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Hydrogeomorphological Characterization of the Riacho Riachão do Natal River Basin, Piauí, Brazil

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A B S T R A C T

The Riacho Riachão do Natal River (RRNR) is one of the greatest tributaries of the Poti River. It is in the left bank of the lower Poti, forming a basin of approximately 448.7 km², encompassing part of Miguel Leão, Olho D'Água, Monsenhor Gil, and Lagoa do Piauí, in state of Piauí, Brazil. The objective of this study was to characterize the RRNR Basin through morphometric analysis. Thirteen parameters were analyzed to improve the information on fluvial environment of this basin, using bibliographical references and thematic maps with scales of 1:1,000,000; 1:250,000; 1:100,000 and 1:20,000, processed on Geographic Information Systems (GIS) tools—ArcGIS, SPRING, and Global Mapper. Field observations were also carried out, making photographic records, and marking points with a GPS. This hydrographic system presents low drainage and hydrographic densities, i.e., low efficiency in forming new fluvial channels, and small probability of floods, but high risks of erosive processes. Thus, understanding the hydrographic pattern of this basin is essential for the local governments, contributing to planning land use and occupation.
Keywords: Relief, Drainage, Morphometric Analysis, Hydrographic System.

Caracterização Hidrogeomorfológica da Bacia do Riacho Riachão Natal, Piauí Brasil

R E S U M O

O Riacho Riachão do Natal é um dos grandes afluentes da margem esquerda do baixo do rio Poti. Sua bacia hidrográfica apresenta uma área de aproximadamente 448,7km², compreendendo parte dos municípios piauienses de Miguel Leão, Olho D'Água, Monsenhor Gil e Lagoa do Piauí. O objetivo geral desta pesquisa consistiu em caracterizar a dinâmica fluvial da bacia hidrográfica do Riacho Riachão do Natal, através de analise morfométrica. Foram analisados 13 (treze) parâmetros buscando ampliar os conhecimentos sobre a dinâmica do ambiente fluvial dessa bacia, utilizando pesquisas de referências bibliográficas, mapeamentos temáticos nas escalas de 1:1. 000.000; 1:250.000; 1:100.000 e 1:20.000, trabalhados em ferramentas de Sistemas de Informação Geográfica (SIG), como os softwares ArcGis, SPRING e Global Mapper. Também foram realizados trabalhos de campo, com registros fotográficos e uso de GPS. Na quarta etapa que correspondeu a última, procedeu a análise e finalização da pesquisa. Os resultados indicam que esse sistema hidrográfico apresenta baixas densidades de drenagem e hidrográfica, ou seja, pouca eficiência em formar novos canais fluviais e pequena probabilidade de ocorrência de enchentes, porém apresentam elevados os riscos de ocorrências de processos erosivos. Assim, constatou-se que compreender a dinâmica hidrográfica dessa bacia torna-se de grande importância para os municípios locais, contribuindo também para subsidiar o planejamento do uso e ocupação da terra.
Palavras-chave: Relevo, Drenagem, Análise Morfométrica, Bacia Hidrográfica.

Introduction

Information on land distribution and physical characteristics of a basin as a spatial unit are important for the environmental planning and management. A river basin is generally described as a depression area in the earth's surface that drains water and materials to a common water stream (Cunha & Guerra, 2006). According to Cunha and Guerra (2006), these basins are integrated units, and the analysis of the effects of their environmental and social variables in the landscape contributes to understanding the processes and changes occurring in them.

Information on the formation, constitution, and integrated processes that occur in a basin assist planners in the management and use of water resources. Moreover, identifying the risks of impact of anthropic activities on the rivers improves the evaluation of possibilities of their use (Guerra & Marçal, 2006).

Therefore, information on a river basin characterizing its temporal and spatial variability, water availability for human activities, and the maintenance of its natural aspects is important.

According to Florenzano (2008), environmental diagnosis must consider the constituent elements and the ecosystem functionalities, with base on geomorphological studies, and approaches involving selection and ranking of physical and biotic attributes.

The Riacho Riachão do Natal River Basin (RRNR) was chosen for this study because it is the largest tributary in the left bank of the lower Poti River, encompassing the municipality of Monsenhor Gil, in the state of Piauí, Brazil, which is one of the most important economic centers of the Middle Parnaíba region. Thus, the objective of this study was to characterize the relief and the water dynamics in the RRNR Basin through the analysis of maps and morphometric data.

Material and methods

The study was conduct with bibliographic research on fluvial geomorphology, and development and surveys on thematic maps based on satellite images with scales of 1:1,000,000; 1:250,000; 1:100,000 and 1:20,000 scales, and maps available in official bodies. Geoprocessing was carried out using the ArcGis, SPRING, and Global Mapper software. Field observations were also carried out, making photographic records, and marking points with a GPS.

Quantitative analysis of the data was based on the parameters described by Horton (1945), Stralher (1952), Hack (1957), Schumm (1956). Melton (1957), and organized by Christofoletti (1980). The main river was defined considering its extension and general direction. The shape of the basin was calculated by the method of David R. Lee and G. Tomas Salle (Christofoletti, 1980), using the geometric figure that is closest to the basin shape, in this case a rectangle.

The longitudinal profile of the main river based on the topographic charts with scale of 1:100,000 (DSG, 1973), and the layout of the river showing its relations with the geological and topographic elements were used to delineate the forest, and middle and lower watercourses of the Riacho Riachão do Natal River (RRNR) basin.

Study area

The RRNR basin is a sub-basin of the Poti River with an area of 448.7 Km².

It is in the left bank of the Poti River, in the center-north region of the state of Piauí, Brazil, between the parallels 05º30'S and 05º40'S, and meridians 42º40'W and 42º30'W (Figure 1). The Poti River is one of the largest tributaries of the Parnaíba River. It has an area of 49,800 km² between the parallels 04º06'S and 06º56'S, and meridians 40º00'W and 42º50'W, covering part of the states of Piauí and Ceará, which puts it in the federal domain (LIMA, 1982).

