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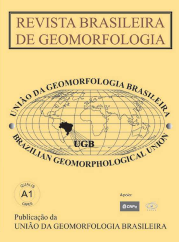

LAND-USE CHANGES AND THE INCREASE IN THE NUMBER ROAD-STREAM CROSSINGS IN A RURAL BASIN SOUTH OF BRAZIL

MUDANÇAS NO USO DA TERRA E O INCREMENTO DO NÚMERO DE CRUZAMENTOS DE ESTRADAS COM RIOS EM BACIA HIDROGRÁFICA RURAL NO SUL DO BRASIL

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Abstract:

Changes in land use interfere with river basin connectivity, affecting the flow dynamics, sediment yield, and density of river connections with roads. In this research we studied the variation of land use from 1980-2002-2016 using vector mappings in the classes: temporary crops, primary and secondary forests; pasture, forestry, buildings, ponds, and the development of crossings between drainage roads (road-stream crossings) in the Guabiroba River basin. Variations in the use and percentages over the 36 years studied were observed. There was a reduction in primary forest and pasture areas and an increase in planted forests and temporary crops. Regarding the crossings, there was an increase in the topographic dimensions and in sectors with sharp slopes and first-order channels. Over the years, the uses in the basin were alternated according to the productive structures, showing needs according to the creation, modification, and suppression of roads. In temporary crops, the period from planting to harvesting is up to 6 months, and slash-and-burn agriculture rage from 3 to 5 years between each planting, and forestry depending on the demands it can range from 4 to 20 years. These variations in time and space, interfere with the productive flows and consequently with the road-stream crossings.

Resumo:

As mudanças no uso da terra interferem na conectividade das bacias hidrográficas, afetando a dinâmica de fluxos, a produção de sedimentos e a densidade de conexões de ríos com estradas. Esta pesquisa visa evidenciar como o uso da terra interfere na dinâmica da bacia hidrográfica, por meio das mudanças na conectividade, com a criação, modificação e supressão de estradas rurais, e com isso avaliar como e por que ocorrem os cruzamentos de estradas com drenagem ao longo do tempo. Para compreender a variação do uso da terra de 1980-2002-2016 utilizou-se de bases vetoriais nas classes: culturas temporais, vegetação primaria e secundária, pastagem, silvicultura, edificações e evolução dos cruzamentos entre estradas rurais com rios na bacia hidrográfica do río Guabiroba. Destaca-se nos resultados a diminuição das áreas com vegetação primária e pastos e o aumento das florestas plantadas com pinus/ eucalipto e das culturas temporárias. Quanto às estradas rurais, ocorreu um aumento de cruzamentos com a drenagem nas cotas topográficas superiores, em setores com declividades acentuadas e em canais de primeira ordem. Conforme os anos, os usos e a dinâmica ambiental da bacia se alternaram com as estruturas produtivas, criando novas necessidades e com isso a criação, modificação e subtração de estradas rurais. O tempo de duração das culturas temporais é de até 6 meses, desde a plantação até a colheita, do cultivo roça de toco é de 3 a 5 anos entre cada plantação, e da silvicultura, dependendo das demandas, pode variar de 4 a 20 anos. Estas variações no tempo e no espaço do uso da terra interferem nos fluxos produtivos e consequentemente nos cruzamentos entre estradas rurais e rios.

1. Introduction

At present, changes in land use are becoming increasingly intense since the world population and the need for food and natural resources for human survival have increased daily (Lanbin *et al.* 2001; Foley, 2005). Land-use change is driven by synergetic factor combinations of resource scarcity leading to an increase in the pressure of production on resources, changing opportunities created by markets, outside policy intervention loss of adaptive capacity, and changes in social organization and attitudes (LAMBIN *et al.* 2003).

Changes in land use in rural areas, at the level of hydrographic basins, result in changes in the basin input and output systems (Li *et al.* 2006; Chalton, 2008). Each land use interferes with the hydrological cycle processes, altering the hydric balance, evapotranspiration, infiltration, and surface runoff (Foley *et al.* 2005; Li *et al.* 2006; Bere and Tundise, 2011; Woldesenbet *et al.* 2017).

Among the anthropic activities standing out in the landscape (Tarolli and Sofia, 2016), the creation and modification of rural roads cause several impacts at the level of hydrographic basins, (Chomitz, and Gray, 1996; Blanton and Marcus, 2009; Forsyth *et al.*, 2006; Fu *et al.*, 2010). Wemple et al (2017) point out the following impacts of rural roads on hydrographic basins: hydrological and geomorphological impacts, which change the flux of sediments and production and transfer of sediments in rivers; eco-hydrological impacts leading to the carrying of sediments in aquatic systems, degradation of water quality, obstruction of channels and connectivity of landscape, and other impacts such as the dissemination of exotic plants along the deforested areas. Sediment production is an example of environmental impact, which, according to the topographical conditions in each road stretch, is 4.97 kg/m²/year (Schultz *et al.* 2012) or even 5.7 kg/m²/year (Ramos-Scharrón and Macdonald, 2007).

Roads are one of the connection elements created in the landscape by man, causing the advance of deforestation (Blanton & Marcus, 2009; Laurence et al 2014; Wemple *et al.* 2017), since they connect the urban centers to give access and support to the land use activities, such as agriculture, livestock farming, and timber production (Freitas *et al.*, 2009, 2010). In addition to allowing the mobility, the roads form a network in the landscape and are connected with drainage systems disposed of in the relief, forming a mosaic of connections (Forman, 1998).

The initial of forests provided the areas for settlement and agriculture, and the subsequent need for communication between the settlements created the pathways and the roads. This type of land use is, therefore, as old as the human organized society (MAN, 1983). Roads are permanent scars on the landscape and facilitate deforestation and forest fragmentation due to increased accessibility and land valorization, which control land-use and land-cover dynamics (FREITAS *et al.* 2010).

In addition to hydrological impacts, the roads in uninhabited regions, with wild forests or in border areas, are an essential conditioning factor of loss and fragmentation of habitat, forest fires, excessive hunting, and other environmental degradation, often causing irreversible impacts on ecosystems (Laurence *et al.*, 2014).

The road-stream crossings (roads that cross rivers/ streams) are another important component, which makes the water running off in their bed arrives quickly to the drainage channels, rapidly increasing the flow and becoming an accessory hydrographic network (Forman e Alexander, 1998; Forsyth *et al.* 2006; Jones *et al.*, 2000). The hydrological effect of the roads depends on many factors, including their location in the watershed, the design of drainage structures that affect the water course through the microbasin, and the proportion of area occupied by roads (GUCINSKI *et al.* 2001). Therefore, roads are elements for direct connection between the watershed and fluvial channel, influencing the basin sediment balance (FU *et al.*, 2010).

