Conference Paper

Future Land-use and Land-cover Scenarios for Mapping Flood-prone Areas in Pato Branco City, Brazil

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Abstract

Urban flooding is the most common type of disaster and the one that hit people most. Unplanned urbanization processes increase the recurrence of these events due to soil impermeabilization. Thus, land-use and land-cover is an important factor for urban flood research. Besides, mapping flood-prone areas has been an alternative for disaster prevention and urban planning. However, the use of future land-use and land-cover scenarios for flood mapping is a factor that still requires investigation. The study that is being developed by the authors of this paper aims to identify flood-prone areas in the upper third of the Ligeiro River basin in the city of Pato Branco, Parana, Brazil. For this purpose, this research makes use of the GIS-AHP integration, considering a current scenario and future land-use and land-cover scenarios. Therefore, the objective of the present study is to construct possible land-use and land-cover scenarios, according to municipal legislation, that could serve as a basis for mapping flood-prone areas. Two scenarios were built using Geographic Information Systems software. This tool proved to be efficient in the elaboration of maps and land representation. Pato Branco already has a history of flooding with the current scenario of land-use and land-cover. With future land-use and land-cover scenarios, it is possible to verify the influence of urban sprawl on urban flooding.

Keywords: Land-use and land-cover (LULC), Floods, Geographic Information Systems (GIS), Analytic Hierarchy Process (AHP)

1. Introduction

Events such as earthquakes, floods, and landslides, for example, are innate to Earth, differ from place to place, and change the environment over time. However, humankind began to occupy areas susceptible to these phenomena, and without adequate infrastructure monitoring. From this moment onwards these events are called disasters [1], a consequence of the urban expansion process.

According to [2], among the types of disasters, floods were the most recurring around the world between 1998 and 2017, with over 43% from a total of 7,255 logged events. Still, according to the same survey, flooding was the type of disaster that hit people most during the same period of 1998 and 2017, with more than 2 billion people affected. In Brazil, [3] pointed out that hydrometeorological disasters, such as floods and droughts, caused the most damage and death during 1999 and 2012.

Urbanization processes in flood-prone areas increase the recurrence of this type of event. Urban areas cause changes in local hydrological conditions as well as hindering infiltration and increasing runoff volumes due to surface sealing [4–6].

Mapping flood-prone areas has been an alternative to assist urban planning and to prevent disasters [1]. The elaboration of these maps has been made from different methodologies and study sites [7, 8]. The Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS) are among the methodologies used.

The integration between AHP and GIS has already been used in other studies [8, 9] for flood mapping. However, a factor that still requires investigation is the use of a future land-use and land-cover scenario to map future flood-prone areas. Thus, a study that is under development aims to identify flood-prone areas in the upper third of the Ligeiro River Basin in Pato Branco city, Paraná State, Brazil, located within the urban perimeter of the municipality. This research aims to identify flood susceptibility with GIS and AHP integration for a current land- use and land-cover (LULC) scenario and future LULC scenario. Therefore, one of the objectives of this main study is to construct possible LULC scenarios, according to municipal legislation, that could serve as a basis for mapping flood-prone areas. This objective and its results are contemplated in this paper.

2. Methodology

2.1. Study Area

The study area is part of the Ligeiro River basin, has 12.46 km^2 and is located in the urban perimeter of Pato Branco city, Paraná State, Brazil, as shown in Figure 1.

Pato Branco has an area of approximately 539,087 km^2 and an estimated population of 81,893 inhabitants for the year 2018 [10]. The city is located in a subtropical climate region with an average annual air temperature between 18 and 19°C and annual precipitation between 2,000 and 2,200 mm [11]. The study area has suffered damages from landslides and flooding. Regarding the floods, the Civil Defense [12] recorded 5