The Parnaíba River Basin has a total area of 344,122 km², comprising almost all the total area of the state of Piauí (99%), and part of the states of Maranhão (19%) and Ceará (10%). It forms the most extensive river basin among the 25 basins in the northeast of Brazil (ANA, 2017).

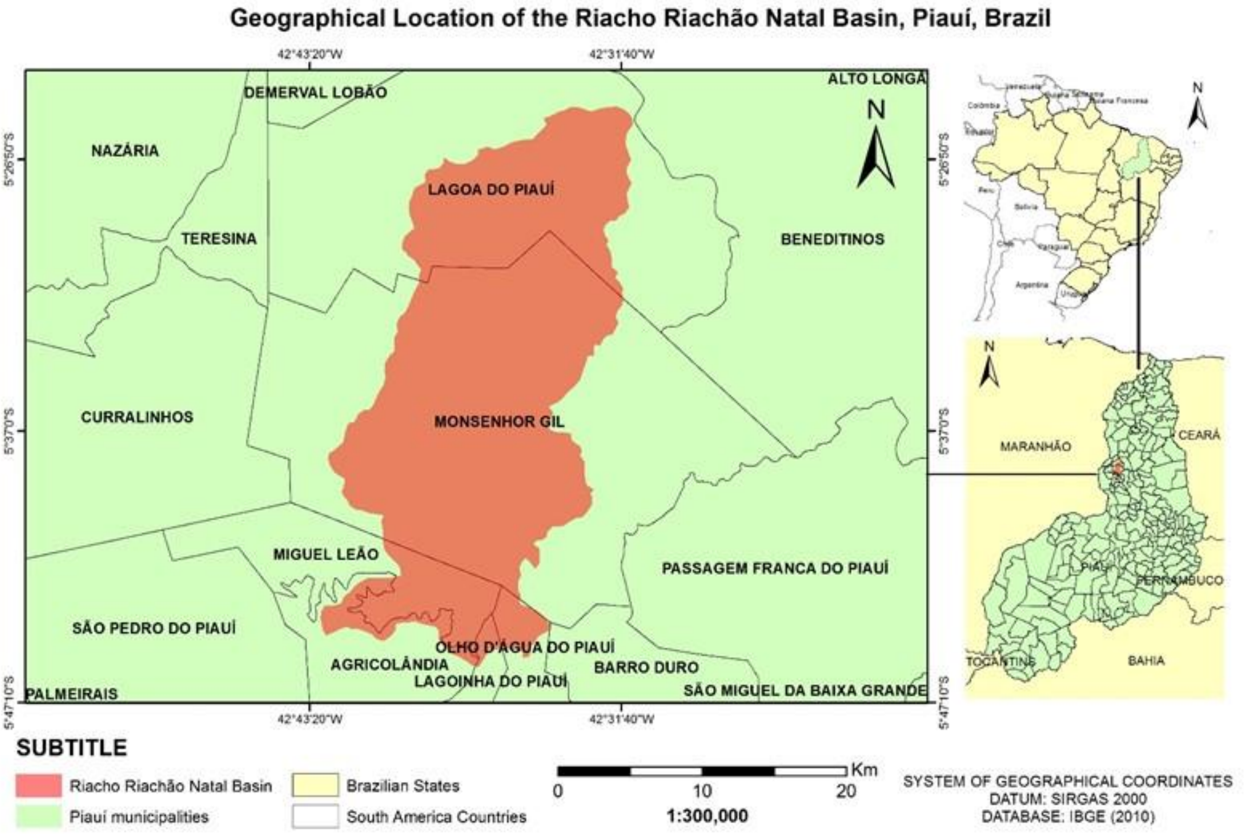

Figure 1: Map of the Riacho Riachão do Natal Basin

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Results and Discussion

Natural environment components and their aspects on the landscapes

Geological and hypsometric aspects - The RRNR basin is in the Parnaíba Sedimentary Basin, which consists of part of the Parnaíba Geological Province, specifically in its outcrop formation area dated from the Paleozoic to the Mesozoic eras. The area of the RRNR basin presents outcrops of *Pastos-Bons* formation in its upper watercourse, *Poti* formation in its middle watercourse, *Piauí* formation in most part of the area of its lower watercourse, and *Pedra-de-Fogo* formation in small parts of the topographic divisors of its lower and upper watercourses (Figure 2) (BRASIL/CPRM, 2006).

The *Poti* formation in the RRNR basin outcrops in a large portion of the middle watercourse, in contact with the *Pastos-Bons* formation from the Mesozoic era, indicating the appearance of a block in the form of a graben, but topographically in the same level of its surrounding formations (LIMA, 2013). This formation is being dissected by the main river and some of its tributaries (Figure 3). The contact with the *Piauí* formation in the northern boundary is rectilinear in the northwest-southeast direction, denoting control of the fault and fracture system of the *Santa-Inês* formation, which affects the areas of the middle and lower watercourses of the Poti River.

