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Physiographic Characterization of the Córrego do Perdido River Basin – Ibatiba/ES

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Abstract

The use of natural resources has been accompanied by serious problems appearing from inadequate management. Thus, knowing the characteristics of the environmental planning units can contribute to minimizing damage and planning conservationist actions. The morphometric characteristics of the Córrego do Perdido river basin were determined for environmental planning purposes. To this end, we used radar data from the Shuttle Radar Topography Mission (SRTM) to represent the Digital Elevation Model (DEM) and geoprocessing techniques in a Geographic Information System (GIS) environment. To elucidate the hydrological behavior of the basin, we estimated some morphometric parameters. The drainage area obtained corresponds to 31.11 km^2, and the perimeter measures 33.57 km. With an irregular shape, the basin presented a shape factor equal to 0.12, compactness coefficient of 1.69, circularity index of 0.347 and small flow extension (0.1052 km). The drainage density found was 2.38 km^{-2}, indicating high drainage capacity. The basin had a strong wavy terrain (47.38% of the total basin area), with an average slope of 30.6% and an average altitude of 1,145 meters. The physiographic characterization revealed through the morphometric indices that the basin has an elongated shape and a dendritic drainage network of fourth order and, disregarding the adverse hydrological events, is not very susceptible to flooding. The high drainage capacity contributes to the infiltration of water into the soil, and the vegetation cover of the slopes must be preserved.

Keywords: Geographical Information Systems. Environmental Planning. Morphometric Characteristics.

Introduction

A watershed represents a natural unit of analysis of the Earth's surface, defined as a geographical area topographically delimited by its water dividers, in which surface waters are drained by a watercourse or a system of watercourses connected in a network until discharge at a single outlet that corresponds to the mouth (SANTANA, 2003; TUCCI, 2009).

Man's increasing interference in the environment has caused changes that affect the dynamics of water in river basins/watersheds due to life and anthropogenic and economic activities (MESQUITA *et al*., 2017; LIRA *et al*., 2020). For rational use of water sources in a basin, a series of systematic studies and the creation of management strategies to mitigate the impacts of human actions and occurrences arising from natural factors are necessary (CARELLI; LOPES, 2011; ROCHA *et al*., 2014). In this way, the multiple dynamics of the basins make these natural environments interesting objects of study (CÂMARA *et al*., 2020).

To know the characteristics of a river basin is important, in view of the conservation of its water resources, especially supported by its physical or morphometric characteristics (RIBEIRO *et al*., 2015), as it allows the understanding of its hydrological behavior and monitoring of interferences and responses to the impacts to which is subjected (FERREIRA; MOURA; CASTRO, 2012). Furthermore, physiographic characterization is one of the main procedures in hydrological and environmental analysis of river basins, as it contributes to the development of more efficient management of water resources and a thorough understanding of local and regional dynamics (FERRARI *et al*., 2013; BERTOLINI; CHEREM, 2016).

The morphometric parameters, among those commonly analyzed as the shape factor, the compactness coefficient, the circularity index, the drainage density and the average extent of surface runoff, combined with other data from a river basin, can differentiate homogeneous areas and establish the determination of hydrological variables in places lacking such information (VILLELA; MATTOS, 1975; ANTONELLI; THOMAZ, 2007). Another important parameter to be analyzed is the river hierarchy, which consists of establishing the classification of a given watercourse (or its drained area) in the total set of the river basin in which it is located, to facilitate and make the morphometric characterization of the basin more objective (CHRISTOFOLETTI, 1980).

Therefore, it is necessary for us to know the characteristics of the river basins, analyzing their morphometric parameters together with the biotic basin for the management and planning of several activities. This will contribute to properly implementing soil and water conservation techniques (FARIA *et al*., 2017; LIRA *et al*., 2020).

