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Evaluation of land use and occupation considering the spatialization of precipitation in the northeastern Mato Grosso sub-basins

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Abstract

This study aimed to analyze the use and land occupation considering the spatialization of precipitation in the hydrographic sub-basins (HS) in the northeast of the state of Mato Grosso. The data used to spatialize the mean accumulated rainfall in northeastern Mato Grosso considered the rainy season between October 1st and April 30th from 2016 to 2020. The isohyet map was obtained and stratified into three classes for discussion and data comparison. The delimitation of the HSs was carried out from a mosaic of images, generating a digital elevation model. To discuss the results, the mean accumulated rainfall isohyet map was superimposed on the HS map. Higher values of accumulated rainfall in the rainy season in northeastern Mato Grosso occur in its eastern portion in relatively lower altitudes, possibly related to the preference of the meteorological systems, which produces maximum (minimum) rainfall on the windward (leeward) of the mountains. In areas with a mean accumulated rainfall above 1,200, the occupations with forestry and grassland vegetation and managed pastures and agriculture add up to 49% and 23% of the total area, respectively. The study revealed that, in the northeast region of the state of Mato Grosso, the area occupied by the delimitation of the mean accumulated precipitation above 1,200 mm has 49% of its extension occupied with natural vegetation areas and 23% of its extension occupied with agricultural or livestock activities.

Keywords: Watersheds; Meteorological systems; Mean accumulated rainfall.

Introduction

Rainfall is the primary mechanism of water entry into the aquifer system, and the amount of recharge water depends mainly on land use and occupation, evapotranspiration, and surface runoff (JYRKAMA; SYKES, 2007). The term "recharge" is the amount of water per unit of area that infiltrates the subsoil until it reaches the water table, thus contributing to the permanent or temporary groundwater reserve of the aquifer (VASCONCELOS, 2005; CHAVES *et al*., 2009). Therefore, preserving recharge areas and adapting them to the type of occupation with resource exploration activities guarantees the continuity of water sources.

However, the changes resulting from human activities on natural areas have impacts, such as reduction in water availability, floods, and destruction, and the production and transport of sediments, harming agricultural activities and the supply of nutrients to springs, with a direct influence on water quality (ANDRADE *et al*., 2013; OLIVEIRA *et al.*, 2020). In this sense, Rodrigues *et al*. (2019) report the need to systematically consider aspects other than the environment, such as social and economic ones, since it is intended to identify, monitor, and eliminate or minimize the phenomena associated with such changes.

The variation of climatic factors, specifically the precipitation in the hydrographic sub-basins, directly interferes with the different activities developed in a given region, exposing them to risks and failures. Thus, the spatial survey of such climatic features is fundamental to environmental (soil management and conservation), agricultural (need for crop irrigation) and hydraulic work (domestic and industrial water supply) planning (ARAI *et al.*, 2010; ALVARENGA *et al.*, 2012).

The intense use of the soil due to agricultural practices and the suppression of natural vegetation intensifies soil degradation (NASCIMENTO *et al*., 2020). Thus, in regions where land use and occupation concentrate areas of natural vegetation and agricultural or livestock activities, attention should be paid to compliance with environmental policies for preservation and the use of sustainable production techniques.

The set represented by the assessment of land use and occupation, morphometric characteristics, and rainfall supports the survey on the environmental diagnosis of the watershed, since measures to protect vegetation and proper management of land use and occupation favor quantitatively or qualitatively the conservation of the water resources of a basin (SILVA *et al*., 2017).