The crossings are not randomly created, they are related to the environment topography, drainage density, agricultural structure, history of occupation, and dynamics of land use (Lane *et al.* 2006; Ellis and Pontius, 2007; Foley *et al.* 2005), which interact with each other, interfering with the creation, modification, and intensification of roads in a given environment (Jones *et al.*, 2000), functioning as an ecosystem (Lugo and Gucinski, 2000).

According to Forman (1998), the roads are connected to each other forming a network, and they vary in the form and purpose. The services offered by the road strongly determine the form of the road network. For example, rectilinear routes have residential purposes, whereas dendritic routes support timber activities in mountainous areas. The ramified patterns of the road network in mountainous relief are formed in part by the arrangement of roads with valley beds and hills, as well as the boundaries defined by the slope from the roads up to the mountains.

Thus, according to the needs and dynamics of land use, roads are configured, which can be suppressed, changed or increased. Therefore, the land use is a dynamic factor that changes the in intra-basin connections (Fu *et al.*, 2010). The uses are arranged in mosaics, and the more they differentiate, the more they disconnect but remain connected by rivers and roads (LANE *et al.*, 2006).

The connection of roads with rivers (stream crossing) is cited in studies carried out by Wemple (1994); Jones *et al.* (2000); and Freitas and Metzger (2010), who point out how this connection interferes with the dynamics of rivers. Depending on the drainage and road density, there may be an interference with the basin morphometric indexes such as the drainage density and extension of the surface course defined by Horton (1945), and the maintenance coefficient (Schumm, 1956), and sometimes the surface and subsurface flow interception (Jones *et al.*, 2000).

The Guabiroba River hydrographic basin (study area) is a rural region with representative characteristics of topographic sectors dissected from the Serra Geral Formation in the south center of Paraná State, Brazil, with land uses with a low level of applied technologies. Several studies have already been carried out in this basin to understand hydrogeomorphological processes on rural roads such as 1) the hydrogeomorphic connectivity on roads crossing in rural headwaters and its effect on stream dynamics (THOMAZ & PERETTO, 2016), 2) the surface and subsurface hydrological processes influenced by crossings of unpaved roads (CUNHA, 2016), 3) the effects of unpaved roads on suspended sediment concentration at varying spatial scales (THOMAZ *et al.* 2014), 4) the use of rural roads as a source of surface runoff (THOMAZ & PEREIRA, 2013), 5) the estimate of sediment production in headwaters with high density of rural roads (THOMAZ *et al.*, 2011), and 6) the land use dynamics and soil degradation in the Guabiroba River basin (THOMAZ, 2007).

Studies on hydrographic basins with land use with a low level of applied technology, topographic slope, and history of environmental degradation, using multitemporal mapping and road-stream crossings, are scarce in the international scenario. Thus, this research aimed to show how land use interferes with the hydrographic basin dynamics, through changes in connection, with the creation, modification, and suppression of rural roads, and thus evaluate how and why road-stream crossings occur over time.

Given the above, the specific aims of this study were to evaluate the land use dynamics over 36 years and its influence on the increase of unpaved roads and verify over time the distribution of unpaved roads in the landscape and the relationship between the crossings and the drainage network in the Guabiroba River hydrographic basin.

2. Material And Methods

2.1 Physical characteristics of the study area

The Guabiroba River basin has 23.74 km², with 90.41 km of roads and 177.14 km of perennial and intermittent rivers up to the 4th order, according to

Strhaler classification (1957), predominantly arranged from east to west, being the affluent of the left bank of the Pedras River, which supplies water for the municipality of Guarapuava (Figure 1).

According to Thomaz *et al.* (2011) and Cunha *et al.* (2013), this basin has rural characteristics, marked by land use by small farmers, who produce food for their subsistence, jointly with monocultures of forestry, temporary crops (soybean, corn, and oats), and leisure activities, resulting in a road system composed of rural roads, pathways and unpaved roadways, contributing to the entrance and interceptions of channels and production of sediment in the rivers crossed by these roads.

According to Thomaz (2007b), this basin has a fragmented and dynamic land use due to the use patterns, consisting of pastures for beef and dairy cattle, vegetal extractivism, temporary agriculture, and subsistence crops such as slash-and-burn agriculture, mate herb (*IIex paraguariensis* St. Hil.), and fruit farming.