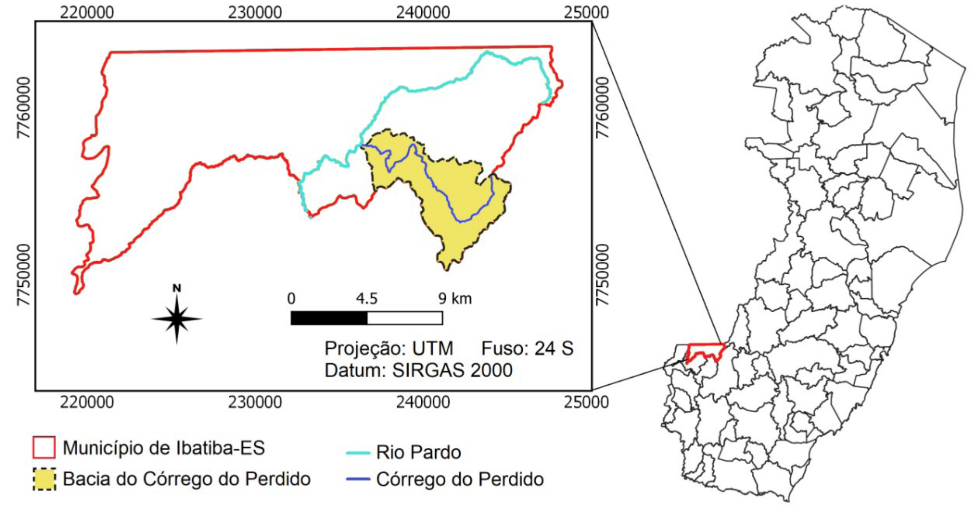
The use of the Geographic Information Systems (GIS), together with the consistent digital forms of terrain representation such as the Digital Elevation Models (DEM), have fostered the development of automatic methods of delimitation and morphometric characterization of basins (CALÇAVARA, 2012), which provide more reliable and reproducible, less subjective results when compared to the manual and traditional methods, previously used in map drawing (ASSIS *et al*., 2012). It is also possible to carry out the environmental management of river basins through GIS in a broader way, with the elaboration and maintenance of a geocoded database containing several statistical information on the characteristics of the study unit (PIRES; SANTOS; DEL PRETTE, 2002).

In this sense, this study aimed to determine the morphometric characteristics of the Córrego Perdido river basin, located in the municipality of Ibatiba-ES, through the GIS and geoprocessing techniques, using the ArcGis/ArcMap® software, so that the results obtained can contribute to a better planning and conservationist use of the basin.

Material and methods

The study area is the hydrographic basin of Córrego Perdido, located in the municipality of Ibatiba, in the region of Caparaó in the state of Espírito Santo (FIGURE 1), inserted in the area of influence of the Sub-Basin of Rio Pardo, belonging to the Itapemirim hydrographic basin (FIGURE 1).

Figure 1 – Location map of the Córrego do Perdido River Basin, Ibatiba-ES.



Source: Prepared by the authors (2020).

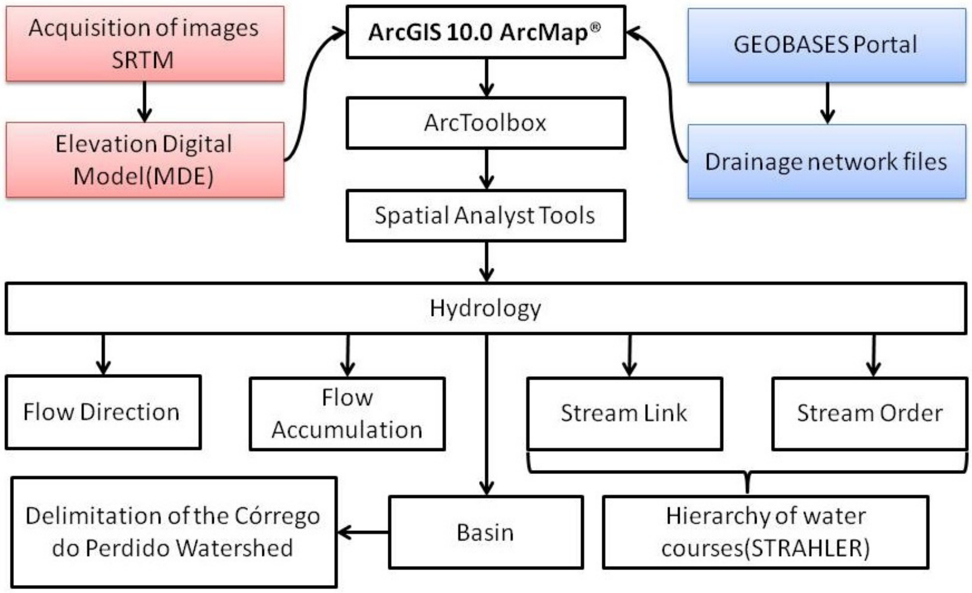
The municipality of Ibatiba is characterized by the presence of small remaining fragments of native vegetation of the Atlantic Forest (SOUZA, 2016), mostly suppressed due to the expansion of agricultural production activities, among which coffee farming stands out. The climate is predominantly tropical in altitude, and its geomorphology derives from the units of Caparaó massifs I, Caparaó massifs II and the staggered steppe of southern Espírito Santo (INGLEZ; DONIZETTI, 2018).