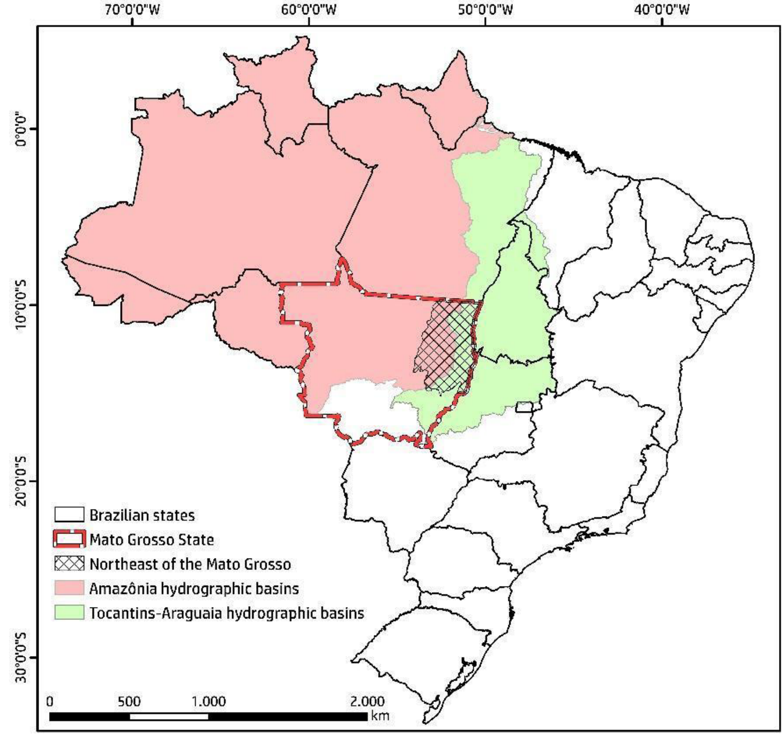
This work aimed to analyze the use and land occupation considering the spatialization of rainfall in the hydrographic sub-basins (HS) in the northeast of the state of Mato Grosso.

Material and methods

The work was carried out in the northeast region of the state of Mato Grosso, Brazil (FIGURE 1; FIGURE 2), consisting of the municipalities mentioned in Figure 2, located between coordinates 13°45'52.48"S, 54°06'9.49"W and 09°50'53.67"S, 50°14'52.8"W. This region has an area of 169,963.59 km^2 and is located in the Amazon and Tocantins-Araguaia watersheds.

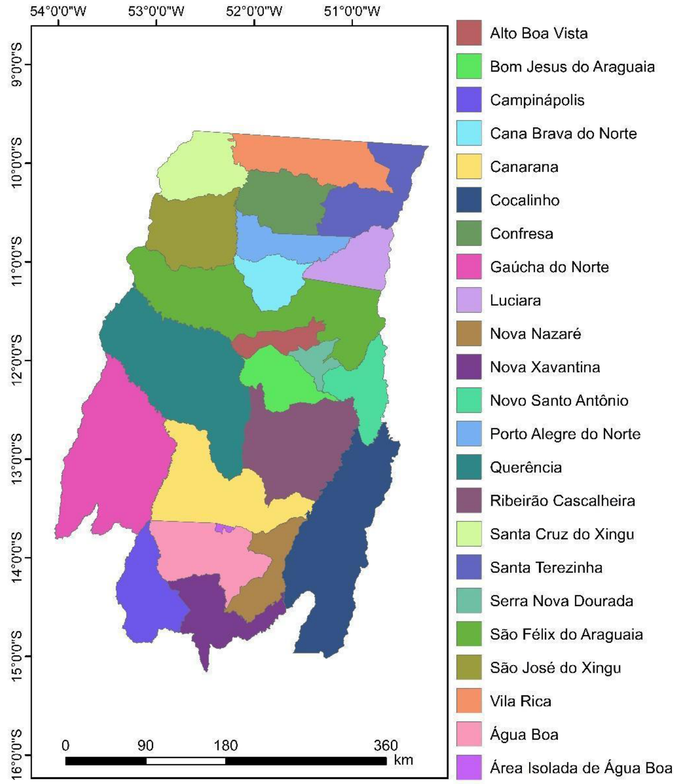
The data used for spatialization of the mean accumulated rainfall in northeastern Mato Grosso were extracted from the historical series

Figure 1. Location of the area of study



Source: Prepared by the authors (2022)

Figure 2. Municipalities of the northeastern region of the state of Mato Grosso, Brazil.



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of the National Institute of Meteorology, from the meteorological stations located in the Brazilian municipalities described in Table 1, considering the rainy season from October 1st to April 30th, from 2016 to 2020. The data gaps in some years in Table 1 are due to failures in registers at the meteorological stations; however, they did not jeopardize the results.

