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Aspectos geomorfológicos e hidrográficos da Serra da Jiboia, Bahia

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R E S U M O

A Serra da Jiboia abriga um dos últimos fragmentos do norte da Mata Atlântica Brasileira, cobrindo uma região de 440 km^2, com uma proposta em andamento para a criação de uma Unidade de Conservação. O contexto geológico e geomorfológico único contribuiu para transformar a Serra da Jiboia em um refúgio ecológico isolado no Estado da Bahia. A peculiaridade da Serra também explica a presença de nascentes de rios importantes do Estado: Dona, Jiquiriçá, Paraguaçu e Jaguaripe. A Serra é uma barreira orográfica, limite entre clima seco e úmido, e a região ao redor é explorado para atividades antropogênicas, principalmente a agricultura. Este estudo teve como objetivo caracterizar o relevo e a morfometria das bacias hidrográficas da Serra da Jiboia como uma das ações fundamentais para apoiar a preservação dos últimos fragmentos florestais. Foram analisados: declividade, razão de relevo, terreno e curvatura da encosta, orientação da encosta, curvas hipsométricas, coeficiente de compactação (Kc), fator de forma (F), densidade de drenagem (Dd), densidade de drenagem (Dd), densidade hidrográfica (Dh), número de canais (N) e sinuosidade (S). Observamos a predominância de áreas com rampa para declive acentuado e presença de bacias mais jovens em áreas de maior declive. A predominância de canais de primeira ordem mostra a fragilidade hidrológica do ecossistema da Serra e a baixa sinuosidade dos rios das principais bacias indica potenciais escoamento superficial, erosão e perda de solos. Concluímos que as características geológicas e geomorfológicas são aspectos fundamentais que comprovam a necessidade de manutenção da vegetação natural para a conservação do solo e da água.

Palavras-chave: floresta ombrófila tropical, fragilidade do solo, unidade de conservação

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A B S T R A C T

The Jiboia Range is one of the last northern fragments of Brazilian Atlantic Tropical Forest, covering a 440 km^2 region, with an ongoing proposal for the creation of a Conservation Unit. The unique geological and geomorphological context contributed to transforming the Jiboia Range into an isolated ecological refuge in Bahia State. The peculiarity of the range also explains the presence of important river sources of the State: Dona, Jiquiriçá, Paraguaçu, and Jaguaripe Rivers. The range is an orographic barrier, separating dry from and humid climate, then the surrounding environment is exploited for anthropogenic activities, mainly agriculture. This study aims to characterize the relief and morphometry of the watersheds in the Jiboia Range as one of the fundamental actions to support the preservation of last forest fragments. We analysed: slope aspect, relief ratio, terrain, and slope curvature, slope orientation, hypsometric curves, compactness coefficient (Kc), form factor (F), drainage density (Dd), hydrographic density (Dh), number of channels (N) and sinuosity (S). We observed the predominance of areas with rolling to steep slope and presence of younger basins in areas of higher slope. The predominance of first-order channels showed the hydrological fragility of the ecosystem of the range and the low sinuosity of the rivers of the main basins indicates potential surface runoff, erosion and soil loss. We concluded that the geological and geomorphological characteristics are fundamental aspects that prove the need to maintain natural vegetation for soil and water conservation.

Keywords: tropical rainforest, soil fragility, conservation unit

Introduction

The Serra da Jiboia (Jiboia Range, Bahia, Brazil) is a critical isolated fragment of the Atlantic Forest whose natural landscape features and water resources are of public interests for its conservation. An interdisciplinary 2-years scientific study resulted in an ongoing proposal for the creation of a Conservation Unit (Blengini et al., 2015). Due to the high economic potential, the Atlantic Forest is the second most threatened forest in the world, with only 7.5% (Myers et al., 2000) to 8.5% (Fundação SOSMA, 2018) of its original area, and so is a primary ecosystem for conservation and preservation (Lagos and Muller, 2007). If smaller fragments of less than 100 ha are taken into considered, Ribeiro et al. (2009) demonstrated that the area covered by remaining Atlantic Forest reaches 16%, reinforcing the importance of ecological corridors and the preservation of fragments. In a large international study (Myers et al., 2000), the Brazilian Atlantic Forest (Brazil's Atlantic Forest) was considered one of the 25 hotspots worldwide due to its high biodiversity, endemism, and anthropogenic pressure. Ribeiro et al. (2009) still report the extremely degraded state of the Atlantic Forest distribution, showing that most of the remaining fragments are less than 50 ha and that the current conservation network is insufficient to sustain the survival of this biome in the long term. A recent study indicates that compliance with existing legislation on private properties may lead to a restoration of the native vegetation cover of the Atlantic Forest by up to 35% (Rezende et al., 2018). If well planned and implemented, it can induce connectivity of vegetation remnants and increase the total coverage of native organisms above the critical biodiversity threshold established for different taxonomic groups. In addition to direct anthropogenic impacts, the effects of global warming also directly affect the maintenance and quality of forest environments. Using models of occurrence of species based on the current climate and projected in 2080, Ferro et al. (2014) evaluated the effectiveness of protected areas in the Brazilian Atlantic Forest in maintaining biodiversity under climate change. The authors found that protected areas in semi-deciduous forests in the western region of the biome would lose more species than expected in climate change.

The distribution of Atlantic Forest remnants is also related to relief, and this is one of the most important environmental factors: mountains soils are commonly inappropriate to agricultural use, so the access and consequently the deforestation are reduced. Unlike the inselbergs that form from differential physical weathering of a batholite with resistant igneous rocks, under semi-arid climate (Römer, 2007), the particular morphogenesis of Jiboia Range comes from an escarpment associated with a tectonic fault zone (IBGE, 2009), due to an Archaean collision of microplates. These geological and climatic contexts (processes of pediplanation and peneplantation) turn the Jiboia Range a unique place in Bahia and Brazil.

