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ASSESSMENT OF THE IMPACT OF CHANGES IN LAND USE AND LAND COVER ON SURFACE RUNOFF

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ARTICLE

Abstract

The aim of this study was to analyze the behavior of surface runoff as a result of changes in land use and land cover (LULC), using the Rio Novo basin (Brazil) as the analysis site. To estimate surface runoff, the curve number (NRCS-CN) method was used; as input data, the LULC classifications provided by the MapBiomas project and the pedological map of the state of São Paulo (1:250,000) were used. The Rio Novo basin was discretized into ten sub-basins. The results showed major changes in LULC between 1992 and 2022, with a reduction in pasture areas and an increase in annual crops and sugarcane fields, as well as in urban areas. Such alterations are conditioning factors of changes in Curve Number (CN) values, which imply changes in surface runoff values. For a rainfall of 130 mm (roughly 10-year return period), the surface runoff depth values ranged from 3.21 mm (areas with forest cover on soils in hydrological group A) to 101.35 mm (for urban areas on soils in hydrological group C). The urbanization process that occurred in sub-basins 1, 6, and 9 led to an increase in areas with the highest CN values (CN equal to 85 and 90). Locations with increased surface runoff values should be considered as critical areas, where soil and water losses may occur, thereby compromising water security in the basin.

Keywords: NRSC-CN method, Geographic Information System, Water Resources Management, MapBiomas.

Resumo / Resumen

AVALIAÇÃO DO IMPACTO DAS MUDANÇAS DE USO E COBERTURA DAS TERRAS NO ESCOAMENTO SUPERFICIAL

O objetivo deste estudo foi analisar o comportamento do escoamento superficial em consequência das mudanças de uso e cobertura das terras (LULC), tendo como local de análise a bacia do Rio Novo (Brasil). Para a estimativa do escoamento superficial, foi utilizado o método da curva número (NRCS-CN) e como dados de entrada, as classificações de LULC fornecidas pelo projeto MapBiomas e o mapa pedológico do estado de São Paulo (1:250.000). A bacia do Rio Novo foi discretizada em dez sub-bacias. Os resultados mostraram mudanças importantes de LULC, entre os anos de 1992 e 2022, com redução das áreas de pastagem e aumento dos cultivos anuais e da cana-de-açúcar, bem como das áreas urbanas. Estas mudanças condicionam alterações nos valores de CN, o que implica em alterações nos valores de escoamento superficial. Para uma chuva de 130mm (~período de retorno de 10 anos), os valores de lâmina de escoamento superficial variaram de 3.21 mm (áreas com cobertura florestal sobre os solos do grupo hidrológico A) até 101.35 mm (para áreas urbanas sobre solos do grupo hidrológico C). O processo de urbanização ocorrido nas sub-bacias 1, 6 e 9, levou a um aumento nas áreas com ocorrência dos maiores valores de CN (CN iguais a 85 e 90). Locais com aumento nos valores de escoamento superficial devem ser considerados como áreas críticas, onde podem ocorrer perdas de solo e água, comprometendo a segurança hídrica na bacia.

Palavras-chave: Método NRSC-CN , Sistema de Informação Geográfica, Manejo de Recursos Hídricos, Mapbiomas

EVALUACIÓN DEL IMPACTO DE LOS CAMBIOS EN EL USO Y COBERTURA DE LA TIERRA EN EL ESCURRIMIENTO SUPERFICIAL

El objetivo de este estudio fue analizar el comportamiento del escurrimiento superficial como resultado de los cambios en el uso y cobertura del suelo (LULC), utilizando la cuenca del Río Novo (Brasil) como sitio de análisis. Para estimar el escurrimiento superficial, se utilizó el método del número de curva (NRCS-CN); como datos de entrada, se utilizaron las clasificaciones de LULC proporcionadas por el proyecto MapBiomas y el mapa pedológico del estado de São Paulo (1:250.000). La cuenca del Río Novo fue dividida en diez subcuencas. Los resultados mostraron cambios importantes en LULC entre 1992 y 2022, con una reducción en las áreas de pastizales y un aumento en los cultivos anuales y los campos de caña de azúcar, así como en las áreas urbanas. Tales alteraciones son factores condicionantes de cambios en los valores del Número de Curva (CN), lo que implica cambios en los valores de escurrimiento superficial. Para una precipitación de 130 mm (aproximadamente un período de retorno de 10 años), los valores de la profundidad de escurrimiento superficial variaron desde 3.21 mm (áreas con cobertura forestal en suelos del grupo hidrológico A) hasta 101.35 mm (para áreas urbanas en suelos del grupo hidrológico C). El proceso de urbanización que ocurrió en las subcuencas 1, 6 y 9 llevó a un aumento en las áreas con los valores más altos de CN (CN igual a 85 y 90). Los lugares con valores de escurrimiento superficial aumentados deben considerarse como áreas críticas, donde pueden ocurrir pérdidas de suelo y agua, comprometiendo así la seguridad hídrica en la cuenca.

Palabras-clave: Método NRCS-CN, Sistema de Información Geográfica, Gestión de Recursos Hídricos, MapBiomas

INTRODUTION

Surface runoff is one of the main components of the hydrological cycle and influences several environmental processes, such as soil erosion, sediment transport, flooding, as well as transport of nutrients and contaminants (PRUSKI et al., 2010). Agricultural areas tend to present higher volumes of surface runoff than those observed in areas with forest cover, resulting in losses of important soil nutrients such as calcium, potassium, sulfur, nitrogen, magnesium, and phosphorus (WANG et al., 2018). The entry of solid particles from the sediments carried, as well as nutrients (mainly nitrates and phosphates) into bodies of water (rivers, lakes, and reservoirs) can cause their eutrophication (AKINNAWO, 2023), resulting in losses, both in water quantity and quality. The advance of urbanization — and the consequent sealing of the soil —causes changes in the hydrological cycle, increasing the volume of water runoff from the land surface, which implies siltation and the entry of contaminants into urban rivers, as well as increases in the frequency of flooding (SARASWAT, et al. 2016). Changes in water availability (quantity and quality), which compromise social and economic activities and the maintenance of ecosystems, are challenges to be faced to ensure water security for rural and urban populations (MISHRA et al., 2021).

