INTERMITTENT RIVERS OF THE BRAZILIAN NORTHEAST: the case of Alto Paraíba, Brazil

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ABSTRACT

A country with continental dimensions such as Brazil has significant environmental diversities throughout its territory. Among these, water resources have unique connotations, from the natural, environmental and social standpoints. The Northeastern region of the country is marked by the presence of temporary rivers, also referred to as intermittent or ephemeral rivers. This condition stems from the characteristic water regime of the Semi-Arid region, as a response to the drought period, the riverbeds remain dry for a period of the year. Thus, in the northeastern region, most rivers are intermittent at least in one of their stretches, as is the case with tributaries of the upper course of the Paraíba River. Given their intermittent condition, the beds of these rivers present significant changes over time and space. Thus, this research aimed to identify the uses of the surface along the area of the Alto Paraíba basin, in particular the existence of natural and anthropogenic vegetation; their physiognomies based on the types of densification; surface uses; and areas susceptible to degradation. To do so, we used geotechnology (satellite images, Geographic Information Systems, and GPS receiver) for the environmental assessments, while conducting a diagnosis of the high course of the Paraíba River. This research identified the predominance of anthropogenic areas to the detriment of natural vegetation. The less degraded areas were located in the higher elevation, with dense and semi-dense vegetation, while the flat ones, with elevation, are mainly of exposed soil, sparse and semi-sparse vegetation. The river courses are the most limited areas, and the presence of water was insignificant across the area, being restricted to artificial reservoirs. It was identified that the presence or

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absence of water is a preponderant factor in the use of the surface. These results enable the scientific, civil and political communities to better know the current conditions of this basin, favoring extensive discussions about its preservation.

KEYWORDS: Alto Paraíba. Temporary rivers. Degradation.

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1 INTRODUCTION

A country of continental dimensions such as Brazil presents significant environmental diversities throughout its territory. Among these, water resources have unique connotations from the natural, environmental and social standpoint. Following their example, the country's Northeast region is home to the temporary rivers, also referred to as intermittent rivers.

This condition derives from the characteristic water regime of the Semi-Arid region. In response to the precipitation, the riverbeds remain dry for a period of the year, establishing a drought period. Thus, in the northeastern region, most rivers are intermittent in at least one of their stretches, as is the case of some tributaries of the Paraíba River.

Another recurrent factor in the Brazilian semi-arid region, as is the case in the area referred to as Cariri Paraibano, is that, in addition to the droughts intrinsic to the region that varies over the years, there are periods of prolonged drought caused by the atmospheric-oceanic phenomenon El Niño. This phenomenon is due to the non-normal flow of surface and subsurface waters of the Tropical Pacific, reflecting the wind patterns (trade winds) on the world scale, which affects rainfall regimes in tropical regions.

The Brazilian Northeast has been under the influence of the El Niño phenomenon, with a subsequent drought in 2015-2016, while the drought of the past six years is being considered by the researchers as the most prolonged of the last one hundred years (***Table 1***) (INPE, 2017). The droughts alter the environmental and natural characteristics and the human actions on this environment.

Table 1 – Years of El Niño, according to the quarters

YEAR	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2010	**1.3**	**1.2**	**0.9**	**0.5**	0.0	-0.4	**-0.9**	**-1.2**	**-1.4**	**-1.5**	**-1.4**	**-1.4**
2011	**-1.3**	**-1.0**	**-0.7**	**-0.5**	-0.4	-0.3	-0.3	**-0.6**	**-0.8**	**-0.9**	**-1.0**	**-0.9**
2012	**-0.7**	**-0.5**	-0.4	-0.4	-0.3	-0.1	0.1	0.3	0.3	0.3	0.1	-0.2
2013	-0.4	-0.4	-0.3	-0.2	-0.2	-0.2	-0.3	-0.3	-0.2	-0.3	-0.3	-0.3
2014	-0.5	-0.5	-0.4	-0.2	-0.1	0.0	-0.1	0.0	0.1	0.4	**0.5**	**0.6**
2015	**0.6**	**0.5**	**0.6**	**0.7**	**0.8**	**1.0**	**1.2**	**1.4**	**1.7**	**2.0**	**2.2**	**2.3**
2016	**2.2**	**2.0**	**1.6**	**1.1**	**0.6**	0.1	-0.3	**-0.6**	**-0.8**	**-0.8**	**-0.8**	**-0.7**

Source: INPEE, 2017.
Note: Red=Hot; Blue=Cold; Black=Neutral

The El Niño phenomenon has a direct effect on vegetation cover reduction on the upper course of the Paraíba River, significantly altering the landscape of the area. Nevertheless, works proposed by the Federal Government seek to transpose the São Francisco River with the aim of making perennial the stretch of this river in 2017. This "solution," however, still requires several studies and is not the subject of this research.