The Jiboia Range, classified as a mountainous region (Martinelli, 2008), is also of great importance from the hydrological point of view, being a recharge zone of the different watersheds of significant regional rivers, i.e., Dona, Paraguaçu, Jaguaripe, and Jequiriçá Rivers. These rivers are present in 30 cities distributed in five Territories of Bahia: Baixo Sul, Jiquiriçá Valley, Piemonte do Paraguaçu, Portal do Sertão and Recôncavo da Bahia. Focus on preservation is needed, as all mountain zones below 4500 m in the intertropical zone have exceeded the population, notably in humid tropical montane biome below 1500 m (Slaymaker and Embleton-Hamann, 2018).

Several studies of water balance in different forest ecosystems, such as central Mexico (Muñoz-Villers et al., 2012), Equatorial Andes (Fleischbein et al., 2006, 2005) and in Germany (Wiekenkamp et al., 2016) clearly showed the fundamental role of the canopy in the protection of the soils, with more significant infiltration of water and a regulation of the water flows. In tropical montane regions, forest ecosystems are known as Tropical Montane Cloud Forest (TMCF) (Mello et al., 2019; Terra et al., 2018) and are classified according to their elevation and dominant species. Mello et al. (2019) point to the need for the availability of TMCF hydrography and hydrology datasets to cover the lack of information in these ecosystems.

Birkel et al. (2016) verified in the Costa Rican forest, with 907 to 1475 m of altitude, the constant contributions of groundwater to river flow during the dry period. In Brazil, in a mountainous tropical environment above 1400 m (Serra da Mantiqueira, Minas Gerais), a recent and detailed water balance study reached similar conclusions, that the subsurface base flow is the main element that maintains the flow of the rivers (70 to 77% of contribution). The phenomenon is observed not only during the flood phase but also for more extended periods, especially during prolonged droughts. Muñoz-Villers et al. (2012), in a hydrological study with isotopes in the central mountainous region of Mexico, have proved that base flow can sustain the flow of rivers, even in a complex environment characterized by steep topography and a bed of fractured rock.

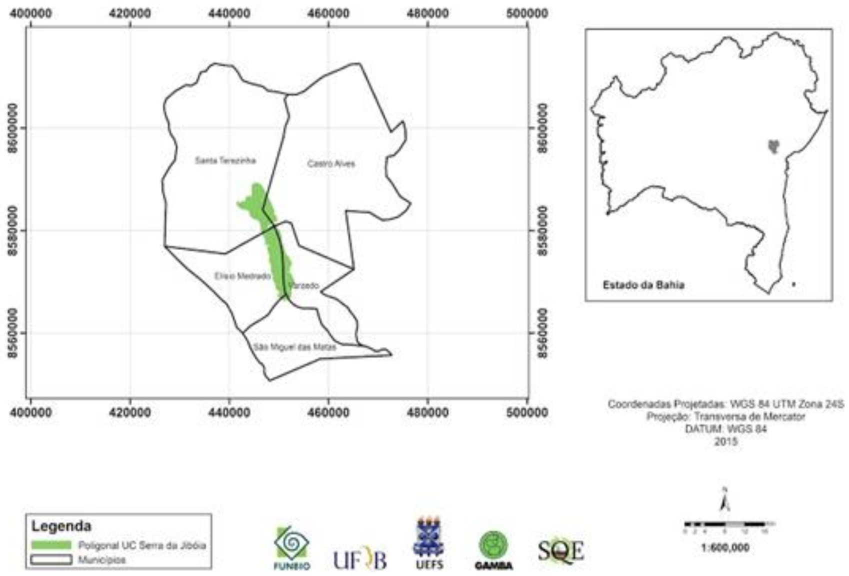

Figure 1. Map of the location of the Jiboia range. Source: IBGE (2010).

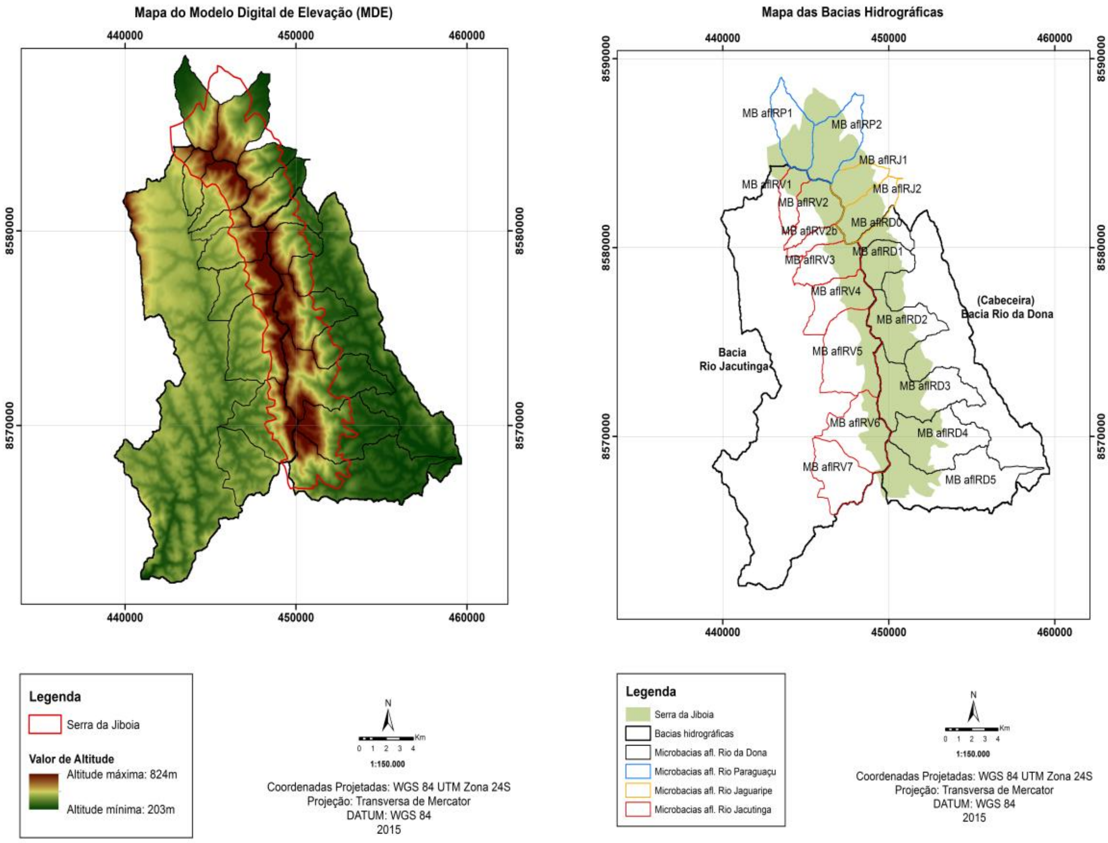

Figure 2. Altitude (a) and watersheds (b) in the Jiboia Range.