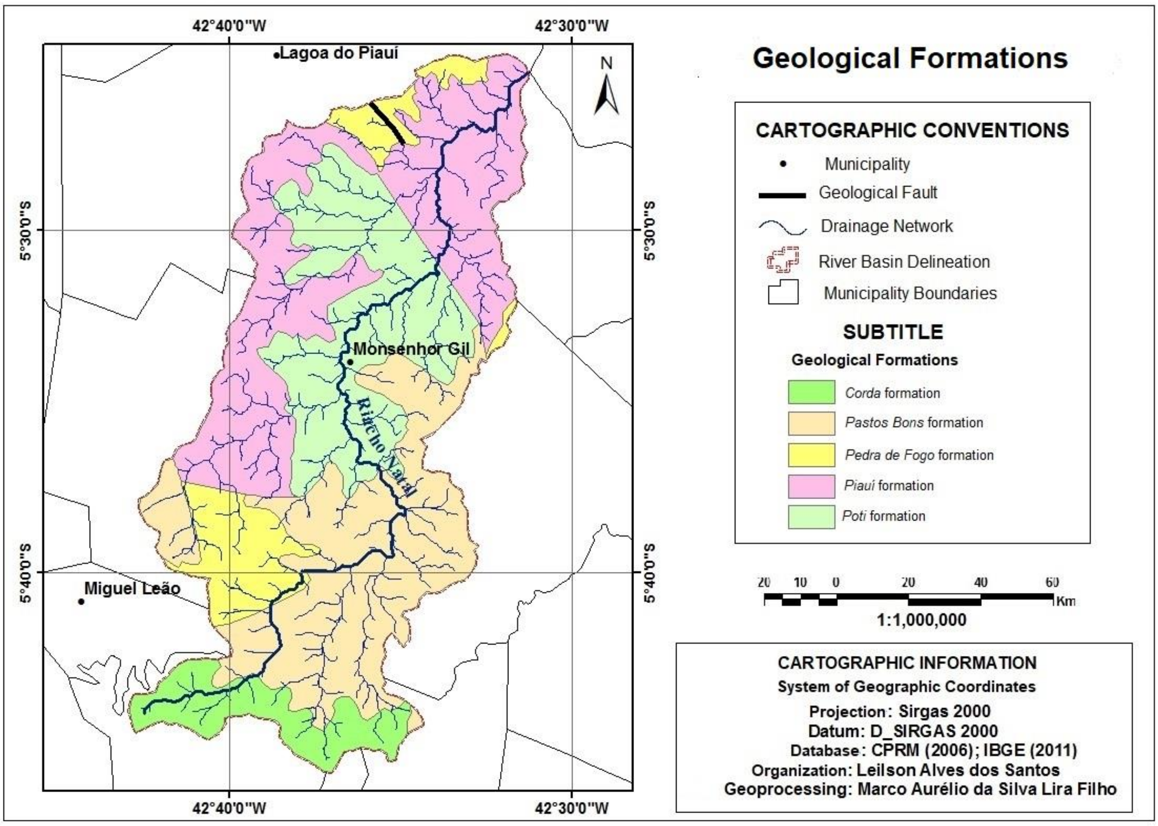

Figure 2: Geological map of the Riacho Riachão do Natal Basin. Source: BRASIL/CPRM (2006); IBGE (2011).

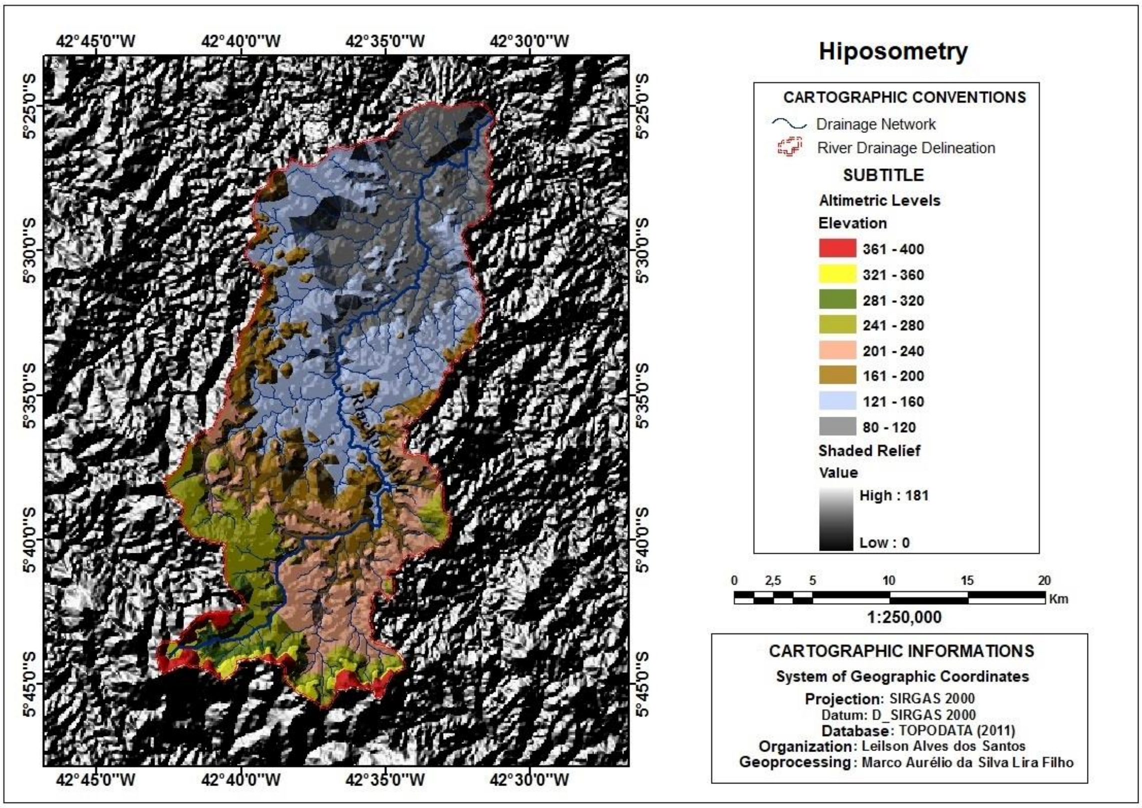

Figure 3: Hypsometric map of the Riacho Riachão do Natal Basin. Source: INPE/TOPODATA (20).

The current morpho-sculpture of the RRNR basin, represented by its relief units, is the result of the action of past tecno-sedimentary and climatic processes, affecting erosive processes, especially on geological structures (BRASIL/CPRM, 2006). This basin is in the Parnaíba Sedimentary Basin on the Paleo-Mesozoic sedimentary coverages; thus, it represents specifically the regional relief compartment that comprises the Lower Plateaus of the Middle-Low Parnaíba (Lima, 1987).

The altimetry of the RRNR lower watercourse has a north-northeast direction, with altitudes varying from 120 m to 80 m near its mouth, in the Poti River (Figure 3), and its main springs present altitudes of up to 400 m—an altitude amplitude of 320 m.