At first time of this research, the high course of the Paraíba River presented typical characteristics of an intermittent course, as well typical caatinga vegetation, under the influence of a long drought period and diversity of anthropic actions. These characteristics alter the landscape due to the direct reduction of the survival of the plant species, as they have a direct impact on the environment of the vegetal cover. As a result, this research, which is based on geotechnologies and interdisciplinary studies associated with these methods used, focused on the methods of analysis, the current situation and the future possibilities of land surface use and/or protection.

Technologies such as Remote Sensing and Geographic Information Systems are examples of possibilities for integrating data to assist in the management of the territory and the environment (ROSA; BRITO, 1996).

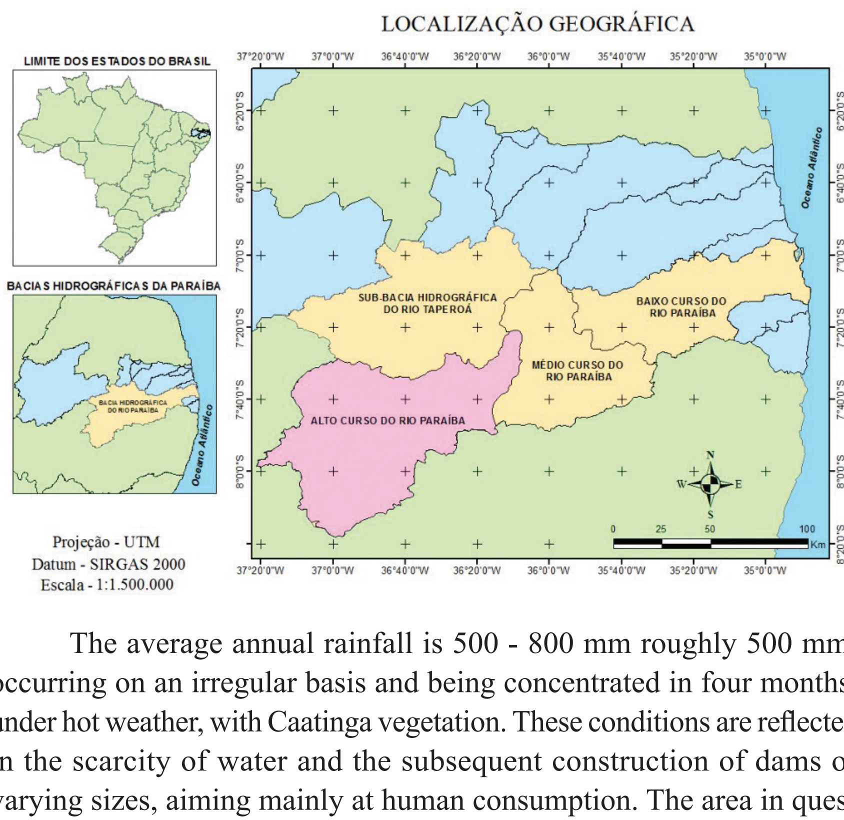
Therefore, this research aimed to identify the uses of the surface along the area of the Alto Paraíba basin, involving, more specifically, the existence of natural and anthropogenic vegetation; physiognomies according to the types of densification; uses of the surface and areas susceptible to degradation.

2 MATERIALS AND METHODS

2.1 DESCRIPTION OF THE STUDY AREA

The Paraíba River basin is located in the Northeast Region of Brazil and comprises an area of 20,071.83 km², it is divided into the Taperoá River sub-basin (5,666.38) to the north and three other regions – High (6,717.39), Medium (3,760.65), and Low (3,925.40) (***Figure 1***) (AESA, 2016). The river is area established as intermittent or temporary is the high course, from Jabitacá Sierra, in the municipality of Monteiro, to the Epitácio Pessoa Dam, in the municipality of Boqueirão (FREITAS; CASTRO, 2012).

