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The drainoff of surface water by the Expresso Porto highway - Municipality of Porto Velho/RO

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Márcio Diógenes do Nascimento
Geographer from the Federal University of Rondônia
E-mail: diogenespvh@hotmail.com

Catia Eliza Zuffo
Doctor, Department of Geography, Federal University of Rondônia
E-mail: catiazuffo@unir.br

Grasiela Rocha Torres Goveia
Master's degree in Geography from the Federal University of Rondônia
E-mail: grasiela.torres@gmail.com

Osmair Oliveira dos Santos
Master's degree in Geography from the Federal University of Rondônia
E-mail: osmairsantos@gmail.com

ABSTRACT
Large government projects in the Brazilian Amazon, particularly the opening of highways, have always caused a strong impact and several territorial transformations marked by aspects related to the abundance of rivers and their considerable flows, as well as the lack of maintenance of drains arranged along these roads. The objective of this article is to demonstrate aspects related to surface runoff on the Rodovia Expresso Porto, in the municipality of Porto Velho, State of Rondônia, Brazil, with emphasis on the three main hydrographic channels that cross the highway. The research presents a qualitative-quantitative approach using the hypothetical-deductive method, seeking to characterize the study area with bibliographical research and the use of remote sensing techniques in the preparation of thematic maps. The results point to problems in two of the three culverts analyzed, not due to insufficient diameter for flow, but rather due to the considerable difference in level at which they were placed, as well as the lack of maintenance to remove soil and other waste at their entrance. In this context, the importance of good topographic studies to support future similar engineering works is evident.

Keywords: Highway, Porto Express, Drainage, Water Flow.

1 INTRODUCTION

In Rondônia, as well as in many Brazilian states, highways are of fundamental importance for the flow of production and to improve people's trafficability. With the opening of the Expresso Porto Highway, traffic within the urban perimeter of the city of Porto Velho (RO) became more fluid, reducing accident rates and increasing the quality of life of the population.

The opening of this 18 km long road led to the suppression of vegetation in its coverage area, which, associated with the slope of the terrain, may cause a faster transport of sediments to the riverbeds, increasing the flow and, consequently, erosion. For Pinto (1976, p. 36), the trajectories described by water in its movement are determined, mainly, by the lines of greater slope of terrain and are influenced by existing obstacles. In this phase, we have the movement of free waters.

According to DNIT (2005, p. 16),

> As the damages resulting from insufficient flow depend on the importance of the work to the system, the values to be adopted for the recurrence period are different, varying according to the type of work. Thus, a highway culvert can cause erosion of slopes near its downstream opening, rupture of the embankment due to water overflow, or flooding of upstream areas.

Using publications by several authors and using tools such as free software with open source code of geographic information system (QGIS) and field visits to understand the dynamics of the physical environment under study, the objective of this study was to demonstrate the aspects related to surface runoff on the Expresso Porto Highway, in the municipality of Porto Velho, Brazil. state of Rondônia.

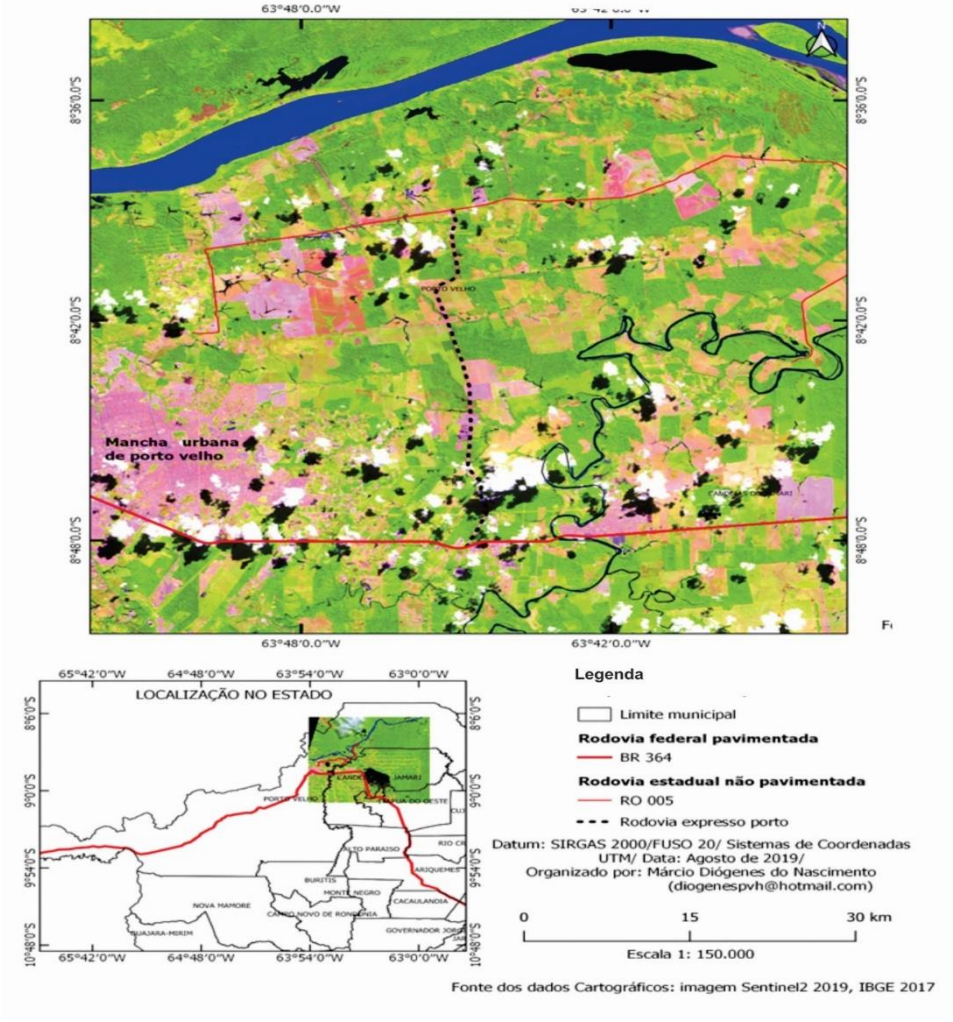
The text is the result of a research of qualitative-quantitative approach with the use of the hypothetical-deductive method, seeking to characterize the study area with bibliographic research and the use of remote sensing techniques in the elaboration of thematic maps, addressing intervening aspects to the flow of existing drainages on the highway and the calculation of flow by the method of floats in the three main streams. in addition to the identification of problems caused by the opening of the highway, aiming at the adoption of mitigating measures for the most common impacts of this type of anthropic action.

In addition to the conceptual part, the article describes characteristics of the physical environment of the area under study, emphasizing the importance of the opening of the highway in question for the economic development of the municipality. It also presents intervening aspects to the drainage of drainages, showing through maps the importance of the topographic study for the execution of drainage works in the region.

2 LOCATION AND CHARACTERISTICS OF THE STUDY AREA

The Expresso Porto Highway has a length of 18 km and is located in the municipality of Porto Velho (RO), Southern Amazon. Its initial stretch is the entrance by BR-364 at the geographic coordinates of latitude 8°48'5.60"S and longitude 63°44'45.76"W and, finally, with the geographic coordinates of latitude 8°38'59.66"S and longitude 63°45'4.05"W, connecting the federal highway to RO-005, as shown in figure 1 below.

Figure 1: Location of the Study Area.



Source: From the authors (2019).