Changes in LULC have consequences for the hydrological processes of river basins, altering patterns of rainfall interception, evapotranspiration, infiltration, and surface runoff (FOHRER et al., 2001; NOSETTO et al., 2012). The increase in population — as well as changes in economic patterns, technologies, and biophysical environmental factors in different parts of the world — have caused changes in land occupancy, inducing the transition from natural areas to agricultural areas, natural areas to urbanized areas, agricultural areas to urbanized areas, or even changes from one agricultural use to another (SOUZA Jr. et al., 2020; HAILU et al., 2020; CUI et al., 2022; DUAN et al., 2023; TECK et al., 2023). Hence, there is a need to estimate the hydrological behavior of the basins vis-à-vis such changes, aimed at establishing strategies for the sustainable management of these areas, considering the current, past, and future LULC scenarios (DELGADO et al., 2020).

Surface runoff is a complex variable, the direct quantification of which is not always possible; however, even for ungauged catchments, it is necessary to understand the impacts of possible changes to assist in decision making. As a result, several models have been developed with the aim of estimating surface runoff using precipitation data and physical characteristics of river basins (BEVEN, 2012). Among them, the Curve Number (CN) model developed by the United States' Natural Resources Conservation Service (NRCS) — NRCS-CN model (USDA 2004) — is widely used in ungauged catchments around the world to estimate the quantity of rain that is converted into surface runoff (SHIRASI et al., 2016; SATHEESHKUMAR et al., 2017; AHMADI-SANI et al., 2022; PROKEŠOVÁ et al., 2022).

In many studies, the NRCS-CN method is used along with a geographic information system (GIS) and through the manipulation of model input variables (LULC, soil classes, spatial distribution of precipitation) in the form of maps, it is possible to spatialize surface runoff values (MELESSE and SHIH, 2002; DELGADO et al., 2020; PROKEŠOVÁ et al., 2022; HAGRAS, 2023). Remote sensing techniques make it possible to assess spatiotemporal changes in the LULC and — integrated with the characterization of the hydrological behavior of soils in a GIS environment — allow for the modeling of surface runoff behavior in space and over time (DELGADO et al., 2020; PROKEŠOVÁ et al., 2022).

In this context, this study used GIS techniques together with the NRCS-CN model to evaluate the spatiotemporal changes in surface runoff as a function of changes in the LULC, considering the years 1992 and 2022 (30 years), having as the investigation location the Rio Novo basin, located in the inland region of the state of São Paulo, in Southeastern Brazil.

MATERIAL AND METHODS

STUDY AREA

The Rio Novo basin is located in the inland region of the state of São Paulo, in southeastern Brazil, between 22° 52' 13.9" and 23° 10' 10.1" south latitude, and 49° 13' 55.8" and 48° 33' 26.6" west longitude, covering a territorial extension of 937.15 km² (FIGURE 1). The Rio Novo begins in the municipality of Itatinga at an altitude of 890 meters and flows into the Rio Pardo at an altitude of 540 meters, with its main riverbed traversing a length of more than 100 km. Its drainage basin encompasses five municipalities in the state of São Paulo (Itatinga, Avaré, Cerqueira César, Iaras, and Águas de Santa Bárbara), and has 569 springs that form first, second, and third order tributaries, which flow into its left and right banks (PIROLI, 2013). Considerable portions of the urban areas of Itatinga, Avaré, and Cerqueira César are located within the Rio Novo drainage basin.

According to the Köppen climate classification, most of the basin is located in a Subtropical (C) climate zone, in the Humid subtropical climate (Cfa) (ALVAREZ et al., 2013). The average annual precipitation is greater than 1300 mm and less than 1500 mm, with the highest values observed in the spring and summer months (southern hemisphere), with the month of January presenting values greater than 220 mm. The lowest amounts of rainfall are recorded in autumn and winter, with the month of August having average precipitation of less than 45 mm (DAEE, 2023). With regard to geology, colluvial deposits in spikes, sands with a clayey matrix, limonite, and quartz gravels at the base occur within the basin, from the Neogene and Quaternary Periods and Pliocene-Pleistocene Eras, in addition to basalts from the Serra Geral Formation, from the Triassic-Cretaceous Periods (LANDIM et al., 1984). The area is dominated by porous aquifer systems formed by sedimentary rocks of the Bauru formation and, to a lesser extent, fractured aquifers in basaltic rocks of the Serra Geral Formation (ANA/GESUB, 2013).