The morphometric analysis of the Córrego Perdido river basin, including the automatic delimitation and determination of its fluvial ordering, was performed in a GIS environment, through the ArcGIS 10.0 ArcMap® *software*, developed by the Environmental Systems Research Institute (ESRI), according to the flowchart presented in Figure 2.

We used the Digital Elevation Model (DEM) made available by the *Shuttle Radar Topography Mission* (SRTM), developed by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) in 2000 as reference data, made available for free by EMBRAPA Satellite Monitoring (MIRANDA, 2005), and also vector files, such as the grid of the state of Espírito Santo and municipalities, made available for free on the GEOBASES PORTAL of the Jones dos Santos Neves Institute (IJSN).

The classification of the drainage pattern followed the criteria established by Christofoletti (1980) and, for the hierarchical organization of watercourses, the ordering method proposed by Strahler (1957) was considered, which has a better understanding and is able to demonstrate the degree of branching of the system (OLIVEIRA; BORSATO, 2011; FERRARI *et al*., 2013). Through the ArcGIS 10.0/ArcMap ® GIS software, the river basin was sorted using the *"ArcToolbox – Spatial Analyst Tools – Hydrology – Stream Link"* and *"ArcToolbox – Spatial Analyst Tools – Hydrology – Stream Order"* modules, respectively (FIGURE 2). The resulting matrix image was then transformed into a vector of lines representing hydrography through the module *"ArcToolbox – Spatial Analyst Tools – Hydrology – Stream Feature"*.

Figure 2 – Flowchart of the methodology used in the delimitation of the Córrego Perdido River Basin and the determination of its river management.



Source: Prepared by the authors (2020).

For the classification of the slope of the basin, we used six distinct intervals of classes, according to the Brazilian Soil Classification System (EMBRAPA, 2009) (TABLE 1).

Table 1 – Slope intervals for classification of the terrain of the Córrego do Perdido river basin, Ibatiba-ES.

Downward slope (%)	Discrimination
0 – 3	Flat Terrain
3 – 8	Gently Wavy Terrain
8 – 20	Wavy Terrain
20 – 45	Strongly Wavy Terrain
45 – 75	Mountainous Terrain
> 75	Escarped Terrain

Source: EMBRAPA (2009).

The morphometric description of the Córrego do Perdido river basin was carried out through the evaluation of the following physical parameters: drainage area (A), perimeter (P), total length of the watercourses (Lt), axial length of the basin (L), length of the main channel, shape factor (F), compactness coefficient (Kc), circularity index (CI), drainage density (Dd), average extent of surface runoff (I) and slope.

The form factor is a parameter that relates the shape of the basin to a rectangle, which is calculated by the ratio between its average width and the axial length of the basin (which corresponds from the mouth to the farthest head). It is obtained by Equation 1, as described by Villela and Mattos (1975).

$$F=A/L^2 \quad (1)$$

at which: F is the form factor, A is the drainage area (km^2) and L is the axial length of the river basin (km).

The compactness coefficient corresponds to the relation of the perimeter of the basin with the circumference of a circle of area equal to that of the basin. Thus, this parameter is characterized by relating the shape of the basin to a circle, and the closer to the unit, i.e., to 1, its value is, the more susceptible the basin is to more pronounced floods, calculated by equation (2) (VILLELA; MATTOS 1975).

$$Kc=0,28*P/\sqrt{A} \quad (2)$$

at which: Kc is the compactness coefficient, P is the perimeter (m), and A is the drainage area of the river basin (m^2).