2.1 CLIMATIC ASPECTS

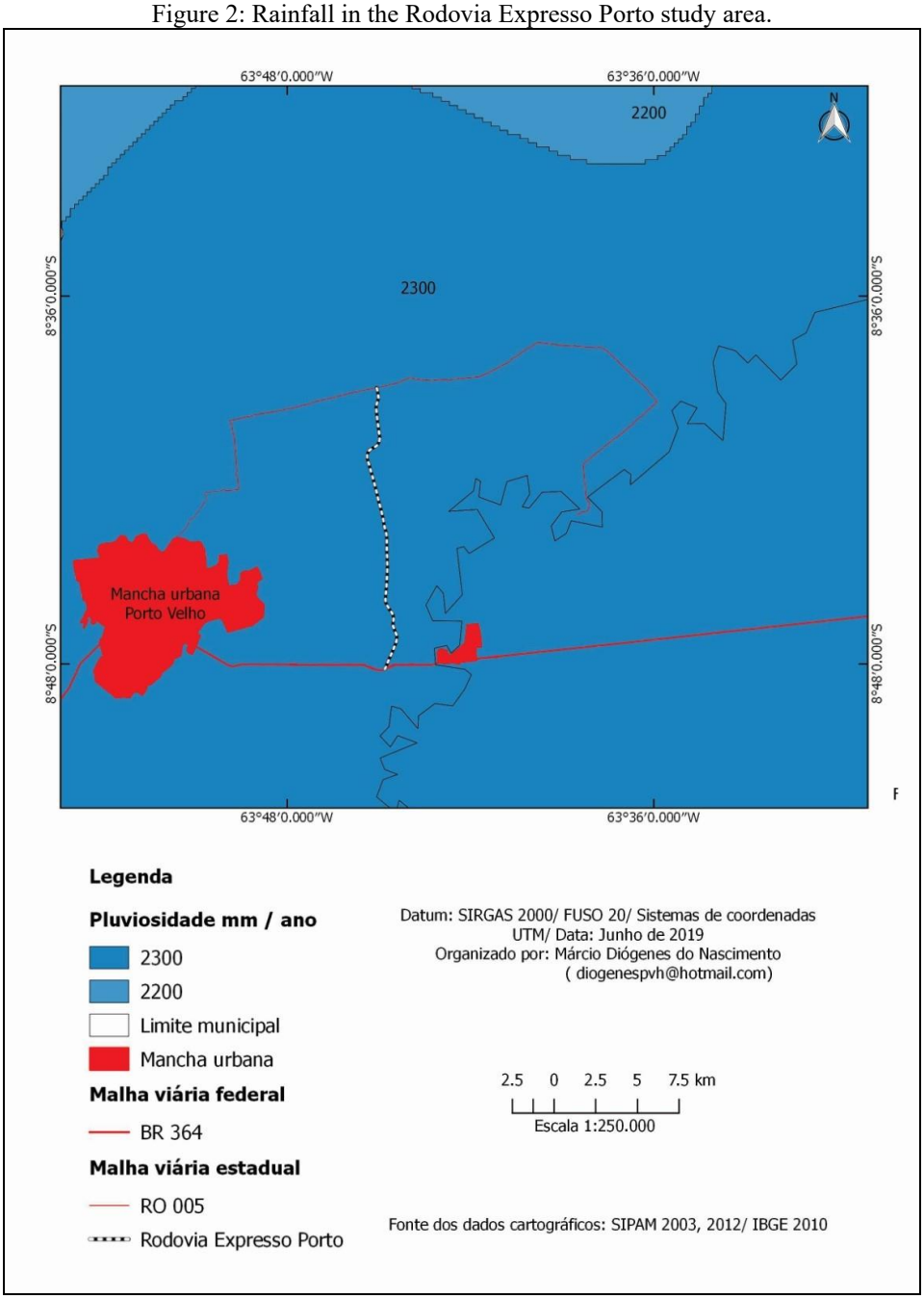
As for temperature, the climate of the state of Rondônia is characterized by a spatial and seasonal homogeneity of the average air temperature, the same not occurring in relation to the rainfall that presents a temporal variability and on a smaller spatial scale, caused by the different atmospheric phenomena that act on the annual precipitation cycle (SEDAM, 2002, p. 3). Also according to the State Secretariat for Environmental Development – SEDAM (RO), according to the parameters of the Köppen classification:

> The region has an Aw – Tropical Rainy Climate climate, where there is a wet season during the summer and a dry season in the winter. It has a well-defined dry period during the winter, when there is a moderate reduction in rainfall levels, reaching rates below 50 mm/month. The climatological average for the months of June, July and August is approximately below 20 mm/month. Because it is under the influence of the Aw climate, the average annual rainfall varies between 1,300 and 2,600 mm per year (SEDAM, 2002, p. 03).

In the portion corresponding to the study area, the average rainfall reaches 2,300 mm per year (figure 2). Its distribution throughout the year is quite irregular, this is due to the dry period in the

Amazon region (June, July and August), which will directly interfere with the runoff of this area, when precipitation and relative humidity reach reduced values. Unlike the rainwater regime, the thermal regime is well defined, with an average annual temperature ranging from 24ºC to 25ºC.

Figure 2: Rainfall in the Rodovia Expresso Porto study area.



Source: From the authors (2019).

2.2 GEOLOGICAL ASPECTS

According to the Brazilian Institute of Geography and Statistics (IBGE, 2006a), the geological unit where the Expresso Porto Highway is located is relatively old, its lithostratigraphic units date back to the Phanerozoic that began 0.01 million years ago (M.A.) and extended to 540 million years (M.A.), described as follows:

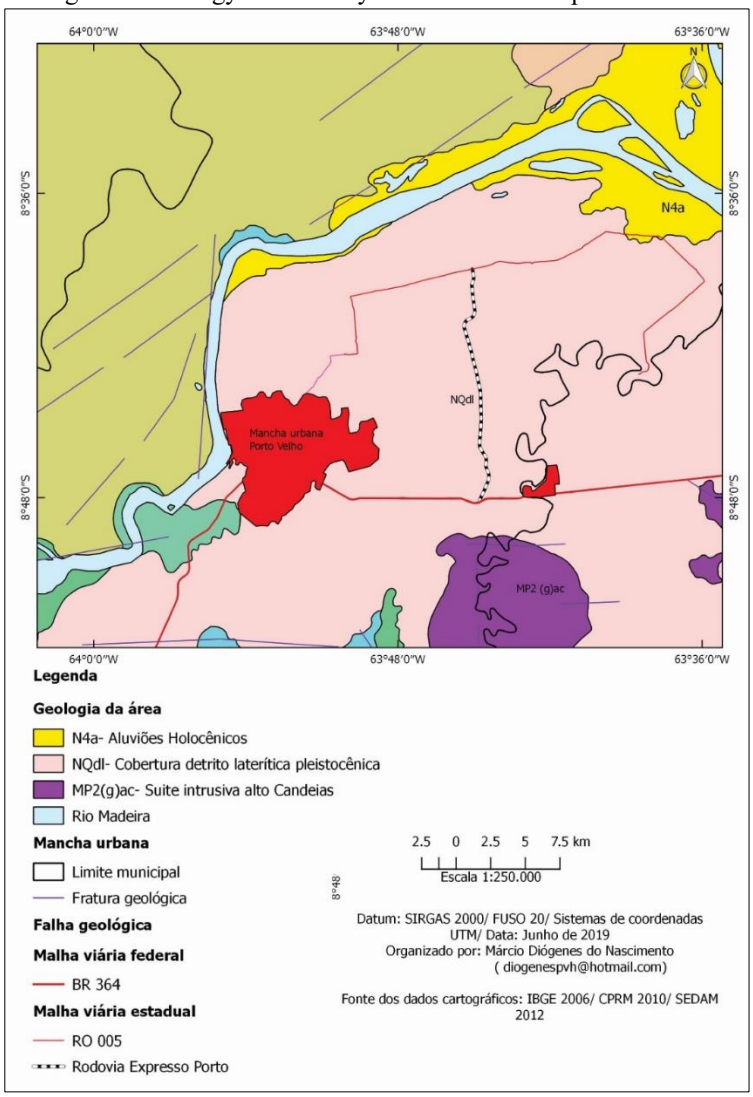
Pleistocene Lateritic Debris Cover: yellowish, kaolinitic, allochthonous, partially or totally pedogenized (Lactosol-Sargillary-Sandy) sediment generated by alluvium-colluvial processes.

Holocene Alluvium: deposits of coarse sands and conglomeratric, representing channel residuals; sandy relative to the bar at point; pelitic depicting those of overflow and fluviolacustres; also aeolian when reworked by the wind.

Alto Candeias Intrusive Suite: amphibolebiothitasienogranites, biotite-monzogranites, quartz-biotite-sienogranite, quartz-biotite-monzogranites, syenites and charnochitosporphyrites, pegmatodes and rapakivites, viborgites, piterlites and ckcharnokites (IBGE, 2006b).

The geology is considerable in the formation of the dynamics and in the layout of the highway, through which the type of material existing in the area will be verified, a factor of extreme importance for the execution of the earthworks. On the occasion of the preparation of the geological map of the area (figure 3), it was found that the route of the highway is located in a portion of the Pleistocene Lateritic Detritus Cover, passing over a geological fault.

Figure 3: Geology of the study area - Rodovia Expresso Porto.



Source: From the authors (2019).