Hydrographic aspects - Data from the RRNR basin and its hydrographic network were the benchmarks used to calculate the indices that represent the basin current processes. The RRNR basin has a perimeter of approximately 129.2 km, and its main river has an extension of 51 km. The main springs of this river are in the borders of two geomorphological compartments—*Grajaú-Sierra* and *Barreirinha-Sierra*—in the rural area of Miguel Leão, in the center-north of Piauí.

The analysis of watercourses in a basin requires information on the basin physical characteristics, potentialities, and limitations, thus, morphometric parameters are essential elements to correlate the different aspects of the natural base and the watercourses of a given drainage area (Christofoletti, 1980; Machado & Torres, 2012). The morphometric indices contribute to the individualization of areas with homogeneous natural characteristics, i.e., the identification of singular characteristics present in the studied area. The parameters described in Table 1 were calculated using the data from the RRNR basin and its hydrographic network, and meet the initial objectives of this study.

Table 1: Parameters of the Riacho Riachão do Natal Basin

Parameter	Value
Basin area	448.7 km
Basin perimeter	129.2 km
Main river length	50 km
Total channel length	549.61 km
Average slope of the main watercourse	0.08%
Basin mean altitude amplitude	320m
Basin slope	6.4 m km^{-1}
Fluvial hierarchy	5^{th} order
Sinuosity index	1.31 km km^{-1}
Circularity index	0.3472
Coefficient of maintenance	819.67 m m^{-2}
Hydrographic density	0.78
Drainage density	1.22 km km^{-2}

Basin shape – The relief relation given by $Rr = \frac{\Delta a}{L}$, wherein Δa is the altitude amplitude, and L is the main channel length, establishes the relation between the altitude amplitude of the main channel and its total length (Schumm, 1956). This value was 0.71, indicating a basin with slightly wavy relief, confirming its capacity of gradually drain water due to its elongated shape.

The hydrographic density is given by $Dr = \frac{n}{A}$, wherein *n* is the number of channels, and *A* is the basin total area. According to Lana, Alves, and Castro (2001), values above 2 channels per km² indicate the large capacity of the basin in generating new watercourses. The RRNR basin had 0.78 channels per km², which denotes a low hydrographic density.

The drainage density, given by $Dd = \frac{C}{A}$, wherein *C* is the total length of the channels, and *A* is the basin total area, indicates the capacity of the basin in generating new watercourses, according to the classification of Christofoletti (1969). Drainage density values smaller than 7.5 km per km² indicate medium drainage density, and above 10.0 km per km² indicate high density. The RRNR basin had 1.22 km per km², which indicates a low drainage density. This result is due mainly to the predominant lithological elements of the study area, since the *Poti* and *Piauí* formations that outcrop in this basin have high permeability, facilitate water infiltration processes and, consequently, reduce the water capacity of sculpturing the relief and formation of new channels (Christofoletti, 1980). Lana, Alves, and Castro (2001) state that impermeable rocks promote better conditions for surface runoff and, consequently, greater attrition favoring the formation of channels.

Components of the hydrographic network - The coefficient of maintenance is given by $Cm = \frac{1}{Dd}1000$, wherein Dd is the drainage density. According to Morais and Almeida (2010), the higher the value obtained the lower the drainage density, since this parameter indicates the minimum area required for the maintenance of one meter of channel flow. This is one of the most important index for drainage systems (Lana, Alves & Castro, 2001). The RRNR basin had a coefficient of maintenance of 819.67m per m², which indicates that, in general, this basin has a deficit of watercourses.

The channel gradient (%), given by $Gc = a_{max} / L$, wherein a_{max} is the maximum altitude, and L is the main channel length, indicates the slope of the watercourses. The RRNR basin had a channel gradient of 0.08%, thus, its channels tend to have a low slope, which is also observed by its longitudinal profile.

Combined parameters - The circularity index (Ci) is given by $Ci = \frac{A}{Ac}$, wherein A is the basin total area, and Ac is the perimeter circle area equal to the A. According to Lana, Alves, and Castro (2001), this index represents the A to Ac ratio to assess the fluvial flow. According to Alves and Castro (2013), a Ci of 0.51 indicates a slight probability of flooding, a Ci greater than 0.51 indicates a basin with a more circular shape that favors flooding, and a Ci lower than 0.51 indicates a more-elongated basin that favors a gradual water flow, and a low probability of flooding during rainy periods. The Ci of the RRNR basin was 0.3472—elongated-shape basin with high flow level and low probability of flooding. However, a resident who lived in this region for more than 70 years, in an informal interview, reported great floods of the main channel in periods of intense rains, affecting mainly the municipality of Monsenhor Gil.

The sinuosity index is given by $Si = \frac{L}{dv}$, wherein L is the main channel length, and dv is the vector distance between the endpoints of the main channel. According to Lana, Alves, and Castro, (2001) and Alves and Castro (2003), sinuosity indices between 1 and 2 indicate transitional, regular, and irregular shape of the channels, since the sediment load, lithological compartmentalization, geological structuring, and channel declivities affect the channel sinuosity. The sinuosity index of the RRNR basin was 1.31, which indicates channels alternating between sinuous and rectilinear with no defined pattern—common in areas with phanerozoic cover.

The fluvial hierarchy of this basin, determined based on the methodology described by Arthur N. Stralher (1952), showed that the main channel (RRNR) is in the fifth categorical order (Figure 4), even with low drainage indices and low hydrographic densities.

According to this methodology, and a map with scale of 1:250,000, 354 channels were identified, comprising permanent, intermittent, and ephemeral channels, with a total length of 549.61 km. These channels are in the first (289), second (48), third (13), fourth (3), and fifth order (1) of the fluvial hierarchy; last one represented by the main channel.