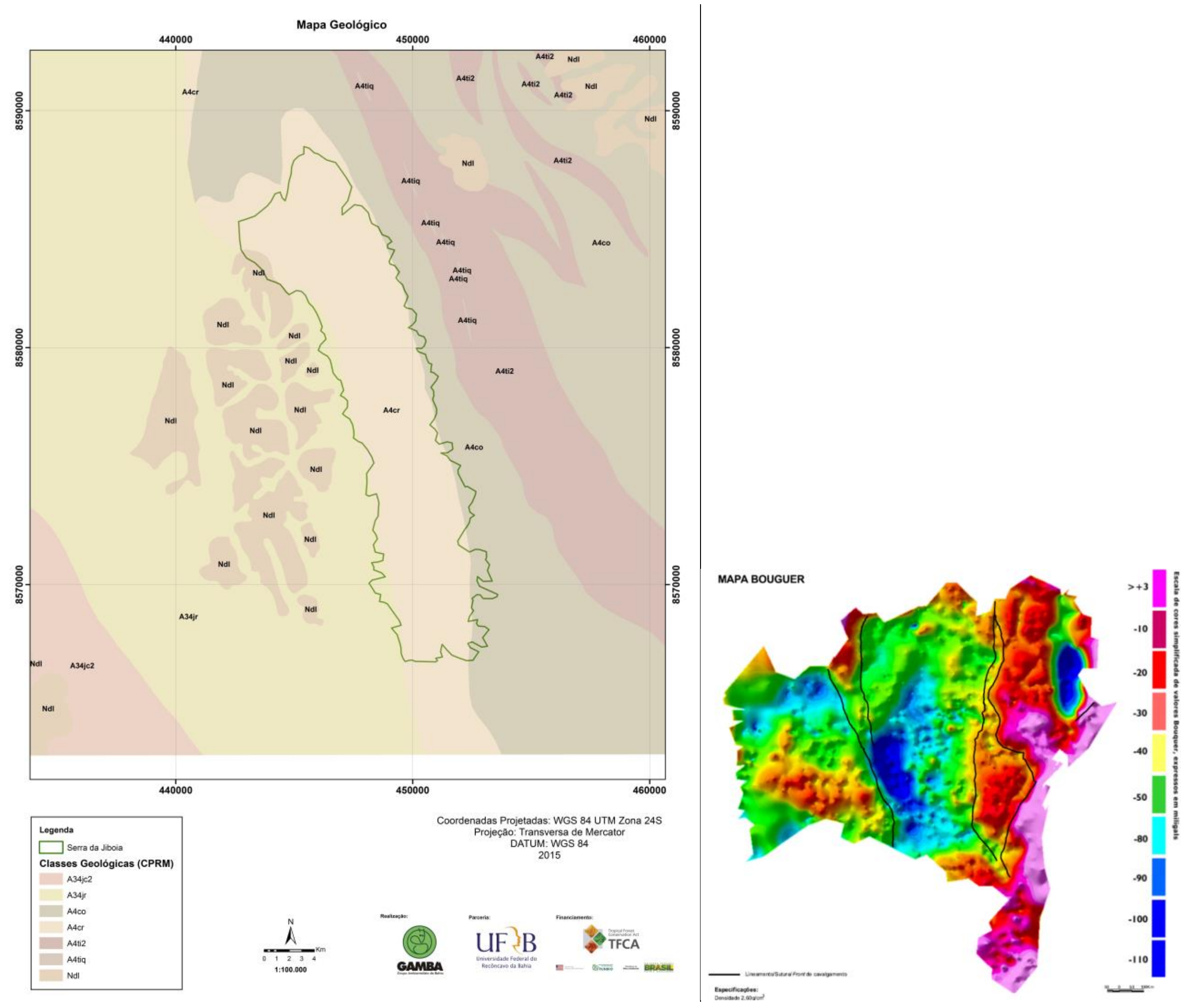

Figure 3. Bouguer and geological map of Jiboia Range. **A4cr**: geological class of the Jiboia Range; Bouguer values in milligals (1 mGal = 10^{-5} m/s²). Source: CPRM (2003).

Anthropogenic pressures in tropical and equatorial forests impact on increased runoff and intermittent rivers. In the Amazon, it is known that the conversion of forest to pasture decreases the hydraulic conductivity and, consequently, increases the frequency and volume of surface runoff (Germer et al., 2010, 2009; Scheffler et al., 2011; Thomaz et al., 2020; Zimmermann et al., 2006). This process is strongly accentuated in TMCF and causes erosion due to reduced infiltration if no preservation management is implemented (Andrade et al., 2020; Phillips et al., 2018). The process can be irreversible due to the low natural fertility of tropical and equatorial soils. Even in countries with efficient steepland forest harvesting management, more geomorphological studies are need to avoid soil erosion landsliding (Phillips et al., 2018). The present study aims to define landscape and watersheds properties of the Jiboia Range, a significant remnant of the Atlantic Forest in Northeastern Brazil, as a base for the maintenance of the scarce water resources in a transitional region between Atlantic Rainforest and Caatinga biomes, for a future Conservation Unit.

Material and methods

Characterization of the study area

The Jiboia Range mountain range is a biodiversity hotspot (Almeida, 2016) located at 12º52'12 "S and 39º28'22" O and extends for approximately 440 km^2, in five municipalities: Elísio Medrado, Santa Teresinha, Castro Alves, Varzedo and São Miguel das Matas (Figure 1). The massif has elevations of up to 820 meters of altitude deeply excavated by drainage and presence of rocky outcrops. The climate of the region varies from tropical semi-arid to semi-humid and according to data published by the Superintendency of Economic Studies (SEI, 2015), the region encompassing the Jiboia Range has a humid type climate (São Miguel das Matas), subhumid to dry (Amargosa, Elísio Medrado, Varzedo and part of Santa Teresinha) and semiarid (part of Santa Teresinha). The average annual temperature is 23ºC, and the average annual precipitation in this region is 1,066 mm with two regular rainy periods: rainy winter and summer with thunderstorms. Jiboia Range has high importance as recharging area of the Dona River (east) and the Jacutinga River (west), as well as some watersheds of tributaries of the Paraguaçu River (north) and Jaguaripe River (northeast, Figure 2).