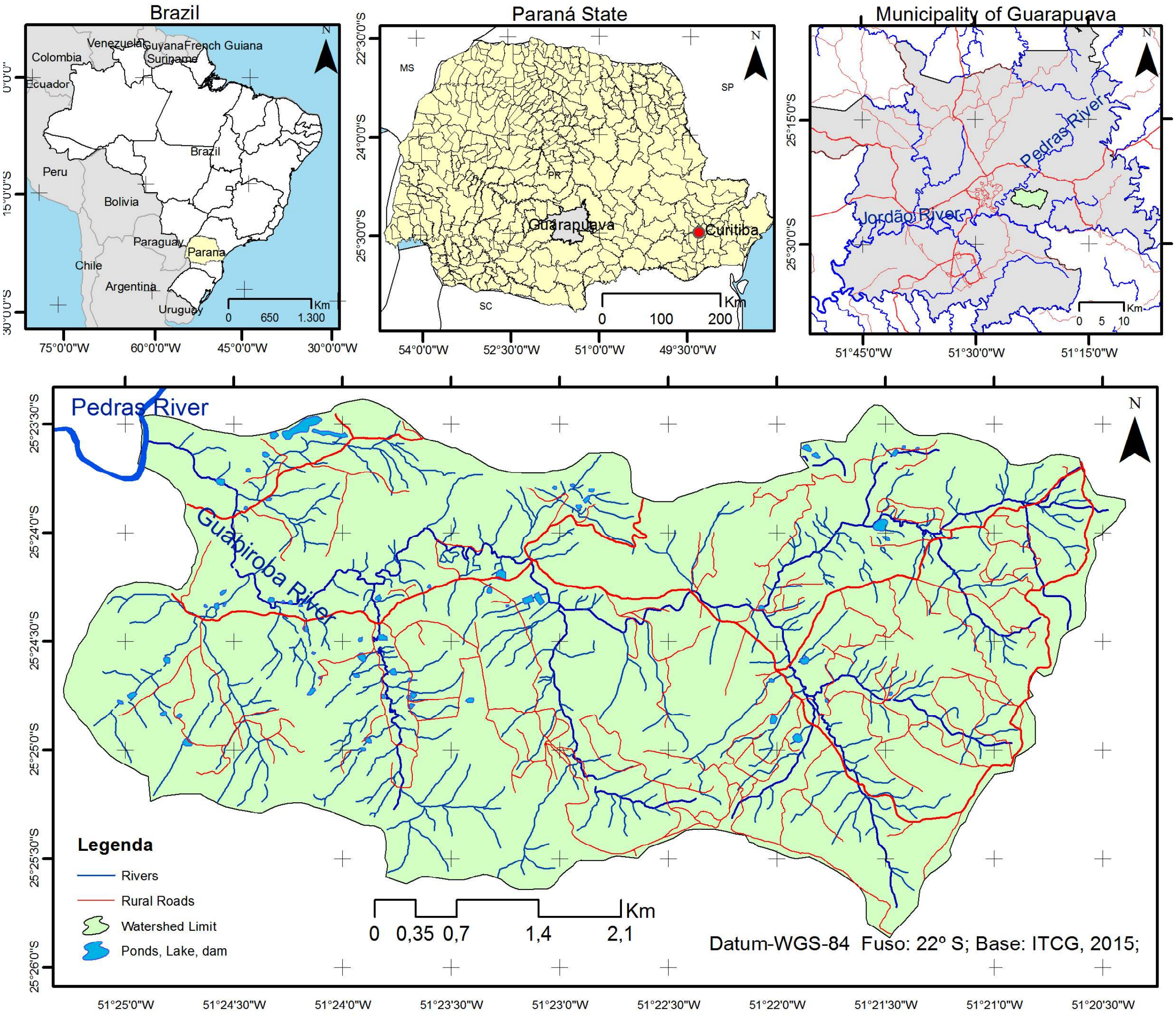


Figure 1 - Location of the Guabiroba River hydrographic basin

The rocky substrate is from the Serra Geral Formation (São Bento group), composed of basic extrusive igneous rocks at the base and acid rocks at the top in a trap form (Frank *et al.*, 2009). Regarding the geomorphological aspects, the region is located in the Morphostructure of the Paraná Sedimentary Basin, Morphosculture of the Third Paranaense Plateau, and in the sub-unit of the Foz do Areia-Ribeirão Claro Plateau (Santos *et al.*, 2006).

The Guabiroba River basin has a relief with sharp gradient, with concave ridges, steep slopes, and embedded valleys. It is characterized by steep slopes, and 65% of the basin have altitudes above 1.145 m. The slope predominance in the basin refers to the classes >12%, accounting for 66.54% of the area, mainly in the fluvial terrace, high, hilltops, and subsidiarily in some sectors of convex slopes (Cunha, 2016). The classes ≤12% represent 33.4% of the study area and are near the fluvial courses. Thus, the basin can be characterized as having medium, predominant (12 to 20%), medium/high (20 to 30% and ≥30%) slopes. These slopes are frequent in segments of convex slopes, generally in sectors lateral to topographical levels (THOMAZ, 2005). Regarding the altitude, the basin has approximately 60% of its areas between 1.040 and 1.160 m altitude (THOMAZ, 2005).

As discussed above, the relief has some compartments related to the lithological variations from the region between acid and basic rocks (Frank *et al.*, 2009), which form scalings from one basalt effusion to another, creating topographical levels on the relief with different levels of erosion (PAISANI *et al.* al. 2008).

The soils in convex slopes dissected by where some roads cross are composed by the association of Alic Cambisols with Alic Litholic Neosols, with a clay texture (>35% clay), under the Araucaria Forest domain (MENDES & CASTRO, 1984, EMBRAPA, 2006). Occasionally there is an outcropping of rocks in passageways of topographical levels, and in sectors where the road bed was deepened and gullied for its development (THOMAZ & PEREIRA, 2013) Figure 2.

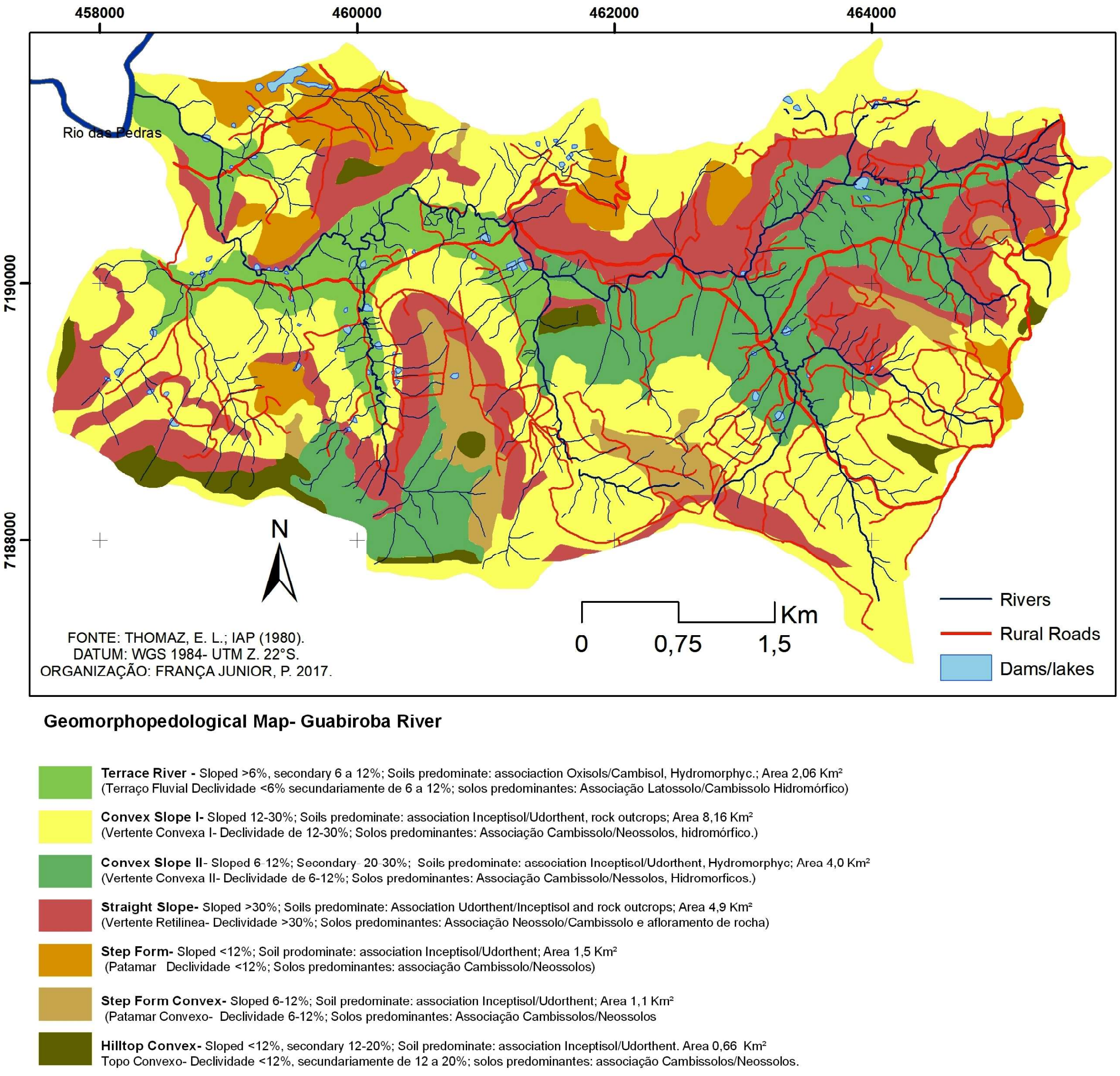


Figure 2 - Geomorphopedological Map Guabiroba River hydrographic basin. Organized by the authors, 2018

The predominant climate in the region is classified as Cfb humid subtropical (temperate climate) with rainy weather, moderate winters with frost and moderately hot summers. From 1976 to 2012, the annual mean temperature was 17.1 °C and the rainfall was 1,916.1 mm, respectively (THOMAZ &VESTENA, 2003).

