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Papers

Analysis of Morphometric Parameters of the Drainage Network and Road Network of the Ribeirão Paraíso Watershed, Jataí - GO

Carine Cabral Souza [1]
Márcia Cristina da Cunha [2]

Keywords
Unpaved roads
Hydrological connectivity
River channels
Crossing roads and rivers

Abstract

Studies related to morphometric analysis are extremely important for hydrogemorphological knowledge in watersheds. However, most rural roads are not considered in these analyses. Therefore, the objective of this article was to verify if the relations between the drainage network, the relief parameters, and the road network indicate changes in the drainage dynamics of a watershed occupied by agricultural use. The sugarcane crop is an influencing factor in the increase in rural roads in the watershed and arrived in the region from 2009 onwards. Therefore, the time frame of 2005, 2010, 2015, and 2020 was chosen for the investigation. Bibliographic research and quantitative measurements were used as a methodology to extract information from the drainage network and road network through morphometric parameters. For this, ArcGIS® 10.6.1 and Excel 2019 software were used. As a result, it was identified that the watershed has a fourth-order river hierarchy; its area is 903.6 km², the drainage density is 0.45 km/km², and when rural roads were included in the analysis in 2005, 2010, 2015, and 2020, corresponding to 2.1, 2.2, 2.4, and 3.1 km/km², respectively. Thus, the average density of roads in the period was 84% higher when considering only natural drainage, increasing mainly after the insertion of sugarcane in the scenario. Therefore, it is concluded that the analysis of morphometric parameters is essential to generate new knowledge about the studied watershed. Rural roads should be included in the analysis since they influence the hydrogeomorphological aspects of the watersheds. In this case, the increase in drainage density is directly related to the increase in roads and sugarcane. With the inclusion of these in the morphometric analysis, the watershed increases its drainage capacity, significantly altering the hydrological response in hydrographic watersheds.

[1] Universidade Federal de Jataí - UFJ, Jataí, GO, Brazil. carinejatai@hotmail.com
[2] Universidade Federal de Jataí - UFJ, Jataí, GO, Brazil. marcia1cunha@ufj.edu.br

INTRODUCTION

Studies related to morphometric analysis in watersheds have been carried out, and its importance has been highlighted by several authors (CHRISTOFOLETTI, 1969; LANA et al., 2001; ALCÂNTARA; AMORIM, 2005; FERRARI et al., 2013; PEREIRA et al., 2019; DORNELLAS et al., 2020). For Teodoro et al. (2007), this is one of the first procedures performed in hydrological and/or environmental analysis of watersheds.

Although morphometric analyzes are highly relevant, often one of the elements present in rural watersheds, rural roads, are not considered in these analyses. According to Pletsch (2020), rural roads connect rural to urban areas, leading people to meet their essential health, education, and leisure needs. Silva et al. (2020) point out that rural roads are one of the main logistical means of crops and agricultural products.

Therefore, including roads in hydrological studies in watersheds is fundamental. Baucke, Pinheiro, and Kaufmann (2019) point out that because roads are built without planning and with little maintenance, they are subject to a high sedimentological contribution to water bodies, and there are few observations made by the scientific community. The studies by Tiecher et al. (2014), who sought to clarify sources of suspended sediment in a watershed, found that rural roads, in rainy periods, represent almost 70% of the total sediment production.

Silva et al. (2018, p.5) report that "crossroads between the road system and the hydrography are characterized by greater susceptibility to obstruction, the greater the fluvial magnitude (order of the channels of the hydrographic network), upstream of the stream section with the road", for the authors this classification was important, as it allowed to characterize the degree of influence that the watercourse has on a road that crosses or touches it.

In addition to the mobility function, the roads are arranged in the landscape in the form of networks and connect with the drainage systems arranged in the relief, forming a mosaic of connections-connectivity (FORMAN, 1998).

In addition, the road network is often built in different landforms, such as mountainous areas, slopes, river terraces, and close to the drainage system. The distribution of these pathways in different slope sectors and their tendency to cross the drainage network affect the movement of water and sediment in the drainage (LUCE; WEMPLE, 2001; CHAPPELL, 2010).

Therefore, including roads in hydrological studies in watersheds is fundamental. Baucke, Pinheiro, and Kaufmann (2019) point out that because roads are built without planning and with little maintenance, they are subject to a high sedimentological contribution to water bodies, and there are few observations made by the scientific community.

The surveys carried out generally focus on the parameters: watershed area, perimeter, length, the total length of river courses, compactness coefficient, and drainage density, among others, leaving gaps in the morphometry of the road network. Although these parameters are fundamental, there is a lack of studies considering roads in morphometric analyses. These should be considered as they change the dynamics of the watershed.

Cunha and Thomaz (2017, p.431) reinforce that "the hydrological behavior of roads is the key to understanding their effects on the dynamics of watersheds" (CUNHA, 2010; CUNHA et al., 2010; CUNHA, 2011; CUNHA et al., 2014). This hydrological behavior of roads is varied; according to Cunha et al. (2021), there is the facility for the road to intercept the subsurface flow; that is, the roads intercept the subsurface water and can expand the natural channel network.

Thus, morphometric studies in watersheds, for Siqueira et al. (2012), are essential for the characterization of potentialities and limitations of land use and the adequate planning of activities to be developed, either through diagnostic studies or analysis of the risks of degradation of natural resources, since the lack of planning can generate impacts on soil and water resources.