Figure 1 – Location of the Alto Paraíba basin, PB



The average annual rainfall is 500 - 800 mm roughly 500 mm, occurring on an irregular basis and being concentrated in four months, under hot weather, with Caatinga vegetation. These conditions are reflected in the scarcity of water and the subsequent construction of dams of varying sizes, aiming mainly at human consumption. The area in question is inserted in the Borborema Plateau on the crystalline area, with non-calcic, litholic and regosol Bruno soils, i.e., it has shallow and stony soils and rocky outcrops (LUCENA; PACHECO, 2017; ALVES, 2009).

In addition to the natural issues, the human pressure on the Cariri region emanates from its past, as this region was the scene of traditional agricultural activities with cotton, as well as extensive livestock, and currently suffers the withdrawal of vegetation for charcoal and firewood for supply of plaster and ceramics hubs, the steelmaking industry and residences of the region (MMA-BRAZIL, 2010). Thus, natural issues such as the water regime and entropic actions such as the removal of vegetation are major factors affecting the environment, contributing to processes of degradation affecting this landscape.

2.2 FIELD DATA COLLECTION

The field data collection via GPS was carried out by Iluliane Maria Gadelha Correia, a regular student enrolled in the Geography course at the Federal University of Campina Grande (UFCG). The displacement to the study areas was performed in an official vehicle, made available by the Federal University of Campina Grande.

The fieldwork was conducted on 5/12/2015, with the aim of proving the data processed in the laboratory and creating a collection of georeferenced photographs relating to field analysis.

The development of support activities for the fieldwork employed the Orbital Sensors of the Landsat-8 multispectral satellite images, referring to the orbit/point 215/65 (15/10/2016) and 215/66 (12/6/2016), in the USGS satellite image collection, in 2017.

The Digital Elevation Model (DEM) based on SRTM data (Shuttle Radar Topographic Mission) was extracted from the geomorphometric database of Brazil, resulting from the TOPODATA project, with a resolution of 30 m, provided by the National Institute of Space Research (INPE). The sheets with identification of 07S375 and 08S375, covering the study area, were selected.

For physical and logical computational support, GPS (Global Positioning System) hardware, a digital camera and the SPRING 5.4.3, ArcGis 10 and MS Excel 2017 software were used.

The use of ArcGis 10 was licensed to the Graduate Studies Laboratory of the Humanities Center of the Federal University of Campina Grande (UFCG).

2.3 IMAGE PROCESSING

The extraction of basic information, such as dams, main federal roads, municipal roads and drainage network, was carried out with the cartographic database of the Brazilian Institute of Geography and Statistics (IBGE).

The preliminary interpretation was executed following a pre-established script for the Digital Processing of the TM/LANDSAT-8 images. The methodology was based on the Systematic Method developed by Santos et al. (1982). Such methodology consists of a sequence of coherent, systemic steps that are independent of previous knowledge of the area.

The IBGE database provided support for the construction of the cartographic base, such as the road network and the main drainage network (control points), aiming at the correct adjustment of the base in the image. In this sense, the visual analysis of images was based on a comparative study between the spectral and textural properties. Each of the spatial phenomena in the several recorded scenes are associated with the different levels of reflectance of several possible phenomena at the time of acquisition of the image related to the spectral targets.

Thus, the identification of the units and/or thematic classes was based on the isolated study of the various elements of interpretation, followed by the joint observation of these elements (drainage, relief, tonality, texture, and surface use).

In the quantification of the coverage for the use of the surface, the adjusted RGB multispectral compositions in bands 3 and 4, as well as NVDI in bands 5 and 6, were used as information layers.

The methodology adopted five cover classes (dense vegetation, semi-dense vegetation, sparse, semi-sparse, and exposed soil). The most critical vegetation cover classes are associated with the darker gray tones detected in band 5 in the images. The most preserved classes and lowest levels are associated with the lighter shades of gray. Within these parameters, vegetation was spatialized based on the classes, in line with vegetation densification per pixel, where dense means 100% vegetation cover; semi-dense, 75%; sparse, 50%; semi-sparse, 25%; and exposed soil, 0% vegetation.

2.3.1 Analysis and Interpretation of the satellite images

The work involved the following different steps: image preprocessing (reading, contrast); processing (segmentation and classification); field sampling for mapping verification; and analysis of the data collected in the field. By means of computational techniques, the aim was to extract information about the targets on the terrestrial surface, as describe here below:

- *Contrast Enhancement*

The technique of contrast enhancement aims to improve the quality of the images under subjective criteria of the human eye. It is commonly used as a preprocessing step for pattern recognition systems (INPE, 2017).