The circularity index and the compactness coefficient tend to the unit as its shape gets circular. However, when the basin has a more elongated shape, the circularity index decreases, unlike the compactness coefficient, which has its value increased as the basin becomes irregular. The circularity index is defined by Equation 3, described by Cardoso *et al*. (2006).

$$IC=(12,57*A)/P^2 \quad (3)$$

at which: IC is the circularity index, A is the drainage area (m^2), P is the perimeter of the river basin (m).

The drainage density is determined by the relationship between the total length of all watercourses (perennial, intermittent, and ephemeral) and their drainage area, according to Equation 4, defined by Horton (1945):

$$Dd=Lt/A \quad (4)$$

at which: Dd is the drainage density (km^{-2}), Lt is the total length of the watercourses (km), and A is the drainage area of the river basin (km^2).

The average extent of the surface runoff (I) is the average distance that rainwater would have to run over the land of a basin, if the runoff was in a straight line, from the drop point in the basin to the nearest watercourse. It is calculated based on Equation 5, described by Villela and Mattos (1975):

$$I=A/4Lt \quad (5)$$

at which: I is the average length of the surface runoff (km), A is the drainage area of the river basin (km^2), and Lt is the total length of the watercourses (km).

The analysis of the results was based on quantitative and qualitative parameters. The reference for the quantitative evaluations were the estimated morphometric indices added to the maps produced. The data obtained were compared with each other and with the literature for morphometric characterization of the hydrographic basin analyzed. Qualitative analyses of the data were accompanied by visits to the watershed, in which the diagnosis of land use and occupation were observed *in loco*.

Results and discussion

The results obtained from the morphometry of the geometric characteristics and the drainage network of the Córrego do Perdido basin (TABLE 2) indicate a small basin or municipal microbasin (FAUSTINO, 1996; CECÍLIO; SANTANA, 2003; REIS, 2006), with a drainage area of 31.11 km^2 and a total perimeter of 33.57 km, drained by the main course, which is 16.3 km long, and its tributaries, later discharged at its mouth on the Pardo river, the main watercourse of the municipality of Ibatiba. Data related to these small basins, especially those contained entirely within a municipality, enable the ecological, hydrological, social, and economic management of the basin, and the management of land use and the conservation of natural resources through a local, integrated, and more efficient approach (SANTANA, 2003; TEODORO *et al*., 2007).

As for the shape, the basin studied has an irregular shape with a tendency to elongation, as ratified by the shape factor (0.12), compactness coefficient (1.69) and circularity index (0.34), whose values move away from the unit (TABLE 2). This fact indicates lower susceptibility to floods under normal precipitation conditions since more elongated basins have a lower concentration of outflows and it is less likely that tributaries simultaneously contribute a large amount of water to the main channel, which reduces the risk of overflow (FRAGA *et al*., 2014; RODRIGUES *et al*., 2016). Analysing the morphometric results of the Igarapé do Una water basins in Belém-PA and the Manhuaçuzinho-MG river, Ribeiro *et al.* (2015) and Mesquita *et al*. (2017) found similar results of Kc, Ic and F, equal to 1.60, 0.39, 0.44 and 1.78, 0.31,

Table 2 – Morphometric characteristics and the drainage network of the Córrego Perdido river basin, Ibatiba-ES.

Morphometric Characterization	
Area (A) - (km^2)	31.11
Perimeter (P) - (km)	33.57
Axial length of the basin (L) - (km)	16.10
Compactness coefficient (Kc)	1.69
Circularity index (Ic)	0.347
Form Factor (F)	0.12
Average length of surface runoff (l) - (km)	0.1052
Characterization of the drainage network	
Total length of watercourses (Lt) - (km)	73.91
Length of the main watercourse (Cp) - (km)	16.3
Drainage density (Dd) - (km km^{-2})	2.38
Basin order	4th
Average downward slope of the basin - %	30.6

