Dam Break and Human Disaster: Córrego do Feijão, Brumadinho, MG

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Abstract. The study area was surrounding Córrego do Feijão Mine, located in the city of Brumadinho/MG, Brazil. From this proposal, we present the analysis of the effect of disruption of one of the tailings dams of the Córrego do Feijão Mine, which took place in January 2019, under the responsibility of Vale S.A. The rupture culminated in mud flow. A study and characterization of the area was made, to understand the flow of the waters, and consequently, the mud. In addition, it was possible to obtain information on the land use of the area before and after the break using remote sensing (Sentinel-2A) supervised image classification. Through a spatial and temporal analysis, it was estimated that the mud reached a total of 2.48 km^2, being the class of robust vegetation the most affected by the disaster in numerical terms. The typology of anthropic areas, despite being the smallest area hit by mud, was the one that suffered the greatest impact. The importance of an analysis of the elements that belong in the area of study and how they behave, in order to avoid and mitigate situations of vulnerability is considered very important. Finally, it is emphasized the relevance of a spatial planning studies that considers the integrated planning between the juxtaposition of human activities, social and spatial relations and their various impacts on the landscape.

Keywords: Territorial planning · Córrego do Feijão Mine · Dam break

O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12255, pp. 1–9, 2020.
https://doi.org/10.1007/978-3-030-58820-5_61

1 Introduction

In the mining sector, space has limitations of choices and alternatives, since the ore location is not where has the best facilities for human activity, it occurs in a specific geological context.

In this sense, mining dams are highly known for generating high environmental impact and landscape transformation, and their management is the target of direct criticism from society (Duarte 2008) [1]. As large anthropic structures are, the possibility of some event cannot be ruled out, even if it has a value close to zero. In this way the risk should be minimized as much as possible and, according to Bowles et al. (1998) [2], one of the premises for this is security, which includes protecting the population that lives with this type of infrastructure.

It is well known that within all the anthropic activities that generate more expressive impacts, mining stands out. Mining affects the territory where it is carried out (Cetem 2014) [3] and, consequently, the leasing of its elements (infrastructure and operation) should contemplate the socio-environmental issues within the watershed in which it is inserted. The elements present downstream should be considered mainly, since in any disaster that may occur, the tendency is that the elements linked to the movement of materials move from the highest quota point to the lowest quota, in general, following the same path of the water flow network.

In this sense, the watershed is considered as a preferential cutout of environmental analysis and planning, as it is a system in which all actions adopted are reflected in its spatial set. Thus, the use of a water network as an analysis unit is relevant, since the watershed, connected to the water network, is a cell in which it is possible to understand the interrelationships existing between the elements and processes of the landscape, being then the hydrographic network, or part of it, is defined as an element of high importance for the study of environmental problems (Botelho 1999) [4].

The present study uses as spatial clipping of the Ferro Carvão Stream in the Paraopeba River, watershed directly affected by the rupture of one of the dams of the Córrego do Feijão Mine, in Brumadinho (MG).

2 Satellite Images

The use of satellite images for digital image processing applications is a very successful technology in data collection for data collection and monitoring of events on a global and local scale (Meneses and Almeida 2012) [5]. This is because the data collection presented is distant from the object under study, because it is not performed *in loco* (Jensen 2009) [6] and there is a possibility of understanding the phenomenon under study on a temporal scale.

It is well known that satellite images, in digital or analog form, are very important and useful for urban planning and land use, as they allow the evaluation of changes in the landscape of a region and during a given period, for example, recording coverage plant at any moment. Another importance is its periodicity of imagery, which is short, enabling the analysis of the phenomenon in whatever its spatial modification (Machado 2002) [7].

The images used was Sentinel-2A, belonging to the Copernicus program of the European Space Agency. This type of image collects data that allows to detect small movements and changes in the terrain, useful for monitoring vegetation, water bodies and structures (ESA 2017) [8]. The images of this satellite are captured in bands of different wavelengths (Table 1), with a spatial resolution of 10 m (red, green and blue).

Table 1. Spatial resolution of the bands Red, Green, Blue and Near Infrared of Sentinel-2A Images. Source: The authors, modified from ESA (2017).

Band number	Central wavelength (μm)	Spatial resolution (m)
Band - 2 (Blue)	0,490	10
Band - 3 (Green)	0,560	10
Band - 4 (Red)	0,665	10

The combination of Bands RGB (Red, Green and Blue) is the most used among the color models (Meneses and Almeida 2012) [5]. This system stands out for the great freedom it presents to the analyst to explore the possible combinations of three colors with three bands in order to obtain the color image of better contrast. Figure 1 demonstrates the conversion of a digital image into the process of forming a colored composition in the RGB standard.