With the mean accumulated rainfall obtained between the years with data available in each meteorological station, the spatialization of the accumulated precipitation was carried out by map algebra operations by vector data. Hence, the Spatial Analyst Tools>Interpolation>Kriging tool was used through the computer app ArcMap 10.5. The final product was a rasterized map of

Table 1. Mean accumulated rainfall values between October 1st and April 30th, from 2016 to 2020

Longitude	Latitude	Pre. accum. (mm)	Municipality	Years considered *
-53.26	-13.18	1041.65	Gaúcha do Norte	2016/2017/2018/2019/2020
-52.21	-14.02	1132.08	Água Boa	2016/2017/2018/2020
-50.73	-11.62	1520.85	São Félix do Araguaia	2016/2017/2018/2019/2020
-50.14	-15.94	1284.69	Goiás	2016/2017/2018/2019/2020
-49.85	-10.83	1245.65	Lagoa da Confusão	2017/2018/2019/2020
-49.72	-9.58	1153.84	Marianópolis	2016/2017/2018/2019/2020
-49.53	-12.59	1328.48	Araguaçu	2017/2018/2019/2020
-52.22	-12.63	1431.65	Querência	2016/2017/2018/2019

Source: Prepared by the authors (2022)

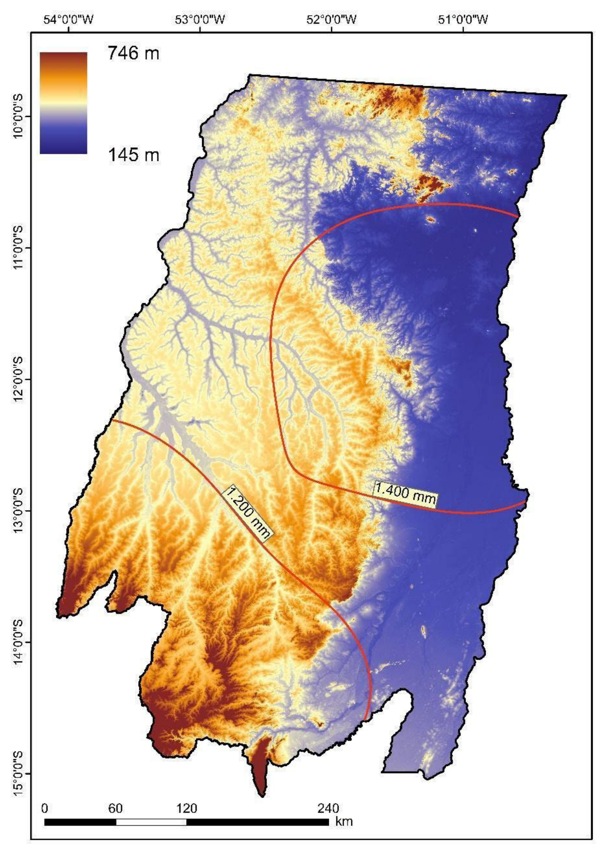
the mean accumulated precipitation, which was used to create the isohyets map through the Spatial Analyst Tools>Surface>Contour function. The accumulated rainfall was stratified into three classes for discussion and data relative comparison, namely: 1,000mm to 1,200mm, >1,200mm to 1,400mm and >1,400mm to 1,600mm.

The delimitation of hydrographic sub-basins in northeastern Mato Grosso was carried out by taking as a basis a mosaic (FIGURE 3) of images of digital models of elevations with spatial resolutions of 90.0 m from the Shuttle Radar Topography Mission project and made available by the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA). For discussion of the results referring to the distribution of precipitation over sub-basins, sub-basins with an area greater than 68,000 ha were considered.

Using the computer app ArcMap 10.5 and its functions from the Spatial Analyst > Hydrology module, the possible depressions (Fill Sinks) were removed from the MDE by “filling”, considering the altitudes of neighboring pixels and producing an image with the correction of spurious depressions (*fill*). Later, through the *fill* file, the vector file *flow direction* was created, and, from this, the hydrographic sub-basins were automatically delimited by the Basin function of the application. The rasterized map of sub-basins was finally vectorized.