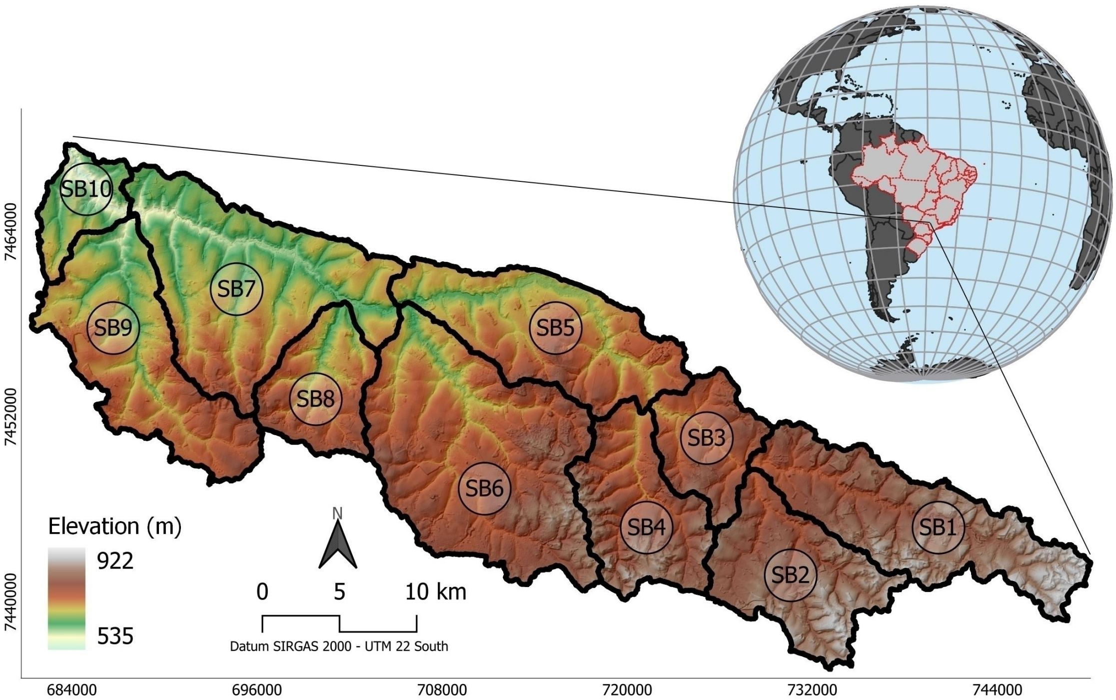

Figure 1 - Location of the study area, with indication of the sub-basins.

METHODOLOGY AND DATABASE

In this study, the NRCS-CN method was applied to spatialize variations in runoff as a function of changes in LULC over time. Were used geoinformation (layers) referring to the area analyzed, such as: Digital Elevation Model (DEM), products derived from images from the Landsat satellite series, containing maps relating to LULC, pedological maps, and meteorological data relating to precipitation. This dataset was processed in a GIS environment, using the Universal Transverse Mercartor (UTM) projection system, Zone 22 South, with SIRGAS 2000 datum. Figure (2) shows the sequence of steps of the methodology.

BASIN DELIMITATION

The delimitation of the Rio Novo drainage basin was carried out automatically, using the CopernicusDEM (EUROPEAN SPACE AGENCY, 2021) with a spatial resolution of 1 arc-second (~30 meters), available on the OpenTopography portal. When defining the limits of the basin, the DEM underwent pre-processing to remove depressions on the surface, which could interrupt the water flow. The next step was to obtain the flow directions, using the Deterministic 8 (D8) method (JENSON and DOMINGUE, 1988). Next, the flow accumulation on the surface was prepared in order to define the drainage networks. The Rio Novo basin was discretized into ten sub-basins, called SB1 (~112.07 km²), SB2 (~82.62 km²), SB3 (~47.35 km²), SB4 (~73.93 km²), SB5 (~ 104.91 km²), SB6 (~179.02 km²), SB7 (~145.60 km²), SB8 (~52.31 km²), SB9 (~109.26 km²), and SB10 (~30.08 km²) (FIGURE 1).

LAND USE AND LAND COVER

To characterize the LULC in the Rio Novo basin in the years 1992 and 2022, products from the MapBiomas project (in its Collection 8) were used. MapBiomas consists of a collaborative network of several institutions (universities, non-governmental organizations, and technology companies) for the annual and continuous mapping of LULC for the entire Brazilian territory, with mappings available from 1985 to 2022 (with updates scheduled for the coming years) (MapBiomas 2023).

MapBiomas is based on the images from the Thematic Mapper (TM) sensors, on board the Landsat 5 satellite, Enhanced Thematic Mapper Plus (ETM+) on Landsat 7, and the Operational Land Imager (OLI) on Landsat 8, with a spatial resolution of 30x30m. The image mosaic is processed with surface reflectance data – USGS Landsat Collection 2 (Tier 1); the Random Forest algorithm is used in order to classify the images on the Google Earth Engine platform (Souza Jr et al., 2020; MapBiomas, 2023). For this study, images from the years 1992 and 2022 were downloaded using the user's toolkit for data access on the Google Earth Engine platform and cropped to the basin area. Subsequently, the original MapBiomas LULC classes were reclassified, resulting in nine final classes, namely: Native forests, Forest plantations (mainly Eucalyptus), Wetlands, Pasture, Sugarcane, Urban areas, Annual crops (e.g. soybeans, maize, and peanuts), Perennial crops (mainly citrus), and Rivers and lakes.

