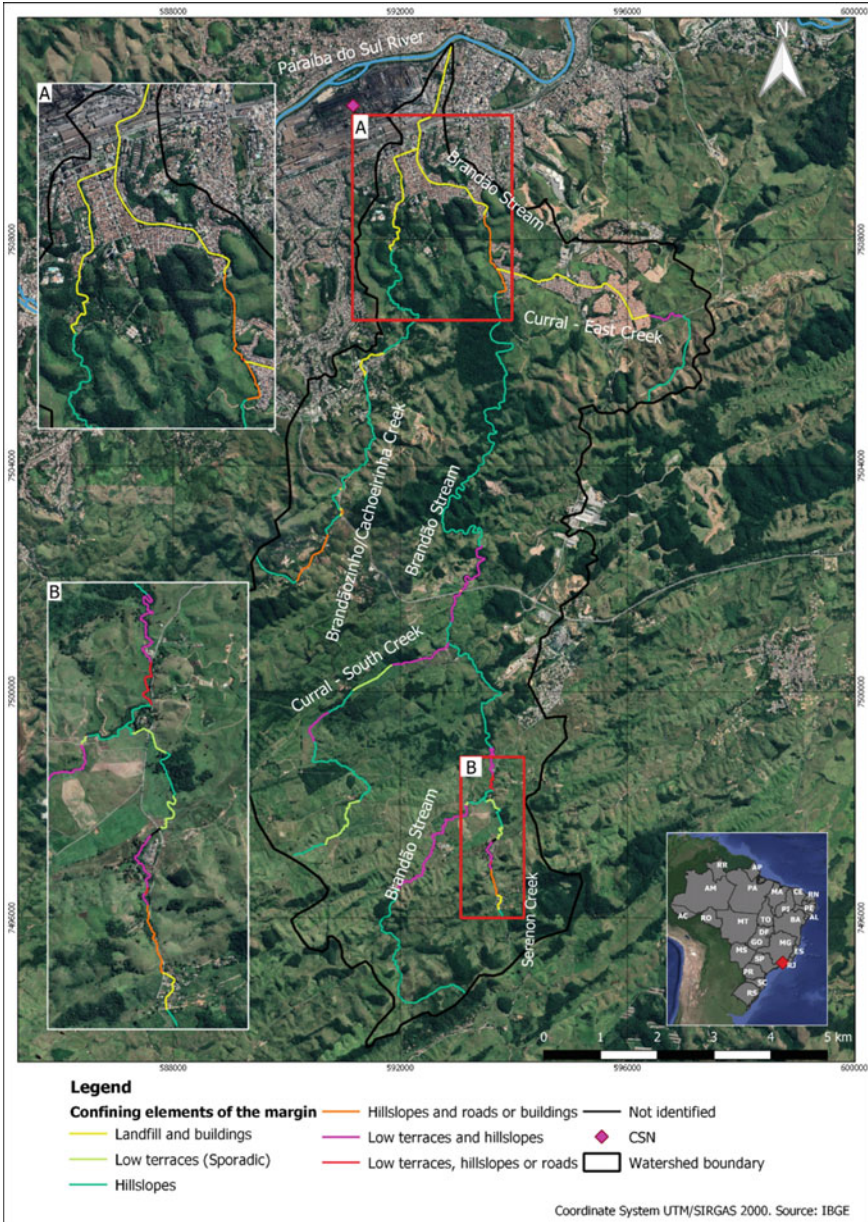


Fig. 2 Spatial distribution of confining features of fluvial channel margins of Brandão Stream and main tributaries, Middle Paraíba do Sul River Valley-Brazil

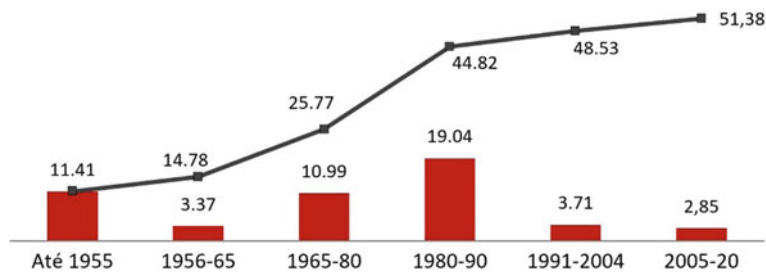


Fig. 3 Technogenic changes in river channels of Volta Redonda urban area between 1955 and 2020, in kilometers per time interval (red vertical bars) and accumulated values (black line)

fluvial incision. The non-incised type channels recognized by Mello (2006), in turn, which are generally found in wider valleys, show correspondence with the stretches of channels with unconfined margins, which present continuous floodplains limited or not by low terraces and with or without the presence of meandering channels, and can also correspond to channels with partially confined margins with discontinuous floodplains and sinuosity controlled by the valley or by roads.