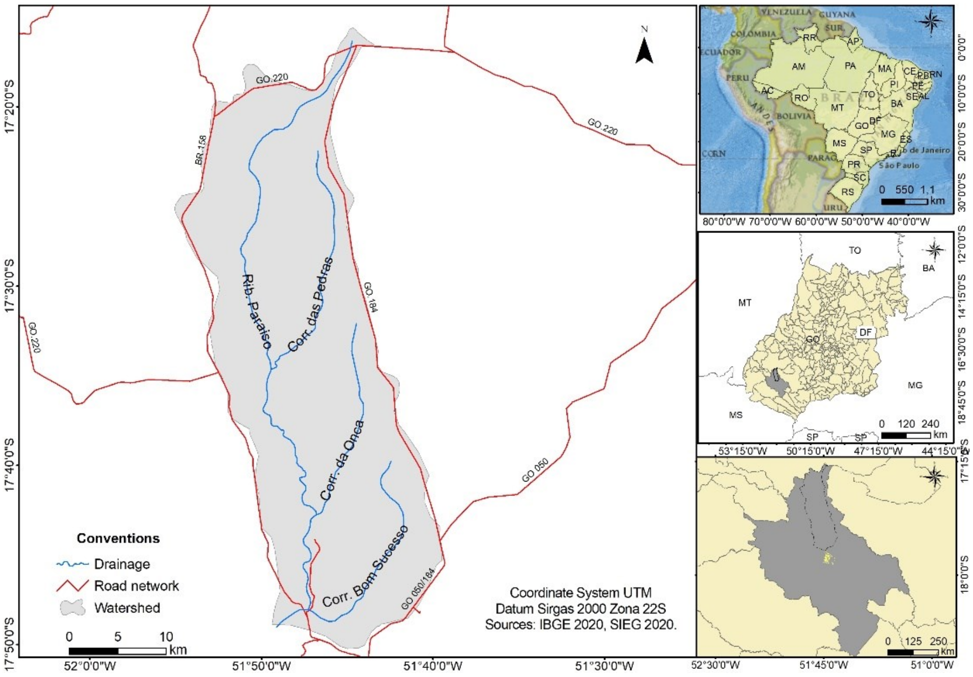
Therefore, morphometric parameters analysis consists of surveying numerical indexes that classify the drainage networks (SIQUEIRA et al., 2012) and the road network (CUNHA et al., 2010; CUNHA, 2011) to clarify the various questions about environmental, local, and regional dynamics. Thus, in this study, we aimed to verify if the relations among the drainage network, the relief parameters, and the road network indicate changes in the drainage dynamics of a watershed occupied by agricultural use.

MATERIAL AND METHODS

Location and characterization of the study area

The research was carried out at RPW in Jataí, the Southwest region of Goiás (Figure 1). It has an area of 903.6 km² and is located in the Rio Claro watershed, which has 13,500 km² and starts in Serra do Caiapó, in Caiapônia (also southwest of the State of Goiás), and flows into the Paranaíba river (ASSMANN, 2016).

Figure 1 – Location of the study area, Rio Paraíso watershed, Jataí-Goiás, Brazil



Elaborated by the authors (2022).

In Jataí, the climate is classified as "AW" hot with summer rain, according to the Köppen-Geiger climate classification (DUBREUIL et al., 2018). It has annual rainfall ranging from 1600mm to 1700mm, and average temperatures from 18°C to 32°C (INMET, 2020). In the municipality, the Cerrado biome and forest remnants are predominantly found, that is, native areas, which are associated with higher air humidity (MELO; DIAS, 2019).

According to Assmann (2016), geologically, the RPW is represented by the Botucatu and the Serra Geral Formations (São Bento Group), which are characterized by basaltic lavas of a tholeiitic nature with a massive, uniform, amygdaloidal, vesicular appearance, containing irregular to subconchoidal fractures, forming variable thicknesses of flows with lenticular intercalations and sandstone dykes. The other formation is the Corumbataí (Pass-Dois Group), which is lithologically constituted by an interstratified succession of fine sandstones, siltstones, leaflet claystone, and silty-clayey sandstones, blades, levels, or chert lenses with rhythmic alternations and fine interleaving. Thus, this configuration facilitates the dynamics of infiltration and drainage of the watershed.

Regarding geomorphology, the region has tabular reliefs generated on layers of horizontal rocks developed in the sedimentary rocks of the Paraná watershed; it develops mainly on basalts of the Serra Geral Formation and presents a relief with excellent conditions for recharge and circulation of infiltrated waters, increasing hydraulic conductivity (GOIÁS, 2006).

The region has its area covered by soils distributed in six orders within the Brazilian Soil Classification System (EMBRAPA, 2013): Latossolos, Argissolos, Cambissolos, Neossolos, Gleissolos, and Nitossolos. About 73% of the soils are classified as Latossolos, followed by Cambissolos, which represent about 12% of the area.

According to Souza et al. (2019), the erosion potential is associated with six intrinsic factors: "climate characteristics, soil properties, topography, vegetation, and soil management".

According to the article by Silva and Mendes (2022), with their analysis of the erosive potential by morphopedological compartments, the argissolo showed little susceptibility to erosion in their study. In contrast, the very susceptible classes are cambissolos and neossolos, not being the case of erosive potential by part of the soils in the RPW.

According to Martins (2012), the relief highlights that the municipality has a relatively flat surface, which is a facilitating factor for the occupation of land with commercial crops, making it one of the largest grain producers in the State of Goiás. “Approximately 95% of the area is classified as Regional Planing Surface, with altitudes ranging from 650 to 1000 meters” (MARTINS, 2012, p.16).

The characteristics of RPW and region are directly related to the object of study (rural roads) of the present work, being the climate, geology, type of relief, and soil characterizations that significantly influence the conservation of rural roads.

Data acquisition

At first, bibliographic research was carried out that allowed a scientific investigation of information and data on the topic raised. Then, we went to the office activities, in which we used the software licensed to use the Geoinformation laboratory at the Federal University of Jataí, ArcGIS® 10.6.1, and Excel 2019 to extract information about the network drainage and the road network of the watershed through morphometric parameters.

In previous research, Souza and Cunha (2021) found that the sugarcane crop significantly influences the increase in rural roads in the RPW for production flow. Therefore, the time frame of 2005, 2010, 2015, and 2020 was chosen for analysis. This cut is because, from 2009, a sugarcane plant was installed in the region, further boosting sugarcane production.

To obtain information on the drainage network, the cartographic base of the watershed boundary and drainage network on a scale of 1:100,000 was used, provided by the SIEG. To obtain road network data, the Google Earth PRO platform was used to generate a cartographic base of rural roads from the years 2005, 2010, 2015, and 2020 and through this base, the extraction of morphometric data was generated. The SRTM image for the year 2020 was used to obtain the relief parameters, and all data were analyzed on a scale of 1:230,000.

The Excel 2019 software executed the equations through the data obtained by the bases.