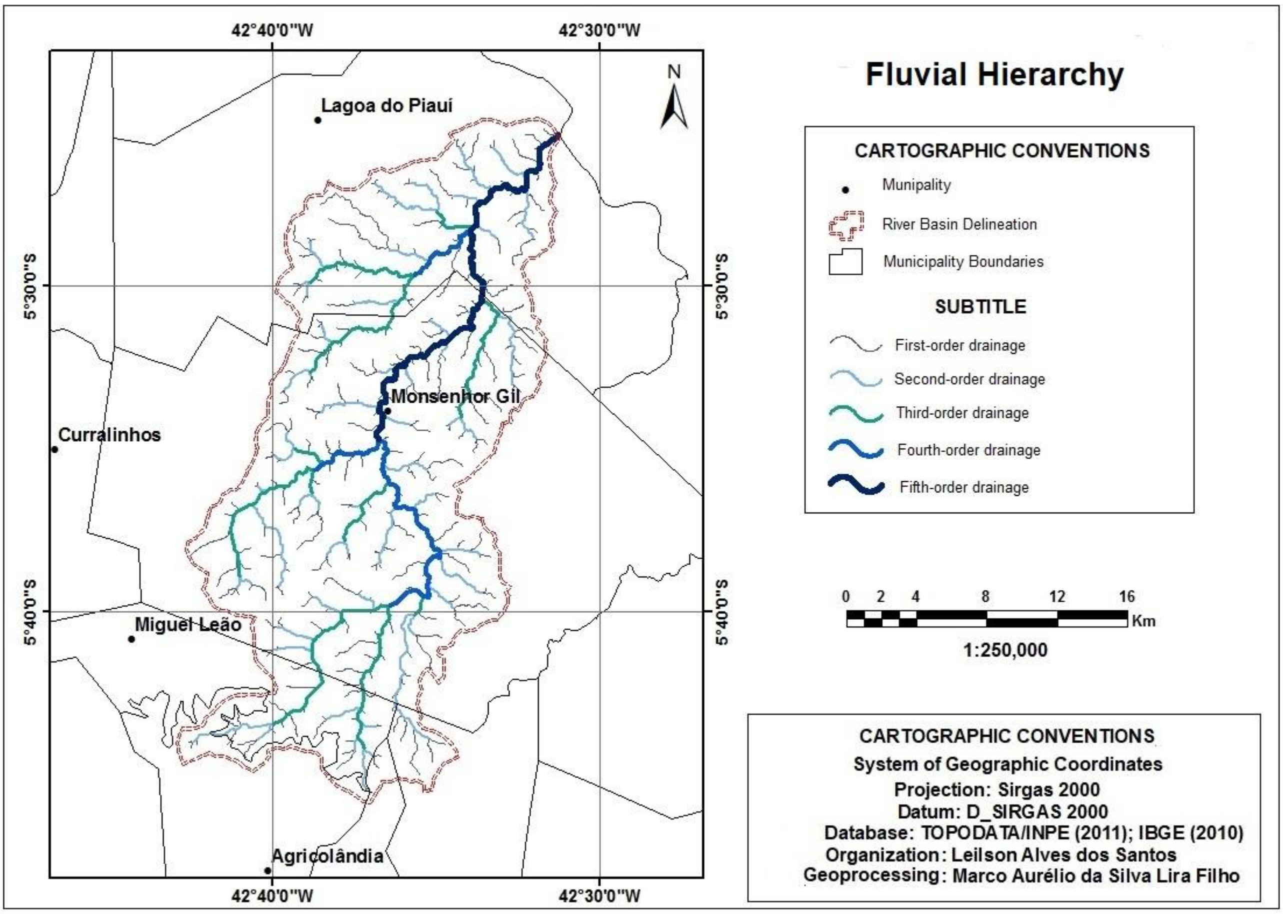

Figure 4: Map of fluvial hierarchy of the Riacho Riachão do Natal Basin. Source: Santos (2013)

First-order channels had 295.43 km in length and average length of 1.02 km. Second-order channels had 106.88 km and average of 2.22 km. Third-order channels had 76.55 km and average of 5.88 km. Fourth-order channels had 42.63 km, and average of 13.87 km. The main channel of the basin is in the fifth order and presents length of 29.12 km.

First-order channels represent 81.63% of the RRNR basin drainage, thus, 289 first-order channels are needed in this drainage network to generate second-order channels; 48 channels to generate third-order channels; 13 channels to generate fourth-order channels; and a total of 353 channels to generate a fifth-order channel, resulting in a hydrographic network consisted of 354 channels (Table 2).

Regarding the general direction, the RRNR presents a small asymmetry tending towards its left bank in the whole basin. However, it presents a small asymmetry in the upper watercourse to its right bank, compared to the springs. A probable structural control determines the change in general direction of the drainage from Northeast to Northwest, after the municipality of Monsenhor Gil—16 km before the river mouth.

Table 2: Characteristics of the drainage channels of the Riacho Riachão do Natal Basin

Channel hierarchical order	Number of channels	Channel total length (km)	Channel average length (km)	Channel area to the total area ratio (%)
First	289	295.43	1.02	81.63
Second	48	106.88	2.22	13.55
Third	13	76.55	5.88	3.68
Fourth	3	41.63	13.87	0.84
Fifth	1	29.12	29.12	0.30
Total	354	549.61	-	100

Climate, relief, soil, and vegetation relationships

The RRNR basin different lithological characteristics and climatic elements are the main factors determining the changes in its relief local compartments, whereas the soil characteristics affect more directly its diversity of vegetation cover physiognomy, generating its different environmental systems.

Climatic data of the lower Poti River have low variation in precipitation and temperature. The climatic data of Monsenhor Gil (Andrade Júnior, 2004) was used in this study because it is the only location within the study area, and it comprises a larger area of this basin. The periods with the high precipitation in this location are concentrated in December to April, with precipitation of up to 330 mm per month; the dry period is in May to November, with precipitation less than 50 mm per month, when the highest mean temperatures are observed—approximately 30ºC.