2.3 GEOMORPHOLOGICAL ASPECTS

Geomorphology is the science that studies landforms, which represent the spatial expression of a surface, composing the different configurations that characterize the topographic modeling of an area (Christofoletti, 1980, p. 01). According to information from the Brazilian Institute of Geography and Statistics (IBGE), the following Geomorphological Units were detected in the study area (IBGE, 2006c):

Porto Velho Depression (262Dt11): it is differential, a set of landforms with tabular tops, forming features of gently sloping ramps and humps carved in sedimentary and crystalline rocks, denoting eventual structural control. They are generally defined by shallow valleys, with slopes of low to medium slope. They result from the establishment of dissection processes acting on the planing surface, their drainage density is very coarse and the deepening of the incision is very weak.

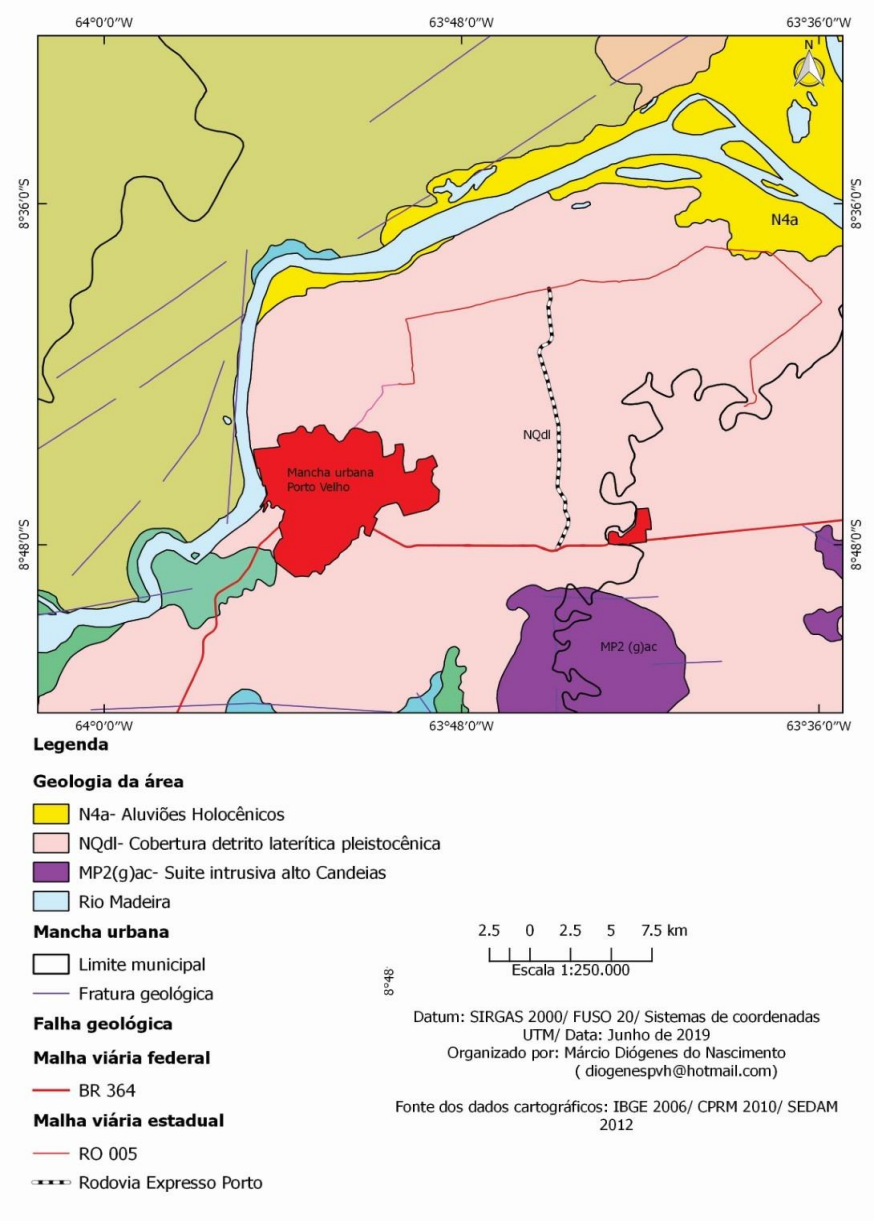
Amazon Plain (151Atf1): formed by the fluvial terrace, fluvial accumulation in a flat, slightly inclined way, presenting a slope rupture in relation to the riverbed and the recent floodplains located at a lower level, notched due to changes in flow conditions and consequent resumption of erosion. Indices 1 and 2 represent two different elevation levels of terraces.

The area that corresponds to the surroundings of the highway route has little geomorphological diversity, as can be seen in figure 4. The flat terrain corresponds to the floodplains and the low terrace suffers flooding annually during the rainy season. They are formed by unconsolidated alluvial sediments.

Also, according to IBGE (2006d, p. 1) and as can be seen in Figure 4, the geomorphological unit Flattening Surface, Level III (200m) is found with low dissection and no or sporadic *Inselbergs* and *Tors.*

All this information is of great relevance to understand the flow process, such as the type of existing material that directly interferes with the soil saturation indices and the supply of the water table, affecting the flow of these channels, among other information, such as the types of relief.

Figure 4: Geomorphology of the Rodovia Expresso Porto study area.



Source: From the authors (2019).

2.4 PEDOLOGICAL ASPECTS

The predominant soil types in the study area of Rodovia Expresso Porto according to IBGE (2006a, p. 1) and map (figure 5) are:

Dystrophic Yellow Latosol (LAD2): 2 – 8% well-drained and sandy, and medium + oxisol, both typical, indiscriminate texture, to moderate flat relief.

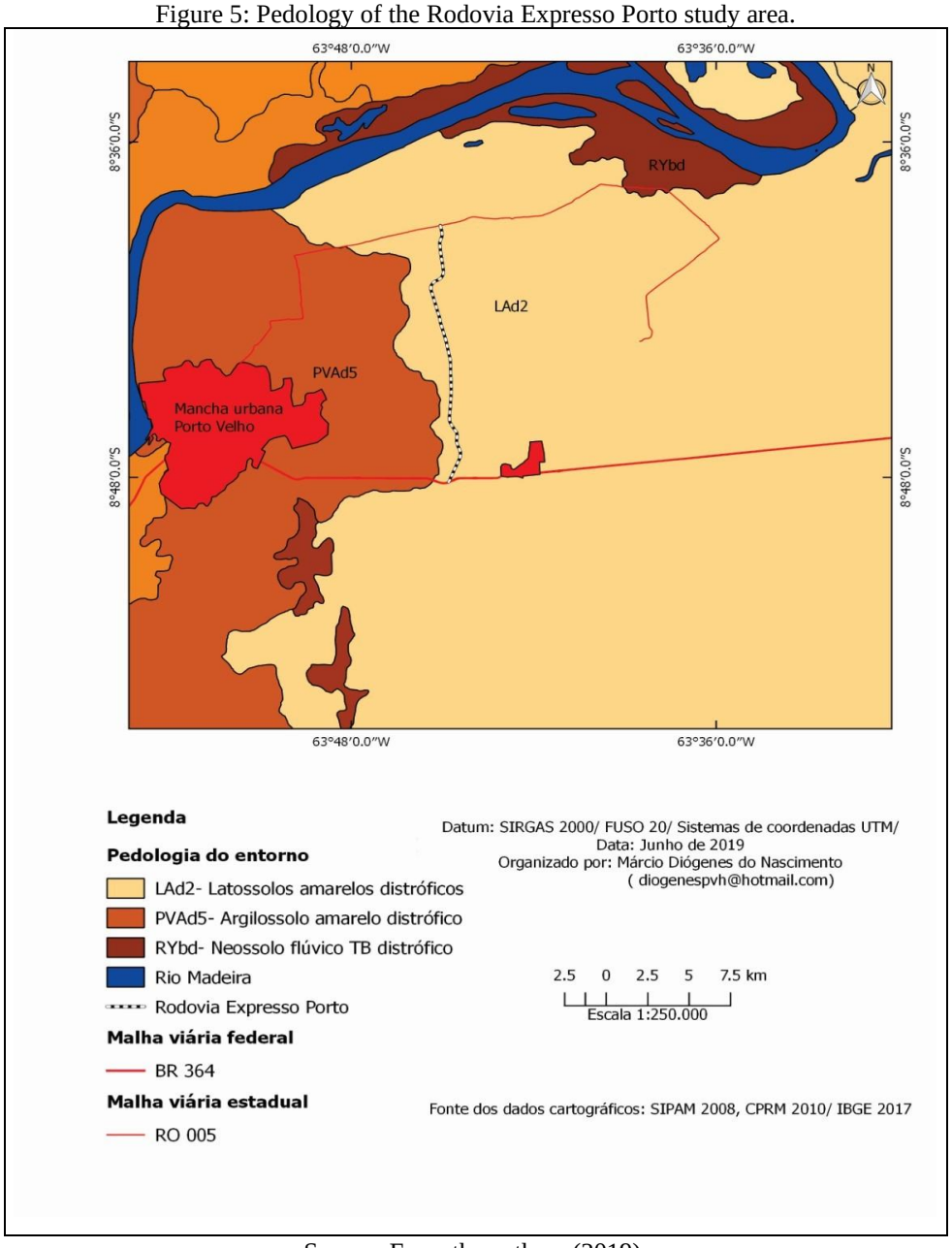
Dystrophic Red-Yellow Agilosol (PVad5): from 0 – 2% well-drained both typical, clayey texture, to moderate, smooth undulating relief.