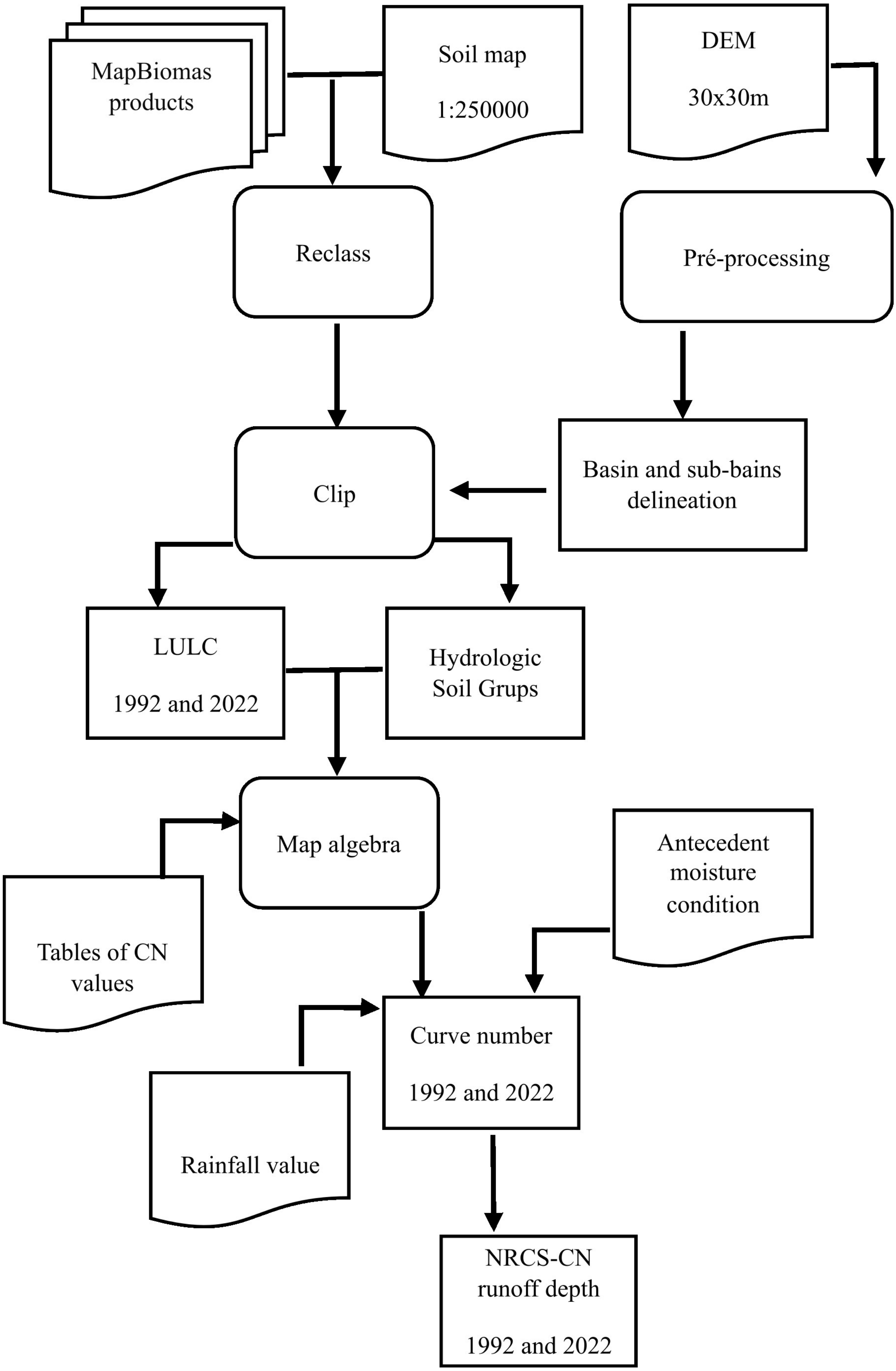

Figure 2 - Flowchart with the methodology for determining surface runoff through the NRCS-CN method in a GIS environment

HYDROLOGICAL SOIL GROUP

The soil classes for the Rio Novo basin were extracted from the Pedological Map of the State of São Paulo, at a scale of 1:250,000 (ROSSI, 2017). In the basin, Latossolos Vermelhos (Ferralsols) are predominant, with Argissolos Vermelho-Amarelos (Acrisols) also occurring. Along the course of the Rio Novo, the presence of Gleissolos (Gleysols) is observed, and to a lesser extent in the basin, Nitossolos (Nitisols).

The runoff depth estimation method developed by the NRCS divides soils into four groups, called “Hydrological Soil Groups” (HSG) (A, B, C, and D) according to their potential for generating surface runoff. Soils with a greater infiltration capacity, and therefore a lower capacity for forming surface runoff, are allocated to group A, while those with a lower infiltration capacity, generating greater runoff depth, are assigned to group D (USDA, 2009).

Originally, soil texture has a major influence on classification into one of the groups, so soils with high clay contents tend to be part of group D. However, for Brazilian conditions, many clayey soils present different behavior from those analyzed in method construction (SARTORI et al., 2005). As a result, the soils within the basin were grouped according to their hydrological behavior, according to the proposal by Sartori et al. (2005), who consider not only texture, but also other characteristics such as soil structure, total porosity, and textural ratio between surface and subsurface horizons, to define their infiltration capacity.

CURVE NUMBER

Cross-referencing between the different HSG and the LULC classes results in the hydrologic soil-cover complex, and each of these complexes is associated with a CN value, which is directly related to the runoff depth. The highest CN value is equal to 100; in this situation, surface runoff will be maximum. In this study, the spatialization of the hydrologic soil-cover complex and its respective CNs were obtained, for the years 1992 and 2022, using map algebra in a raster calculator in the QGIS software. The CN values for each complex were extracted from tables presented in USDA (2004a), Hong and Adler (2008), and Jia et al. (2023).

ESTIMATION OF SURFACE RUNOFF

To estimate surface runoff, the NRCS-CN model (USDA 2004b) was used, in which the amount of surface runoff is related to the value of CN and rainfall over the area. Considering the initial abstraction (rain interception, infiltration in the initial moments of rain, and retention in depressions on the surface) equal to 20% of the maximum water retention capacity (Ia = 0.2S), the runoff depth was obtained by Equation 1.

$$Q = \frac{(P-0.2S)^2}{(130+0.8S)} \qquad (1)$$

Where: Q is the runoff (mm), P is the precipitation (mm), and S is the maximum water retention capacity prior to the onset of the runoff (mm).

The S value was obtained from the ratio between land use and land cover and the hydrological characteristics of the soils, expressed by the CN value (EQUATION 2).

$$S = \frac{25400}{CN} - 254 \qquad (2)$$

To estimate surface runoff, a rainfall equal to 130 mm was used. This value is close to the maximum daily precipitation expected for a 10-year return period, obtained with the parameters of the intense rainfall equation provided by the Plúvio 2.1 software, in the locality of Avaré (SB6). In the rain gauges maintained by the Department of Water and Electricity and located in SB6 (23° 05' 58" south latitude and 48° 54' 44" west longitude) and close to SB10 (22° 52' 34" south latitude and 49° 14' 11" west longitude) on June 27, 2020, precipitation values of 126.2 mm and 130 mm were recorded, respectively. Surface runoff estimates (for 130 mm of rainfall) were obtained for the dates 1992 and 2022, considering standard CN values (also called CNII).

Surface runoff was also obtained for the same periods, considering an antecedent moisture scenario in which the soil is saturated or close to saturation at the onset of rain (antecedent runoff condition III - ARCIII). So, new CN values are considered, called CNIII, and calculated from the CN values (CNII), according to Equation 3 (Hawkins et al., 1985).

$$CN_{III} = \frac{CN_{II}}{0.427+0.00573CN_{II}} \quad (3)$$

RESULTS AND DISCUSSION

CHANGES IN LAND USE AND LAND COVER

The spatial distribution of LULC classes in the Rio Novo sub-basins, for the years 1992 and 2022, are shown in Figure 3 and Figure 4, respectively, and the areas of each class are shown in Table 1 and Table 2. Over the course of 30 years, the area underwent major changes with respect to LULC; in general, there was a reduction in pasture and an increase in annual crops, perennial crops, and forest plantations.