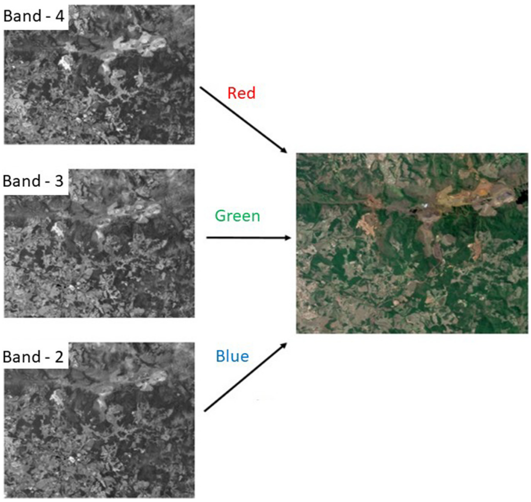

Fig. 1. Combination of Red Bands, Green, Blue to Generate True Color Image. (Color figure online) Source: The authors

Each element of the Earth's surface has a spectral signature that is related to the relative intensity with which the body reflects or emits electromagnetic waves at different lengths, in response to the action of sunlight on its surface. That means, a part of sunlight is absorbed by the body, another part is scattered, and the remaining part is reflected. This reflected part is captured by the satellite. These interactions are dependent on the physical and chemical characteristics of the target on which the incidence of light occurs.

In this case study, based on the composition with the specified bands, supervised classification of satellite images in the study area was made, with the use of classifiers per region that use, in addition to the spectral information of each pixel, the information of conformation or spatial arrangement. This involves the relationship between pixels and their neighbors and seeks to simulate the behavior of a photo interpretation, recognizing homogeneous areas of images, based on the spectral and spatial properties of the images (Santos et al. 2010) [9]. By comparing one pixel to other pixels of known identity, you can group those whose spectral reflectance are similar in more or less homogeneous classes (Santos et al. 2010) [9]. This activity need the use of geoprocessing software to visualize the images and to select the samples of the structural that in analyze.

3 Methodology

The work consisted of the elaboration of supervised classification of satellite images in order to obtain the final temporal and spatial analysis, following the subsequent methodological steps, present in the flowchart of Fig. 2 and described below:

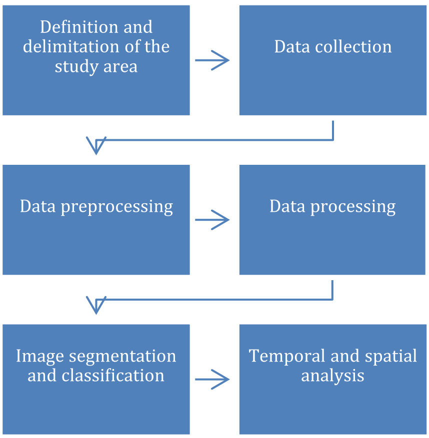

Fig. 2. Flowchart of methodological procedures. Source: The authors

On January 25th of 2019, there was a rupture of one of the dams of the Córrego do Feijão Mine in Brumadinho (MG), under the responsibility of the company Vale S.A. With the disruption, 12 million cubic meters of wet iron ore tailings leaked and went through the bed of the Ferro Carvão Stream, reaching the locality of Córrego do Feijão and later the city of Brumadinho.

The area is located within the municipality of Brumadinho (Fig. 3), Minas Gerais, and is 32.4 km^2 long. The watershed of Ferro Carvão Stream is inserted in the Paraopeba River basin, in the São Francisco Hydrographic Region.

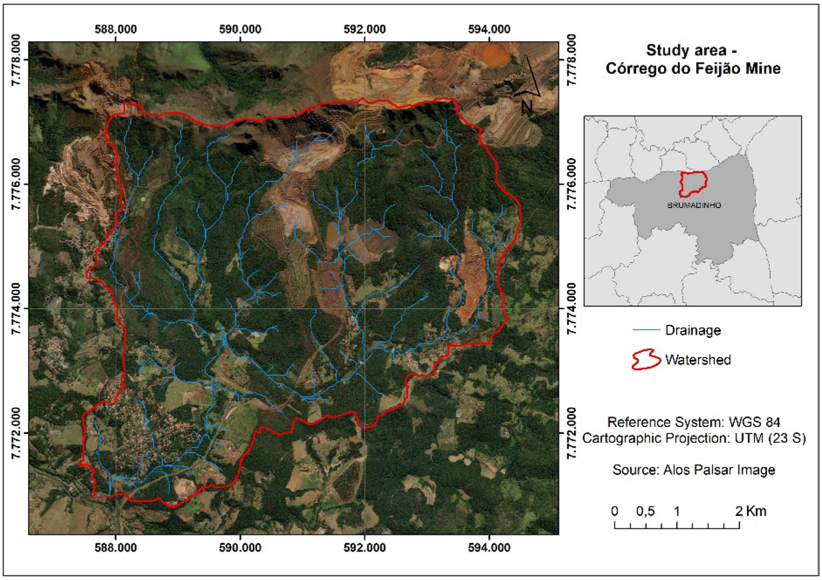

Fig. 3. Location of the study area. The watershed that the Córrego do Feijão mine is inserted, Brumadinho/Brazil. Source: The authors