Dystrophic TB Fluvic Neosol (RYbd): 0 – 2% moderate, drained all typical, indiscriminate texture, moderate flat relief.

Throughout the length of the highway, the predominant soil is the Dystrophic Yellow Latosol, through its coloration it is possible to understand the predominant type of source material, with significant accumulation of iron hydroxide. According to Schneider, Klamt and Giasson (2007, p. 31):

> The reddish, orange, and yellowish colors indicate the presence of different types of iron hydroxide. These are formed and stable in different environmental conditions, and through their evaluation it is possible to better understand the genetic processes that gave rise to a soil.

Figure 5: Pedology of the Rodovia Expresso Porto study area.



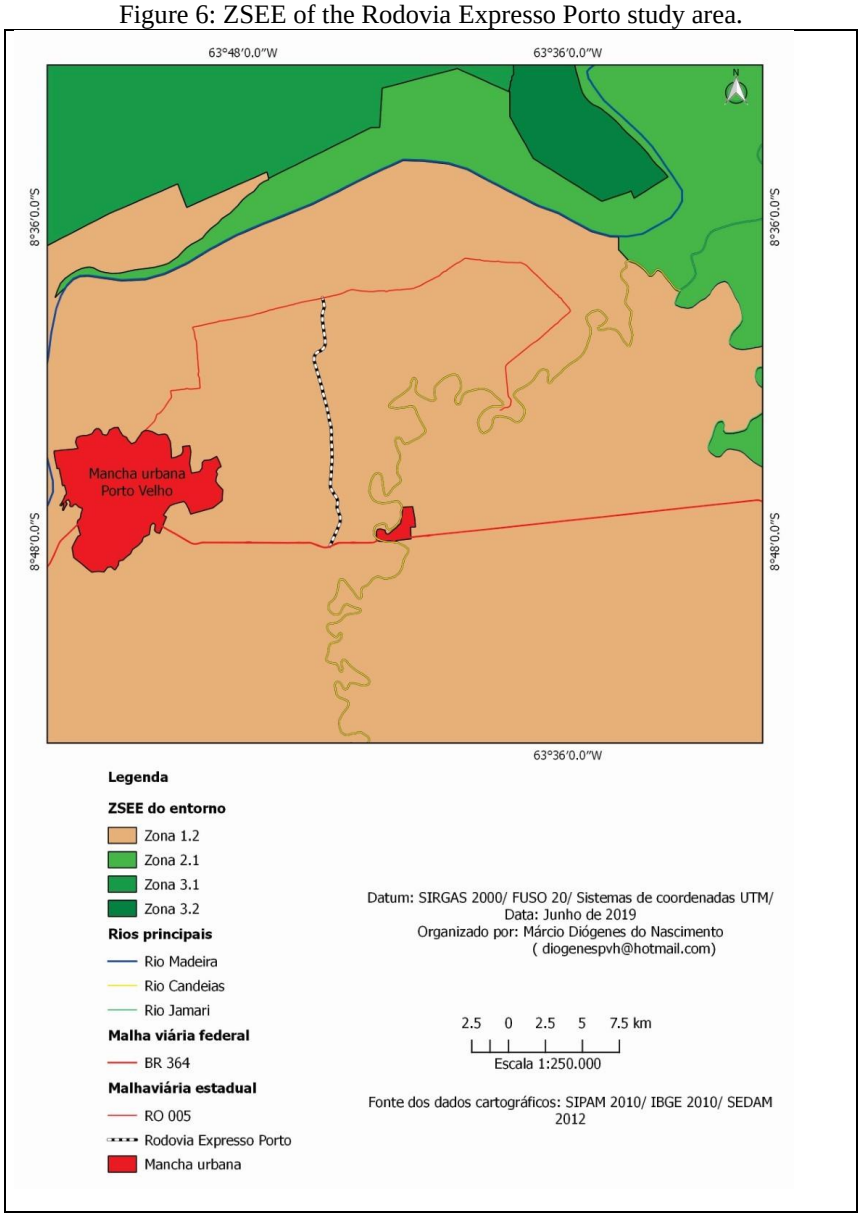
Source: From the authors (2019).

3 SOCIOECONOMIC AND ECOLOGICAL ZONING

According to SEDAM (2010, p. 12), the Socioeconomic and Ecological Zoning of Rondônia has several zones. Zone 1 has specific characteristics, being composed of areas of agricultural, agroforestry and forestry use, covering 120,310.48 km², equivalent to 50.45% of the total area of the

state. Thus, Zone 1 was divided into 4 subzones and it can be seen in figure 6 that the highway was completely within subzone 1.2, where, according to SEDAM (2010, p. 13), it is an area with medium social potential, with a predominance of natural vegetation cover, with an accelerated process of occupation, and with uncontrolled deforestation. Its agricultural suitability is regular, with low to medium vulnerability to erosion.

Figure 6: ZSEE of the Rodovia Expresso Porto study area.



Source: From the authors (2019).

4 VEGETATION

The vegetation is predominantly composed of Submontane Open Forest and Savannah/Ombrophilous Forest Contact, which respectively cover the northern and southern strips of the Highway. Anthropized areas occur to a greater extent in the municipal boundaries between Candeias do Jamari and Porto Velho. Such anthropic occupations result from the proximity to the

highway network, especially the BR-364, which is the main grain flow route in the state, in addition to the easy access provided by the state and municipal roads that connect the municipalities.

Lowland ombrophilous forest: occurs in flat to gently undulating relief not exceeding 100m in altitude.