In 1992, pastures represented 64.3, 80.0, 69.4, 67.3, 52.3, 45.6, 57.5, 66.8, 52.3, and 61.3% of the areas of sub-basins SB1 to SB10, respectively, rising to roughly 18% in SB4 and 3.7% in SB5, after 30 years. In the entire Rio Novo basin, an advance in annual crops was observed, with a total increase of approximately 78%. For example, in SB3, land use in this class jumped from 11.5% to over 48% of the sub-basin area. In 2022, SB4 presented around 48.4% of its territory with annual crops, while in 1992 it was 21%.

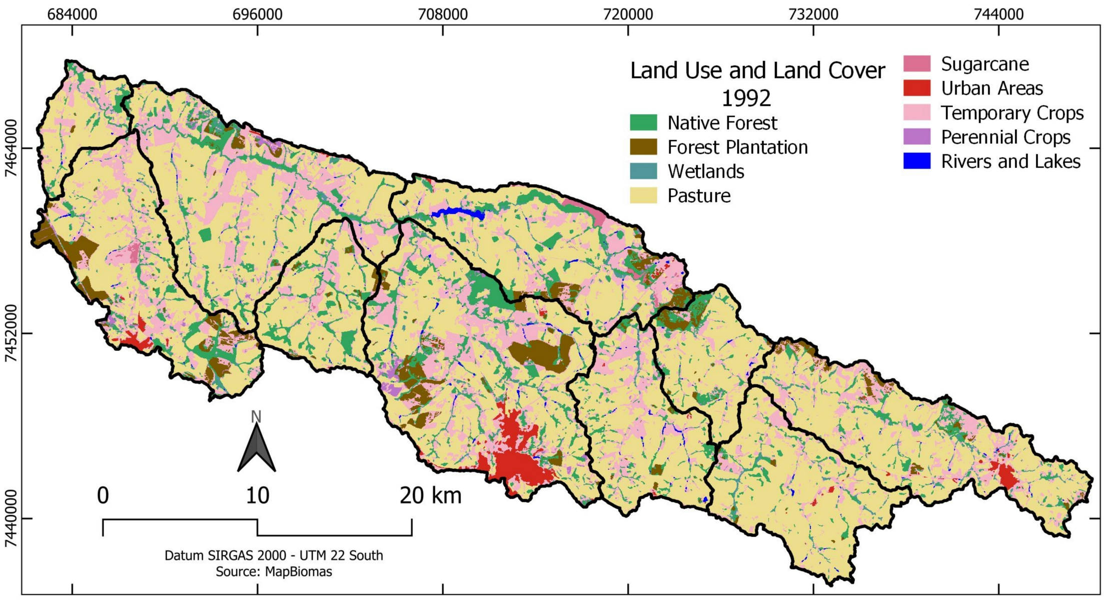

Figure 3 - Land Use and Land Cover in 1992

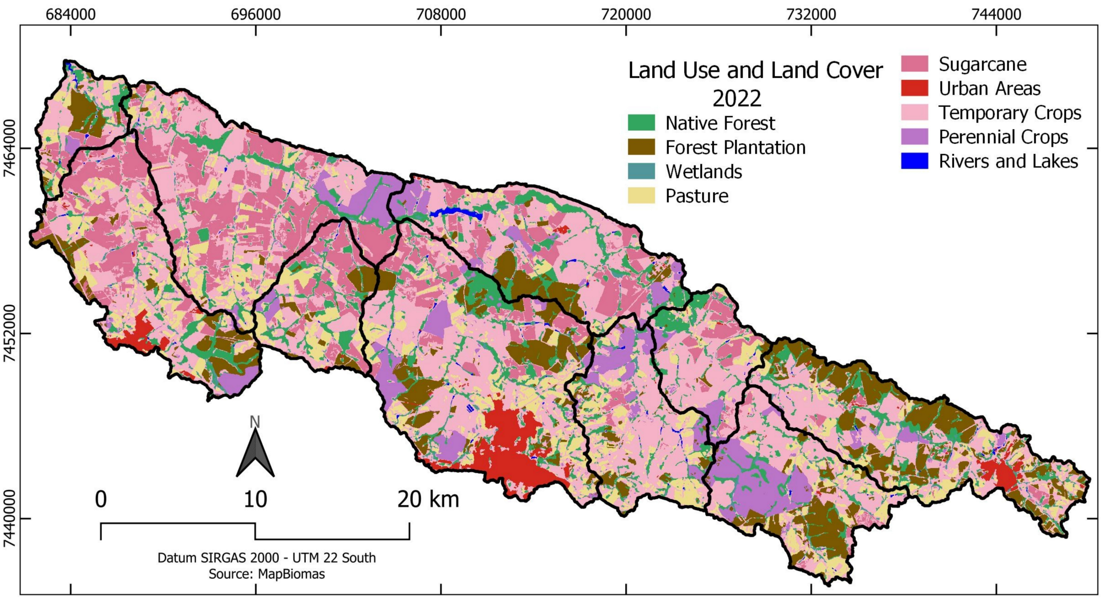

Figure 4 - Land Use and Land Cover in 2022

	Land Use and Land Cover Areas (km²) - 1992									
Land use class	SB1	SB2	SB3	SB4	SB5	SB6	SB7	SB8	SB9	SB10
Native Forest	8,024	4,485	5,738	6,054	14,142	21,128	15,507	7,519	9,943	3,347
Forest Plantation	3,662	0,572	2,546	1,072	5,451	13,139	2,030	1,266	10,434	0,186
Wetlands	2,256	1,483	0,475	0,671	1,810	3,218	2,498	0,262	1,129	0,359
Pasture	72,069	66,104	32,859	49,789	54,826	81,590	83,788	34,968	57,189	18,447
Sugarcane	0,004	0,000	0,000	0,006	2,043	0,000	0,000	0,101	0,689	0,000
Urban Areas	2,061	0,263	0,020	0,161	0,455	11,700	0,364	0,016	1,949	0,000
Temporary Crops	23,700	9,317	5,428	15,517	24,161	45,121	39,884	7,895	26,551	7,668
Perennial Crops	0,048	0,187	0,114	0,160	0,401	2,262	1,233	0,207	1,154	0,015
Rivers and lakes	0,249	0,204	0,169	0,503	1,623	0,862	0,298	0,079	0,222	0,055