The climatic characteristics of the RRNR basin correspond to transition areas with sub-humid characteristics, but its few months of humidity concentration denote the predominance of physical weathering. Regarding the pedogenetic processes, the soils of the RRNR basin are, in general, under erosion or dissection conditions. Dystrophic Red-Yellow Argisols (Ultisols) are found practically in all the basin area, in which plant species of the Cerrado biome are predominant. Dystrophic Yellow Latosols (Oxisols) are concentrated in parts of the springs and extremities of its middle watercourse, where dystrophic lithoidal Neosols (Entisols) are found. The later are also found in greater concentration in the municipality of Monsenhor Gil, where there are fragments of mixed secondary forest. Dystrophic Plinthsol (Oxisols) are found exclusively in its lower watercourse, in the mouth area, and presents sporadic Field vegetation (Figure 6).

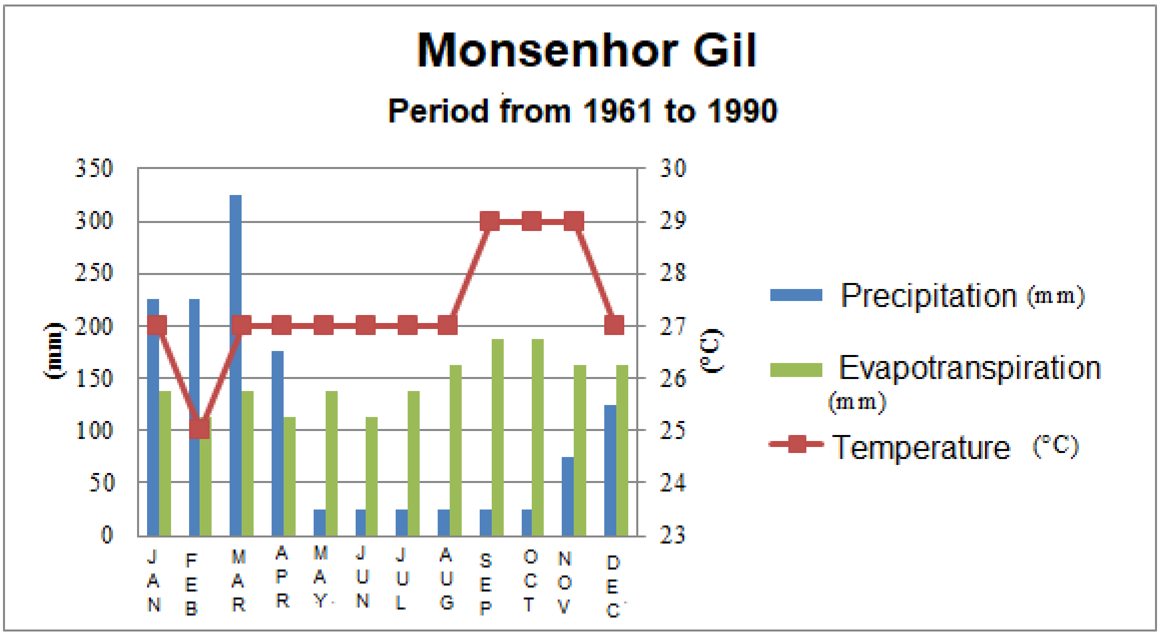

Figure 5: Climatic data of Monsenhor Gil, Piauí, Brazil. Source: EMBRAPA (2004); Lima (2013)