The contrast enhancement technique aimed to equalize the bands, so that all could exert a similar influence in the process of segmentation of the image. In the case of the colored composition 4, 5 and 6 used, band 5 presented the most comprehensive pixel distribution histogram in relation to the 256 possible gray levels (high-contrast image), while bands 4 and 6 presented narrower pixel distribution histograms (low-contrast images). In order for the segmenter to consider the three bands in an equivalent way, it was necessary to redistribute the gray levels of bands 4, 5 and 6 to cover the 256 gray levels possible in each of them.

The operation involved in correcting the gray levels of the colored composition used was the linear adjustment.

- *Arithmetic operations*

The interband ratio (NVDI) served to increase the contrast between soil and vegetation. The ratio between red and near infrared bands is used, forming the so-called vegetation index (NDVI).

It has been used in the computation of the multispectral composite C.

- $C = G * ((A - B)/(A + B)) + O$, where:
- A = near infrared band – band 5
- B = red band – band 4
- G = gain (value 256 was used)
- O = offset (value 64 was used)

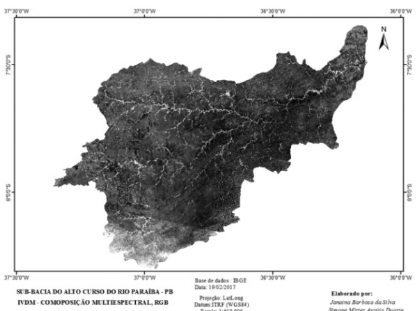
The result applied to the satellite image is shown in Figure 2A, in addition to increasing the spectral contrast between vegetation and soil, this multispectral composite has the effects of enhancing lighting and slope, partially offset by the index (CAMARA, 1996).

2.3.2 Adjusted Multispectral Composition (b4 + NDVI + b3)

This composition corresponds to an RGB transformation in which the red light source (R) is assigned to band 4, the green source (G) to the NDVI image, and the blue source (B) to band 3. The result is shown in Figure 2B where areas with a high NDVI value will appear in green (occurrence of vegetation) and areas with a low NDVI will appear in red or blue (magenta or cyan), indicating the presence of exposed soils.

Figure 2 – A) Multispectral composition – NDVI. B) Adjusted multispectral composition of the bands – AMC.

A)



B)

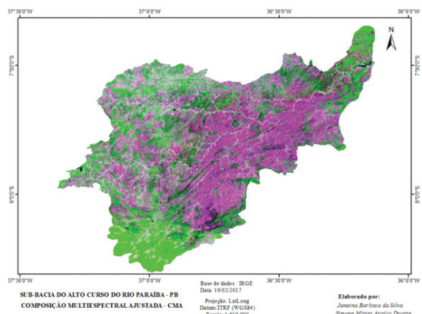


Figure 2 clearly shows the extensive areas of exposed soils, vulnerable to soil degradation processes, such as laminar erosion, furrows and gullies. The areas with high NDVI values, in green, denoting the occurrence of vegetation, show the progress of anthropogenic activity. On the other hand, areas with low NDVI values, in magenta or cyan, show predominance of exposed soils.

Using the AMC composition, we performed a segmentation, subdividing the image into homogeneous regions, considering some of their attributes, such as the level of gray of the pixels and the texture, with the aim of characterizing the representativeness of the objects in the scene. Segmentation involves the generation of internally homogeneous objects, on which classification is then applied. This approach presents some limitations as it is based only on spectral attributes. To overcome these limitations, image segmentation, prior to the classification phase, was used to extract the relevant objects to the desired application. In this process, the image is divided into regions that should correspond to the areas of interest of the application, in which the set of contiguous pixels that spread bi-directionally are considered uniform.

- *Pattern Classification*

Following the segmentation, the classification of standards is a decision process in which a group of pixels is defined as belonging to a given class. The classification of patterns is divided by the phases of region segmentation, classification, and mapping.

For the classification, we employed the "*Bhattacharrya*" classifier of Spring 5.4.3. (2016), which uses training samples to estimate the probability density function for the pointed classes. At the end, all regions are associated with a class defined by the algorithm, and the user is required to associate these classes or themes with the classes defined by the algorithm in the database.

The classified images were vectorized through the ***"****Mapping****"*** function, which allowed the quantification of the classes of surface use.

- *SRTM Images*

ArcGIS 10 Geographic Information System program, using the ArcMap application, has been used to prepare and manipulate the hypsometry and slope maps. In addition, all thematic maps were handled in this GIS.