Geological and geomorphological contexts

The Jiboia Range belongs to the São Francisco Craton, that is a geotectonic province consolidated before the Brazilian Cycle (> 850 million years). The presence of the Jiboia Range in the landscape is directly associated with large-scale geotectonic processes that occur in the Rhyacian period (Paleoproterozoic, 2.6 to 2.8 billion years), called the Rhyacian glaciation, resulting in the Itabuna- Salvador-Curaçá. During this period, there was a collision of three archaean tectonic microplates, the Salvador-Itabuna Domain, the Salvador-Curaçá Domain, and the Jequié Block (Figure 3).

The boundary between these two last geotectonic units is defined by the Jiboia Range (east) and the hills on the left margin of the Paraguaçu River (north). This limit is a shear zone, caused by former oblique subduction of the western blocks under the eastern blocks (da Silva and Miranda, 2002).

The Archaean and Paleoproterozoic rocks of this Craton are predominantly metamorphic rocks of high to medium degree of metamorphism that cover about 50% of the total area of Bahia (Barbosa, 1997). The main rocks occurring in Jiboia Range and the surrounding are enderbites/charnockites (Jequié unit 1) and orthogneisses (Jequié 2 unit), both in granulite facies (Miranda and Lopes, 2008), and with the presence of pure or calcissilicitic quartzite. In the northwest of the range there are typical eluvial lateritic sediments (Ndl unit, Figure 3): clayey to sandy deposits with gravel and some sandy-rudy colluvion deposits.

Regarding the landscape, dissection aspect prevails at a higher altitude, with forms of denudation predominantly convex, sometimes slightly tabular. Around the Jiboia Range, at lower altitude, there are three types of flattening landscape units: (a) pediments, near the range, constituted by colluvial detrital material, with a gentle slope; (b) dissected flat plateaus of alluvial sediments of the Neogene, (c) large pediplain, further from the Range, developed by physical weathering under subhumid to semi-arid climate. Inselbergs represent part of the mountain landforms, related to differential dissection generally of batholith (resistant igneous rocks), under a semi-arid climate that favors physical weathering (Römer, 2007). On the other hand, the particular morphogenesis of the Jiboia Range is associated with local fault tectonics: the range developed on a fault-adapted escarpment (IBGE, 2009), originating from the transcurrent fault zone.

This failed zone also causes the development of structural valleys.

Thus, the geological and climatic context of the range provided suitable conditions for the development of the Atlantic Forest fragment in the region. The differential erosion of the metamorphosed rocks of this site associated with a transitional subhumid to semi-arid climate formed the Jiboia Range.

Soil environment

There are five predominant classes of soils in the Jiboia Range (Blengini et al., 2015): (1) Typical Dystrophic Yellow Latosol, on convex ramps, between drainage lines in upper region of the range, (upper and middle slopes), with relief predominantly undulated and strongly undulated; (2) Haplic Tb Dystrophic leptic Cambisol, in the concave drainage lines that form the main rivers of the region; (3) Typical Dystrophic Humic Cambisol, in subperenifolia tropical vegetation preserved with limited erosive processes, in smooth undulating to wavy relief (upper slope); (4) Red Latosol, in the convex ramps between the drainage lines, formed in drier climates, in the northwestern region; (5) Typical hystic Neosol, in the top and upper areas where hydric and aeolian erosive processes are more intense.

Analysis of the geomorphological characteristics of the river basins

The geomorphological study based on 4 scenes of the satellite image of the MDE (Digital Elevation Model) of the SRTM (Shuttle Radar Topography Mission) mission with spatial resolution of 30 m. The processing was made in ArcGis 10.2, using the Hydrology, *flow direction, flow accumulation,* and *watershed* tools. The watersheds of Jacutinga River, Dona River, Paraguaçu River, and the Jaguaripe River are located in the western, eastern, northern and northeastern region of the mountain range, respectively. The degree of stability of the watershed was obtained from the ratio between the differential altitude (Δh) and the greatest distance between two points in the watershed (Schumm, 1956). The slope map was generated from the *Slope tool* in Spatial Analyst Tools and classified according to Embrapa (1979): flat (0-3%), undulating (3-8%), rolling (8-20%), hilly (20-45%), mountainous (45-75%) and steep (> 75%). The curvature analysis was also performed in the Spatial Analyst Tools.

Hypsometric analysis

The hypsometric analysis provided an estimative of the maturation stage of the watershed and information about the predominance of erosive or depositional processes (Stralher, 1952; Zavoianu, 1985). The hypsometric integral was generated by calculating the fraction of the total area delimited by two contour curves. In the vertical axis of the graph, the standard altitude h/H varied from 0 to 1, where h is the altitude and H the maximum altitude. The procedure for the volumetric integral curve is similar; however, volumetric fractions were used instead of area fractions.

Morphometric analysis of watersheds

The Stralher order for rivers was determined according to Stralher (1957). We calculated the following indices for each watershed: (a) the compactness coefficient ($Kc = 0.28\ P.A^{1/2}$, where P is the perimeter and A the area) that estimates the flood risk (Villela and Mattos, 1975); (b) the form factor ($F = A/L^2$, where L is the watershed axis length), also an estimator fo flood risk, (c) the drainage density (Dd = Lt/A, where Lt is the total length of the channels), (d) the Channel-Segment Frequency (Dh ou Cf = N/A where N is total number of segments of all orders), and (e) the sinuosity (S = Cr/D, where Cr is the length of the main river and D is the distance between the most distant source and the river mouth).

Results

The range divided into 17 catchments, with an average watershed altitude of 818 m (Table 1). The basins of Jacutinga River and Dona River have mean slope values of 2.7 and 2.8, respectively, that is, undulating to hilly (Table 2). On the other hand, the watersheds of their tributaries have more inclined landforms (hilly to mountainous), as well as the watersheds of the northern region of the range (tributaries of the Paraguaçu and Jaguaripe rivers).