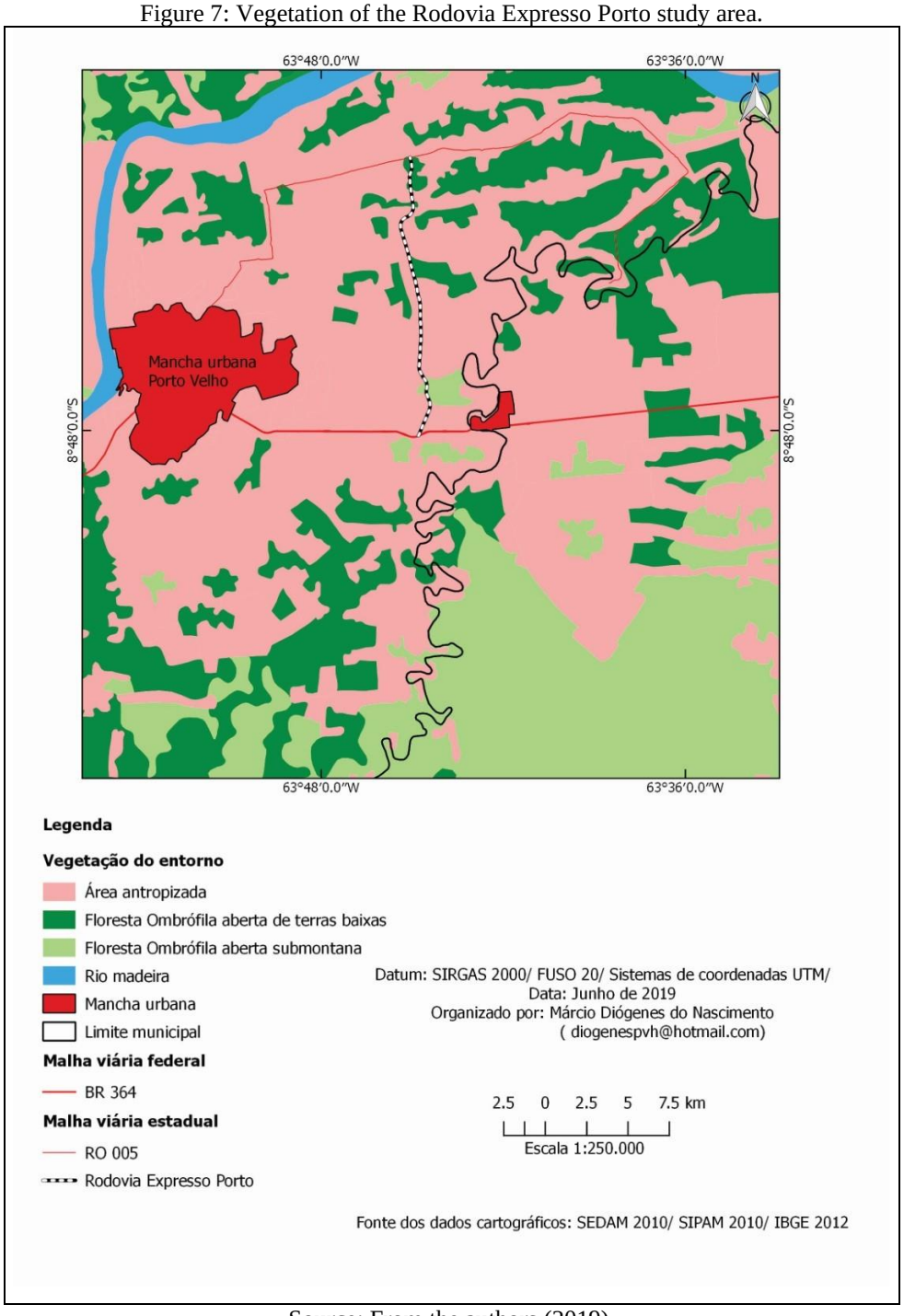
Submontane open ombrophilous forest: occurs in more accentuated reliefs, ranging from 100 to 600m in altitude.

Open ombrophilous forest is characterized by the discontinuity of the canopy, allowing sunlight to reach the understory, favoring its regeneration. The trunks are more spaced in the highest stratum, which reaches about thirty meters in height, while the understory is stratified (SEDAM, 2002, p. 03).

Vegetation is important because it plays a fundamental role in surface runoff, working as a precipitation blocker, preventing direct contact with the soil, reducing erosion in this area and supplying the water table. According to Florenzano (2011, p. 88), the vegetation cover intercepts part of the precipitation and slows down the flow of rainwater, while the impermeable surfaces of urban areas accelerate the flow of water and, consequently, the flow of rivers.

Figure 7 below shows the distribution of vegetation and anthropic action in the vicinity of the highway route, emphasizing the date of the sources, it is believed that the suppression of native vegetation has increased since then.

Figure 7: Vegetation of the Rodovia Expresso Porto study area.



Source: From the authors (2019).

5 DRAINAGE OF THE SURROUNDINGS OF THE STUDY AREA

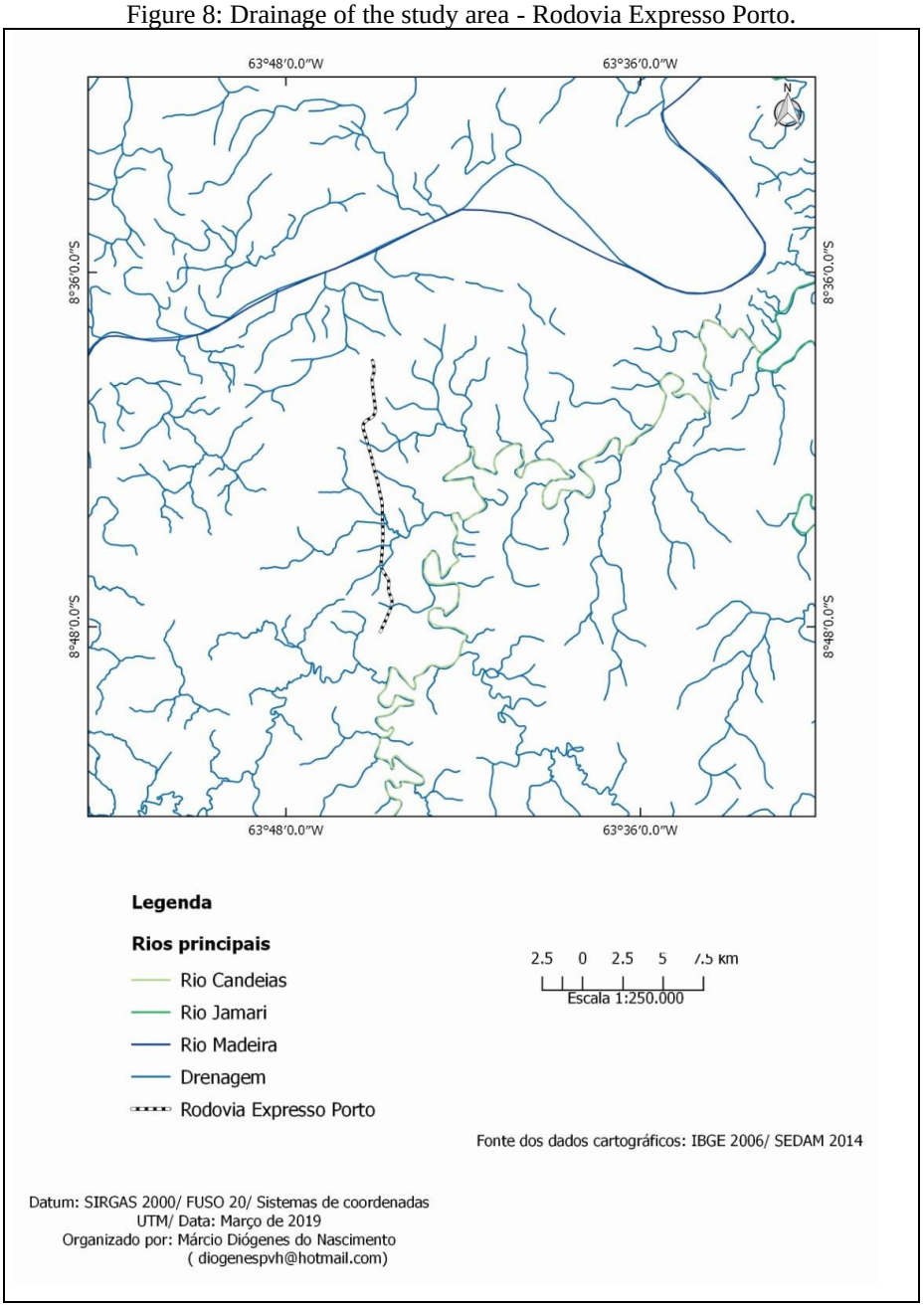
According to Christofoletti (1980, p. 102):

> Drainage is composed of a set of interrelated channels that form the drainage basin, defined as the area drained by a particular river or river system. The amount of water that reaches the river courses depends on the size of the area occupied by the basin, the total precipitation and its regime, and the losses due to evapotranspiration and infiltration.

The drainage pattern found in the channels that cross the Expresso Porto Highway is dendritic (Figure 8), due to its development resembling the configuration of a tree. This pattern is defined based

on the type of rock material in the trajectory of the existing channels, influenced by the type of soil and slope, essential factors for the definition of the model. They are patterns developed on rocks of uniform resistance, or on sedimentary structures.

Figure 8: Drainage of the study area - Rodovia Expresso Porto.



Source: From the authors (2019).