Table 1 - Area (km²) of the land use and land cover classes for the study area in 1992

	Land Use and Land Cover Areas (km²) - 2022									
Land use class	SB1	SB2	SB3	SB4	SB5	SB6	SB7	SB8	SB9	SB10
Native Forest	12,734	6,912	6,392	6,630	14,738	18,094	13,206	7,377	8,253	3,891
Forest Plantation	32,947	14,201	1,025	4,572	10,811	22,215	1,238	5,015	11,683	5,334
Wetlands	2,361	1,217	0,606	0,816	1,654	2,791	1,165	0,303	1,327	0,257
Pasture	11,988	10,152	4,228	13,419	3,910	20,308	14,806	8,306	13,496	4,146
Sugarcane	1,769	1,813	7,993	1,760	18,494	15,915	47,598	13,715	25,493	3,641
Urban Areas	3,974	0,117	0,096	0,058	0,689	19,799	0,482	0,184	4,699	0,028
Temporary Crops	43,111	29,906	22,928	35,760	44,385	66,902	56,776	15,098	40,067	11,516
Perennial Crops	2,982	18,172	3,979	10,617	8,887	12,368	10,166	2,254	4,064	0,945
Rivers and lakes	0,208	0,126	0,102	0,301	1,344	0,629	0,165	0,060	0,176	0,320

Table 2 - Area (km²) of the land use and land cover classes for the study area in 2022

During the period analyzed, sugarcane crops showed a significant increase, mainly in SB5, SB6, SB7, SB8, and SB9, which contained a maximum of 2 km² (SB5) in 1992, rising to 18.49, 15.91, 47.59, 13.71, and 25.49 km² in 2022, respectively. In the case of SB7, sugarcane represented 32.7% of its total area in 2022. This pattern of growth in areas with sugarcane cultivation has also been observed in other regions of the state of São Paulo, mainly between 1999 and 2009 (OGURA et al., 2022). The increase in perennial crops, such as citrus, was more considerable in SB2, SB4, SB6, and SB7, with cultivated areas exceeding 10 km² in each sub-basin in 2022. Forest plantations (Eucalyptus silviculture) increased in SB1, leaping from 3.66 km² in 1992 to 32.95 km² in 2022.

Regarding native forest, an increase in forest cover was observed in SB1, SB2, SB3, SB4, SB5, and SB10, while the other sub-basins showed a decrease for this class. Urban areas occur within SB1 (municipality of Itatinga), SB6 (municipality of Avaré), and SB9 (municipality of Cerqueira César), and showed increases during this period. In SB1, urbanized areas occupied an area of 2.06 km² in 1992, increasing to 3.97 km² by 2022. In SB6, this occupancy increased from 11.7 km² to 19.8 km², and in SB9, from 1.95 km² to 4.7 km², in the same period.

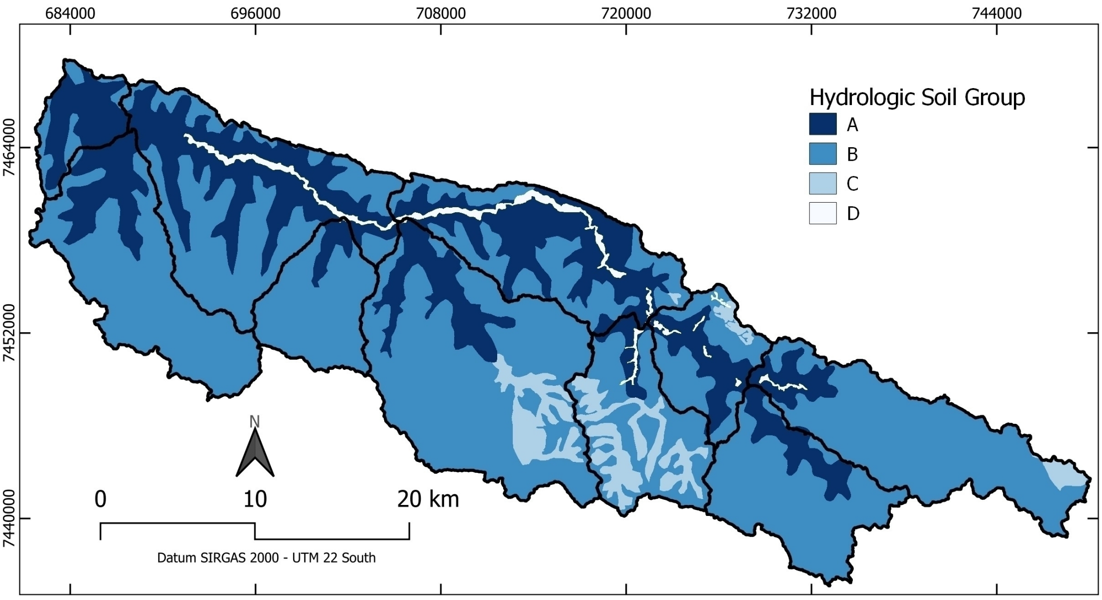

Figure 5 - Hydrologic Soil Groups

HYDROLOGICAL SOIL GROUP

Based on the soil classes extracted from the pedological map of the State of São Paulo, at a scale of 1:250,000, and considering the entire area of the Rio Novo drainage basin, the four hydrological groups of soils were identified (FIGURE 5). However, not all groups are present in all sub-basins. The classification of soils in HSG is based on their minimum infiltration rate (USDA, 2009), but these values are not always available, especially for large areas. In this case, a frequently used alternative is classification based on soil texture (UWIZEYIMANA et al., 2019; GUPTA and DIXIT, 2022). However, this classification based simply on soil texture may not be suitable for many soil classes in Brazil (SARTORI et al., 2005); thus, soil structure becomes relevant for determining the HSG. Latossolos Vermelhos (Ferralsols) are predominant in the basin as a whole, being classified in groups A and B (SARTORI et al., 2005), while hydromorphic soils, with high influence of the water table, were classified in group D; these occur primarily in SB5 and SB7.