In the Jibóia Range, the slopes ranges from rolling (19.1% of the area) to mountainous (15.4% of the area), with a predominance of hilly relief occurring in 62.6% of the total area (Table 2). In the watershed of Dona River, the slopes are mainly flat (19.6%), undulating (27.8%) or hilly (40.5%), and in the watershed of Jacutinga River, the relief is similar (flat - 15.7%, to hilly - 22.6%, with predominance of rolling slope – 40.1%. The main landform of the watersheds of tributaries of Jacutinga is predominantly hilly (mean slope: 36.0%). In the other areas, the relief of watersheds is more mountainous, with a mean slope of 41.8, 48.4%. and 58.8%, respectively for tributaries of Jaguaripe, Dona and Paraguaçu rivers.

Table 1. Physical characteristics of the watersheds of the Jiboia Range

	Area (km^2)	**Mean higher altitude (m)**	**Mean lower altitude (m)**	**Mean slope ratio ($m\ m^{-1}$)**	**Mean slope value**	**Mean slope class**
Dona River watershed (headwater)	103.1	800	205	0.034	2.8	Undulating
Jacutinga River watershed	144.4	818	246	0.051	2.7	Undulating
Watersheds[1] (Dona)	10.7 a[2]	779 a	225 b	0.110 a	3.5 a[2]	Rolling to steep
Watersheds[1] (Jacutinga)	7.6 a	703 a	333 a	0.084 a	3.2 a	Rolling to steep
Watersheds [1] (Paraguaçu)	8.5 a	807 a	206 b	0.113 a	3.3 a	Rolling to steep
Watersheds [1] (Jaguaripe)	5.8 a	727 a	258 b	0.113 a	3.7 a	Rolling to steep

[1] Watersheds of the tributaries of the river within parentheses
[2] Values followed by different letter within a column are significantly different (Tuckey Test, $p<0.05$).

Table 2. Slope classification in % of the watersheds of the tributaries of the rivers: RD = Dona; RJ = Jacutinga; RP = Paraguaçu; RJ = Jaguaripe

Slope	**RJ1**	**RJ2**	**RJ2b**	**RJ3**	**RJ4**	**RJ5**	**RJ6**	**RJ7**
Flat	7.5	3.6	7.8	7.3	8.0	4.9	4.7	7,7
Undulating	20.4	9.5	18.9	15.3	17.3	11.2	8.4	20,5
Rolling	40.8	33.8	44.4	35.4	33.1	32.1	26.1	47,1
Hilly	28.0	45.7	28.4	37.9	33.5	40.3	47.1	24,7
Mountainous	3.2	7.4	0.4	4.1	8.1	11.6	12.3	0,1
Steep	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0,0
	RD0	**RD1**	**RD2**	**RD3**	**RD4**	**RD5**		
Flat	5.0	2.3	4.0	3.4	9.2	7.2		
Undulating	9.0	4.5	5.6	7.2	10.3	14.0		
Rolling	32.1	19.6	24.9	26.6	32.5	37.4		
Hilly	46.4	58.6	50.7	51.8	46.4	36.7		
Mountainous	7.4	14.5	14.4	10.9	6.7	4.6		
Steep	0.1	0.6	0.3	0.1	0.0	0.1		
	RP1	**RP2**	**RJ1**	**RJ2**	**Dona Watershed**	**Jacutinga Watershed**	**Jiboia Range**	
Flat	6.5	3.7	1.8	2.3	19.6	15.7	0.4	
Undulating	29.5	8.7	6.0	6.0	27.8	20.5	1.9	
Rolling	22.8	28.1	22.6	26.6	8.8	40.1	19.1	
Hilly	32.2	51.4	60.0	57.6	40.5	22.6	62.6	
Mountainous	8.6	7.1	9.5	7.4	3.2	1.0	15.4	
Steep	0.4	0.9	0.0	0.0	0.1	0.0	0.6	