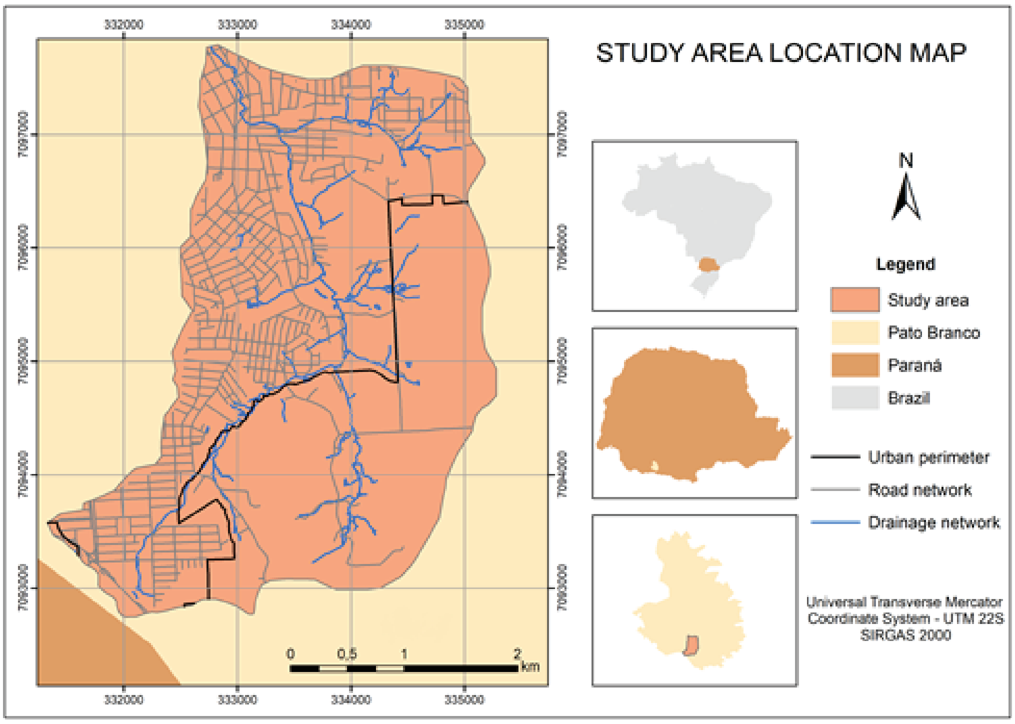

Figure 1: Study area location.

occurrences between 2015 and 2017. Thus, it is possible to understand the floods as recurring events in the city. In 2018, as shown in Figure 2, Pato Branco also underwent flood events.

Figure 2: Flood in the central region of Pato Branco in 2018.

By the year 2010, Pato Branco already had urbanization degree of 94.09% (which corresponds to the percentage of the urban population regarding the total population) and population growth rate of 1.52% [10]. That is, with a high degree of urbanization and

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in the process of population growth, local hydrological conditions can change due to soil sealing and the occurrences of floods may increase [4–6].

Thus, it is necessary to map flood-prone areas. Also, mapping the areas that may suffer from flooding as urbanization progresses and restricting occupancy in these locations can avoid greater proportions resulting from these events.

2.2. Construction of the Criteria Maps

To map flood-prone areas, we will follow the methodological steps shown in Figure 3.