Drainage network morphometric parameters

Information on the drainage network was extracted from the SIEG base, based on the proposal of the authors: Horton (1945), Strahler (1957), Christofoletti (1980), and Villela and Mattos (1975). With the help of software and equations, the following information was obtained:

1- Watershed area (A): corresponds to the entire area drained by the river system as a whole, projected in a horizontal plane;

2- Perimeter of the watershed (P): this is the polygon that delimits the perimeter area of the watershed, and its (km) is determined using the metric operations option;

3- Watershed length (L): it is the longest distance measured, in a straight line, between the river mouth and a certain point along the perimeter;

4- Total length of river courses (Lt): this index refers to the sum of all river lengths (km) in the watershed.

5- Compactness coefficient (kc); relates the shape of the watershed to a circle. A watershed will be more susceptible to more severe flooding when its Kc is closer to unity (1). Kc is determined based on the following equation:

$$Kc = 0.28\frac{P}{\sqrt{A}} \qquad \text{Equation (1)}$$

Where: Kc is the compactness coefficient, P is the perimeter (m), and A is the drainage area (m^2) Source: Villela and Mattos (1975).

6- Drainage density (Dd): the drainage density correlates the total length of the drainage channels with the area of the watershed, which can be calculated by the equation:

$$Dd = \frac{Lt}{A} \qquad \text{Equation (2)}$$

Where: Dd corresponds to the drainage density, Lt is the total length of channels, and A is the watershed area Source: Villela and Mattos (1975).

7- Total number of segments (Ns): according to Strahler, all watercourses without tributaries are of the first order, the confluence of two first-order channels establishes the second-order stretches, and the third-order stretches are formed by the confluence of two second-order channels and so on.

8- Length of the main river (Rm): it is the distance that extends along the watercourse from the river mouth to a certain source.

9- Length of the surface course (Esc): represents the average distance covered by a runoff between the interfluve and the permanent channel, corresponding to one of the most essential interdependent variables that affect both the hydrological and physiographic development of watersheds. It is calculated as follows:

$$Esc = \frac{1}{2Dd} \qquad \text{Equation (3)}$$

Where: Eps represents the length of the surface course, and Dd is the drainage density value Source: Christofoletti (1980).

10- Maintenance coefficient (Cm): proposed by S. A. Schumm (1956), this index provides the minimum area necessary to maintain one meter of the flow channel. It is calculated as follows:

$$Cm = \frac{1}{Dd} \cdot 100 \qquad \text{Equation (4)}$$

Where: Cm is the maintenance coefficient, and Dd is the drainage density value, expressed in meters. Taking the square kilometer as an example, it represents the area of this unit divided by the drainage density Source: Schumm (1956).

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11- River density (Dr): is the relationship between the number of rivers or water courses and the area of the watershed. It can be calculated as follows:

$$Dr = \frac{N}{A} \qquad \text{Equation (5)}$$

Where: Dr is the density of rivers, N is the total number of rivers or streams, and A is the area of the watershed considered. Source: Christofoletti (1980).

12- Relief ratio (Rr): is the ratio between the altimetric amplitude of the watershed and the length of the main channel.

$$Rr = \frac{H}{L} \qquad \text{Equation (6)}$$

Where: Rr is the relief ratio, H is the difference in altitude between the highest and lowest point of the watershed, and L is the length of the main channel. Source: Schumm (1956).

Morphometric parameters of the road network

The extraction of information followed the methodology of the authors: Cunha (2010) and Cunha (2011), and it is also a methodology of its own authorship (SOUZA, 2022). With the help of software and equations, the following information was obtained:

13- Total length of rural roads (Lrr): is the total length of rural roads.

14- Road density (De). It can be calculated as follows:

$$De = \frac{R}{A} \qquad \text{Equation (7)}$$

Where: Dr is the road density, R is the total number of roads, and A is the considered watershed area Source: Cunha (2010, 2011).

15- Length of surface course intercepted by roads (LscR): represents the average distance traveled by a runoff between the interfluve and the road. It is calculated as follows:

$$LscR = \frac{1}{2Dr} \qquad \text{Equation (8)}$$

Where: LscR represents the length of the intercepted surface course, and Dr is the value of the road density. Source: Cunha (2010, 2011).

16- Number of crossings of river channels X roads: a survey was carried out in ArcGIS of the number of crossings of roads with rivers through cartographic bases of the two variables, made with ten random control points in the watershed, being them low, medium, and high slope, this distribution aimed to cover the entire watershed. To estimate the number of crossings per 1 km², the average of the total number of crossings per 10 km² was obtained, which was multiplied by the area of the watershed; thus, the total number of crossings was obtained. For this survey, only perennial rivers were considered because there is no formation of intermittent rivers in the watershed in question. It is noteworthy that in other watersheds where intermittent rivers are present, it is necessary to consider them in the analyses since the results may differ from when only perennial rivers are considered.

The data were tabulated and presented through tables and maps to discuss the results.

RESULTS AND DISCUSSION

Information on the drainage network and road network of the Ribeirão Paraíso watershed

It was identified that the RPW has a fourth-order river hierarchy; its area is 903.6 km^2, its perimeter is 167.36 km, the watershed length is 61.44 km, and the total length of the water courses is 404.61 km.

The result of the RPW compactness coefficient was 1.6. For Villela and Mattos (1975), the more irregular the watershed, the greater this coefficient; if the value is above 1, the watershed has low susceptibility to flooding, and if it is below 1, close to 0, there is a possibility of flooding. According to Teodoro et al. (2007) and Alves et al. (2017), the coefficient below or equal to 1 corresponds to a circular watershed and, if it is greater than that, to an elongated watershed. Thus, the RPW is elongated and with low susceptibility to flooding.

On the other hand, the drainage density of the RPW resulted in 0.45 km/km^2, which, according to Villela and Mattos (1975) and Christofoletti (1969), indicates a watershed with low drainage, with the parameter ranging from watersheds with low drainage (0.5km/km^2) to well drained (3.5km/km^2).

Rural roads showed a change in temporal dynamics (2005, 2010, 2015, and 2020), as with the influence of the introduction of sugarcane production in the watershed, roads had a significant increase of 11.48% in the period, and this was reflected in the rise in the density of roads (11.25%) (Table 1).