2.2 Land-use mapping

Data collection for land use and road mapping was carried using information from the vectorization of data in available databases. According to the IBGE (2013), the mapping unit is the representation of the homogeneity and diversity of objects that cover the earth surface. It corresponds to a homogeneous cover (forest, roads, water, etc.) or a combination of homogeneous elementary areas, which in their variations represent the terrestrial surface cover. It is characterized by being distinguishable from the units of its surroundings and by representing a significant portion of land at a given scale. Land-use activities correlated to its cover need to be interpreted from models, tonalities, textures, shapes, spatial arrangements of activities, and location on the ground.

Cartographic databases from 1980 made available by the ITCG (Instituto de Terras Cartografia e Geodésia) were used for the vector mapping of the land-use in the Guabiroba River basin. These data consisted of aerial photographs obtained from the ITC 1: 20,000 and topographic maps from the Army Ministry (Ministério do Exército), page MI-2838/3-SG. 22-V-D-III/3 (1980). For 2002, we used the database from the Municipality Council of Guarapuava at a scale of 1: 25.000. For 2016, the mapping was obtained from the Google Earth images. Furthermore, field work and bibliographic references of articles and theses corroborated the information to found the mapping.

After the vector mapping, data on land use and roads were organized in tables to make the percentage correlations, and later to understand their temporal evolution.

Land uses were organized and vectorized in temporary crops (soy, corn, oats and wheat), primary and secondary forests (native vegetation of Araucaria Forest) and successions with different levels of canopies ("capoeira"/secondary forest, extractivism, faxinal system), pastures (dirty field and clean field), forestry (Pinus and Eucalyptus), buildings (houses, sheds, stables, rodeo tracks, and orchards), and lakes, ponds and dams (for fish farming, leisure and to quench animal thirst). The pictures representing the main land uses in the Guabiroba River basin in 2016, as well as a brief description of the areas from where the images were taken, are shown in Table 1.

2.3 Mapping and road-stream crossings

According to Baesso and Gonçalves (2003), the roads of in Guabiroba River basin can be classified as their management (municipal or private), function (collectors and locals), physical characteristics (unpaved with single roads with double and single lane). Also, they were classified by Cunha (2016), as primaries (1), secondaries (2) and tertiaries (3). The primary ones are the main roads which have the largest flow of vehicles and are on average 6m wide. Secondary roads which have an average width of 4.5 m, and adjacent to these there are the tertiary roads, with an average width of 2 m, called internal paths and roadways of rural properties.

According to Thomaz & Pereira (2013), some stretches have their bed covered by earth and gravel and have traffic from very low to medium intensities.

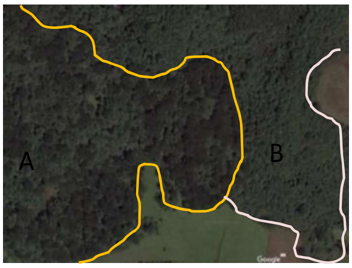
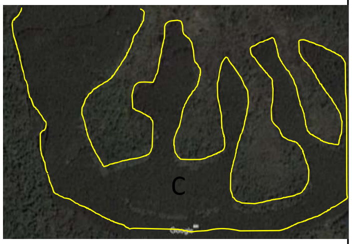
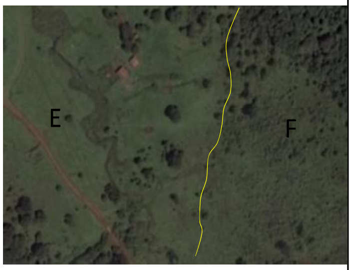
Regarding the topography, Cunha (2016) points out that the roads of the basin are characterized by stretches of low slope along the rivers and main affluents, since they consist of flatter stretches; however, these roads branch from sectors of low to high slopes, following courses of the affluents until reaching the highest levels of the basin. In this trajectory, the roads cross the channels that drain the watersheds, at different orders, altitudes, and slope levels.

The road-stream crossings were mapping in a GIS environment, by adding points for each intersection (roads/stream) to analyze the information in the years surveyed (1980, 2002 and 2016), in which the operational variables (order of the channels, altimetry, and slope) were used.

Regarding the order of the channels, Strhaler (1957) classifies the first-order channel as a stretch from the channel source until it meets another channel (1 + 1 = 2), after this meeting, it becomes a second order channel (2 + 2 = 3) and so on.

Altimetry was performed using 5 m (P.M.G) level curves and SRTM data classified at 50 m pre-defined intervals: 978-1028, 1029-1078, 1079-1128, 1129-1178, and 1179-1221m

Table 1: Pictures and description of the Guabiroba River basin.

Land Use Picture	Description	Land Use Picture	Description
	**Primary/Secondary Forests** A- Mixed Ombrophilous Seasonal Forest - Primary Forest B- Forest in the process of regeneration or secondary forest fallow.		**Forestry** C - Area for the plantation of Eucalyptus and Pinus interspersed with riparian vegetation in spring sectors.
	**Temporary Crops** D - Temporary crop area corresponding to the production of grains. In this case, the soybean had been harvested, and later there was the planting of oats to cover the soil and be used to feed cattle.		**Pasture** E - Pastures with a low level of technology. F - Dirty field - associated pasture and "capoeira" area.
	**Buildings** G - Houses, sheds, stables, and living areas. It is the densest area regarding residences**.**		**Lakes, Dams** H - Small lakes for fish farming and leisure purposes. It is noticed in the picture the lack of riparian vegetation near the canal.
	**Unpaved Roads - Primary/Secondary** I - Primary or main road that especially goes through the valley beds and areas with a lower slope along almost the entire basin. J - Secondary roads and paths connecting the farms and crops with the main road.		**Rivers** The ephemeral and intermittent rivers were considered.

Organized by the authors, 2018

The slope was measured using TIN grid generated by the 5 m (P.M.G) curves using the classes of 0-6, 6-12,12-20, 20-30 and >30% slope.