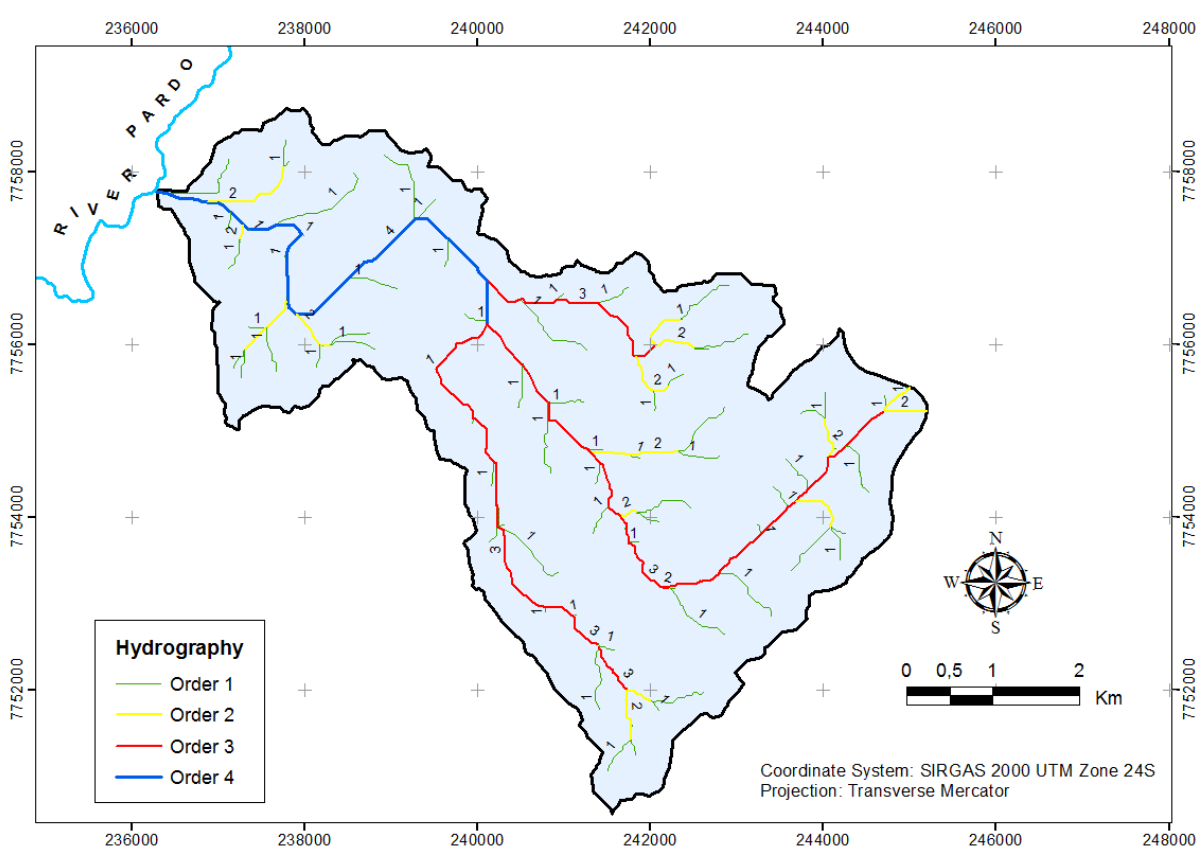
Source: Prepared by the authors (2020).

0.23, respectively, and concluded an elongated trend in the basins, therefore not susceptible to flooding under normal precipitation conditions. On the other hand, Tolentino, Silva, and Ferrari (2015), characterizing the watershed of the Brisa stream in Alegre/ES, and Alvarenga *et al*. (2019), characterizing the morphometry of the watershed formed by the watercourses of the central region in the municipality of Itabira/MG, found that both are more prone to floods due to their more circular than elongated forms, since the morphometric indices of Kc, Ic and F were equal to 1.17, 0.72, 0.44 and 1.33, 0.56, 0.33, respectively.

The Córrego do Perdido basin has a drainage pattern with a dendritic type arrangement and is considered to be 4th Order (FIGURE 3), therefore being quite branched compared to its area, since small basins generally have an order equal to or less than four, and therefore its drainage system tends to be more efficient (TONELLO *et al.*, 2006). This fact also influences the increase in the total length of the watercourses, increasing the drainage density and reducing the extent of surface runoff, corroborating the morphometric data discussed above.