In general, Latossolos tend to have a high infiltration capacity. Pessoa & Libardi (2022) found saturated hydraulic conductivity values ranging from 20 mm.h-1 to more than 200 mm.h-1, for the Bw horizons in different classes of Latossolos, this variation occurred as a function of the texture and mainly the structure of these horizons. It is worth noting that changes in land use and management practices in agricultural areas — conventional tillage, minimum or no-tillage — can alter the physical characteristics of the soil and, consequently, its hydrological behavior (ALMEIDA et al., 2018; SANTANA et al., 2023).

CURVE NUMBER AND SURFACE RUNOFF

The CN values, obtained for each hydrologic soil-cover complex, were spatialized for each sub-basin for the years 1992 and 2022, considering the standard ARC condition (ARCII, resulting in CNII). These maps are shown in (FIGURE 6). The occupied areas for each CN value are shown in (FIGURE 7).

For all the sub-basins, there was a reduction in areas with CN 65; this was associated with the hydrologic soil-cover complex formed by the crossing of pasture areas with HSG B. The advance of silviculture and sugarcane cultivation contributed to the decrease in CN values; the transition from pasture to silviculture in group B soils resulted in a reduction in CN values from 65 to 60, and the transition from pasture to sugarcane led to a decrease from 65 to 61 between 1992 and 2022. Annual crops contributed to the increase in CN 69 in all sub-basins, as well as the increase in CN 58, except for SB4 and SB7. The highest CN values (85 and 90) are associated with urban areas, occurring in SB1, SB6, and SB9, which have undergone expansion over the 30-year period analyzed. The areas with CN 85 increased for SB1 and SB9, while in SB6, an increase in areas was observed in both CN 85 and CN 90.

Figure 6 shows the locations where CN values either remained constant, increased or decreased during the period analyzed, which implies that the potential for generating surface runoff were either maintained, decreased or increased. Locations with increased CN values, and consequently higher potential for runoff generation, are subject to higher rates of soil loss (WEI et al., 2007); thus, it is crucial to adopt conservation practices for soil and water management, aimed at reducing the erosion potential in these locations (Du et al., 2022). Considering the weighted average of CN values (MUNNA et al., 2021) for each sub-basin, the greatest change occurred in SB6, with an increase of 4.43%. In SB8, a 1.13% reduction in the weighted average value was observed.

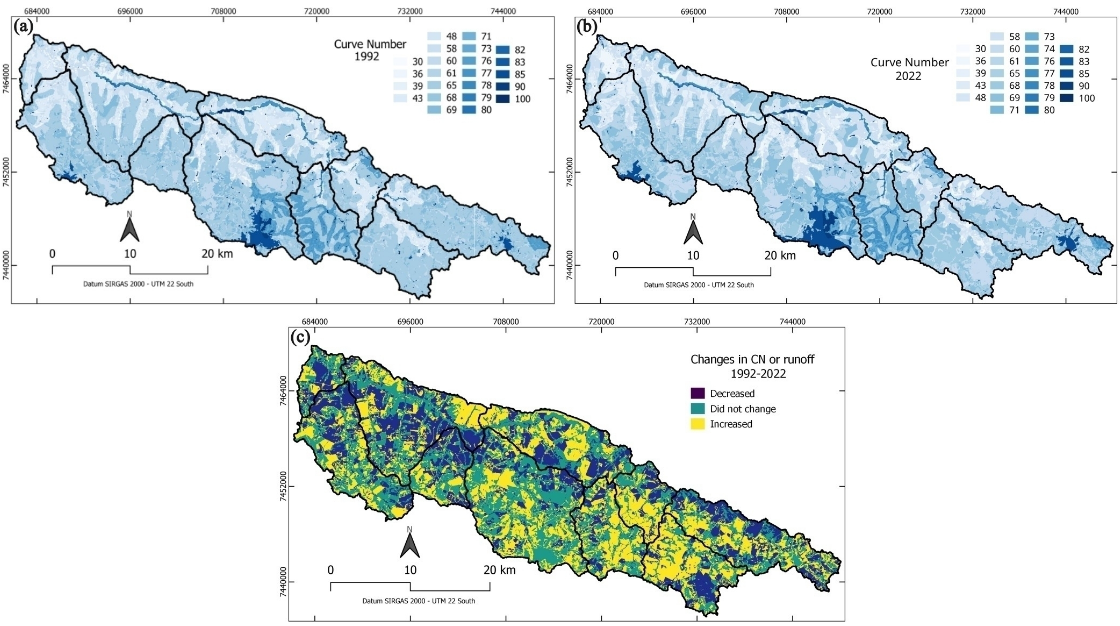

Figure 6 - Distribution of the Curve Number values in the study area, (a) Curve Number values in 1992, (b) Curve Number values in 2022, (c) Changes in number curve values between 1992 and 2022