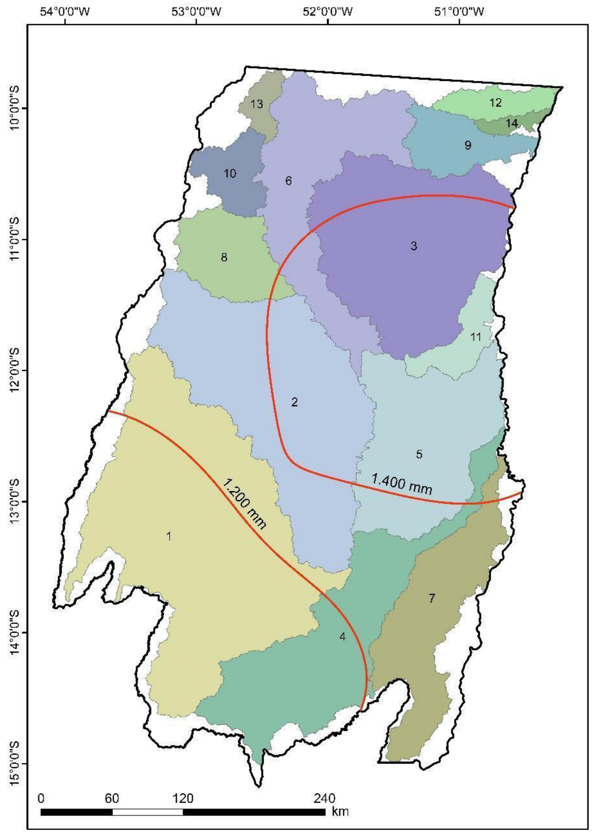
Therefore, to discuss the results, the isohyet map of the mean accumulated rainfall was superimposed in three points with the vectorized map of sub-basins for the northeastern region of Mato Grosso (FIGURE 4).

Figure 3. Digital elevation model (altitudes) created from the Shuttle Radar Topography Mission image mosaic and mean accumulated precipitation isohyets for the period in the northeast region of Mato Grosso.



Source: Prepared by the authors (2022)

Figure 4. Sub-basins identified by numbers from 1 to 14 and isohyets of mean accumulated rainfall for the period in the northeastern region of Mato Grosso.



Source: Prepared by the authors (2022)

Figure 5 shows the procedural flow for obtaining the maps of the mean accumulated rainfall and the sub-basins in the northeastern region of Mato Grosso, Brazil.

The land use and occupation map for the northeastern region of Mato Grosso was adapted from IBGE (2018) and superimposed on the isohyetal map of the average accumulated rainfall in the three mentioned classes (FIGURE 6). To discuss the results related to the distribution of the precipitation on soil use and occupation, the total area of the northeastern region of Mato Grosso was considered.

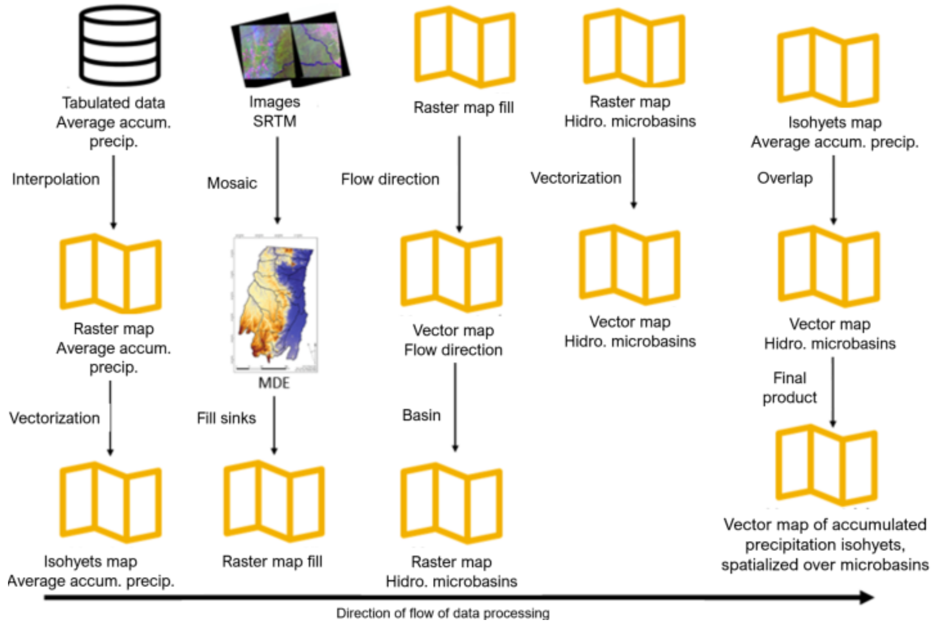
Results and discussion

Figures 3 and 4 show variability in the spatialization of the mean accumulated rainfall in the studied area. Carmo *et al*. (2015) observed a wide variation in precipitation when analyzing the spatio-temporal distribution of rainfall in the Abiaí-PB watershed. In the southern Agreste of the state of Pernambuco, a high significance of rainfall variability was observed (*ANDRADE et al*., 2018)

The highest values of accumulated precipitation in the rainy season (October 1st to April 30th) occur in the eastern portion of the area of interest, in places with a predominance of lower altitudes (FIGURE 3). On the other hand, in the places where the highest altitudes were observed (southwest portion) in the northeast of Mato Grosso, the lowest values of accumulated precipitation were identified in the rainy season.