Table 1 – Indexes and results obtained from morphometric parameters.

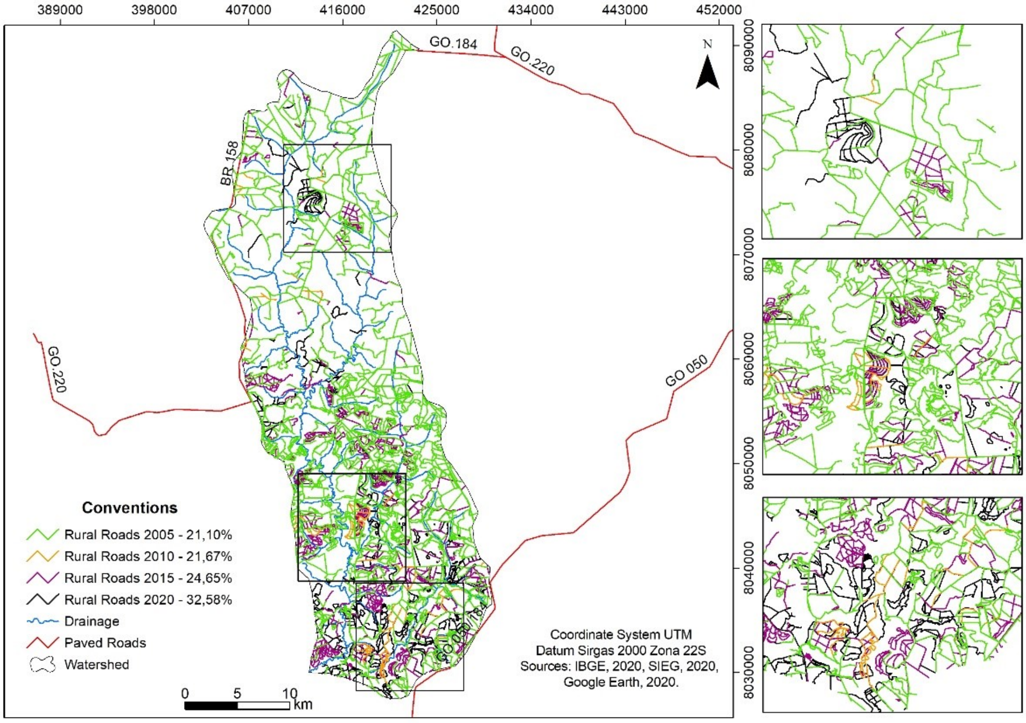
Indexes	**Results Obtained**
Area (A)	903 km^2
Perimeter (P)	167.36 km
Watershed length (L)	61.44 km
Total length of river courses (Lt)	404.61 km
Compactness coefficient (Kc)	1.6
Drainage density (Dd)	0.45 km/km^2
Total number of segments (Strahler, 1952) (Nr)	106
Length of main river (Rm)	98.4 km
Length of the surface course (Esc)	1.11 km
Maintenance coefficient (Cm)	2,222.22 m^2/m
River density (Dr)	0.1
Maximum altitude	1,035 m
Average altitude	786 m
Minimum altitude	627 m
Altimetric range	408 m
Relief ratio (Rr)	6.64 m/km

	2005	**2010**	**2015**	**2020**
Total length of rural roads (Ce)	1,564.2 km	1,607.6 km	1,828.7 km	2,416.8 km
Road density (Dr)	1.7 km/km^2	1.7 km/km^2	2.0 km/km^2	2.6 km/km^2
Length of surface course intercepted by roads (LscR)	0.294 km	0.294 km	0.250 km	0.192 km
Number of crossings of river channels X roads	903	903	993.3	1,173.9

Source: Horton (1945), Strahler (1957), Christofoletti (1980) e Villela e Mattos (1975).
Elaborated by the authors (2022).

The road density remained stable in 2005 and 2010 (1.7 km/km²); however, when this density was analyzed in 2015 and 2020, years with a significant increase in sugarcane areas in the scenario: 2010 (0. 36%), 2015 (6.53%) and 2020 (8.50%) the value was 2.0 km/km² and 2.6 km/km², respectively, that is, greater than the density of natural drainage in the analyzed historical series (0.45 km/km²).

Figure 2 – Comparison map of rural roads in the years: 2005, 2010, 2015, and 2020



Elaborated by the authors (2022).

Adding to the natural drainage network and the road network, the extension reaches 1,968.8 km (2005), 2,012.2 km (2010), 2,233.3 km (2015), and 2,821.4 km (2020), increasing the density to 2.1 km/km² (2005), 2.2 km/km² (2010), 2.4 km/km² (2015), and 3.1 km/km² (2020). Therefore, the average density of roads in the period was 84% higher than when considering only natural drainage.

In a similar study in the Rio Guabiroba watershed, Guarapuava-PR, Cunha, Oliveira, and Thomaz (2014) reported that the road density was 4.02 km/km², which is higher than the natural drainage network (3.4 km/km²). Adding the natural drainage network and the road network, the extension reached 181.51 km, increasing the density to 7.5 km/km². Therefore, adding the total density with the inclusion of roads was 54% higher than considering only natural drainage.

Considering only the natural drainage network, RPW has a low drainage density; however, with the inclusion of roads, it can increase its drainage capacity. In contrast, when road beds are deepened, they intercept subsurface flow. In other words, roads are important hydrological (water circulation) and geomorphological (sediment production and transfer) elements that must be considered in studies aimed at natural resource planning (CUNHA; THOMAZ, 2017).

For Villela and Mattos (1975), the length of the surface course is the average distance of rainwater runoff from the fall of water to the closest point on the bed of any river course in the watershed, considering the runoff in a straight line. In the case of RPW, the average distance of rainwater runoff is 1.11 km.

When the length of the surface course was analyzed with the interception of rainwater runoff through the roads, the result was smaller when compared to the length of the natural surface course because, in this case, the roads can intercept the runoff and cause a faster detour than the river itself. As there was an increase in the number of roads in the analyzed period, the extension of the surface route intercepted by the roads had a total decrease of 0.102 km.