3. Results

3.1 Land use change from 1980 to 2016

Noticeable land use changes occurred from 1980 to 2016 (Table 2). In 1980 the annual crops were absent. However, in 2002 and 2016 annual crops increased around 6 and 8% respectively. In 36 years, forest decreased by 57%, and most changes occurred from 2002 to 2016. Pasture areas had a reduction of 25% from 1980 to 2016. Commercial forest, particularly, Eucalyptus and Pinus increased five times from 1980 to 2016 (Figure 3).

Noticeable landscape fragmentation is observed from 1980 to 2016. In 1980 the land use patch, especially forest and pasture, was higher and continuous along the hydrographic basin. Commercial forest occupies only a small patch in the north of the hydrographic basin border. In 2002, it was observed a strong fragmentation with an increased number of discontinuous land use patches. Temporary crops and commercial forestry also increased. In 2016, the land use had a pattern similar to that observed in 2002; however, the commercial forestry significantly increased in this period (~69%).

Table 2: Land Use in the Guabiroba hydrographic basin in1980, 2002 to 2016

Land Use	1980		2002		2016	
	%	ha	%	ha	%	ha
1. Temporary crops	Nd	Nd	6.4	157	7.8	186
2. Forest - Primary/Secondary	60.7	1475	59.3	1440	42.8	845
3. Pasture	32.8	797	22.3	543	24.7	593
4. Forestry	4.3	103.6	13.9	337	23.8	571
5. Buildings	2.3	56	1.2	29	1.9	45
6. Ponds	0.0	0.1	0.2	4	0.6	15
1. Primary Roads	0.4	9.6	0.5	11.8	0.5	11.8
2. Secondary Roads	0.9	23.3	1.0	22.8	1.1	24.9

Organized by the authors, 2018.

The construction of buildings was irregular over the year; however, it accounted for 19% of reduction, whereas ponds increased gradually from 1980 to 2016. Overall, the area occupied by primary and secondary roads increased about 18% in 36 years.

3.2 Expansion of Primary and Secondary rural roads from 1980 to 2016

The primary (19.43 km) and secondary (70.98 km) rural roads currently account for 90.4 km, corresponding to a density of 3.7 km for each km² of the Guabiroba River basin. From 1980 to 2016, the secondary rural roads had an increase of 8 km, which multiplied by an average width of 3.5 m corresponds to 1.6 ha (Table 3).

The unpaved road network increased slightly from 1980 to 2016. The main road increased by 17% and secondary roads only 6%. Overall, the total road network had an increase of 50% in drainage density, considering the road as natural drainage.

3.3 Stream crossing characteristics and landscape position

The number of road-stream crossings increased in 1980 to 2016, particularly on the first and third order stream, 12 and 18%, respectively. The most interesting change in stream crossing characteristics occurred in this period was related to its landscape position, i.e., altimetry and slope. The stream crossing increased 44% on the higher landscape topography. Also, the stream crossing frequency increased 71%, mainly on the steep slope ≥ 30% and on moderate relief of 12 to 30% slope. Finally, in 2016 the hydrographic basin had 11 road-stream crossings per kilometer square (Table 4).

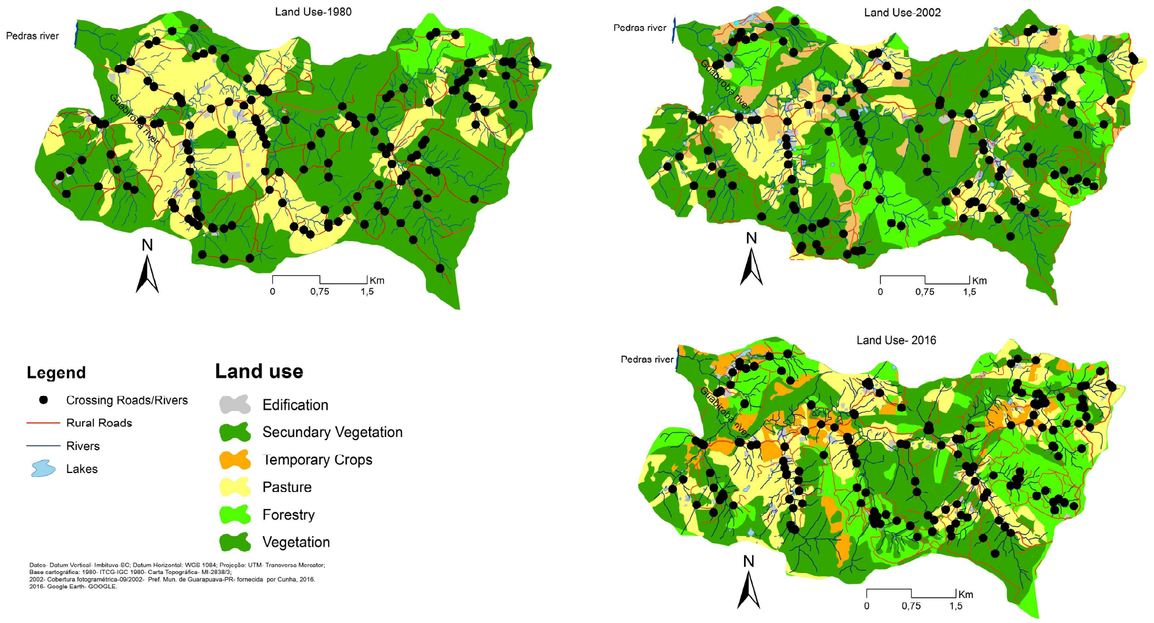


Figure 3 - Land use and landscape fragmentation in the Guabiroba hydrographic basin from 1980 to 2016. Organized by the authors, 2018

Table 3: Unpaved roads development in the Guabiroba River basin

Items / Years	1980	2002	2016
Primary roads	16.0	19.4	19.4
Secondary roads	66.6	65.0	71.0
Total road (Km)	82.6	84.4	90.4
River network extension	177.1	177.1	177.1
Drainage density	7.3	7.3	7.3
Roads Density	3.4	3.5	3.7
Drainage + roads density	10.7	10.8	11.0

Source: Authors, 2018.

It is observed a clustering pattern of intersections between roads and channels. This clustering occurs according to the orientation of the roads in the bed of valley parallel to the rivers. The main roads branch off along the main rivers, and as they advance to the higher sectors, they cross the third, second and first order channels towards the highest altitudes. However, the highest density of crossings occurs at lower altitudes, and over the years the highest altitudes are reached with an increase in the number of points (Figure 4).

The road network is controlled by the landforms and topography (Figure 5). In the hydrographic basin, the main and secondary roads are located on the valley bed following the watercourses (79%). On this area, the relief slope is ≤ 6 to ≤12%.

From 1980 to 2016 the number of road-stream crossings (Figure 6) increased gradually. Road-stream crossings at higher altitude are practically absent in 1980. From 2002 to 2016, road-stream crossings on higher topography are observed, especially, on the bordering hydrographic basin divide.