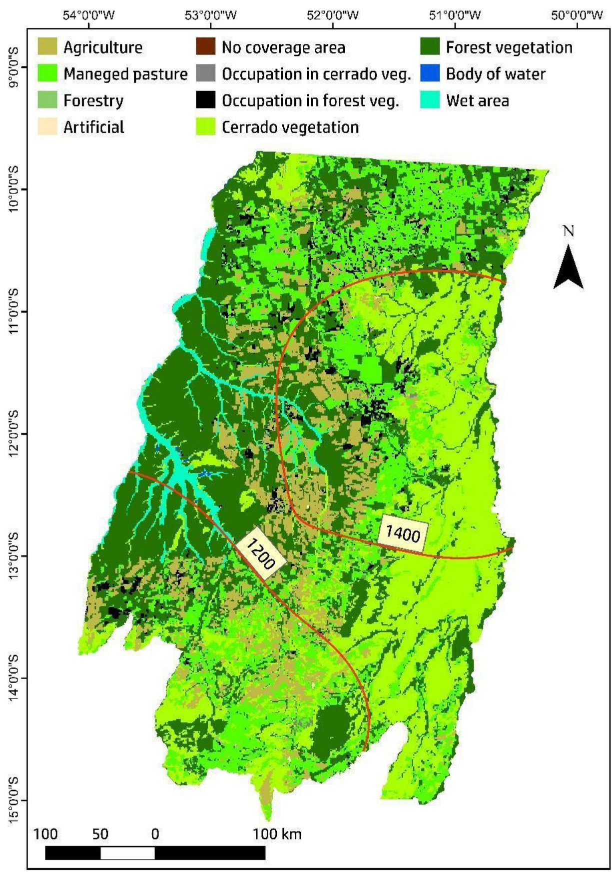
Santos *et al*. (2007) emphasize the differences in altitude within the basin as an influential factor in the spatialization of precipitation, although referring to a region of

Figure 5. Flowchart of computational processes performed to obtain the mean accumulated rainfall and sub-basin maps in the northeastern region of Mato Grosso, Brazil.



Source: Prepared by the authors (2022)

Figure 6. Land use and cover and average accumulated rainfall (mm) isohyets for the rainy season in the northeastern region of Mato Grosso.



Source: Adapted from IBGE (2018).

different topographic amplitude than the one studied here and considering that the circulation mechanism atmosphere behaves similarly. The precipitation distribution can be explained by the preferential displacement of the meteorological systems producing maximum (minimum) rainfall on the mountainous windward (leeward) (DERECZNSKI *et al*. 2009). In the present study, possibly, the moisture-laden air mass coming from the Araguaia River to the east is “blocked” by a high-altitude mountain range (*serras*). This air-mass upward movement is saturated with moisture just before reaching the top of the mountain range, culminating in precipitation on the windward side. At higher altitudes, the air mass that arrives is “dry”, as it has lost moisture on the windward; therefore, on the leeward, it can cause an environment with less precipitation or incur more extended drought periods.

Using the map in Figure 4, estimates were made of the areas of the hydrographic sub-basins (HS) present in the three stratification classes of the mean accumulated rainfall for the rainy season in the northeastern region of Mato Grosso (TABLE 2).

Table 2 shows that only HS n.11 does not have an area in the mean accumulated rainfall class >1,200 mm to 1,400 mm, and, in this study, 48% of the total HS areas were identified in this range. However, 29% of the total HS areas identified are in the >1,400 mm to 1,600 mm class. Only two HSs (N.1 and N.4) have areas in the mean accumulated rainfall class from 1,000 mm to 1,200 mm, which corresponds to 23% of the areas of the MHs identified in this study; however, such areas of HSs N.1 and N.4 constituted in this later class of precipitation correspond to 73% and 62% of their total areas, respectively.

Considering what was described in the previous paragraphs, it is necessary to highlight the relevance of rainfall in the hydrographic sub-basins in relation to the impact on the flow of the important rivers that form them. Gomes *et al*. (2019) considered monitoring rainfall variability

Table 2. Estimation of the areas (hectare) of the hydrographic sub-basins defined in the northeastern region of Mato Grosso in the classes of mean accumulated rainfall in the rainy season.