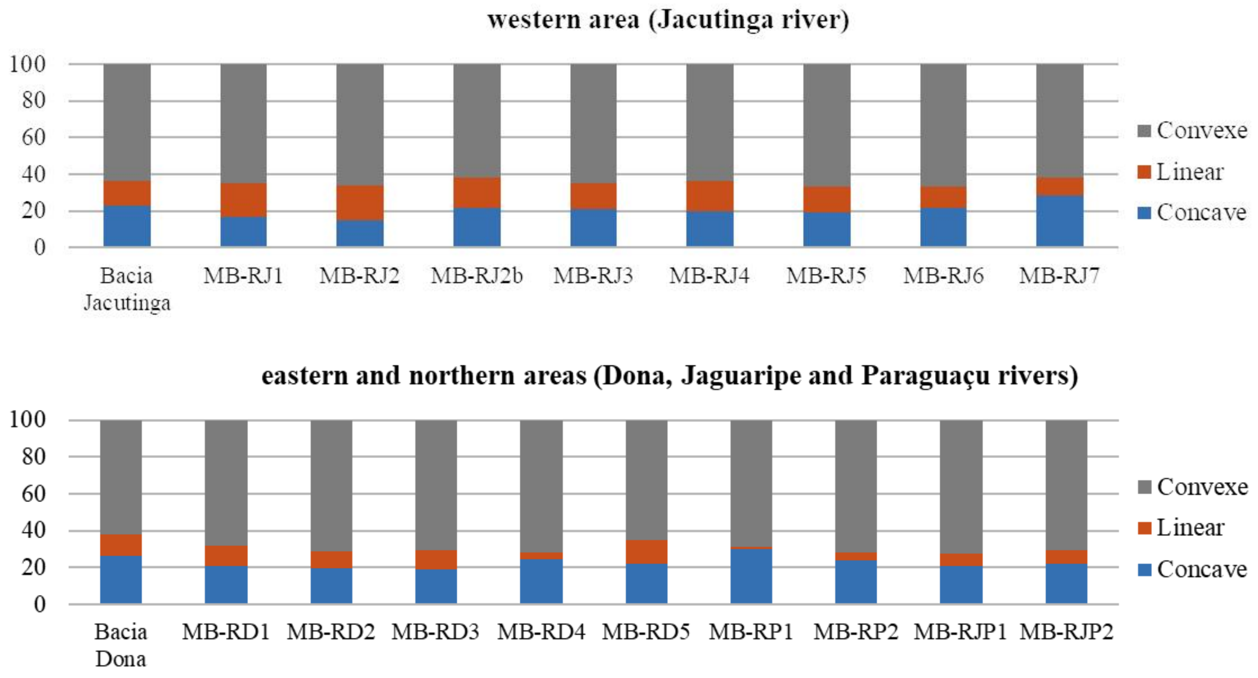

Figure 4. Profile curvature of the watersheds of Jacutinga and Dona rivers and of watersheds of the tributaries of Jacutinga (RJ), Dona (RD), Paraguaçu (RP), and Jaguaripe (RJP) rivers. (RP), and Jaguaripe (RJP) rivers.

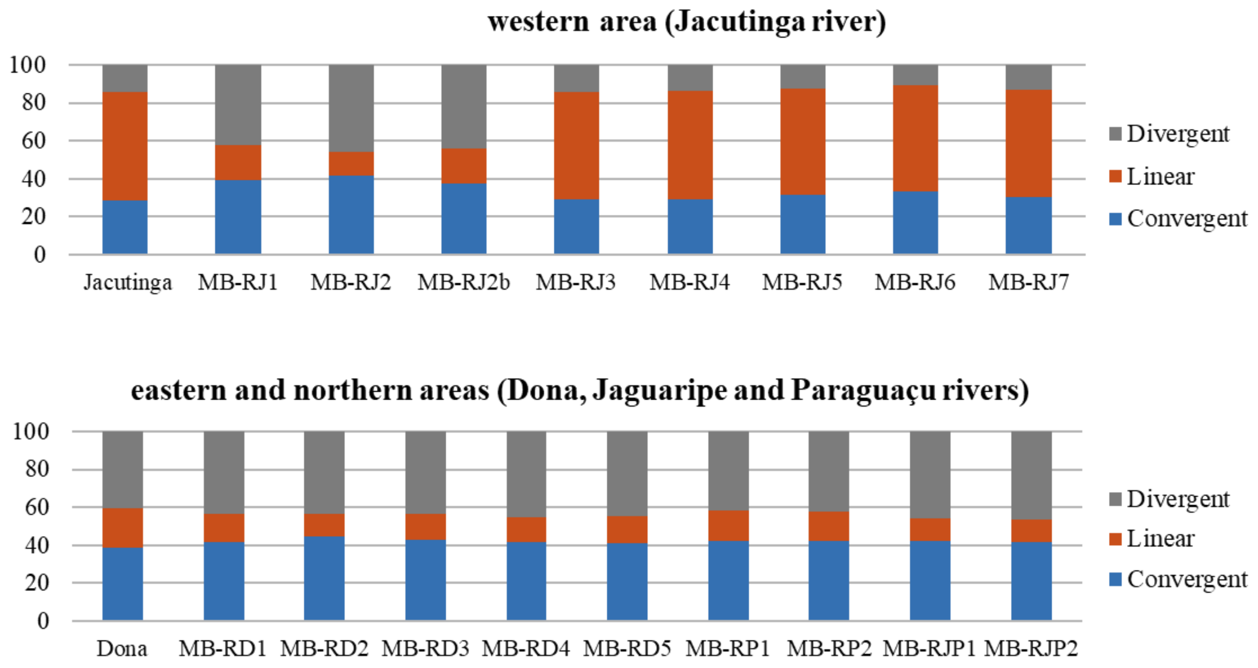

Figure 5. Plan curvature of the watersheds of Jacutinga and Dona rivers and of watersheds of the tributaries of Jacutinga (RJ), Dona (RD), Paraguaçu (RP), and Jaguaripe (RJP) rivers.

Table 3. Morphometric characteristics of Jiboia Range. Kc = compactness coefficient; F = form factor; Dd = drainage density; Dh = segment channel density; N = number of channels; S = sinuosity

	Kc	*F*	*Dd*	*Dh*	*N*	*S*
Dona River watershed (headwater)	1.89	0.34	1.66	2.5	258	1.06
Jacutinga River watershed	2.07	0.29	0.90	3.48	503	1.27
Watersheds[1] (Dona)	1.86 a[2]	0.33 a	2.57 a	2.00 a	24 a	1.33 ab
Watersheds[1] (Jacutinga)	1.53 a	0.36 a	1.95 ab	1.62 a	12 ab	1.16 b
Watersheds [1] (Paraguaçu)	1.60 a	0.30 a	0.74 b	0.41 b	4 ab	1.19 ab
Watersheds [1] (Jaguaripe)	1.61 a	0.32 a	0.77 b	0.38 b	2 b	1.64 a

[2] *Watersheds of the tributaries of the river within parentheses*

[2] *Values followed by different letter within a column are significantly different (Tuckey Test, p<0.05).*

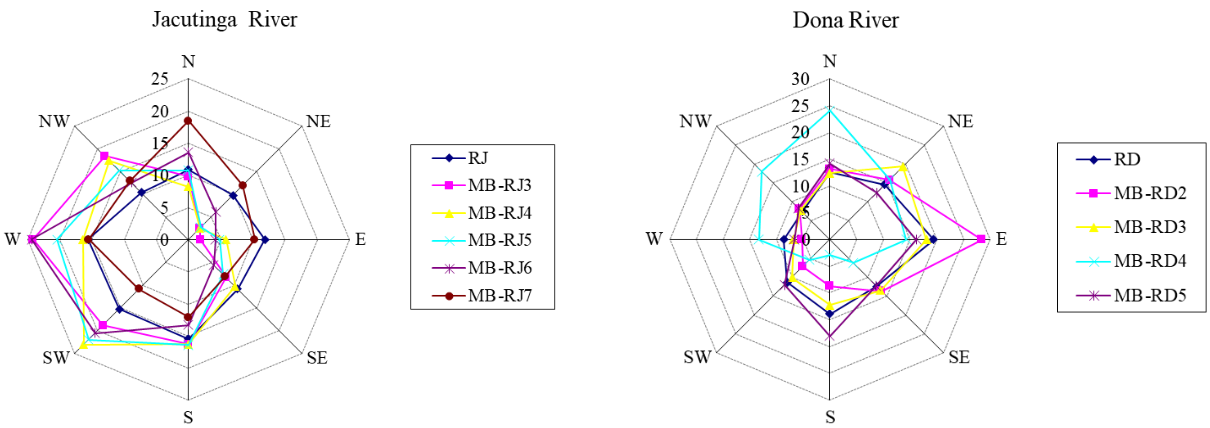

Figure 4. Orientation of the slope according to the watershed.