An important fact to consider is the frequency of first-order channels compared to the those of higher orders. A total of 64% of the channels in the basin correspond to first-order channels (Cunha, 2016). When verifying the frequency of crossings, it is observed that the number of crossings in first-order channels is 61.1% in 1980 and 66.2 % in 2016. Therefore, there is a positive correlation between the number of first-order channels and the number of crossings of these channels with the roads

Table 4: Number and characteristics of stream-road crossings

Analyzed Categories	**1980**		**2002**		**2016**	
Stream order (Sthraler. 1957)	Number of stream crossing	%	Number of road-stream crossings	%	Number of road-stream crossings	%
1	91	61.1	92	67.6	104	66.2
2	33	22.1	24	17.6	23	14.6
3	18	12.1	17	12.5	22	14.0
4	7	4.7	3	2.2	8	5.1
Altimetry (m)	FA	%	FA	%	FA	%
978-1028	14	9.4	13	9.6	11	7.01
1029-1078	57	38.3	47	34.6	57	36.3
1079-1128	39	26.2	30	22	38	24.2
1129-1178	29	19.5	34	25.0	33	21
1179-1221	10	6.7	12	8.8	18	11.5
Slope (%)	FA	%	FA	%	FA	%
> 6	32	22	28	21	31	20
6-12	55	38	44	32	47	31
12-20	38	26	41	30	46	30
20-30	19	13	18	13	23	15
> 30	2	1	5	4	7	5
Total	149	100	136	100	157	100

Organized by the authors, 2018.

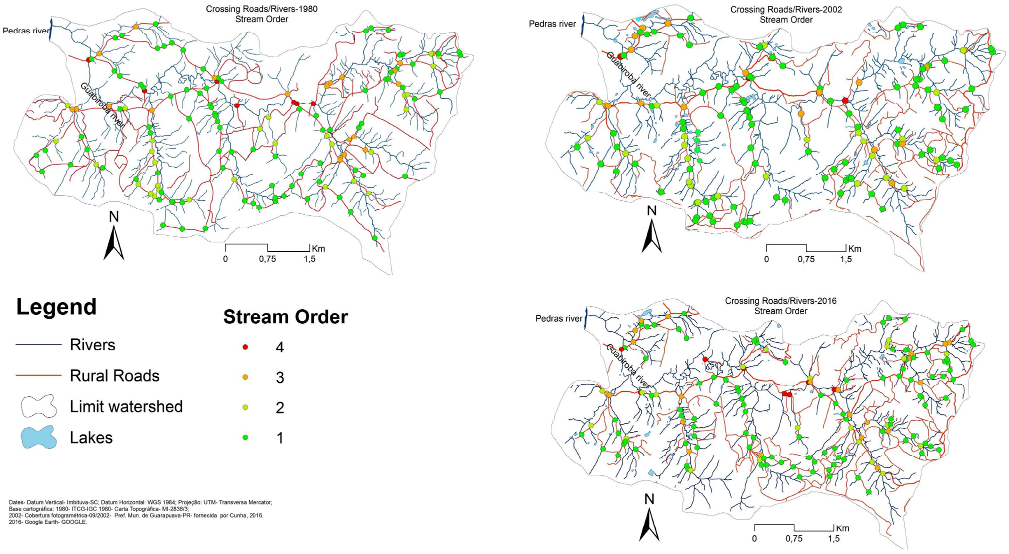
The second order channels correspond to 15.7% of the basin (Cunha, 2016). In Table 4, it is observed that there is also a positive correlation between the percentage of crossings and the percentage of channels of the same order.

The percentages relating to the third order and fourth order channels are 13.2% and 7.2%, respectively, in relation to the basin. The number of crossings in third order channels ranges from 12.1 to 14% and of fourth order channels from 2.2 to 5.1% (Table 4). The data relating to crossings of fourth order channels are out of perspective of the percentage of channels and are below the average, with negative correlation compared to lower order channels. This fact may be related to the difficulty in crossing larger and abundant channels, which requires structures of bridges, shackles, etc., reducing the number of crossings.

Regarding the altimetry, the group of the altitudes 1028-1078 and 1078-1128 accounts for 60% of the number of crossings. The altitudes that have the largest area in the basin are between 1040 and 1160 m, in a positive correlation with the number of crossings (Figure 4).

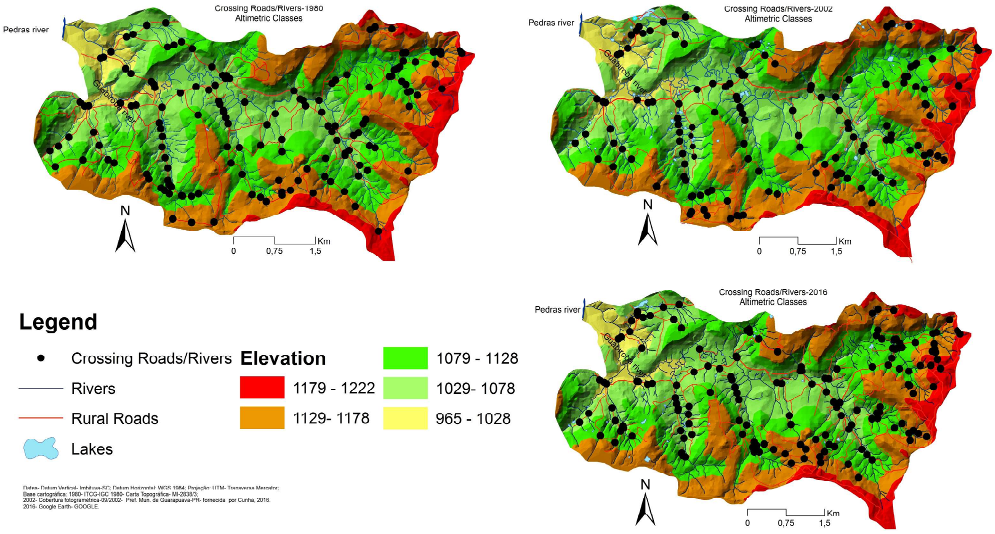
A fact to be considered is that some crossing points were extinguished whereas new ones were created from 1980 to 2002 and 2016, especially in the sectors to the south and east of the basin.

Regarding the slope, the number of crossings also has a positive correlation with the percentage of areas of 6-12% (65%) and 12-30% (33%), in which 60% of the points cross in these slope patterns. The increase in the number of crossings in sectors with sharp slopes, between 20-30% and >30 over the years, stands out (Figure 6).