- *Imagine Mosaic*

Using the ArcGIS Image Mosaic tool, we inserted two SRTM images and directed the output, maintaining the "Tiff" format of the image. The cut was made using the shapefile files of the sub-basin, made available by the Brazilian Institute of Geography and Statistics (IBGE). The SRTM image of the study area, as a means of viewing the altitude of the area, has been classified and colored for analysis .

- *Slope*

Slope is an attribute used in environmental studies due to its considerable influence on the surface and subsurface runoff, since it interferes with its velocities. Thus, the terrain slope is directly related to the forms of relief, types of erosion, and possibilities of use for agriculture.

To view the slope, we adopted the following procedures on ArcGis: Arctoolbox → 3D analysttools → Raster surface → 3D Slope → Input (SRTM image of the Area) → Option degrees → Output.

We then used, in *Properties*, the *Symbology* option, followed by the *Stretched* option, classifying and coloring the image for analysis.

- *Hillshade (3D view)*

Hillshade was used to provide a 3D view of the image relating to the area slope. To compose this image, we adopted the following procedures: 3D analysttools → Raster surface → Hillshade → Inputraster (SRTM image) → (Z factor = elevation exaggeration) → Output.

3 RESULTS AND DISCUSSIONS

The maps obtained allowed the confirmation of the environmental conditions present in the study area, where no precipitation has been recorded in the Alto Paraíba region (according to AESA, 2017) during the 30 days preceeding the recording of each image. This condition directly affected the landscape of the typical Caatinga vegetation, which is xerophilous, i.e., the plants lose their leaves to minimize evaporation.

The elaboration of the Natural and Anthropogenic Cover (***Figure 3***), Hypsometry (***Figure 4***) and Slope (***Figure 5***) maps provided a general picture of the condition of the Alto Paraíba River Basin.

Figure 3 – Natural and Anthropogenic Cover Map.