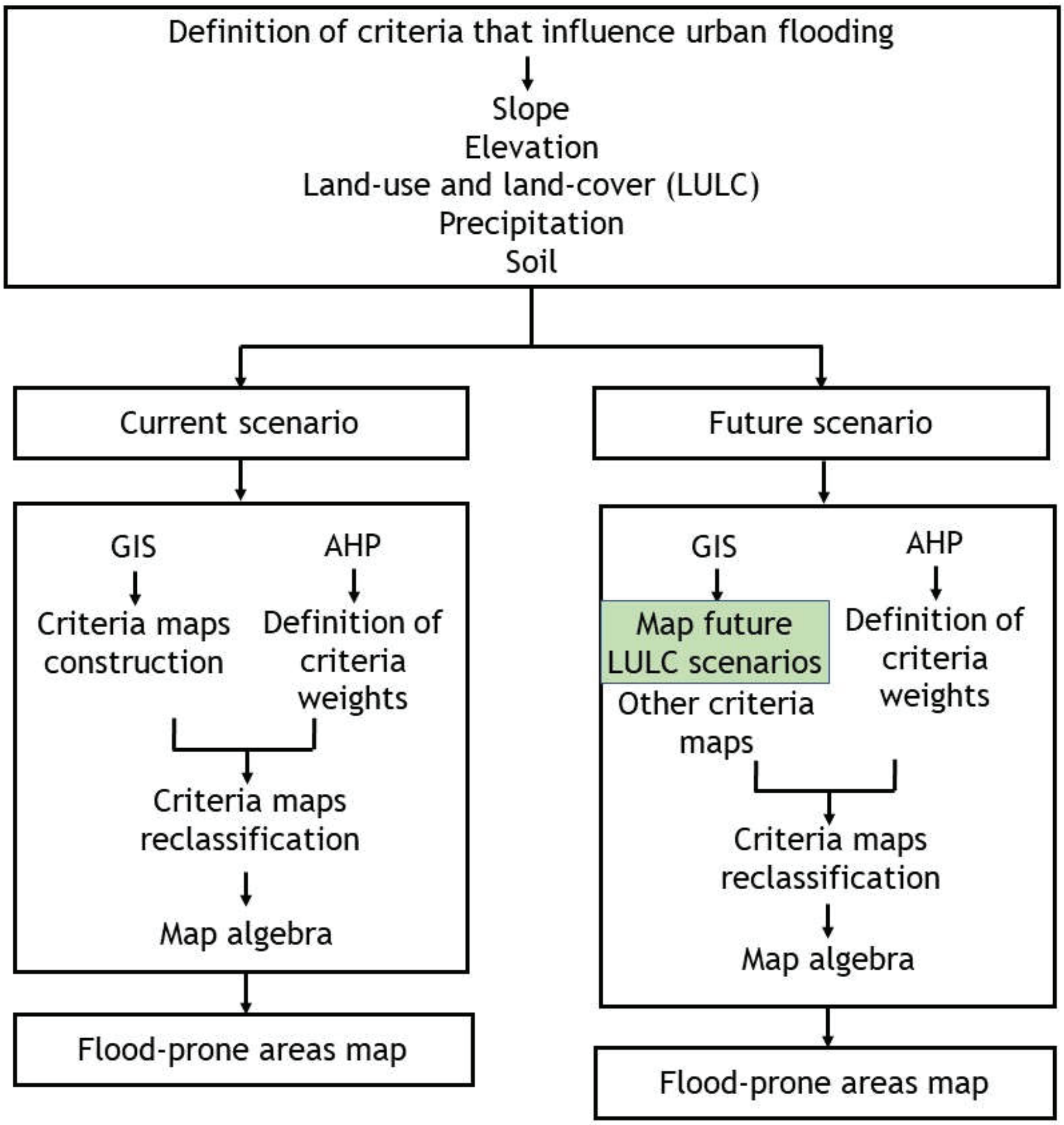

Figure 3: The overall framework to map flood-prone areas (in green, the step performed in this study).

The step highlighted in green is the one developed in this paper. This step is part of a work that is under development and which final objective is mapping flood-prone areas, using AHP and GIS.

GIS allows to visualize the direction, shape, and density of urbanization, and show the influence of urbanization on flooding [7, 13]. AHP is a simple, accurate and easy to understand decision-making methodology. It can convert particular and personal preferences to weights through a mathematical structure with matrices and auto vectors. These weights classify the criteria involved and support the individual in their choice. One of the main features of this method is its flexibility. This aspect makes AHP possible to be used in many areas and combined with several methodologies [14, 15]. The integration of these methods proved to be efficient in other studies [8, 9, 16].

The current scenario considers the ongoing conditions of urbanization. For the future scenario, the urbanization potential of the city is taken into account. To map the flood-prone areas in the future scenario, new land-use and land-cover maps are prepared following municipal legislation. In this study, the focus is only on the development of land-use and land-cover maps for the future scenario. These maps were prepared in a GIS environment.

The future LULC map was based on current LULC map. It used CBERS 4 - China-Brazil Earth- Resources Satellite images captured by the PAN 10 sensor in the year of 2019. These images were chosen for the spatial resolution of 10 meters and for being freely available in the image catalog of INPE - National Institute for Space Research.

For the elaboration of the current LULC map, a combined image classification, between manual and automated, was used. First, 432 (near-infrared, red and green) band composition was performed and then automated supervised classification was done.

The supervised classification of an image takes samples of the classes to be identified and indicates them to the software used. For this, this classification requires prior knowledge of the study area and its land-use and land-cover classes. One of the methods of this type of classification is the Maximum Likelihood that is based on statistics. In this method, image samples are selected according to each class and the method calculates, through the gray levels of the classes, the probability of the other areas of the image following the considered class [17].