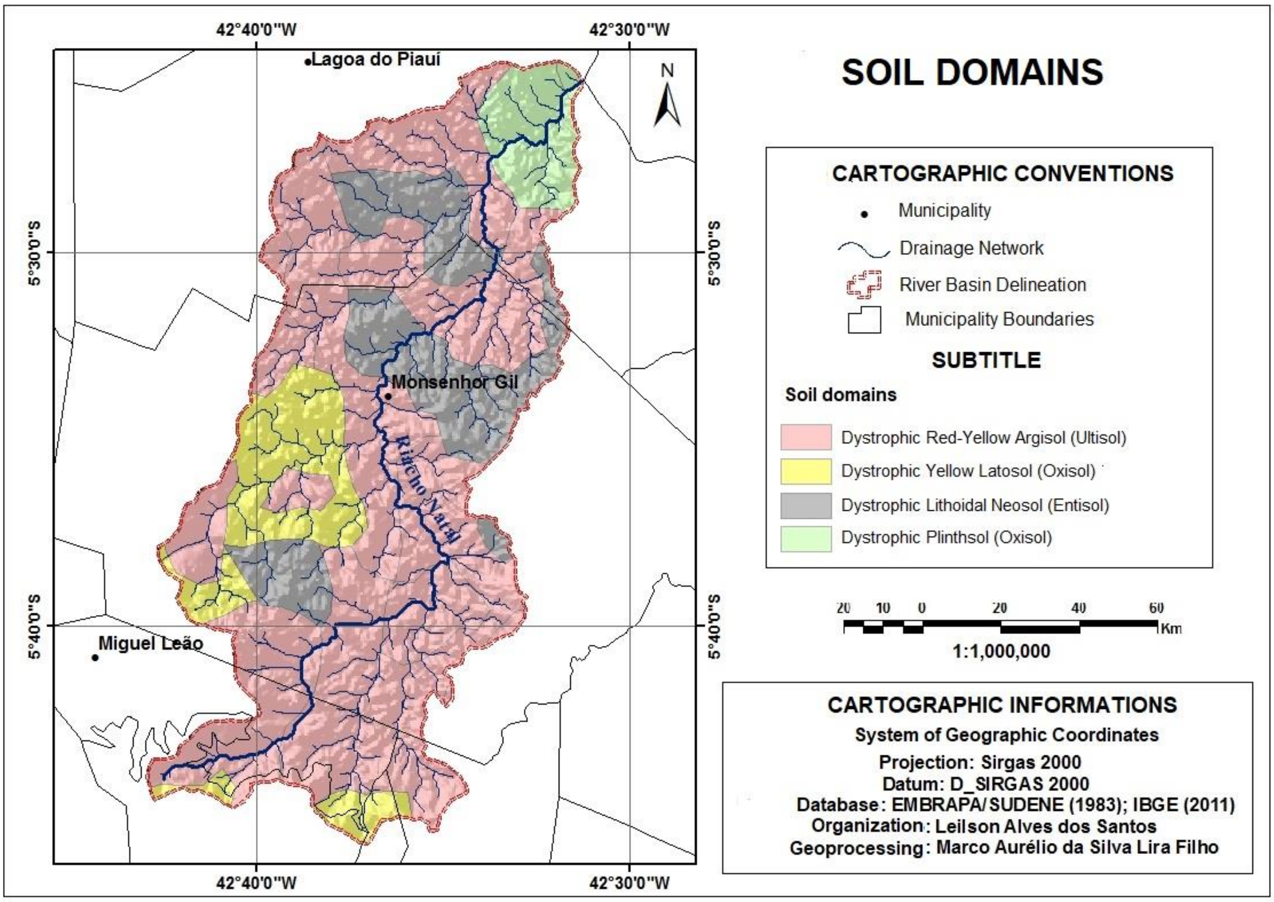

Figure 6: Map of soils of the Riacho Riachão do Natal Basin. Fonte: Santos (2013)

According to Lima (2013), the RRNR basin is located predominantly in the Cerrado Field Phytoecological Unit, presenting Field, and Mixed Secondary Forest fragments in its middle watercourse area, and Field fragments at a lesser extent in its lower watercourse near the mouth. Field observations showed partially preserved riparian forest in some stretches along the main channel, presenting typical physiognomy of Cerrado and great frequency of arboreal species (Figures 7 and 8). This vegetation reduces, to a certain extent, the contribution of coarse sediments to the RRNR riverbed.

Figure 7 shows the typical aspect of Cerrado vegetation with herbaceous stratum in the foreground, and shrub and arboreal strata from the top to the base of the slope in the background. The riparian forests of the region are preserved, with arboreal vegetation, highlighting the presence of babassu palms, and the river presents a rocky riverbed (Figure 8).

Figure 7: Photograph highlighting aspects of the Cerrado vegetation present in the Riacho Riachão do Natal Basin, downstream of Monsenhor Gil, Piauí, Brazil (2012)

Figure 8: Photograph of the Riacho Riachão do Natal riverbed on a stretch in Monsenhor Gil, Piauí, Brazil (Feb/2016)

Longitudinal profile of the main river, and the topographic profile of the Riacho Riachão do Natal Basin

The delineation of the upper, middle, and lower watercourses of the RRNR was carried out through altimetry based on its longitudinal profile. Thus, the upper watercourse was determined as the stretch from main springs up to a height of 180 m, extending a length of 4 km. The middle watercourse was determined as the stretch from 180 m to 80 m, with approximately 3 km. Field observations showed a significant extension of the valley in this stretch, denoting well-active processes of erosion, and carrying of sediments. The lower watercourse was determined as the stretch from 80 m to its mouth, in the Poti River (05º25'2"S and 42º31'59"W), near Lagoa do Piauí, Piauí, Brazil.

The longitudinal profile of the RRNR presents characteristics of a river in process of equilibrium (Figure 9). A channel in this stage has effective carrying of dendritic load, not carving rocks or depositing sediments, and can be considered a sediment carrier; when it reaches uniformity between erosion processes and fluvial deposition, it can be considered a river with equilibrium (Christofoletti, 1980).

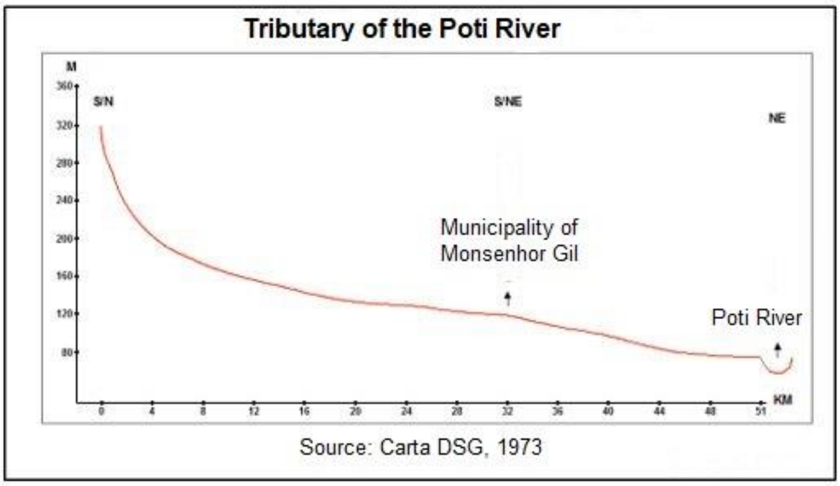

Figure 9: Longitudinal profile of the Riacho Riachão do Natal. Source: Lima (2013)

According to Christofoletti (1980), when a river reaches the ideal drainage, a gradual decrease of slopes occurs, reducing the water speed from the spring to the mouth, the carving competence, and the granulometry of the sediments that compose the riverbed.

Thus, the sediment carrying processes are predominant in the RRNR basin, mainly in its lower watercourse, however, erosion processes continue to predominate in its upper watercourse, especially in smaller channels, favoring local changes.

Analysis of topographic and geological charts, and field observations showed that the springs of the main channel are under the *Corda* formation in a stretch of approximately 4 km, the main channel in a local fracture in the NE direction for 6.5 km until the Baixão da Ribeira village; and, from this point, stretches of the RRNR cutting dikes of diabase rocks for a length of 10 km. Then, the RRNR enters the *Poti* formation for about 9 km in NE direction until Monsenhor Gil, and turns to the N direction for about 3.5 km, where it returns to the NE direction.

The RRNR makes confluence with Seco River—one of its largest tributaries in its left bank—at 1 km upstream of Monsenhor Gil, at the bottom of the valley, where diabase rocks outcrop for a stretch of approximately 1 km. Then, the river found rocks of the *Piauí* formation for a stretch of 12 km until reaching its mouth, in the Poti River (Figure 10). The valley in the final stretch of the RRNR, in Lagoa do Piauí, presents a local fault of NE-NW direction, with rocky outcrops, sporadic vegetation, absence of formations of terraces and fluvial plains in the surrounding areas.