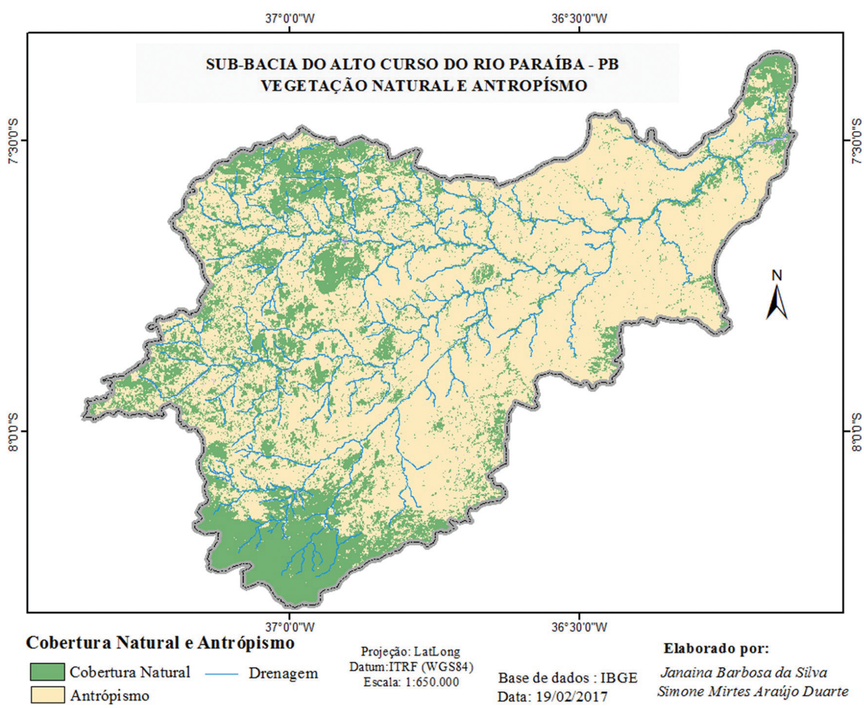


Figure 4 – Hypsometric Map

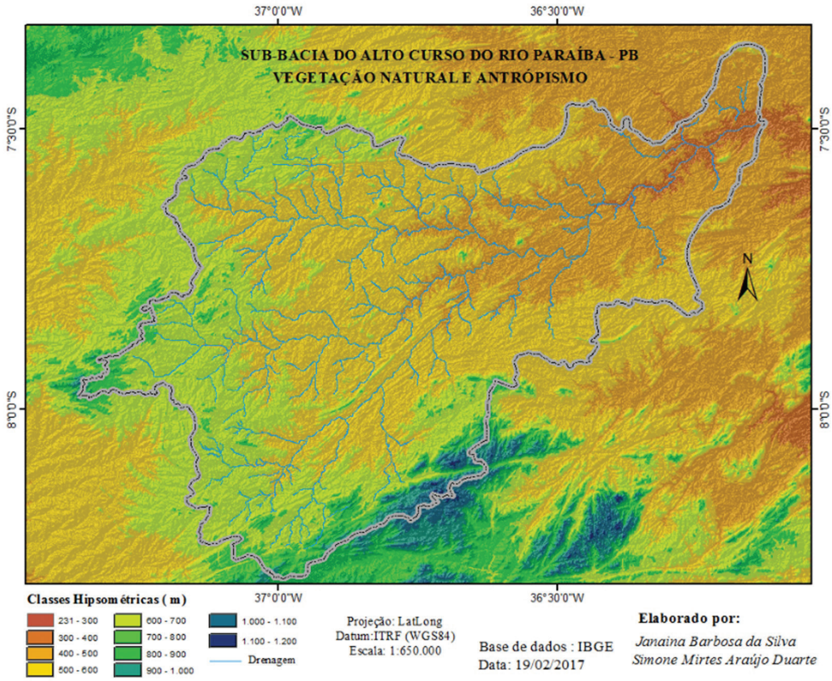
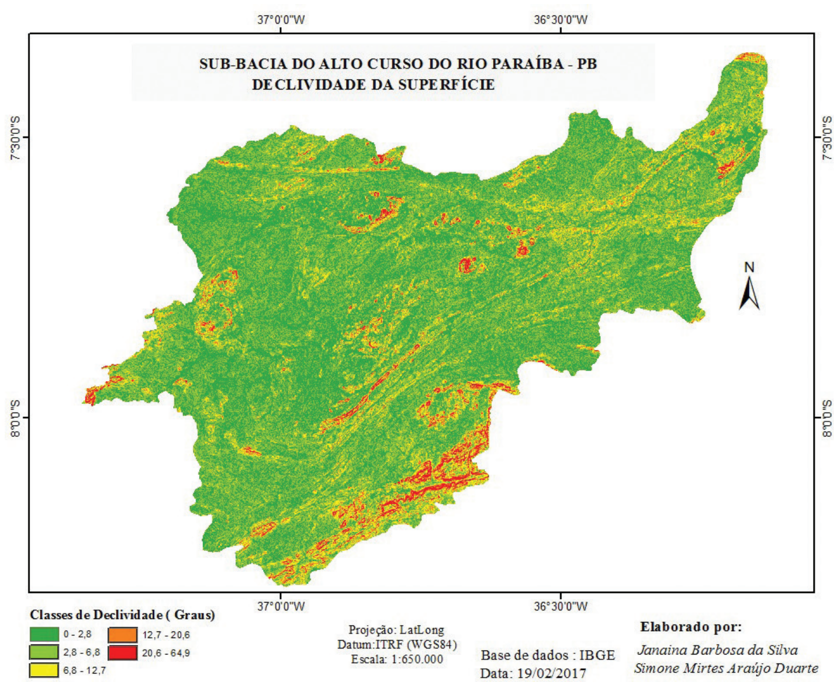


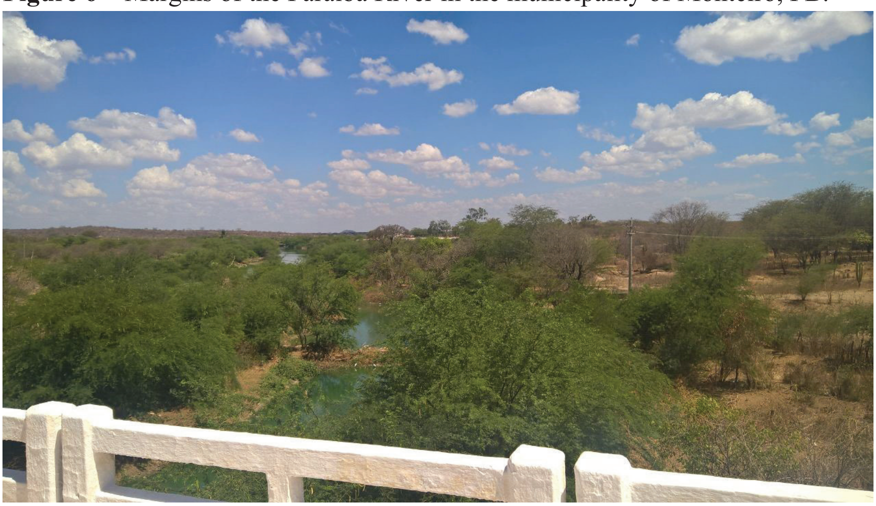
Figure 5 – Slope Map



The area is predominantly characterized by human modifications in the region situated between 170 to 600 meters, predominantly with a flat relief, and mainly in the margins of the waterways. This is due to intermittent agriculture, which is typical of environments with low rainfall and shallow soils, as is commonly the case in the areas of the Northeastern Sertão.