In their research, [18] used the Maximum Likelihood method to predict the LULC of a watershed. The authors concluded that the method presents accurate classification even with several land-use classes. Thus, the study area was initially classified by the

Maximum Likelihood method. Then, the identified classes were manually delimited by polygons in the ArcGIS software.

For the elaboration of future scenarios, it was considered that urban expansion can evolve until the urban perimeter line, as defined in municipal legislation. Besides, green areas along rivers have been preserved. Thus, the regions not yet urbanized within the urban perimeter and capable of urbanization according to the legislation were considered as urban areas in two ways:

- First, changes 50% of the remaining and capable of urbanization areas to urban areas;
- Second, changes 100% of the remaining and capable of urbanization areas as urban areas.

The future scenarios were built manually in a GIS environment.

3. Results and Discussions

Future LULC scenarios were based on the current LULC map, shown in Figure 4. For the current LULC map, 5 land use classes were identified. The predominant class in the study area is the urban area in pink, followed by agriculture in orange.

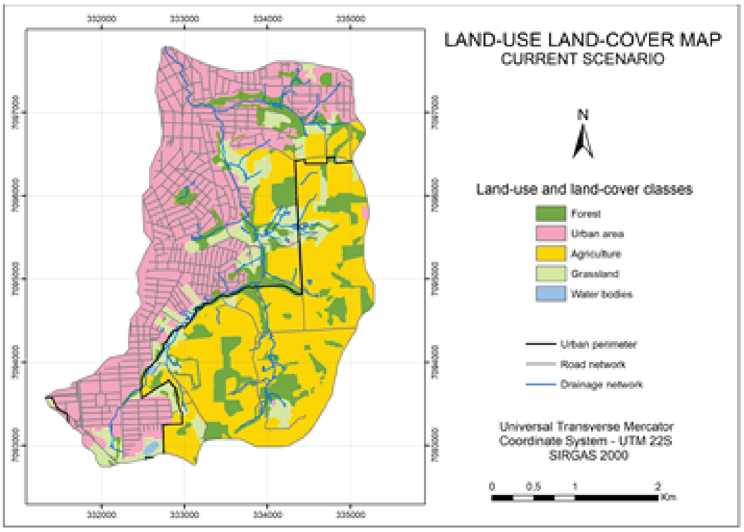

Figure 4: Land-use and land-cover map for the current scenario.

The first future scenario shown in Figure 5, occupied, as urban area, about 50% of the remaining area for urbanization. The value of 50% of the area for urbanization was chosen to test flood behavior if half of the study area was waterproofed. Figure 6 presents the second future scenario with 100% of the remaining area for urbanization occupied as urban area.

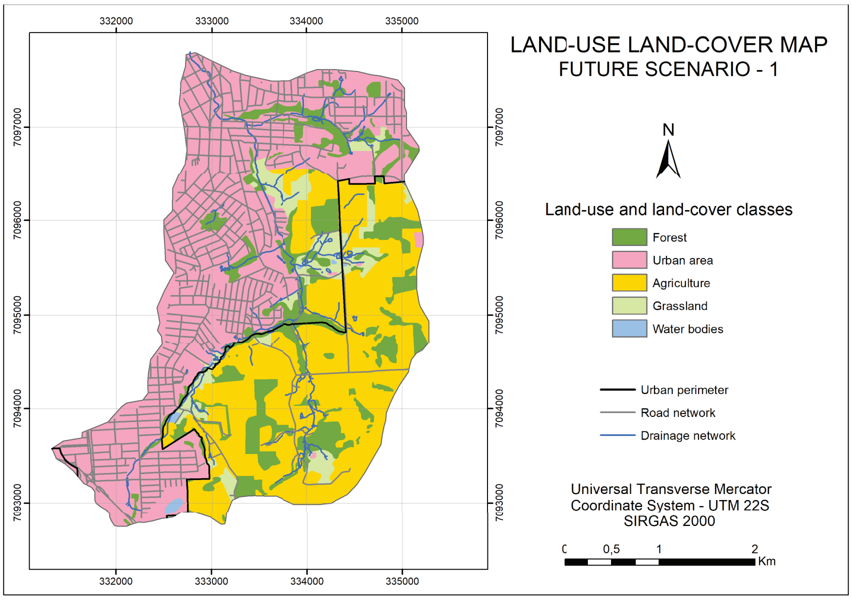

Figure 5: Land-use and land-cover map for the first future scenario.