Figure 10: Satellite image of the Riacho Riachão do Natal mouth on the Poti River. Source: Google Earth (2017)

Topographic profile and cross-sections of the study area showed the characteristics of the valleys and main channel (Figure 11). The upper watercourse of the main river is in a valley (Figure 11, A-B) with the tops presenting a moderate to strongly dissecting level and round trend, denoting the carving energy of the most prominent valleys in this drainage network.

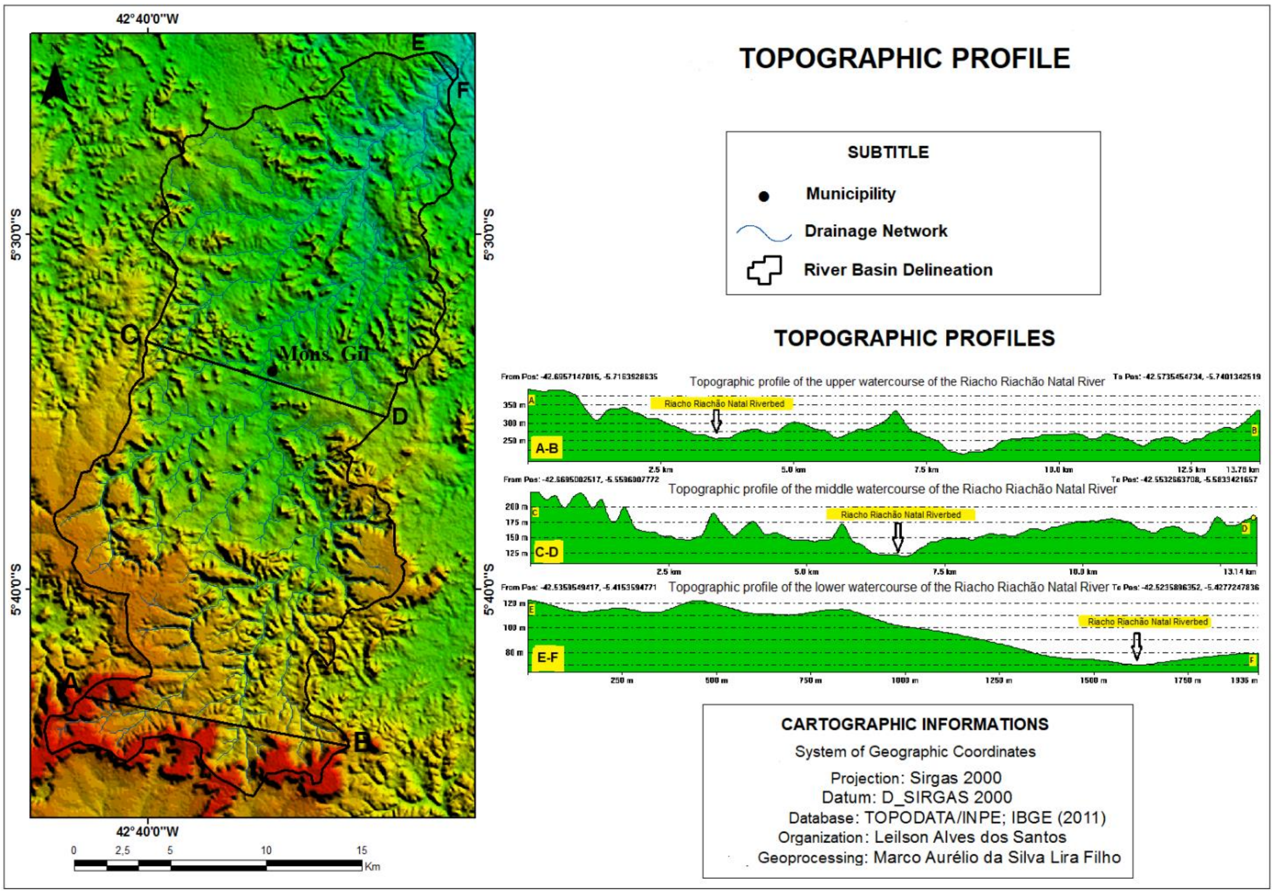

Figure 11: Cross-sections of the topographical profile of upper, middle, and lower watercourses of the Riacho Riachão do Natal Basin, (2017)

The main channel is wider in its middle watercourse (Figure 11, C-D), however, it is flows in the valley, with much more dissected tops in its left bank than in its right bank. The river banks in the lower watercourse (Figure 11, E-F) has an expressive asymmetry. Its left bank is higher and less dissected than in the middle watercourse, and its right bank is a narrow stretch of land, forming low divisors with small basins upstream of other rivers that also have its mouth in the lower Poti River.

Final considerations

The analysis of the geoenvironmental elements of the Riacho Riachão do Natal (RRNR) Basin showed the most important natural characteristics and socioeconomic aspects for the understanding of the environmental dynamics of this hydrographic system. The RRNR basin physiognomy and changes are partially dependent on geological structural controls at the local level, especially in its drainage system.

According to the fluvial hierarchy classification described by Stralher (1952), it is a fifth-order basin formed predominantly by intermittent channels, with 80% of its fluvial channels in the first hierarchical order. The morphometric parameters of this basin showed its low drainage capacity, which results directly in low capacity of generating new channels. This can be attributed to its lithological characteristics—predominance of highly permeable sedimentary rocks, shallow soils, and tending to flat to slightly wavy relief. However, well-preserved riparian forest fragments were found.

This river basin does not undergo great floods, except in periods of intense rains. This is attributed to its elongated geometric shape, which favors the gradual surface runoff of the waters, and minimizes flood risks.

Therefore, this study is an initial step towards the understanding of the hydrogeomorphological aspects of the Riacho Riachão Natal Basin, and a contribution for further studies on the physical geography of the state of Piauí on a medium scale. It provides information on the local physical environment of this important basin of the center-north of Piauí, Brazil.

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