Hartsog et al. (1997) and Cunha et al. (2014) mention that the interception, concentration, redirection, or interruption of the flow of surface and subsurface water by a road cut can lead to an increase in the amount of surface water, to accelerated erosion rates, to a greater flow of peak flow and the reduction of soil moisture. However, this condition cannot be proven in the study area since it was not possible to monitor the flow and sediment loads.

In the study by Alves et al. (2016), the length of the surface course resulted in 0.330 km in the watershed of the Ribeirão das Abóboras Rio Verde-GO; The authors consider a longer runoff and longer water concentration time, having a greater risk of erosion, and therefore emphasize that "the intensive use of this soil must be associated with complex soil conservation practices" (ALVES et al. al., 2017, p. 29).

Therefore, surface and subsurface flow interception have different working mechanisms. These different mechanisms of the hydrological functioning of intercepted areas can alter the natural dynamics of the hydrographic watershed, thus producing a smaller hydrological response than through infiltration and transfer of internal flow in the soil, connecting the slope and river in an accelerated way (CUNHA; THOMAZ, 2017).

"The maintenance coefficient represents a measure of soil texture, and basically serves to determine the minimum area necessary for the maintenance of 1 m of permanent flow channel" (TRAJANO et al., 2012, p. 21). For Moura (2017, p. 83), "this parameter corresponds to the area needed to form a channel with the perennial flow" the minimum area required for maintenance at 1 m in the RPW is 2,222.22 m^2/m.

In studies with watersheds similar to RPW, Silva et al. (2018) highlight that the maintenance coefficient data (1,408.45 m^2/m) are high, requiring a large area for maintenance. Also, for Degrande and Firmino (2020), the maintenance coefficient (1,402.5 m^2/m) is considered high, and also for Teixeira et al. (2019), the watershed maintenance coefficient is considered high (1,496.80 m^2/m).

The results of the studies by Bolotari Júnior (2019) indicate 1,356.5 m^2/m of area needed to keep each meter of the channel in the watershed perennial. Queiroz et al. (2018) had a value of 1,785 m^2/m found, and emphasize that the value is high and indicates that the watershed is not rich in water courses; they also report that this coefficient is predominant in areas of relief flatter and that this value decreases in more wavy reliefs.

Bolotari Júnior (2019) highlights that the behavior can be explained by the occurrence of heavy rainfall in flat areas (characteristics similar to those of the RPW, with a well-defined rainy season and mostly flat relief) in which surface runoff tends to concentrate and form preferential flows generating the channels that make up the drainage network, while in the more rugged relief the flow tends to follow the natural slope of the terrain, digging the soil at points of lesser resistance, causing a greater concentration of natural channels and, therefore, way, higher drainage density. These characteristics of climate and relief can explain the high index of maintenance coefficient in the RPW.

The density of rivers, for Machado and Souza (2005, p. 8375), makes it possible to identify the properties of the rocky substrate and the permeability of the terrain; thus, "low densities show that the substrate is rocky, while high densities show a more permeable substrate". In the watershed, the result was 0.1, considering a rocky substrate.

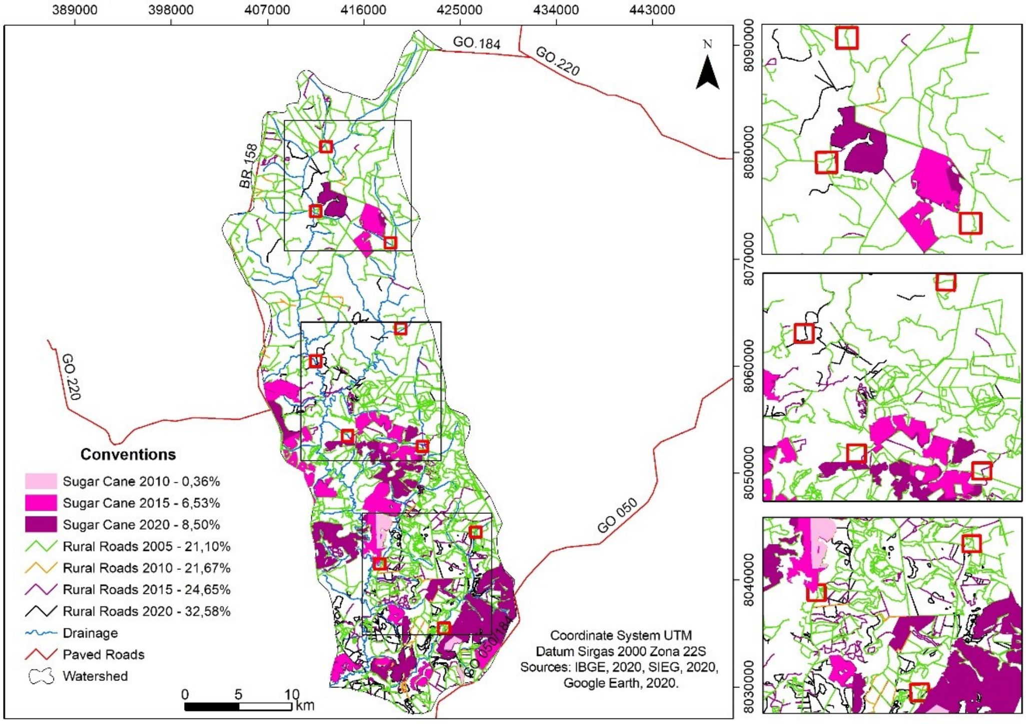
For the possibility of generating new watercourses, Oliveira et al. (2013) emphasize that the result must be valued greater than 2.0; however, in the RPW, the value is lower than that proposed by the authors, indicating difficulty in generating new channels due to the lithostructure of the watershed.

Regarding the relief characteristics, the RPW has a maximum and minimum altitude of 1,035 and 627, respectively; thus, the value found for altimetric amplitude was 408 m, resulting in a relief ratio of 6.64 m/km, indicative of a watershed with flat reliefs. For Lopes et al. (2018, p.36): "the relief influences the development of the soil profile, the rainfall-runoff responses, and its respective surface runoff velocity".

Regarding the number of crossings of roads X river channels, taking into account its area (903 km^2), there was a total of 903 in 2005 and 2010, 993.3 in 2015, and 1,173.9 in 2020. Remember that they considered the perennial rivers with unpaved side roads for this analysis.