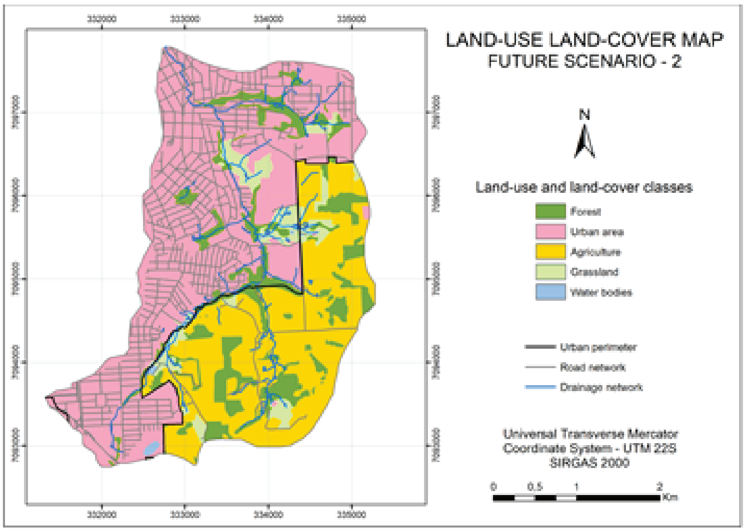

Figure 6: Land-use and land-cover map for the second future scenario.

Table 1 presents the areas of each LULC class for each scenario considered.

In future LULC scenarios, urban area corresponds to 46.87% of the entire study area in scenario 1 and 53.93% in scenario 2. This means that municipal legislation allows more than half of the study area to be waterproofed by the urban area. Note that only the upper third of the Ligeiro River Basin was considered to define the study area, as other parts of the basin have already been studied with different methodologies. Thus, land-use and land-cover is an important factor for flood research. Vegetation-covered

Table 1: Comparison of LULC areas between current scenario, future scenario 1 and future scenario 2.

CLASSES OF LULC	CURRENT SCENARIO	FUTURE SCENARIO 1	FUTURE SCENARIO 2
	Km^2		
Agriculture	4.25	4.25	3.65
Forest	1.87	1.82	1.56
Grassland	1.29	0.51	0.49
Urban area	5.01	5.84	6.72
Water bodies	0.04	0.04	0.04

regions allow water to infiltrate the soil and are less prone to flooding. On the other hand, the soil impermeabilization in urban areas makes these spaces more exposed to this kind of events [9]. As already presented in this paper, Pato Branco already has a history of urban flooding for the current scenario of LULC. If urbanization extends into the study area as shown in Figure 5 and, in the worst-case scenario, as in Figure 6, already recurring urban flooding may be intensified.

In highly urbanized areas it is difficult to use engineering or structural measures to mitigate floods as the surface and underground are already occupied by buildings and pipelines. Thus, the best way to mitigate flooding is to consider non-structural measures such as urban flood risk warning methods [19] and spatial planning policies [6]. Space planning in urban areas is a sustainable way to manage flood risk [6]. Therefore, investigation of future LULC scenarios may contribute to urban planning and mitigation of flood events.

4. Conclusions

Flooding is the most recurring type of disaster around the world. The intensity of these events has worsened over the years with population growth and unplanned urbanization. Soil impermeabilization in urban centers increases runoff and the possibility of flooding.

Therefore, land-use and land-cover may impact local hydrological processes, which makes LULC an important criterion in the analysis of flood-prone areas.

Thus, identifying flood-prone areas can contribute to the correct adoption of mitigation measures. Also, recognizing regions that may suffer from flooding through urban sprawl can help in urban planning and prevent the intensification of these events. This can be done using GIS, which enables rapid simulation of different land-use and land-cover scenarios.

This study produced two future scenario maps of LULC in a GIS environment. GIS has proven to be an easy and efficient tool for future LULC mapping. The maps produced can be used in future researches, both with the proposed methodology (GIS-AHP integration) and with other methodologies, to verify the influence of urban sprawl on floods. Besides, the maps can assist in urban planning as a non-structural mitigation measure for floods and other types of disasters.

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