Sub-basin	1,000 mm to 1,200 mm	>1,200 mm to 1,400 mm	>1,400 mm to 1,600 mm	TOTAL
1	2,430,564.47	911,576.43	-	3,342,140.90
2	-	1,431,080.30	945,356.80	2,376,437.10
3	-	481,836.68	1,523,095.86	2,004,932.54
4	964,130.84	514,630.17	85,259.90	1,564,020.91
5	-	257,785.10	1,159,444.01	1,417,229.11
6	-	1,023,180.19	330,105.53	1,353,285.72
7	-	999,925.55	38,995.49	1,038,921.04
8	-	518,759.75	25,640.69	544,400.44
9	-	389,006.84	-	389,006.84
10	-	296,514.96	-	296,514.96
11	-	-	263,893.76	263,893.76
12	-	207,741.90	-	207,741.90
13	-	125,772.35	-	125,772.35
14	-	68,655.03	-	68,655.03
TOTAL	**3,394,695.31**	**7,226,465.25**	**4,371,792.04**	**14,992,952.60**

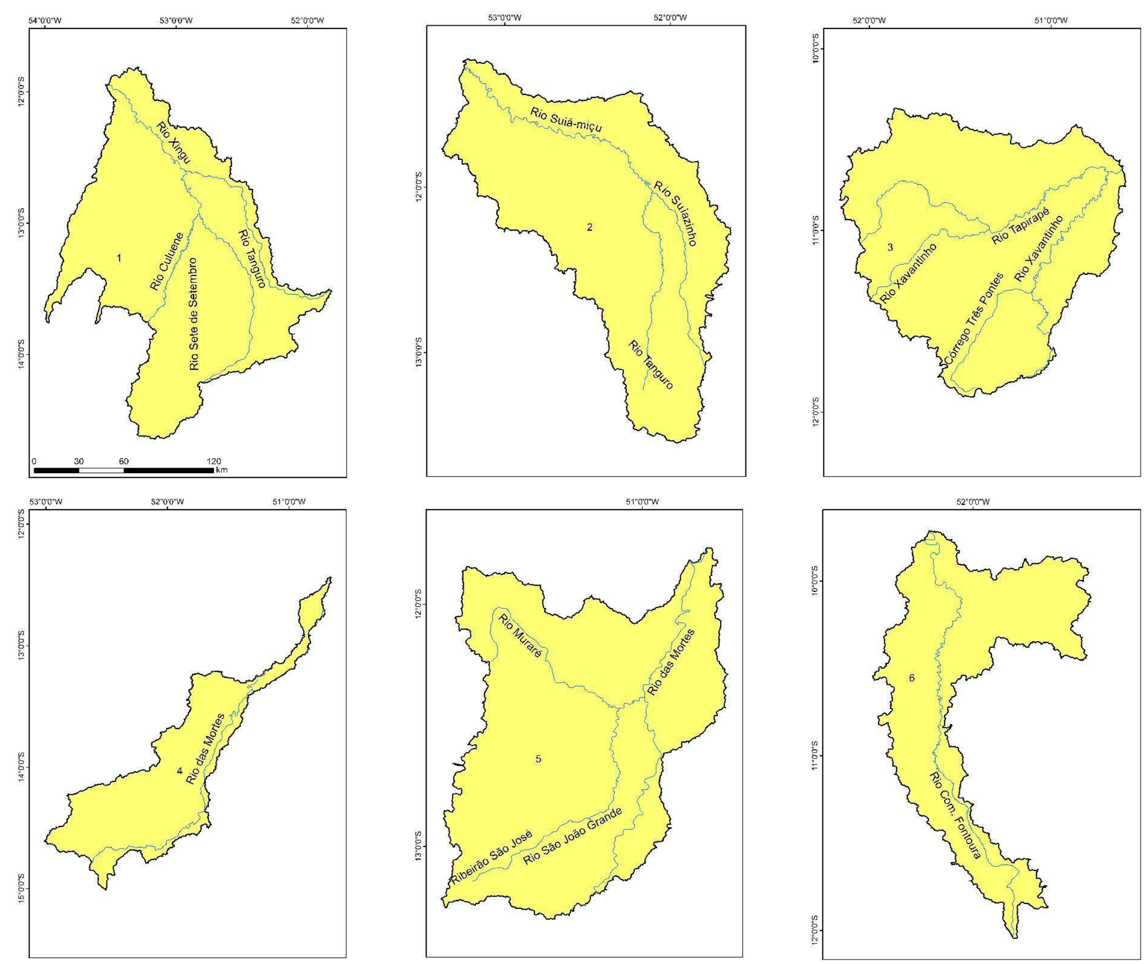
Source: Prepared by the authors (2022)

in the Araguaia River watershed to be paramount, mainly for discussing social and agricultural impacts. These authors observed that the monthly distribution of the rainfall regime affects the flows of that river at the different verification points, indicating that morphometric variables of the watershed and the soil cover correlate with the maximum rainfall and the river flow.