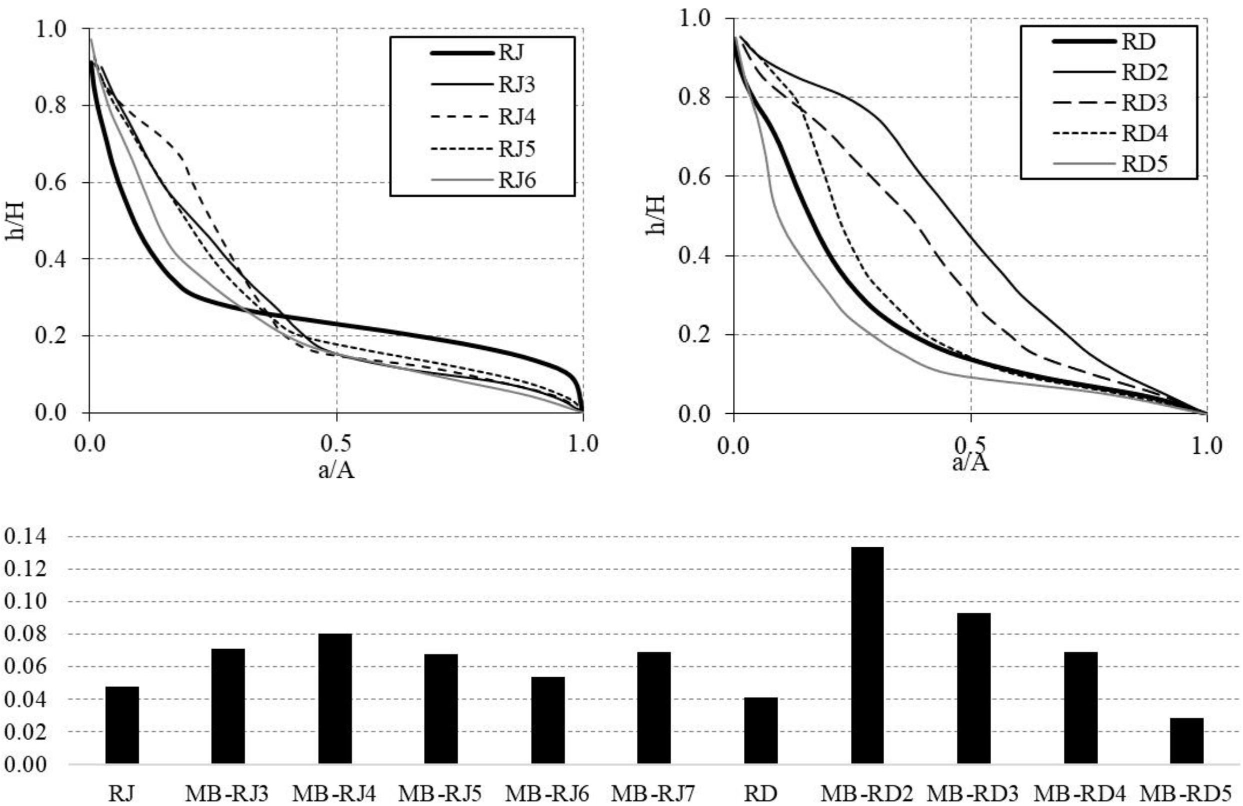

Figure 5. Hypsometric curves (a, b) and relation of eroded material (c). RJ: watershed of Jacutinga River and its tributaries (RJ3 to RJ6). RD: watershed of Dona River and its tributaries (RD2 to RD5).

The profile curvature is the range is homogeneous, predominantly convex in more than 60% of the area in all the watersheds (Figure 4). In term of plan curvature (Figure 5), the slopes are both divergent and convergent, while they are predominantly linear in the Jacutinga watersheds. The slopes have opposite orientation in the Jacutinga River basin (western) and Dona River basins (eastern) (Figure 6). The hypsometric analysis indicates the stage of erosive evolution and stability of the river basins (Figure 7). The hypsometric curves correlated with the relation of eroded material reveal significant differences between the basins.

Regarding the morphometry of the watersheds (Table 3), the coefficients of compactness (Kc) and form factor (F) do not differ significantly, the watersheds are typically elongated. The drainage and number of channels are high in the watersheds of the tributaries of the Dona River, on the eastern side of the Range, due to the retention of the oceanic-source moisture.

Discussion

The interaction between geological context and historical climate reflects on the evolution of landscapes. providing certain peculiarities and characteristics of the landscapes of each region (Fritzsons and Mantovani, 2010). The uniqueness of the Jiboia Range in its geomorphological and hydrological features provides a rare interaction that enhances the importance of its preservation to maintain water quality (Schussel and Nascimento Neto, 2015) and local soils.

The Jiboia Range is an orographic barrier that separates humid areas to the east of semi-arid areas to the west of the region. This environment defines the headwaters of the Jacutinga and Dona River and the watersheds of their tributaries and other large rivers that drain in the region (Paraguaçu and Jaguaripe).

The watersheds presented similar size, (variation of 2.7 to 19.3 km^2, but without significant difference - Table 1). The watersheds are small, and have high values of relief ratio (0.08 to 0.11 mm^{-1}). These values indicate higher instability of the slopes in relation to their respective main basins (Mioto et al., 2015; Piedade, 1980; Soares et al., 2016). The steep slope can result in the occurrence of flood peaks due to the rainwater flow velocity and its rapid concentration in the river channels, with reduction of the rate of water infiltration in the soil and enhancement of erosive processes and degradation of unprotected vegetation soils (Aparecido et al., 2016). The first two watershed of the Dona River basin have a relief ratio up to 0.17 m m^{-1}, corresponding to very deep slopes, where rocky outcrops and shallow soils, such as Neosols, are observed. This indicates the erosion potential of this region and the need for soil and water conservation actions. Even in countries with effective policies about mountainous forest harvesting, such New Zealand, control of erosion and landslide are major concerns that need more advanced geomorphological studies (Phillips et al., 2018).