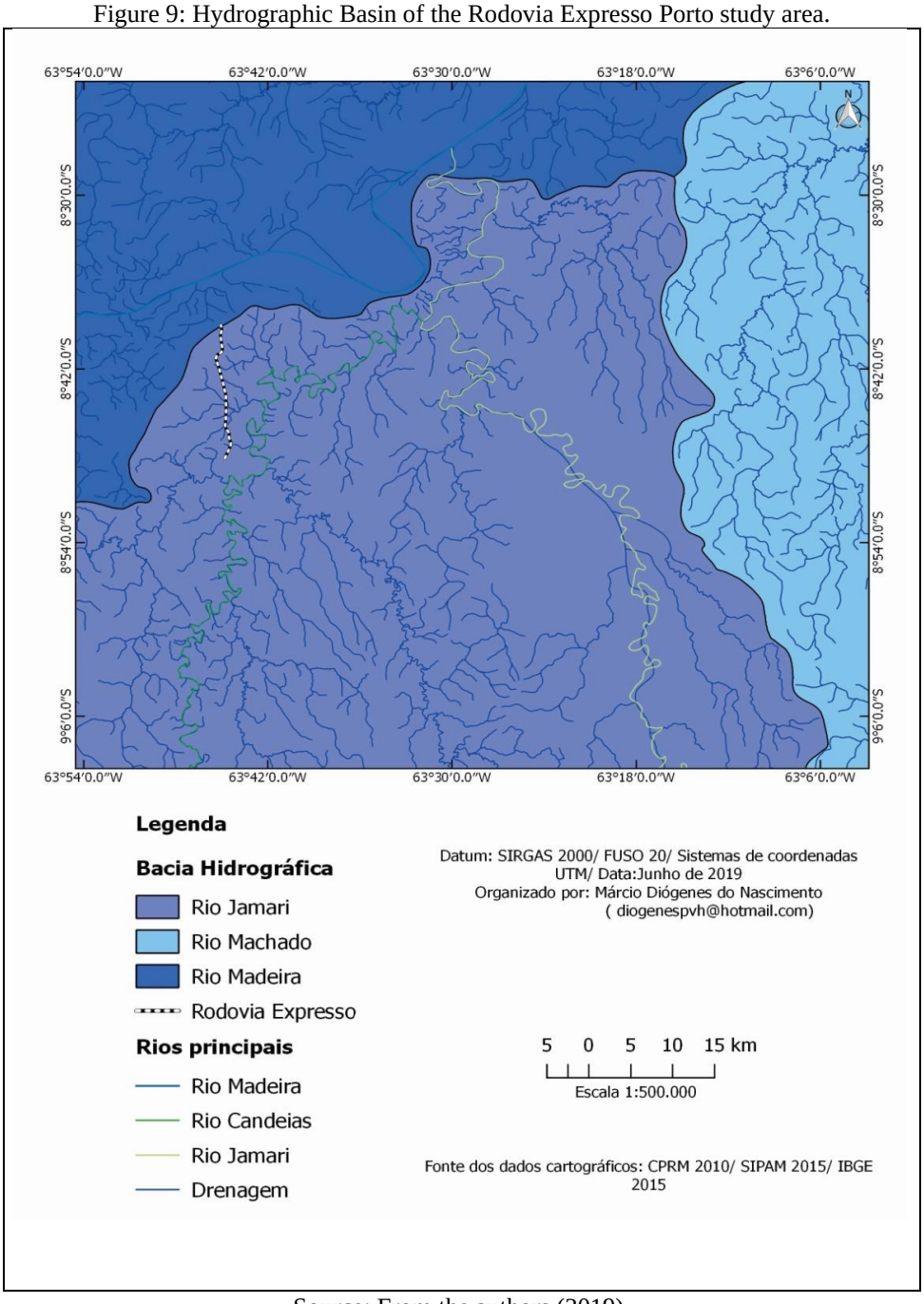
5.1 HYDROGRAPHY

A watershed is defined as an area drained by a watercourse and its tributaries upstream of a given cross-section, to which the waters that drain the area under consideration converge (Brasil, 1997). Within the segments of the hydrological cycle, the basic inputs in terms of water are precipitation, with surface and groundwater being the most used for the various uses.

The main river basin of the study area is the Jamari River, which is divided into four sub-basins: Upper Candeias River, Lower Candeias River, Upper Jamari River and Lower Jamari River. The Expresso Porto Highway, in its full extension, is located in the sub-basin of the lower Candeias River, which has an area of 7,960.827 km² and a perimeter of 564.72 km (Figure 9).

Predicting the behavior of the watershed facilitates studies related to paving works, to avoid future problems related to surface runoff, such as knowing the size of the basin's area of influence, since "any intervention carried out in fluvial hydrological systems is to increase or decrease the flow, form reservoirs or modify" (Bastos; Freitas, 2009, p. 24), can directly influence the flow of the channel and the surface runoff of the area.

Figure 9: Hydrographic Basin of the Rodovia Expresso Porto study area.



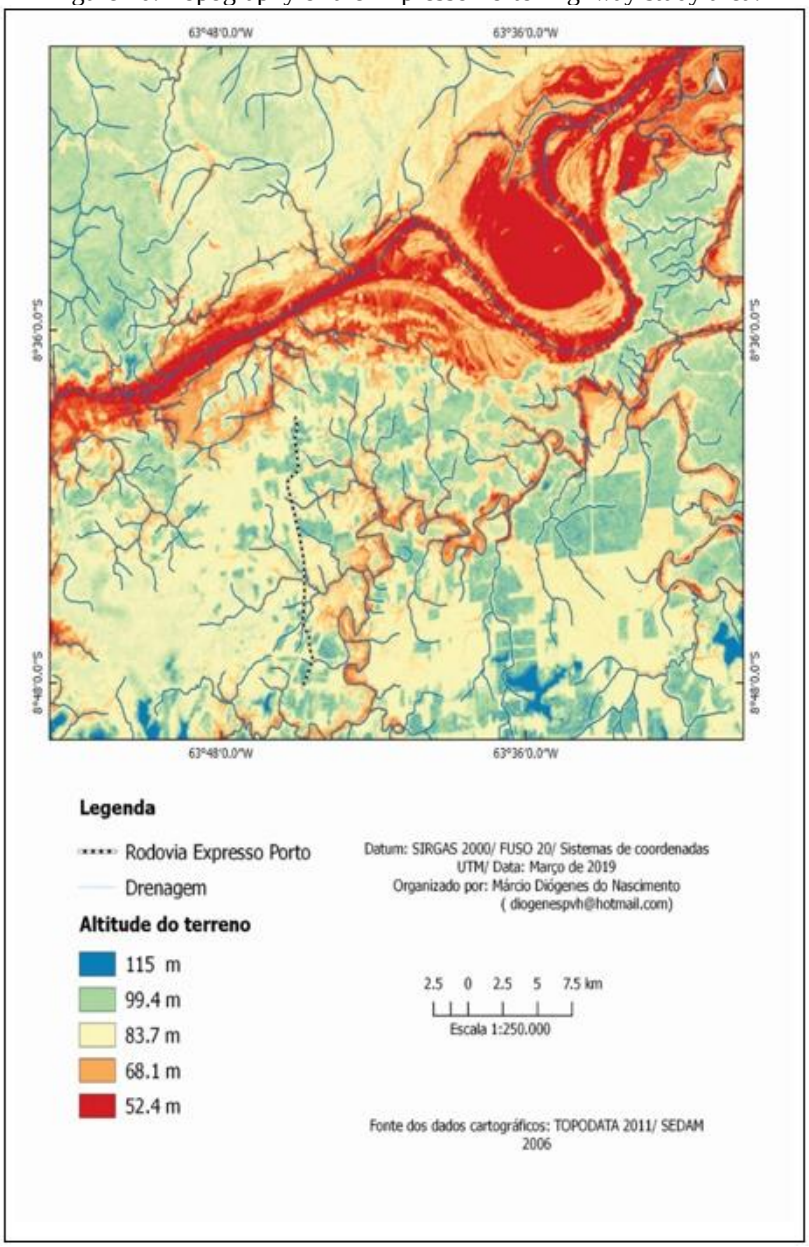
Source: From the authors (2019).

6 TOPOGRAPHIC ANALYSIS

The dynamics of the terrain, among other factors, directly influences the flow of water bodies located in each area. Works such as the construction of highways cause a significant transformation in the landscape with the removal of vegetation in its surroundings, construction of culverts and embankments, especially around the route of the road for the construction of the road.

In the area in question, there was a small elevation of the terrain in the part of the route. In the initial part of the road, the height of the land is 50 meters and at the end of the route, it reaches almost 90 meters, that is, an increase of 40 meters in relation to BR-364, which led to a large embankment near it, making a region vulnerable to erosive processes. The layout of the Expresso Porto Highway is shown in figure 10.

Figure 10: Topography of the Expresso Porto Highway study area.



Source: From the authors (2019).