In this study, it is noteworthy that in the area covered by the highest mean accumulated precipitation class (>1,400 mm), in the northeastern region of Mato Grosso (FIGURE 4), which includes 48% of the total area of defined HS, there are important surface water bodies such as Suiá-Miçu, Tapirapé, das Mortes (part) and Comandante Fontoura Rivers contained in the HSs n.2, n.3, n.5 and n.6, respectively (FIGURE 7). In the lowest mean accumulated rainfall class, the Xingu River (HS n.1) and another part of the das Mortes River (HS n.4) are the main surface water bodies.

Table 3 shows that the land use classes “Forest vegetation”, “Grassland vegetation”, “Managed pastures”, and “Agricultural” together add up to 94% of the area in the northeastern Mato Grosso, with natural areas (forest and grassland vegetation) and areas for agricultural or livestock use together account for 62% and 32% respectively. In areas with a mean accumulated rainfall above 1,200, the occupations that use forest and grassland vegetation and managed

Figure 7. Main bodies of surface water in the six major hydrographic sub-basins defined in the northeastern region of Mato Grosso. The numbering of each sub-basin is associated with its area, as described in Table 2.



Source: Prepared by the authors (2022)

Table 3. Estimation of areas (*hectare) with land use and occupation in the northeastern region of Mato Grosso in the classes of mean accumulated rainfall in the rainy season.

Use/occup.	1,000 mm to 1,200 mm	>1,200 mm to 1,400 mm	>1,400 mm to 1,600 mm	TOTAL
Forest vegetation	1,429,100.72	3,397,236.06	1,095,148.54	5,921,485.32
Grassland vegetation	873,396.13	1,916,007.41	1,840,034.93	4,629,438.47
Managed pasture	990,022.03	1,773,358.97	751,690.27	3,515,071.27
Agricultural	623,735.75	776,382.32	575,611.22	1,975,729.29
Forest areas occup.	62,301.22	249,521.65	133,419.83	445,242.70
Wet area	83,859.53	291,788.36	43,753.78	419,401.67
Occup. Grassland vegetation	13,897.40	15,217.02	17,464.27	46,578.69
Body of water	703.93	17,909.00	5,079.09	23,692.02
Artificial	3,899.48	4,633.19	2,598.37	11,131.04
Forestry	4,200.47	4,297.28	-	8,497.75
Bare area	-	91.01	-	91.01
TOTAL	**4,085,116.66**	**8,446,442.27**	**4,464,800.30**	**16,996,359.20**

Source: Prepared by the authors (2022)

pastures and agriculture add up to 49% and 23% of the total area, respectively.

Different land uses promote other changes in aquifer recharge regarding quantity, notably by changing the rates of basic water infiltration into the soil (CODEPLAN, 2018). Thus, the importance of the relationship of land use and occupation with the spatialization of precipitation in a given region is limited to aspects of soil conservation.

This study provides elements that report the need to preserve or provide "maintenance" to natural plant areas through the adoption and implementation of environmental policies and sustainable production practices in livestock or agricultural use and occupation areas. Therefore, it is necessary to discuss the possibilities in managing water resources through geoprocessing tools based on historical series. Studies such as these contribute to the extraction of this environmental information, favoring the interpretation of geographic space and obtaining spatial information important for conserving and managing natural resources as a whole (ALVES *et al.*, 2016).

Conclusions

In this study, it was possible to identify, in the northeast region of the state of Mato Grosso, that the area occupied by the delimitation of the mean accumulated rainfall above 1,200 mm has 49% of its extension occupied with natural vegetation areas and 23% of its extension occupied with agricultural or livestock activities. Such a fact highlights the need to preserve or provide "maintenance" to natural plant areas through adopting and implementing environmental policies and sustainable production practices in livestock or agricultural use and occupation areas.

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