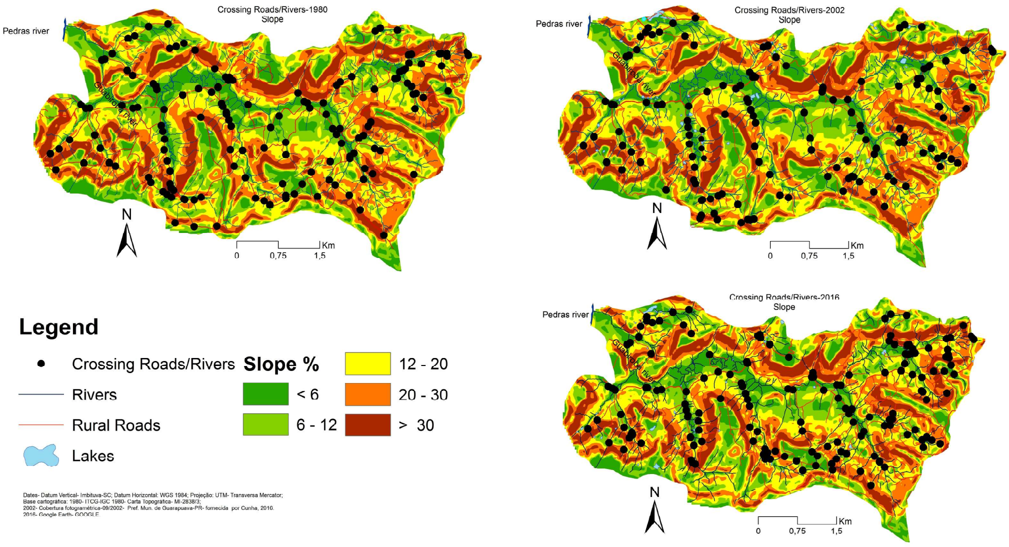
Dates- Datum Vertical- Imbituva-SC; Datum Horizontal: WGS 1984; Projeção: UTM- Transversa Mercator;
Base cartográfica: 1980- ITCG-IGC 1980- Carta Topográfica- MI-2838/3;
2002- Cobertura fotogramétrica-09/2002- Pref. Mun. de Guarapuava-PR- fornecida por Cunha, 2016.
2016- Google Earth- GOOGLE.

Figure 4 - Crossing between rural roads and drainage – order of the channels. Organized by the authors, 2018.



Dates- Datum Vertical- Imbituva-SC; Datum Horizontal: WGS 1984; Projeção: UTM- Transversa Mercator;
Base cartográfica: 1980- ITCG-IGC 1980- Carta Topográfica- MI-2838/3;
2002- Cobertura fotogramétrica-09/2002- Pref. Mun. de Guarapuava-PR- fornecida por Cunha, 2016.
2016- Google Earth- GOOGLE.

Figure 5 - Crossings of rural roads and drainage – altimetry classes. Organized by the authors, 2018.



Dates- Datum Vertical- Imbituva-SC; Datum Horizontal: WGS 1984; Projeção: UTM- Transversa Mercator;
Base cartográfica: 1980- ITCG-IGC 1980- Carta Topográfica- MI-2838/3;
2002- Cobertura fotogramétrica-09/2002- Pref. Mun. de Guarapuava-PR- fornecida por Cunha, 2010.
2016- Google Earth- GOOGLE.

Figure 6 - Slope in the Guabiroba River basin from 1980 to 2016. Organized by the authors, 2018.

4. Discussions

4.1 Land use change from 1980 to 2016 and influence on the increase of unpaved roads

The results from the mapping of the Guabiroba River basin (Figure 4 and Table 2) show a forest fragmentation over the years. In 1980 there were already deforested areas, and the insertion of forestry was 4.3%, and many areas were at a phase of vegetation succession. After the incessant deforestation in the state of Paraná (Kohlhepp, 1969; Luz, 1980; Brannstrom, 2002; Santos, 2009; Gomes, 2013), several fiscal, tax and political incentives were offered for the planting of new crops, such as forestry (Bacha, 1991) and temporary crops (Trintin, 2006), which invigorated changes in land use.

Land uses in the Guabiroba River basin are related according to the topography and have been modified over time, especially in the sectors of slopes >6 and from 6 to 12% in the altitudes of 965 to 1078 m which correspond to the valley beds. These topographic sectors are occupied by the population residing in the basin, and they are represented in the mapping by the buildings, which include the residences, dams, stables and agricultural practices of temporary crops. Therefore, the relief is a factor that plays a fundamental role in the land use practices in the basin.

In the Guabiroba River basin, there is a process of replacing the primary forest by other uses. In 1980, there was the implementation of subsistence agriculture and pastures, with the inclusion of forestry, dam constructions, and temporary mechanized crops. In 2016, 18% of the 42.8% of forested areas had native species such as Pine (*Araucária angustifólia) (*Behling and Pillar, 2007). In the rest of the forested areas, there were only a few sparse fragments and the growth of Bracatinga (*Mimosa scabrella Benth*), mate herb (*Ilex paraguairienses*), and slash-and-burn agriculture that mix with secondary forests. In summary, the vegetated areas of the basin have a significant degree of anthropization, since the natural vegetation was replaced and altered.

The local farming practices, as they were already pointed out, provide the significant presence of secondary forests. Moreover, land uses in the basin have a temporal and spatial variation, which determine different planting, harvesting and maintenance practices. Forestry is one of the agricultural practices that most need rural roads for crop removal and planting (Forsyth *et al.* 2006), but these processes may be delayed. Agricultural practices such as the growth of Pinus and Eucalyptus, and Bracatinga for the use in charcoal, as firewood, and in domestic uses, last from 5 to 20 years (from planting to harvesting) to be developed, which leads to the abandonment and reactivation of roads in varying periods. Information on land use, growth time, and about the authors who described the process can be better understood in Table 5.

The mapping (Figure 3; Table 2) shows that from 2002, in some sectors of the basin, there was a transitory replacement of the subsistence practices, highlighted by Thomaz (2007), by commercial practices, with the increase of forestry. This is a worldwide phenomenon, and it is one of the causes of the increased deforestation (Geist and Lambin, 2002).

The forest areas decreased from 59.3% in 2002 to 42.8% in 2016 (a decrease of 16.5%), whereas the forestry in the basin increased 9.5% from 1980 to 2016, increasing from 4.3% in 1980 to 23.8% in 2016 (Table 2). These variations show the adaptation and reorganization of space to expand economic uses rather than the natural rehabilitation, or even rather than the application of the environmental laws, such as Law No. 12.651/2012, which deals with forest protection areas, but also discriminates actions in areas with the already established occupation.

It should be noted that the productive sectors of the municipality, together with the lack of technologies in the rural area and with the cultural practices of management, and the land changes throughout the occupation caused a change in the land use, interfering with the dynamics of economic circulation in the basin, and secondly in the construction and suppression of roads, since there is a routine need for the management of temporary crops and longer management of permanent crops and pastures.