Despite the strong erosive potential in the headwaters. the presence of convex slopes along Jiboia Range (Figures 4 and 5) indicate low vulnerability to soil loss (Palma and Lages, 2005); this explains the broad domain of Oxisols in this environment. There are still large concave areas - more than 20% of the range, highly vulnerable to erosion (Neto, 2013; Valeriano, 2003), which can contribute to the silting and degradation of rivers. visible in the lowlands.

The curvature of the terrain is responsible for modifying the surface flow of the water and influencing the path of its movement through the soil. In the tributary watersheds of Dona, Jaguaripe and Paraguaçu rivers, more than 40% of the area is divergent (Figure 6), where the erosive processes are less active (Guadagnin et al., 2015). On the western side of the range, in the watersheds of the Jacutinga river, the slopes are predominantly rectilinear-convergent, where surface runoff is higher and erosion processes are more active (Hall and Olson, 1991; Neto, 2013; Valeriano, 2003).

About the orientation of the slopes (Figure 6), higher water production is expected in the south and east oriented springs and lower production in the north and west oriented springs (Aparecido et al., 2016) because the north and west orientations disperse more moisture (greater evapotranspiration). Thus, the springs in the tributaries watersheds of Dona River produce more water that the Jacutinga, Jaguaripe and Paraguaçu springs. Differences in the solar incidence and loss of moisture not only influence the production of water but can also influence the formation and development of vegetation. For Silveira and da Silva (2010) the orientation of the slope still interferes in the biodiversity.

Regarding the stability of the basin, the Jacutinga River basin presents concave hypsometric curve, indicating that their watersheds are mature, with a balance between loss and soil deposition processes. They are old watershed from an erosive and sedimentary point of view with low erosion and low accumulation of sediments in the river beds. The weathering of regolith is attenuated and the transport and deposition of sediments occurs only inside the watersheds (Rossi and Pfeifer, 1999; Stralher, 1952). The elevation at the right side of the hypsometric curve of Jacutinga River basin (slightly convex) indicates late erosive processes, i.e. a drop of the base level by erosion of the recent Neogene sedimentary material.

The hypsometric characteristics of the watersheds of the Dona River tributaries are more variable, with more convex curves in the northern watersheds, due to an erosive rejuvenation in this region. This region of the Jiboia Range has characteristics of young watersheds, few evolved, with constant erosive processes and high susceptibility to surface runoff, soil loss, landslides, and floods, as found by Farhan et al. (2016), and consequently with high eroded material ratio value. Reduction of soil stability and landslide are considered two of the three major human impact in landscape (Slaymaker and Embleton-Hamann, 2018). In the northern area of the Jiboia Range, the curves are convex, related to the transition to a semi-arid climate under the occurrence of physical weathering superior to the chemical weathering. The erosion is intense, thermal-mechanical and produces immature sediments with little mobility due to their coarse granulation and lack of water transport, which accumulate in pediments (***slopefoot***) and evolution to pediplain in the long term (Farhan et al., 2016). The problem of soil erosion in impacted ecosystem can be reverted with some actions, such vegetation thinning, where underbrush growing dissipates the energy flux of surface and soil loss (Andrade et al., 2020, 2018).

As shown in Table 4, the shape indices of the watershed mean a global relief relatively uniform. with an average medium risk of flooding (Almeida et al., 2017; Lorenzon et al., 2015; Villela and Mattos, 1975). Despite this, some high values of Kc and F indicate elongation with efficient drainage under normal precipitation conditions, according to previous studies (Cardoso et al., 2006; Nardini et al., 2013). The streams on the western face (Jacutinga River basin) are more sinuous than those on the eastern face (Dona and Jaguaripe Rivers basins), due to a larger western slope. Deposition processes of sediments are therefore more prominent at the slopefoot of the Range in the Jacutinga basin, enhanced by low discharge (oceanic moisture retained in the eastern side. The Dona River itself presents low sinuosity, the river channel is controlled by a continuous geological pseudo-rectilinear fault, that induces more effective drainage and sediment transport.

The drainage density (Dd) in the range is higher than in the basins themselves (for Jacutinga and Dona Rivers), and while the tendency is inverse for hydrodynamic density (Dh). The smaller number of channels, but of greater extension in the mountain range explains these tendencies. This scarce number of streams in the mountain turns fundamental to their preservation. In the northern region of the Jiboia Range, the Dd and Dh values decrease drastically, due to the proximity to the semiarid climate. The development of channels is incipient and makes this hydric ecosystem even more fragile, as pointed by Calil et al. (2012). Under semiarid climate, precipitation concentrates in some weeks, and intense rainy events can cause severe of soil erosion and consequently siltation of rivers (Andrade et al., 2018). This process can be compared to storm events in temperate climate regions (Phillips 2018), which is a principal issue related to soil erosion and land instability. In such cases, geomorphological studies are essential and should support any land management, as claimed by several authors (Basher et al., 2015; Marden et al., 2015; Phillips et al., 2018; Slaymaker and Embleton-Hamann, 2018). During the last 30 years, the population in mountains has tripled, mainly in the intertropical mountains (Slaymaker and Embleton-Hamann, 2018), due to climate change. Unique primary mountainous ranges, pressured by the surrounding semiarid environment, definitively need maximal conservation.

Conclusion

The geomorphological and hydrographic characteristics of Jiboia Range revealed an unstable and fragile environment that highlights the necessity of maintenance of natural vegetation for the conservation of soil and water in this environment.

The drainage system shows fragility in the main basins, with predominance of first-order channels and so greater dissection of the relief probably due to structural control, such as faults, fractures or folds. In this case, the production of sediments is naturally accelerated, which, in case of removal of native vegetation, will definitely increase an intense soil degradation, silting of rivers and reduction of water sources in the region.

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