It is evident that this significant increase in the number of crossings of roads X river channels in the years 2015 and especially 2020 is associated with the rise in rural roads and the cultivation of sugarcane (Figure 3).

Figure 3 – Number of crossing river channels X roads: 2005, 2010, 2015, and 2020.



Elaborated by the authors (2022).

Thus, the hydrogeomorphic connectivity on the roads that cross the rivers can affect the dynamics of the natural flow, which can be completely controlled by the hydrogeomorphological processes of the road network (THOMAZ; PERETTO, 2016).

Lima (2004), França Júnior, and Cunha (2020) point out that in rural areas, generally unpaved road networks function as an entry point for sedimentary load when connected to river channels through crossings. Lima (2004) classifies mechanisms of sediment transfer from roads: (1) erosion of roads parallel to channels, (2) erosion of roads that cross channels, and (3) rupture of embankments with crossings.

Reid and Dunne (1984) emphasize that unpaved roads deserve special attention due to the hydrological connectivity that transfers sediments directly to the channels. For Thomaz (2005), the roads cut many rivers, and the lateral drainage on the roads makes the water quickly reach the drainage networks and increase the flow.

Therefore, rural roads interfere with the hydrological dynamics of the RPW. With the increase in drainage density that alters the other morphometric processes, even though roads are fundamental for economic and social development in rural areas, it is necessary to give due attention to their implementation and maintenance since changes in the drainage system are directly linked to their presence.

CONCLUSION

It is essential that the morphometric parameters of rural roads be included in the analyses, as they can bring different results than when only the “main” parameters are considered, which are usual in most environmental studies generated in watersheds.

At RPW, the increase in drainage density is directly related to the increase in roads and sugarcane, especially in 2015 and 2020, changing its morphometric dynamics.

The total increase in road and river channel crossings was 270.9 in the analyzed period. This significant increase in road crossings with the river can directly imply the transport of sediments to river channels, silting, and river pollution. On the other hand, the length of the surface course gradually decreases as the roads increase, which may reflect on the alteration of the drainage system of the watershed and the interception of the surface and subsurface flow.

The morphometric studies underwent essential innovations with the use of geotechnologies, optimizing and facilitating the collection and handling of data. Including rural roads in the analyses makes the studies more complete, as the roads are present in hydrographic watersheds and are often not questioned in research.

Therefore, rural roads constitute an essential element for the economic and social development of the RPW community, and studies regarding the hydrological behavior of rural watersheds are essential for preserving and maintaining environmental quality, especially concerning the use of water resources.

Thus, the objective of the research was achieved, where it was found that the relationships between road network, drainage network, and relief parameters indicate changes in the drainage dynamics of the RPW, caused mainly by the increase in sugarcane. However, it is recommended that in later studies, the monitoring of flow and sediment loads is carried out to complement the data.

Research for the region is an advance as a reference, as these studies on rural roads can significantly change the view on erosive processes, silting, and conservation of water courses. However, with the proposal in mind, it is the role of city managers to put into action the practices (maintenance, restoration) reinforced here since they are part of profitable activities, both economic and environmental, local.

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REFERENCES

ALCÂNTARA, E. H.; AMORIM, A. de J. Morphometric analysis of a coastal watershed: a case study. **Caminhos de Geografia**, v. 7, n. 14 p. 70-77, feb/2005.

ALVES, W. *et al.* Analysis of physical aspects of the Bonsucesso stream basin, located in Jataí (GO), Brazil, supported by geotechnologies. **Rev. Geogr. Acadêmica,** v. 11, n. 1, 2017.

ALVES, W. S. *et al.* Morphometric analysis of the Ribeirão das Abóboras watershed – Rio Verde (GO). **Geociências**, v. 35, n. 4, p. 652-667, 2016.

ASSMANN, S. M. **There is a plantation on the riverbank:** studying the new forest code in the Ribeirão Paraíso watershed, Jataí – GO. 2016. 102 f. Dissertation (Master in Geography) - Universidade Federal de Goiás – Regional Jataí, 2016.

BAUCKE, A. S.; PINHEIRO, A.; KAUFMANN, V. Hydrosedimentological contribution of rural roads in watersheds with small and medium properties. **Revista Brasileira de Ciências Ambientais (Online)**, n. 53, p. 13-32, December 30, 2019. https://doi.org/10.5327/Z2176-947820190503

BOLOTARI JÚNIOR, N. **Morphometric and hydrological analysis of the Ribeirão Estiva watershed, a tributary of the Paraibuna River, Juiz de Fora-MG**. 2019. Final paper (Sanitary and Environmental Engineering Course) - Universidade Federal de Juiz de Fora, MG, 2019.

CHAPPELL, N. A. Soil pipe distribution and hydrological functioning within the humid tropics: a synthesis. Hydrol. Process., v. 24, n.12, p. 1567-1581, 2010. https://doi.org/10.1002/hyp.7634

CHRISTOFOLETTI, A. **Geomorphology.** 2 ed. São Paulo: Edgar Blücher, 1980.

CHRISTOFOLETTI. A. Morphometric analysis of watersheds. **Notícias Geomorfológicas**, v. 18, n. 9, p. 35-64, 1969.

CUNHA, M. C. **Evaluation of the effectiveness of sediment containment boxes on unpaved rural roads in the Rio Das Pedras Watersheds, Guarapuava-PR.** 2011. 132 f. Dissertation (Master in Geography) - Universidade Estadual do Centro Oeste, Guarapuava, 2011.

CUNHA, M. C. Characterization of unpaved rural roads as recent elements in the landscape of the Rio das Pedras watershed, Guarapuava-PR. **Revista Geomae - Geografia, Meio Ambiente e Ensino,** v. 01, n. 02, ISSN 2178-3306, 2010.

CUNHA, M. C.; OLIVEIRA, F. A.; THOMAZ, E. L. Interception of subsurface flow caused by rural roads in the Guabiroba river basin, Guarapuava-PR. **Revista Geonorte**, v. 5 n. 14, p. 164 – 169, 2014.