4.2 Unpaved road network pattern and stream crossing change

The dynamics of land use interferes with the basin connectivity relations (Forman, 1998; 2003), both for forestry, which ranges from the growth to the cutting and from the paring to the harvesting, and for annual crops, which require the transit of loads by trucks and tractors. The needs imposed by the economic matters lead to changes of uses in sectors and topographic positions, as well as to technological advance of the mechanical equipment that allows planting and harvesting in areas with a higher slope (Laurance *et al.*, 2014).

Table 5: Harvest time in different land uses

Land use	Temporal Scale	Authors
Slash-and-burn agriculture	3 to 10 years	Thomaz (2009)
Forestry - *Pinnus elioty*	7.5 to 25 years 5-10 years	Bacha (1991) Glufke *et al.* (1997) Goer *et al.* (2012)
Forestry - *Eucalyptus*	According to the management 4 to 7 years - firewood 13 to 20 years - wood	Higa *et al.* (2011) Goer *et al.* (2012)
Forestry - Bracatinga (*Mimosa scabrella Benth*)	According to the management 3 to 8 years	Carpanezzi and Laurent (1988), Thomaz (2010)
Temporary crops (soybeans, corn, wheat, oats)	4 to 6 months	Embrapa (2018)

Organized by the authors, 2018.

The land use in the Guabiroba River basin during the years 1980-2002-2016 caused changes in the characteristics of road-stream crossings, by creating roads in higher topographic sectors, crossing by channels of first and second orders in areas with a higher slope.

According to Freitas *et al.* (2009), the lower altitude areas have the lowest slopes and correspond to the areas more propitious to agricultural activities and consequently to roads. However, in the Guabiroba River basin, since more than 40% of the basin is located in areas above 20% slope (Thomaz, 2005), there will be roads crossing these sectors, mainly perpendicularly to the valleys, and crossing by ephemeral and intermittent channels, and even capturing drains, as highlighted by Cunha (2016).

The results found by Freitas *et al.* (2010) corroborate the degree of connectivity and the density of roads, as well as the spatial pattern of the density of roads per relief. These results demonstrate there was an increase in road density over the surveyed years, from the highest to the lowest topographic altitudes, due to the plain relief of low slope, which favors the construction of rectilinear roads along the valleys. In the Guabiroba River basin, there was a similar process relating to the effectiveness of the primary roads on the valley beds; however, on the secondary roads and pathways, there was an inverse effect, with an increase in the number of roads and road crossings with channels in areas of high altitudes, sharp slope, and in first and second order channels (Table 4).

According to the spatial-temporal dynamics of land use in the basin, structural mechanisms have been created to access, support and produce in areas with higher topographies and altitudes. When this dynamic occurs, there is a need to create pathways to arrive and to leave with the products generated locally, even in environments with edaphic constraints. Therefore, the predominant land uses in the basin are of a spatial-temporal character of long-term, and interfere with the environmental dynamics of the basin, since they create and modify the roads for the planting and harvesting of these products (Table 5).

Fransen *et al.* (2001) described that the increased number of roads led to erosive processes in several regions in New Zealand, especially in planted (exotic) forests, and Takken *et al.* (2001) point out the erosive process in three compartments of roads: in road-stream crossings, gullied pathways, and diffuse pathways, i.e., the creation and/or modification of roads directly interfere with the sedimentological dynamics of the basin.

There was no significant change in the main road length dimensions in the Guabiroba River basin; there was an increase of 3 km from 1980 to 2002, and in 2016 these length dimensions were maintained. However, secondary roads had an increase of 8 km from 1980 to 2016, which may be related to the fragmentation of land use in the basin. Goer *et al.* (2012) point out that the increased forestry requires roads for the removal of wood every 5 and 10 years, which may cause the abandonment and suppression of some stretches amid the secondary vegetation and their reactivation during the cutting and replanting.

The problem of abandoned roads and their dynamics of activation and deactivation and the creation of new roads in rural areas is their connection with the rivers. At these connection points, the roads in steep areas interfere with the drainage dynamics. According to Jones *et al.* (2000), the roads that cross rivers are related to the basin topography, whereas the density of crossings is related to the local hydrological characteristics.

There is a concern regarding the increased number of crossings in hydrographic basins in the world (Forman and Alexander, 2006; Jones *et al.* 2000; Lane *et al.* 2006; Li *et al.* 2006) since this fact contributes to the rapid surface runoff from the basin into the drainage channels. Roads may become an accessory channel, increasing the drainage density and decreasing the surface course (Horton, 1945), as well as a coefficient of maintenance of hydrographic basins (Schumm, 1956).

The Guabiroba River basin has a high drainage density, with 7.3 km/km² (Table 3), including intermittent channels, but when the roads are considered, this density increases to 11 km/km². This value consists of a maintenance coefficient of 90 m, i.e., the higher the basin density, the faster the drained water will arrive at a channel, stopping the infiltration and allowing a rapid runoff, altering the flow rate and the sediment loading capacity, as well as the local ecological conditions, as reported by Negrão *et al.* (2017).

Another aspect to be detailed is that, when creating roads from the basin low altitudes (965-1128) to the high ones (1129-1222), a zone of high slope (>30%) is crossed, and gullied pathways are needed. According to Cunha (2016), this process can provide the capture of drainage, making the road a waterway of intermittent and ephemeral channels. Moreover, the gullied pathways can trigger debris flows, peak flows (Jones *et al.*, 2000), and large sediment transport capacity (Ramos-Scharrón and Macdonald, 2007; Schultz *et al.* 2012) as a result of the slope created.

Conclusions

Changes in land use interfere with the basin connectivity, both natural (drainage) and anthropogenic (rural roads) changes, especially in permanent and long cycle uses. In these uses, they interfere with the creation, modification, suppression, and reactivation of roads.

The roads can interfere with drainage density, as they create and intercept river channels, leading to a rapid and concentrated runoff, which, depending on the dynamics of land use, can occur superficially towards the drainage channels, interfering with the increase in the flow, turbidity indexes, and consequently in the water quality. Thus, the roads change the drainage maintenance coefficient and reduce the runoff course, which are essential parameters for the understanding of the natural dynamics in hydrographic basins.

This research demonstrated how land use has interfered with the formation, construction, and abandonment of rural roads over time. According to the management, the land-use requires the creation of pathways and vicinal roads for the planting and harvesting, varying in the time of permanence of each use. Pinus growth lasts from planting to harvesting up to 20 years, the Eucalyptus from 4 to 20 years, slash-and-burn agriculture from 3 to 5 years, and temporary crops up to six months.

Primary roads have been maintained over 36 years, with an increase of 8 km in secondary roads. The number of crossings had an increase in the highest slope sectors (20-30% and >30) and in the basin highest altitude (1128-1178 and 1179-1221), especially in 2002 and 2016. These findings are related to the dynamics of land use in other sectors of the basin.

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