7 INTERVENING ASPECTS TO THE DRAINAGE OF THE DRAINAGES

It refers to the physical environment of the study area, i.e., the type of soil that directly interferes in the erosive processes, or the vegetation that, with its removal, causes the direct contact of precipitation with the soil, caused by the saturation and topographic profile of the terrain, the transport of materials to the lower parts of the surroundings. According to DNIT (2005, p. 17):

> Although several simplifying procedures are adopted, perfectly justifiable for the nature of the designed works, the physiographic characteristics of the basins, which are independent of climatic conditions, should be given as much importance as the pedological characteristics, which indicate the behavior of the watercourses as a function of the soils and vegetation cover.

Through the hydrological cycle the amount of water vapor present in the atmosphere and also in large surfaces in the vicinity exposed to evaporation, as well as the meteorological and topographic conditions are favorable to evaporation.

The hydrological cycle is the "process of evaporation, condensation, precipitation, detention and flow, infiltration, percolation of water in the soil and aquifers, river flows and interactions between these components" (Righetto, 1998, p. 9).

There are other factors that directly interfere with the surface runoff of existing highway drainages, in the case of Expresso Porto, in the municipality of Porto Velho (RO), the insufficiency of the flow, in many cases, is related to the construction of culverts. Not because they have disagreed dimensions, but because of unevenness in relation to the water level, a factor that causes damage to the highway, such as slope overflow and erosion (Figure 11) which can dam upstream and cause holes downstream.

Figure 11: Culvert with a 1.50m shackle, where silting and silting problems were found. Erosive processes downstream of the channel

Source: From the authors (2019).

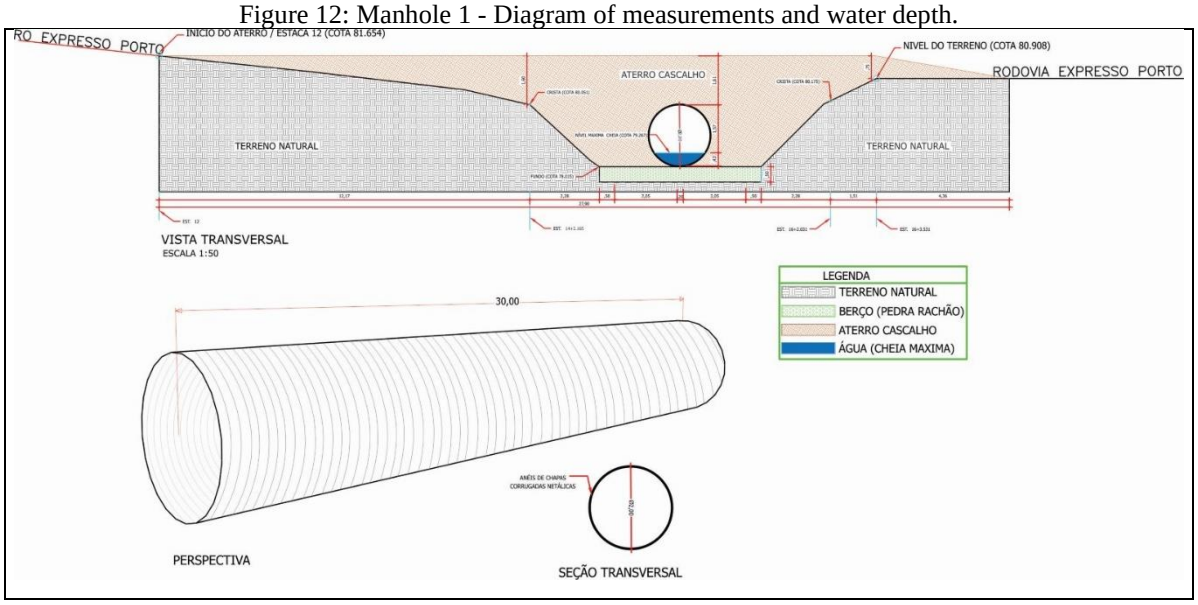
A highway culvert with incapacity for flow can cause erosion of the "slopes near the downstream mouth, rupture of the embankment due to overflowing water, or flooding of upstream areas" (DNIT, 2005, p.19). Another problem found on the Expresso Porto Highway, through images and complementary readings of the DNIT Basic Hydrology Manual (2005), was the use of culverts in disagreement with the flow of the canal.

8 FLOW CALCULATIONS OF THE MAIN CULVERTS

To know the flow of water bodies in the area of the Expresso Porto Highway, the flow calculations of three main culverts were carried out, using the float method, in March 2019, showing through technical drawings the water depth of each culvert and their respective measurements used in the calculations. It should be noted that the flow of a canal or river is influenced by the distribution and volume of rainfall, the size of the respective watershed, which will define, among other factors, its absorption and infiltration capacity and the amount of water that will drain superficially.

In the culvert (figure 12), geographic coordinates 8°45'51.74"S and 63°44'46.61"W, the correction indices were used to calculate the flow and, through the illustrative scheme, it was found that the flow inside the culvert, during the field survey, was only 43 centimeters, leaving 1.57 meters for the total filling of the internal space. In other words, there is no lack of space for the flow in this culvert, but an unevenness in the placement, leading to the damming of the upstream stream.

Figure 12: Manhole 1 - Diagram of measurements and water depth.



Source: From the authors (2019).

Calculation of the area and flow in culvert 01 of 2 meters in diameter:

Calculate the speed

$A = \pi.D^2/4$

$A=3,14.2^2/4 =$ **$3,14m^2$**

Calculate Average Speed

Vm = Sm/Tm

VM=30m/21s

Vm = 1.43m/s

Corrected average speed

vmc = ic.vm

Vmc = 0,83.1,43

Vmc = 1.18m/s

Flow

Q = A.Vmc

Q = 3,14.1,18

Q = 3.70m³/s.78% OFF

Q = 2.88m³/s or 2,880 litres per second

Calculation of the area and flow in culvert 02 of 3 meters in diameter (figure 13):

Calculate the speed

Vm = Sm/Tm

Calculate Average Speed

A= π.D²/4

A= 7.06m²

VM = 33m/15s

Vm = 2.2m/s

Corrected average speed

Vmc = Ic.vm

Vmc = 0,83.2,2

Vmc = 1.82m/s

Flow

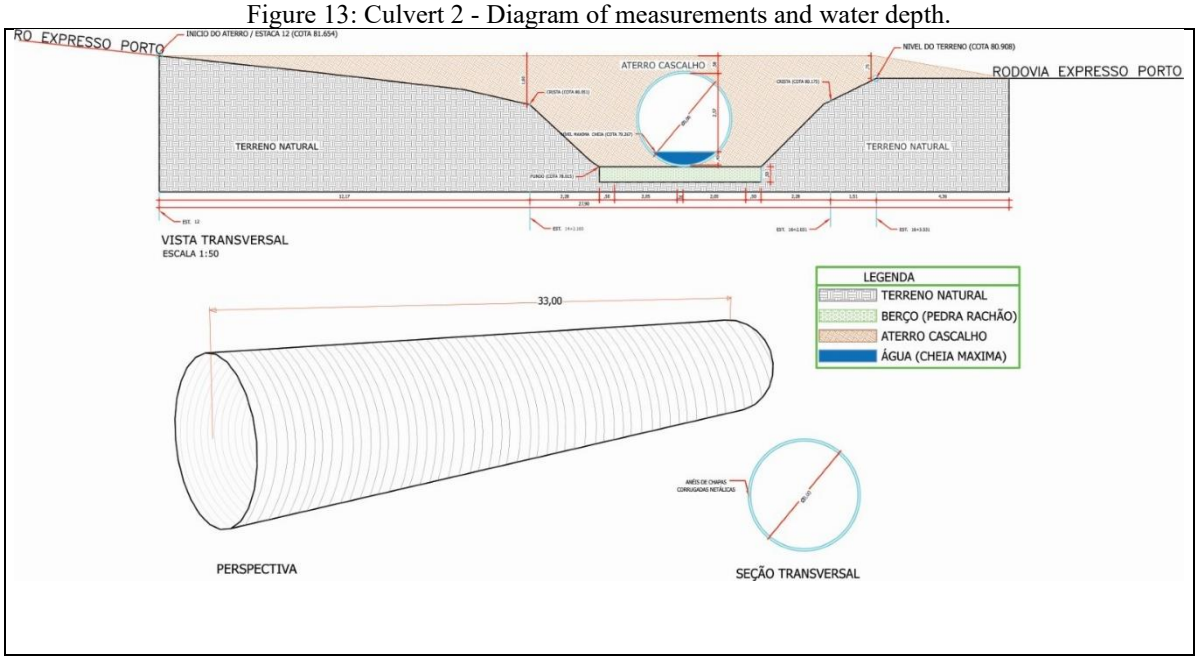
Q= A.Vmc

Q= 7.06 x 1.82

Q= 12.84m³/s.52% OFF

Q = 6.67m³/s or 6,670 litres per second

Figure 13: Culvert 2 - Diagram of measurements and water depth.