We thus identified that the main channel of the river and its tributaries present a bare surface, with isolated spots with vegetation. Consequently, in the normalization of occurrence of the rainy season, the soil is expected to be eroded from the surrounding areas into the river-beds, triggering sedimentation processes with subsequent assoriament of the river chanell (***Figure 6***).

Figure 6 – Margins of the Paraíba River in the municipality of Monteiro, PB.



Thus, we immediately notice the characterized disrespect by compliance with the Brazilian legislation, regarding the Forest Code, Act 12,651/12, which establishes intermittent or non-intermittent river-bank areas as Permanent Preservation Areas, with the aim of preventing soil degradation and silting. However, within the historical, social and economic conditions, it is known that this use is a common practice throughout the Northeastern territory[1].

As in the Alto Paraíba River Basin, the natural cover susceptible to anthropic activity also occurs in specific portions of other regions of Brazil, in particular from 700 to 1,200 meters of altitude and with a slope between 10.8 to 56.3 degrees. Due to naturally adverse issues, with high slope and steep environments, these areas are inherently difficult for human occupation, particularly in shallow and stony soils, as illustrated by the picture of ***Figure 7***.

Figure 7 – Environment of the Jabiatá Sierra – Monteiro, PB.

These factors are related to the lack of preservation, contrary to Article 10 of the Forest Code. In areas of high population density, such as in the Brazilian capitals of Recife and Rio de Janeiro, where there is a high population density in hills with slopes over 20° and in deep soils[3].

In the analysis of vegetation cover and surface use, we identified six classes according to the order of predominance (***Figure 8***). Exposed Soil (38.96%), Semi-Sparse (32.17%), Sparse (19.68%), Semi-Dense (7.44%), Dense (1.55%), and, finally, Water (0.2%), respectively (***Table 2***).

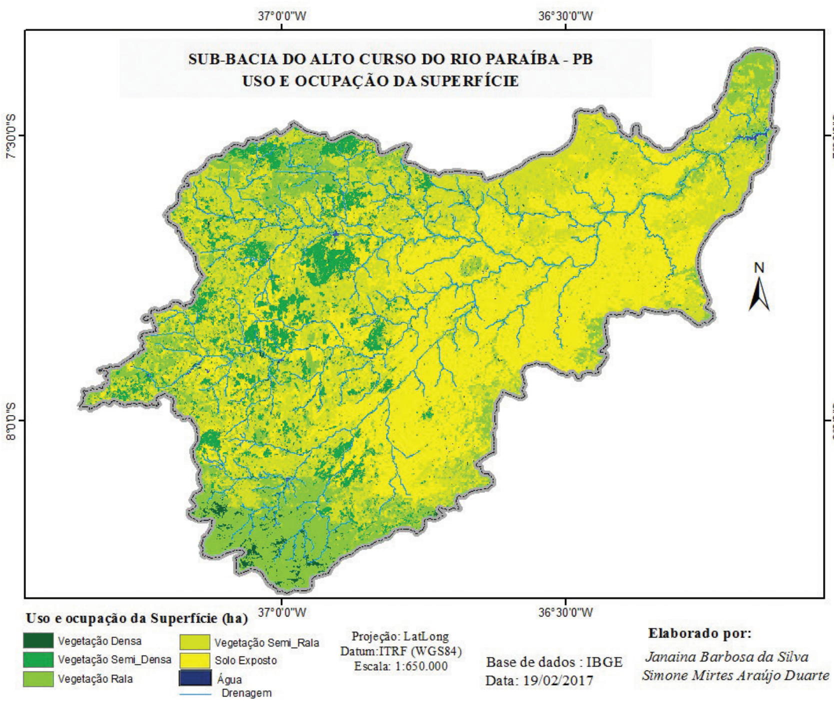
Table 2 – Classes identified for the High Paraíba Basis.