According to Villela and Mattos (1975), a drainage density of 0.5 km^{-2} is considered poor and a drainage of 3.5 km^{-2} or more is exceptional. Christofoletti (1974) defined two intermediate classes of drainage density, a median between 0.50 km^{-2} and 2.00 km^{-2} and another high between 2.01 km^{-2} and 3.50 km^{-2}. The index obtained for the Córrego do Perdido basin (2.38 km^{-2}) can be considered high, which denotes a contribution surface area congruent to the total length of the watercourses, allowing adequate drainage. However, its surface runoff

Figure 3 – River management of the Córrego Perdido river basin, Ibatiba-ES.



Source: Prepared by the authors (2020).

extension of 0.1052 km (TABLE 2) is considered small (OLSZEVSKI *et al*., 2011), which can contribute to flooding in case of intense hydrological events due to the lower possibility of water infiltration into the soil, and to the reduction of groundwater supply.

Morphometrically characterizing the Córrego da Brisa river basin in Alegre-ES, Tolentino, Silva, and Ferrari (2015) determined that it had a regular drainage density (2.87 km^{-2}), a high value according to Christofoletti (1974), similar to the class found in this study. However, Sousa and Paula (2016), studying the hydrological behavior of the Tapuio River Basin/CE, found that, despite the large number of branches of the drainage network of the river basin (5th order), it had an average drainage capacity (1.2002 km km^{-2}). The authors point out that the drainage order is related to the potential use of natural resources, which is a relevant index for the planning of use and occupation, because the more branched the drainage network, the greater its efficiency will be in the integration between the various components and processes that occur in the river basin. In the analysis of river basins, this is a relevant parameter, because the higher the numerical value of the drainage density, the smaller the sizes of the river components of the drainage basins will be (ALVARENGA *et al*., 2019).

In terms of the terrain characteristics evaluated, the Córrego do Perdido basin presented a large variation in altitude, with a minimum of 740 m, maximum of 1,550 m, average of 1,145 m and amplitude of 810 m (TABLE 3). Given this strong amplitude, these data are important for the correct management of the use and conservation of the different areas of the basin, taking into account that areas of higher altitude are more prone to dissection and areas of lower altitude to accumulation, in addition to favoring the analysis of different climatic elements and areas of erosion (SILVA *et al.*, 2010).

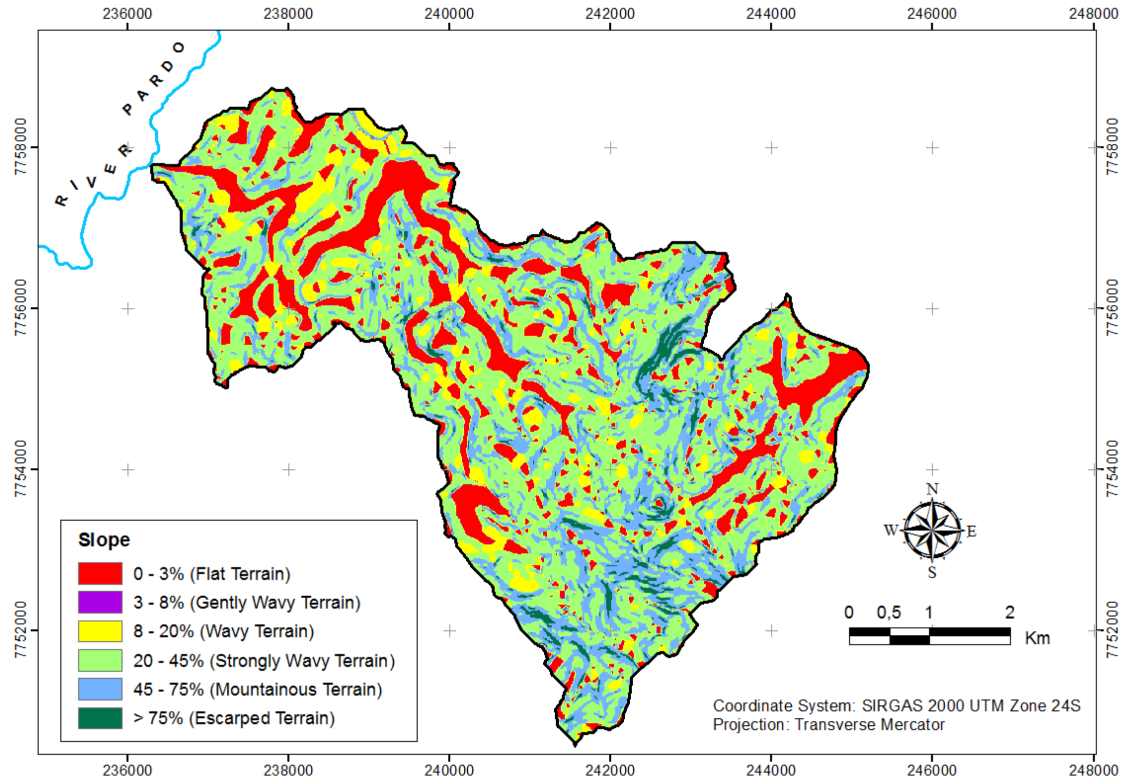
Table 3 – Distribution of the classes of downward slope, average downward slope, and altitudes of the Córrego Perdido river basin, Ibatiba-ES.