Image processing has been done by acquisition of the satellite images for the area, from two dates, one of the pre-break (24/09/2018) and another related to the post-breakup (01/02/2019). The processing with an interactive classification of images was performed in the *ArcMap 10.7* software, in which the spectral characteristics of the pixel are considered. The processing of the images is a combination of Bands RGB (Red, Green and Blue), for the conversion of a digital image into the process of forming a colored composition in the RGB standard.

This technic requires sample areas, of each type of class. These samples are the training areas, which are obtained by selecting previous samples of each type of class. This step is done by the operator of the program and it is a visual selection, based on elements such as tonality/color, shape and texture of the pixels of each image. The classification was divided differently for each of the two images. In the image corresponding to the pre-rupture of the dam, four classes of land use and occupation were defined: robust vegetation, no vegetation, mining area and other anthropized areas. In the image corresponding to the post rupture of the dam, five classes of land use and occupation were highlighted: robust vegetation, no vegetation, mining area, tailings and other anthropized areas. Urban areas, roads, agriculture and pastures were grouped in the class for 'other anthropized areas'.

4 Characterization of the Area and Consequences of the Event

The area of this case study is located on the southern axis of the fragment of the metropolis of Belo Horizonte that corresponds to one of the main vectors of territorial expansion, composed of the municipality of Brumadinho, in which the Córrego do Feijão Mine is located. In this space there are several urban, environmental and economic conflicts – related to mining mainly – which often operate without articulation.

Thus, the interest in redirecting the use of space as an economic instrument for capital production generates the phenomenon of large open-air mining and the lack of planning of the territory by the public authorities, with fragility in the definition of areas appropriate for each type of activity, some of them conflicting. Therefore, the action of the State must become a fundamental instrument in the management of the territory in order to organize and plan the same.

Mining, at the study site, tends to occur in places with high topography, since in the local geological constitution of this mineral province iron deposits are located in lithologies that are in higher topography (Faria 2012) [10]. This situation may cause, if there is a disaster with the infrastructure of mines, the movement of the material from the higher local topographic point to the local topographic low, thus, there is a greater need for the Public Power to know its territory well and avoid possible overlap of urban, environmental and economic interests. An important way to solve the use of municipal space could be the adoption of environmental conservation units in impact amortization spaces, thus environmental protection instruments could fulfill functions that would enable the control of space use (Costa 2006) [11].

The rupture of the dam allowed the tailings mud to flow by the surface water determined by the differences of altitudes. The dam was located in a large section of the area and with a greater slope than other adjacent areas (Fig. 4), moving through the path of the Ferro Carvão Stream, reaching the locality of Córrego do Feijão and later the city of Brumadinho. All the structures that where across the path of the mud has been destroyed, such as the cafeteria and the administrative office of the mine. The rural local community was also directly reached by the mud (Fig. 5).

The classification of images also allows us to extract information about the territory of analysis. By classifying satellite images from the study site, information on the use and occupation of the soil of the watershed was extracted before and after the rupture of one of the dams of the Córrego do Feijão Mine (Fig. 5).

It was possible to calculate the areas representing the classes of land use and occupation before and after the rupture of the dam. Additional information was obtained from the area affected by mud for each type of land use and occupation, as well as the total area affected by mining tailings.

Table 2 shows that the most mud-affected class was robust vegetation, representing a total of 0.94 km^2, followed by the mining area, with 0.87 km^2. The anthropized area, which for this analysis represents urban areas, rural residences, roads and agriculture, was hit by mud in an area of 0.66 km^2. Despite being the least achieved class of use and occupation in numerical terms, it is the typology that has suffered the greatest impacts, since it directly affected people and animals.