Source: From the authors (2019).

With these calculations it was also clear that in culvert 02, with geographic coordinates 8°44'28.40"S and 63°44'42.93"W, despite presenting a higher flow in this stream, the culvert was not using great drainage capacity, therefore, in addition to being larger than the first in thickness, the water depth was very low, proportionally representing similar value to culvert 01.

Calculation of the area and flow in culvert 03 of 3 meters in diameter (Figure 14):

Calculate the speed

A= π.D²/4

A= 3,14.3²/4= **7,06m**

Calculate Average Speed

Vm = Sm/Tm

VM = 26m/9.6s

Vm = 2.70m/s

Corrected average speed

Vmc= ic.vm

Vmc = 0,83.2,70

Vmc = 2.24m/s

Flow

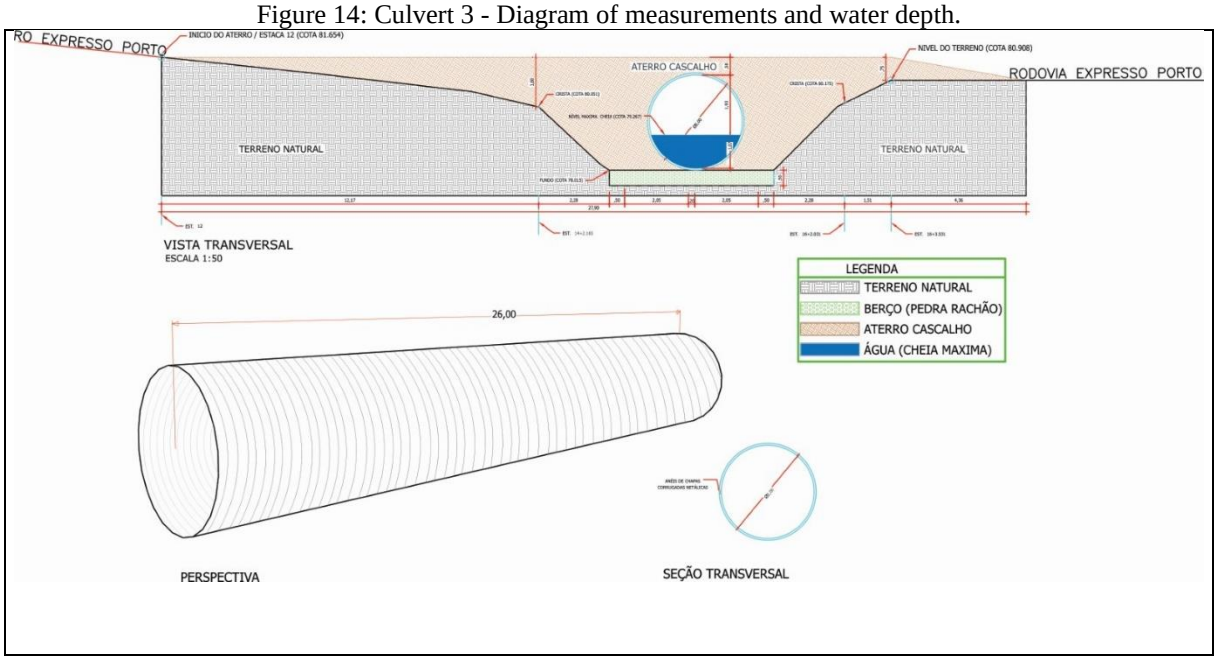
Q= A.Vmc

Q= 7,06.2,24

Q= 15.81m³/s.64%

Q= 10.12m³/s or 10,120 litres per second

Figure 14: Culvert 3 - Diagram of measurements and water depth.



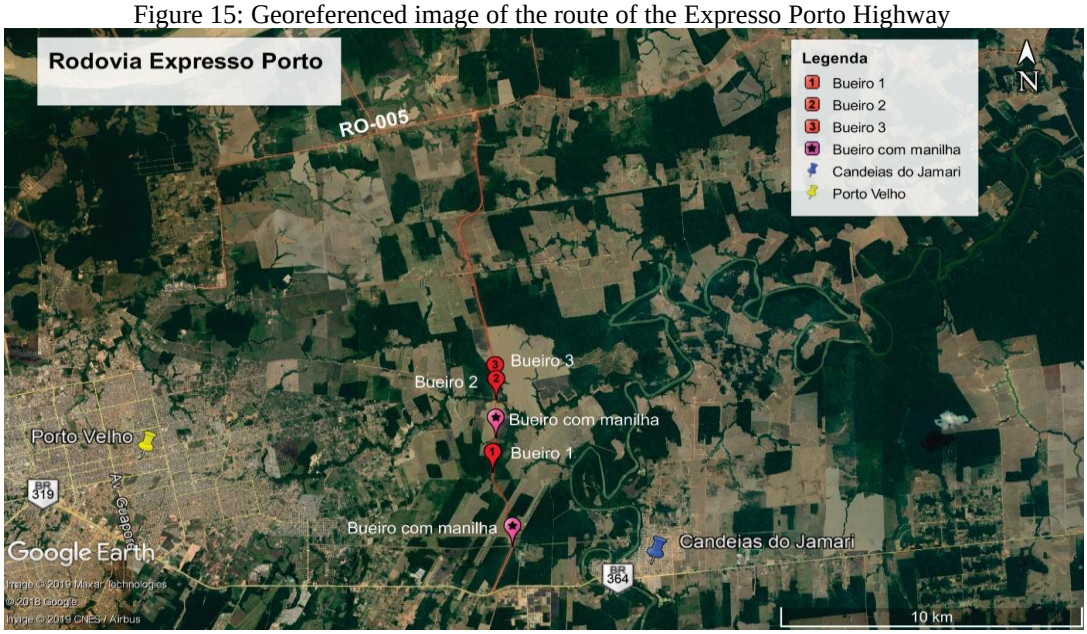
Source: From the authors (2019).

In culvert 03, with the geographical coordinates 8°44'12.56"S and 63°44'43.95"W, the calculated flow was higher, exceeding 10,000 l/sec, being the only one of the three that has an adequate installation next to the watercourse.

The calculations show that the culverts of the highway, object of this study (figure 15), have adequate capacity to flow the flow of the respective streams, however, there is a significant difference in level from upstream to downstream, embankment of the slopes and erosion downstream causing large holes, among other problems.

The trafficability of vehicles is safe with the installation of vertical signaling, in accordance with technical standards and contributes to the economic development of the municipality of Porto Velho, since the ring road (Terminal Remoto/Expresso Porto) will be a corridor for the flow of grain production from the State of Mato Grosso and the Southern Cone of Rondônia for export by river.

Figure 15: Georeferenced image of the route of the Expresso Porto Highway



Source: Google Earth adaptation by the authors (2019).

9 FINAL THOUGHTS

It is pertinent that, not only in the state of Rondônia, there are problems related to the construction of highways, but throughout the national territory. In the case of the Expresso Porto Highway, in the municipality of Porto Velho (RO), the study showed that surface runoff has been undergoing changes in intensity, due to anthropic actions in the physical environment, such as the removal of vegetation and the installation of culverts of varying dimensions. This fact shows that significant rainfall, with the increase in the flow of some canals, especially those that were diverted to carry out hydraulic works, can cause collapse in the headwaters of culverts and slope collapse.

Through the geographic information system, such as remote sensing for the preparation of maps, it was possible to demonstrate factors that influence surface runoff. The calculation of the flow of the main water bodies where there was a need for the construction of culverts showed that their diameter meets the need for flow, however, in some there are problems of unevenness, that is, they were placed above the level of surface drainage. This has led to the impoundment of water and erosion of upstream slopes and the appearance of holes in the channel of the streams downstream.

These and other impacts, reflections of human action, such as the suppression of vegetation and drainage works on the highway itself, require the implementation of mitigating measures by the government. The study also showed the importance of carrying out good topographic studies to support future similar engineering works, as well as the need for technical monitoring in their execution.

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