CUNHA, M. C.; THOMAZ, E. L. Subsurface flow intercepted by rural road: characteristics and distribution in the landscape. **Boletim Goiano de Geografia**, [S. l.], v. 37, n. 3, p. 429–447, 2017. http://doi.org/10.5216/bgg.v37i3.50763

CUNHA, M. C.; THOMAZ, E. L.; OLIVEIRA, F. A. Subsurface hydrological processes influenced by rural road cuts in the Guabiroba river basin,, Guarapuava, Paraná, Brasil. **Revista caminhos de geografia.** v. 22, n. 80, p.53-67, 2021. https://doi.org/10.14393/RCG228054556

CUNHA, M. C.; THOMAZ, E. L.; VESTENA, L. R. Evaluation of the effectiveness of sediment control measures (containment boxes) on unpaved rural roads in the Rio das Pedras watershed, Guarapuava-PR. *In:* XVI NATIONAL MEETING OF GEOGRAPHERS, Porto Alegre, RS. 2010.

DEGRANDE, E. J. S.; FIRMINO, G. V. Morphometric and land use analysis of the Córrego da Onça watershed, Presidente Prudente-SP. **Revista Geonorte**, v. 11, n. 38, p. 125-145, 2020. (ISSN 2237-1419) https://doi.org/10.21170/geonorte.2020.V.11.N.38.125.145

DORNELLAS, P. da C. *et al.* Morphometric analysis of the upper Rio Paraíba watershed, semi-arid region of the state of Paraíba. **Rev. Bras. Geomorfol. (Online)**, São Paulo, v. 21, n. 3, (jul.-set.) p. 601-614, 2020. https://doi.org/10.20502/rbg.v21i3.1757

DUBREUIL, V.; FANTE, K. P; SANT'ANNA NETO, J. L. The types of annual climates in Brazil: an application of the Köppen classification from 1961 to 2015. **Revista Franco-Brasileira de Geografia**, n. 37, 2018. https://doi.org/10.4000/confins.15738

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária, 2013.

FERRARI, J. L. *et al*. Morphometric analysis of the hydrographic sub-watershed of the Horizonte stream, Alegre-ES. **Revista Brasileira de Ciências Agrárias**, v. 8, n. 2, p. 181-188, 2013. https://doi.org/10.5039/agraria.v8i2a1575

FORMAN, R. T., & ALEXANDER, L. E. Roads and their major ecological effects. Annual review of ecology and systematics, 29(1), 207-231. 1998. https://doi.org/10.1146/annurev.ecolsys.29.1.207

FRANÇA JÚNIOR, P.; CUNHA, M. C. Connectivity of rural roads and rivers and their geomorphological dynamics in rural watersheds. *In:* FRANÇA JÚNIOR, P. (org.). Technogen and Anthropocene geomorphology: **theoretical perspectives and applied studies in urban environments.** Ituiutaba: Barlavento, 2020. 426 p. Available: https://asebabaolorigbin.files.wordpress.com/2021/04/geomorfologia-tecno-antropo.pdf. Acessed on: 04 de may de 2022

GOOGLE. Google Earth PRO, 2020

GOIÁS. Secretaria de Indústria de Comércio. Superintendência de Geologia e Mineração. **Geomorphology of the State of Goiás and the Federal District.** Goiânia: Secretaria de Indústria de Comércio, 2006.

HARTSOG, W.; KAHKLEN, K.; MOLL, J.; SWANSTON, D. N. A Monitoring System for Measuring Effects of Roads on Groundwater: Equipment and Installation. United States Department of Agriculture Forest Service Technology e Development Program, 1997.

HORTON, R. E. Erosional development of streams and their drainage basins: a hydrophysical approach to quantitative morphology. **Geol Soe. Am. Bull**, v. 56, n. 3, p. 275-370, 1945. https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

IBGE - Brazilian Institute of Geography and Statistics. 2020.

INMET - National Institute of Meteorology, 2020.

LANA, C. E.; ALVES, J. M. P.; CASTRO, P. T. A. Morphometric analysis of the Rio do Tanque watershed, MG – Brazil. **Revista Escola de Minas**, v. 54, n. 2, p. 121-126, 2001. https://doi.org/10.1590/S0370-44672001000200008

LIMA, A. G. Methodology for the inventory of sediment production potential at road crossings with river channels. *In:* BATTISTELLI, M.; FILHO, M. C.; HEERDT, B. (Org.). **Protection and Management of the Rio das Pedras watershed: an** experience report. Guarapuava: Editora B & D Ltda, v. 1. p. 100-108, 2004.

LOPES, I.; LEAL, B. G.; RAMOS, C. M. C. Morphometric characterization of a watershed in the semiarid region of Pernambuco using SRTM data in free software. **Journal of Hyperspectral Remote Sensing**, v. 8, n. 1 p. 31-40, 2018. https://doi.org/10.29150/jhrs.v8.1.p31-40

LUCE, C. H. WEMPLE, B. C. Introduction to Special Issue on Hydrologic and Geomorphic Effects of Forest Roads. Earth Surf. Proc. Land. 26 (2), 111 113, 2001. https://doi.org/10.1002/1096-9837(200102)26:2<111::AID-ESP165>3.0.CO;2-2

MACHADO, G.; SOUZA, J. O. P. Morphometric Analysis of the Chôco River watershed – Ibaiti – PR. **Proceedings of the X Meeting of Latin American Geographers** – March 20 to 26, 2005 – Universidade de São Paulo.

MELO, B. M; DIAS, D. P. Microclimate and thermal comfort of urban forest remnants in the municipality of Jataí - GO. **REVSBAU**, Curitiba – PR, v. 14, n. 2, p. 01-15, 2019. https://doi.org/10.5380/revsbau.v14i2.66637

MARTINS, A. P.; & OLIVEIRA, R. M. Environmental diagnosis of watersheds in the urban area of Jataí – GO. v. 01, p. 1-159, 2012.MOURA, D. M. B. **Environmental and physiographic assessment of the Ribeirão Santo Antônio watershed, with a view to supplying water to the city of Iporá (GO).** 2017. 107 f. Dissertation (Master in Geography) - Universidade Federal de Goiás, Jataí, 2017.