Downward slope - %	Discrimination	Area km^2	% Area
0 - 3	Flat Terrain	5.31	17.08
3 - 8	Gently Wavy Terrain	0.59	1.91
8 - 20	Wavy Terrain	3.26	10.49
20 - 45	Strongly Wavy Terrain	14.74	47.38
45 - 75	Mountainous Terrain	6.28	20.19
> 75	Escarped Terrain	0.92	2.95
Average Downward Slope (%) 30.6			
Maximum Altitude (m) 1,550			
Average Altitude (m) 1,145			
Minimum Altitude (m) 740			

Source: Prepared by the authors (2020).

An average downward slope of 30.6 % was found, with the highest slope concentration in the class from 20 % to 45 %, classified as strongly wavy, with 47.38 % of the total area, distributed uniformly throughout the basin, and a considerable portion of the area (20.19 %) of the mountainous terrain, in the class from 45 % to 75 % (TABLE 3), located mostly in the southwest portion (FIGURE 4). The flat terrain areas (from 0 % to 3 % of slope) are more concentrated in the northwest portion of the basin, near the Pardo river, and may indicate

Figure 4 – Spatial distribution of the downward slope of the Córrego Perdido river basin - Ibatiba/ES.



Source: Prepared by the authors (2020).

areas with possible floating of the water table, such as swamps and floodplains, susceptible to seasonal and temporary flooding (FIGURE 4). Analyzing the morphometric characteristics of the Igarapé Carrapato river basin in Boa Vista/RR, Faria *et al*. (2017) found a low altimetric amplitude (64 m) for this basin, indicating that it has little movement, which is confirmed by the predominant slope classes of the area (47.2 % flat and 49.5 % gently wavy area).

The predominance of strongly wavy terrain added to the characteristics of the use and occupation of the soil of the Córrego do Perdido basin, which was found, through on-site visitation, to be mostly pastures and coffee crops, directly influence the intensity of degradation and the occurrence of erosive processes in the agroecosystem of the basin, since the replacement of native vegetation by agricultural areas exposes the soil to a series of degradation factors (OLSZEVSKI *et al*., 2011).

Among the losses, it is important to highlight the soil loss, reducing its physical and chemical quality and consequently its productive capacity, and the silting and pollution of the watercourses (SPERANDIO *et al*., 2012), capable of greatly impacting ecological and socioeconomic aspects in the context of the basin and generating a great burden for the local community and the municipality. Thus, the importance of joint planning for the implementation and maintenance of activities, management of land use and management (SILVA *et al.*, 2018), as well as the adoption of conservationist practices and environmental regularization of properties, is emphasized.

Conclusion

Disregarding hydrological events of abnormal intensities, the Córrego do Perdido river basin is not very susceptible to flooding, as it has an irregularly elongated shape, since its compactness coefficient, the form factor and the circularity index present values away from the unit, that is, the closer to 1, the greater the risk of flooding. The high drainage density contributes to the infiltration of water into the soil and the supply of the water table, consequently to the lower loss of water and soil by erosion. However, if adverse hydrological events happen, the safety against flooding is jeopardized, as the extent of surface runoff is considered small. The drainage system is very branched because it is a fourth order basin. The vegetation cover of the surface of the slopes must be preserved to prevent the degradation of natural resources since the terrain is predominantly strongly wavy.

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