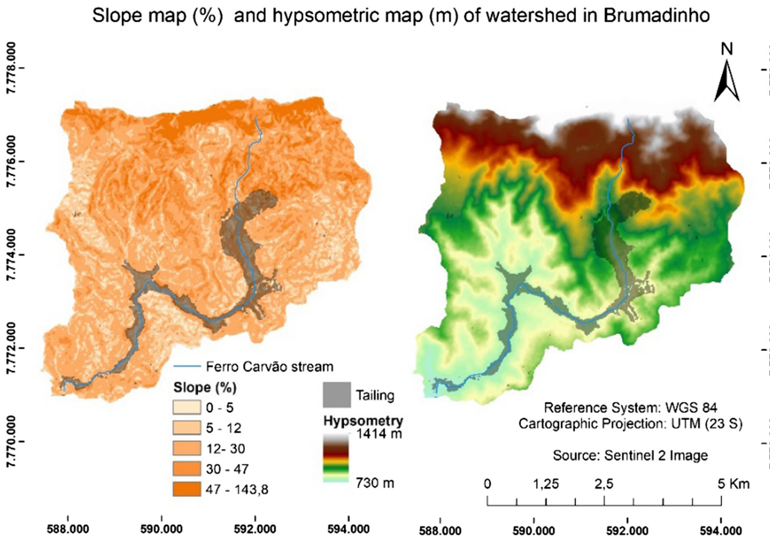

Fig. 4. Slope (left) and Hypsometric (right) maps. Source: The authors

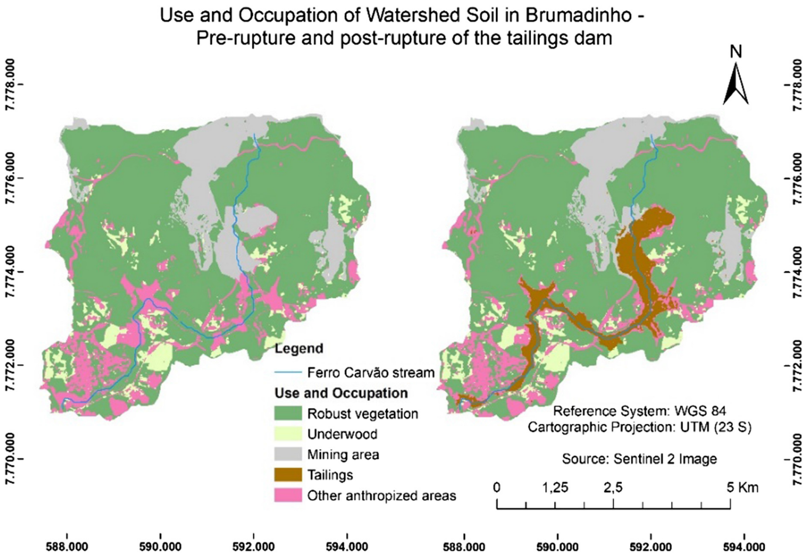

Fig. 5. Use and Occupation of the soil of watershed in Brumadinho - Previous (left) and Post Breakup (right). Source: The authors

It is important to highlight that this analysis is limited to the watershed area of immediate influence, delimited to the study. It is known that after the mud hit the Valley of the Ferro Carvão Stream and adjacent streams, this was towards the

Table 2. Estimated areas corresponding to the use and occupation of the soil and areas affected by the tailings. Source: The authors.

Land use and occupation	Area (km^2) Pre-breakup	Post-breakup area (km^2)	Tailings-stricken area (km^2)
Robust vegetation	21,71	20,77	0,94
No vegetation	1,87	1,87	0,00
Other anthropized areas	4,34	3,67	0,66
Mining area	4,77	3,90	0,87
Reject	0,00	2,48	–
Total	32,69	32,69	2,48

Paraopeba River and the city of Brumadinho, reaching new areas and causing other impacts.

The study makes a temporal and spatial analysis of the study area, taking into consideration the hydrographic watershed directly affected by the rupture. It is also sought to understand how the dynamics and distribution of mud had been determined by the spatial organization of the watershed, according to its hypsometric, slope, drainage, urban occupation. This allowed the characterization of the types of use and occupation of the most vulnerable sites when reached by the mud-flow.

5 Conclusion

Currently, with remote sensing techniques it is possible to characterize areas vulnerable to a certain risk, in this case the rupture of a dam. Access to satellite images is free, and you can use free software (*QGIS*, e.g.) to perform the same process presented here. The images already have a good temporal resolution, which means the possibility of monitoring changes in soil coverage by any user who makes use of geoinformation technologies. Similarly, access to topographic data is also free, which favors users from devising three-dimensional modeling to understand the territory. Studies of this nature are possible for any public administration.

We highlight a broader perspective, that nature is treated as a subject, that is entitled, and not as an object to be explored (Calgaro et al. 2016) [12]. Thus, activities related to man must contemplate the geographical space that has the greatest affinity to be allocated and not how it is currently carried out, where the project is first elaborated and then becomes the physical means for it to adhere to the enterprise.

Finally, we note the demand for attention to the subject relationship and nature in order to consider that nature is the main element taken into account when there are human interventions and not that the determining object is the activity to be developed by man, and the profit to be achieved, as usually occurs.

Acknowledgments. The authors would like to thank the CNPq support through the project “Geodesign and Parametric Modeling of Territorial Occupation: Geoprocessing for the proposal of a Master Plan for the Landscape for the Quadrilátero Ferrífero-MG”, Process 401066/2016-9, Edital Universal 01/2016 and FAPEMIG PPM-00368-18.

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