OLIVEIRA, S. F. de *et al.* Environmental analysis of the watershed of the Córrego da Onça, in the municipality of Jataí - GO. **Geoambiente On-line**, [S. l.], n. 10, p. 01–24, 2013. https://doi.org/10.5216/geoambie.v0i10.25957

PEREIRA, L. C. F. et al. Morphometric analysis of the watershed of the rio dos Patos, GO. **Ipê Agronomic Journal,** v. 3, n. 1, p. 4-13, 2019. https://doi.org/10.37951/2595-6906.2019v3i1.4319

PLETSCH, L. **Conditions of Use of Unpaved Rural Roads:** Functional Evaluation of the Bearing Surface of a Section of the Road Mesh in the Municipality of Ijuí-RS. 2020. Final paper (Civil Engineering Course) - Universidade Regional do Noroeste do Estado do Rio Grande do Sul – UNIJUÍ, Ijuí, 2020.

QUEIROZ, P. H. B.; SALES, M. C. L.; CRISPIM, A. B. Application of morphometric parameters in a segment of the middle course of the Pacoti-CE river basin: a contribution to the understanding of hydrogeomorphological processes. *In:* BARBOSA, L. N. *et al* (org.). **Watersheds and analysis of their quantitative parameters.** Mossoró – RN: EDUERN, 2018. P. 200. Available: http://www.ppggeografia.ufc.br/images/documentos/C7T4_compressed.pdf Acessed on: 12 de mar. de 2022

REID, L. M.; DUNNE, T. Sediment production from forest road surfaces. **Water Resources Research**, v. 20, n. 11, p. 1755, 1984. https://doi.org/10.1029/WR020i011p01753

SCHUMM, S. A. Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey**. Geological Society of America Bulletin**, 67, p. 597-646. 1956. http://dx.doi.org/10.1130/0016-7606(1956)67[597:eodsas]2.0.co;2

SIEG - State Geoinformation System, 2020

SILVA, G. C. *et al.* Morphometric characterization of the Riacho Rangel-Piauí watershed, Brazil. **Enciclopédia Biosfera**, Centro Científico Conhecer, Goiânia, v. 15 n. 28; p. 244, 2018. https://doi.org/10.18677/EnciBio_2018B22

SILVA, Í. B.; MENDES, L. M. S. Analysis of Erosive Potential by Morphopedological Compartments as a Subsidy for Land Use and Occupancy Planning in Alto Banabuiú-Ceará. **Revista Brasileira de Geomorfologia**, v. 23, n. 1, p. 1226, 2022. https://doi.org/10.20502/rbg.v23i1.1945

SILVA, M. *et al.* Importance, pathologies and technical recommendations for unpaved roads in the region of the municipality of Alegrete. **Proceedings of the International Exhibition of Teaching, Research, and Extension,** v. 12, n. 2, December 4, 2020.

SIQUEIRA, H. E. *et al.* Morphometric analysis and definition of the land use potential of the Rio Veríssimo microbasin, Veríssimo – MG. **Enciclopédia Biosfera**, Goiânia-GO, v. 8, n. 15, p. 2236-2246. 2012.

SOUZA, A. R. et al. Zoneamentos da vulnerabilidade ambiental e expectativa de perda de solo: é possível usar a USLE na determinação de vulnerabilidade ambiental? São Paulo, UNESP, **Geociências**, v. 38, n. 4, p. 1105 - 1119, 2019. https://doi.org/10.5016/geociencias.v38i4.14083

SOUZA, C. C.; CUNHA, M. C. Characterization of the state of conservation of rural roads in the Ribeirão Paraíso watershed, Jataí-GO. **Revista Brasileira de Geografia Física**, v. 14, n. 03, p. 1767-1786, 2021. https://doi.org/10.26848/rbgf.v14.3.p1767-1786

SOUZA, C. C.; Mapping of the temporal dynamics (2005/2010/2015/2020) of rural roads in the Ribeirão Paraíso watershed influenced by the increase in sugarcane production, 2022. Master's Thesis (Geography Course) – Universidade Federal de Jataí – UFJ, 2022.

STRAHLER, A. N. Quantitative analysis of watershed geomorphology. New Halen: Transactions: **American Geophysical Union**, v. 38. p. 913-920. 1957. https://doi.org/10.1029/TR038i006p00913

TEIXEIRA, L. F. da C. *et al.* M. Environmental management of hydrographic basins: application of geoprocessing as a contribution to the morphometric analysis of a sub-basin of the Jaguaribe River, Ceará. *In:* X BRAZILIAN ENVIRONMENTAL MANAGEMENT CONGRESS FORTALEZA/CE – November 04 to 07, 2019

TEODORO, V. L. I. *et al.* The Watershed Concept and the Importance of Morphometric Characterization for Understanding Local Environmental Dynamics. **Revista Brasileira Multidisciplinar**, [S. l.], v. 11, n. 1, p. 137-156, 2007. https://doi.org/10.25061/2527-2675/ReBraM/2007.v11i1.236

THOMAZ, E. L Hydrogeomorphological Processes and Land Use in a Subtropical Environment – Guarapuava-PR. São Paulo: USP. Thesis (Doctorate), 2005.

THOMAZ, E. L.; PERETTO, G. T. Hydrogeomorphic connectivity on roads crossing in rural headwaters and its effect on stream dynamics. **Science of the Total Environment**., v. 550, n. 1, p. 547-555, 2016. https://doi.org/10.1016/j.scitotenv.2016.01.100

TIECHER, T. et al. Contribution of sediment sources in an agricultural watershed under no-tillage. Revista Brasileira de Ciências do Solo, Santa Maria, v. 38, n. 2, p. 639-649, 2014. http://dx.doi.org/10.1590/S01000683201400020028

TRAJANO, S. R. R. da S. *et al.* Morphometric analysis of watershed: subsidy to territorial management, case study in the upper and middle Mamanguape. **Boletim de Pesquisa e Desenvolvimento / Embrapa Gestão Territorial,** Campinas, SP, p. 33, 2012.

VILLELA, S. M.; MATTOS, A. **Applied hydrology.** São Paulo: McGraw-Hill of Brazil, 1975. 245 p.

AUTHORS' CONTRIBUTION

The authors collected, analyzed and generated the results of the present study, as well as wrote the entire text of the article.