It is verified, on the other hand, that the introduction of technogenic elements in the identification criteria of channel confinement resulted in a significant change in the interpretation of the general picture of fluvial confinement since most of the margins are shown to be confined by both Quaternary relief features and built structures associated with the urbanization process of the city of Volta Redonda and the region where it is inserted.

In the context of the regional evolutionary history, the intense dissection of the crystalline and sedimentary substrate by the drainage systems in the hillsides where the basin is located resulted in a topography with few stretches of significant valley widening, restricting the formation of broad floodplains. The fitting of the drainage network after the deposition of the Manso Aloformation, resulting in the formation of the highest fluvial terrace or, sometimes, also in low terraces, configure confining elements of the current fluvial channels, according to the classification used. In the lower course of the basin, on the other hand, although plains and terraces associated with the Paraíba do Sul River predominate, Ribeirão Brandão has its banks confined by landforms and buildings, showing a condition of significant restriction by the presence of technogenic features and deposits.

Another important aspect to be highlighted with respect to the methodology employed refers to the interpretation of the fluvial terraces in the identification of the type of confinement of the fluvial channels. In the case of the low terraces, we should consider the possibility of an induced technogenic origin, as shown by studies and records of technogenic fluvial deposits in the region (Mello et al. 1995), which would indicate a situation of confinement associated with anthropogenic channel margins. Thus, there is a need to improve this criterion, starting with specific investigations on the origin and evolution of the fluvial sedimentation levels (especially the low terraces).

Mello (2006; unpublished), when mapping the extension of technogenic modifications in the river channels in Volta Redonda, identifies several pulses of modification in the rivers and streams of the city, linked to different phases of production of the urban-industrial space (Fig. 3). In the first phase, which goes from the beginning of the 1940s until 1965, the construction of Companhia Siderúrgica Nacional (CSN) caused great population attraction to the region and was a determining factor for the Brazilian industrial advance. In the urbanization process that occurred in Volta Redonda, the planned occupation areas were intended for workers, technicians, and managers of the steel mill, excluding a large mass of temporary workers who began to occupy areas without infrastructure adjacent to the projected urban core.

In the second phase, from 1965 to the early 1990s, CSN began to incorporate other urban areas with a view to building and selling housing units, but still not meeting the high demand from population groups attracted by job opportunities and not absorbed by the company, which began to form “nuclei of possession” and irregular subdivisions. This is the phase of greatest territorial expansion of the city and, consequently, of acceleration in the changes in the river channels, both in the planned areas and in those of disorderly occupation. In the third phase, after the early 1990s, marked by the privatization of CSN and reduction of jobs, the pace of production of urban space slowed down, and the pace of expansion of the modified river channels was also reduced, although new works on the banks and the rectification of previously altered channels have been frequent.

These aspects demonstrate differences in the forms and technical sets of intervention in the river channels, with the types of confinement and modification of rivers and streams being associated with the urban expansion fronts and the spatially selective processes of implementation of the city’s basic infrastructure, as well as with the urbanization models adopted.

5 Final Considerations

The application of the methodology proposed by Wheaton et al. (2015) in the definition of river channel bank types for the main collectors of the Ribeirão Brandão watershed presented positive overall results for the mapping of technogenic fluvial features. The use of Google Earth Pro and Google Street View images enabled the visualization of the characteristics of the surroundings of the different stretches of the analyzed fluvial channels, allowing the classification of the channel, both regarding its level of confinement and its confining elements (either constructed or associated with regionally recognized Quaternary depositional features) to be satisfactorily performed. The limitations of Google Street View due to the fact that the photographs are taken from roads led us to select stretches for detailed analysis, being an important complement to the visual plan analysis.

Thus, we verified that the spatialization and analysis of technogenic modifications in the margins of river channels based on the taxonomy of Wheaton et al.

(2015) can contribute to the advancement of research on the mapping of technogenic relief in the crystalline plateaus of southeastern Brazil. Considering that the employed classification is also integrated with the framework of fluvial styles, we understand that the improvement of the procedures and their application in other geomorphological domains will contribute to the identification of patterns of fluvial behavior and geomorphological conditions of rivers in different urban and rural environments of Brazil. This knowledge, together with the evolution of basins and drainage systems, should subsidize the construction of scenarios and trajectories of technogenic geomorphological changes in already urbanized areas and in the urbanization expansion fronts, both in the southeast and in other Brazilian regions.

The study carried out in the Ribeirão Brandão watershed allows confirming, still, the relevance of the geotechnical approach for the fluvial geomorphology. Although in the urban evolution of Volta Redonda the role of CSN (together with the state power) as hegemonic modeling agent of the urban space is determinant for the rhythm of rivers confinement (Mello, unpublished), the processes of selectivity and spatial marginalization documented there are present in several Brazilian cities and may have effects on the speed and spatiality of the modifications in the river channels. Thus, the mapping of technogenic modifications in the river networks must be anchored in the investigation of the processes and forms of materialization of the urban metabolism.

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