CLASSES	HECTARES (ha)	PERCENTAGE (%)
Dense Vegetation	10,601	1.55
Semi-Dense Vegetation	50,888	7.44
Sparse Vegetation	134,559	19.68
Semi-Sparse Vegetation	219,984	32.17
Exposed Soil	266,462	38.96
Water	1,396	0.20
Total	683,891	100.00

[3] *"A Terra e o Homem no Nordeste"* by Manoel Correia de Andrade (1980), and *"Geografia da Fome"* by Josué de Castro (1946), are recommended readings.

The data in ***Table 2*** reveal a considerable extension of Exposed Soil. As a matter of fact, human activities based upon agriculture and livestock have been recently abandoned (***Figure 9***) in areas of dry reservoirs, because of the long drought. In response to the removal of this vegetation cover, sediments have been carried to the beds of the canals, causing loss of soil fertility, with the possibility of causing desertification of the area.

Figure 8 – Vegetation cover and surface use.



The study from Nascimento, Lima and Lima (2014) corroborates the above finding. They identified, in the period 1989-2000, a considerable transformation of the surface, with predominance of agriculture and livestock, with impacts on the degradation of Alto Paraíba.

In the Sparse and Semi-Sparse vegetation areas the soil is only partially covered. It is more strongly affected by wind and solar erosion and affected by sporadic and concentrated precipitation and by animal trampling. Thus, the soil ends up becoming compacted and eroded, with low fertility.

Figure 9 – Bare areas around artificial reservoirs.

According to Sampaio and Batista (2017), the degradation of human activity in the municipalities that compose the Alto Paraíba course is considerably low, as identified by socioeconomic data. Nevertheless, for the result of this research, the environmental assessments reflect a condition of fragility that may raise this value from low to medium.

In the city of Monteiro, PB, around Jabitacá Sierra, where the source of the Paraíba River is located, we observed the use of slopes for agricultural activities in the Semi-Sparse physiognomy (***Figure 10***). Araújo, Sampaio and Rodal (1995) stated that erosion is aggravated when this activity is carried out on slopes, by intensifying the water flow and leading in low harvest.

The typical Dense Caatinga Vegetation predominates in the tops of the sierras (***Figure 11***) or in cores near the rivers, often with presence of algarrobas – an exotic species. According to Alves (2009), the areas of "dense dry forest is called 'good forest', consisting of arboreal Caatinga that still retains its original features and, apparently, has not been previously felled".

The Semi-Dense class occurs in pockets of native and exotic vegetation, which, besides being able to conserve the soil, serves as pasture for the extensive herds surviving in the area during the long drought.

Figure 10 – Semi-Sparse vegetation in Jabitiacá Sierra, PB.

Figure 11 – Dense vegetation in Jabitiacá Sierra, PB.

The Water class was difficult to identify, accounting only for about 1,400 hectares, or 0.20% of the area assessed (***Table 2***). These significantly low values are reflecting the dry period, enhanced by the last six years of drought. Regarding its location in the image, it is found in the artificial reservoirs of Poções, Camalaú and Epitácio Pessoa (***Figure 12***), all of which operate with dead storage.

Figure 12 – Epitácio Pessoa Dam – Queimadas, PB.

4 CONCLUSIONS AND DISCUSSION

In this paper, we identified the following findings:

- Predominance of anthropogenic areas, to the detriment of natural vegetation;
- Less degraded areas are located at higher altimetric heights, with dense and semi-dense vegetation, whereas flat areas at lower heights are mostly composed of exposed soil and sparse and semi-sparse vegetation;
- The rivers are the most bare areas and the presence of water was insignificant considering the extension of the region, being restricted to artificial reservoirs, mainly because it is a semi-arid area and the drought is very long;

The results enable the scientific, civil and political communities to learn about the current conditions of this river basin, favoring extensive discussions about conservation and use, since it was identified that the presence or absence of water is a preponderant factor in the use of surface.

Because water is a determining factor for human presence and its activities, the implementation of the São Francisco River elevation and transfer, which will make perennial the stretch of the Alto Paraíba River, must be properly considered, as it may change the local reality. Multiple possibilities for the use of the surface will arise, due for already existent processes of degradation along the watercourses and loss of the natural vegetation. Once water is available, what will protect those pockets of native vegetation and steep areas? How will the preservation of the margins be carried out in accordance with the Brazilian Forest Code? Finally, how will this water change not only the landscape, but also the conditions of those who have always resisted long periods of drought?

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