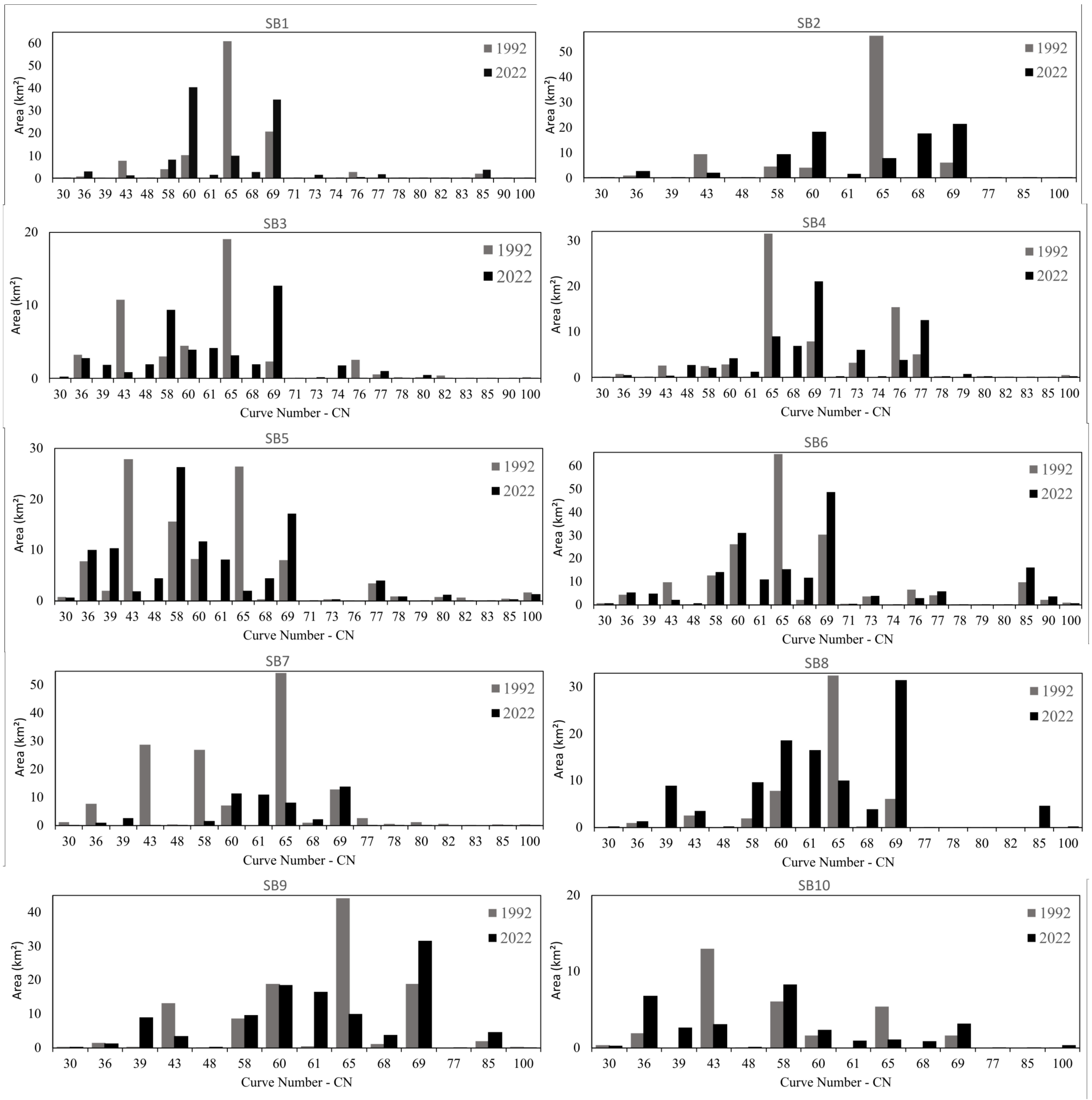

Figure 7 - Area covered by Curve Number values for each sub-basin in 1992 and 2022 .

To obtain runoff depth values, a rainfall of 130 mm was used (roughly the maximum daily rainfall value for a 10-year return period), along with Equation 1 of the NRCS-CN method and ARCII. For both periods (1992 and 2022), the lowest runoff depth values occurred in areas covered by native forests, associated with HSG A, with values on the order of 3.21 mm, while the highest values occurred in urban areas, ranging from 88.32 mm to 101.35 mm. To facilitate the viewing of the variations in runoff depth over time and due to changes in LULC, the values were reclassified into ranges; these are shown in Figure 8 for the years 1992 and 2022.

In the Rio Novo basin as a whole, a decrease was observed for the runoff depth classes less than 20 mm and 40–60 mm; the other runoff classes showed increases in the areas of occurrence for the period analyzed, with the exception of class 60–80 mm, which remained practically constant.

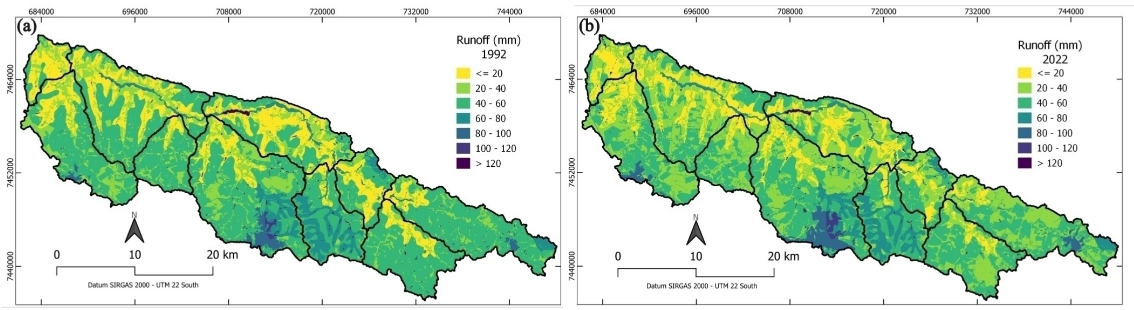

Figure 8 - Surface runoff depth considering a rainfall of 130 mm (a) in 1922, (b) in 2022.

In the sub-basins with urban areas (SB1, SB6, and SB9), with the increase in soil sealing due to the urbanization process, there is a decrease in water infiltration into the soil locally, and consequently an increase in surface runoff. This contributes toward an increase in the occurrence of peak flows, and increases the chances of flooding (Kumar et al., 2013) if urban drainage structures are not properly planned. Even urban areas, with totally or partially impermeable surfaces, occupying less than 5% of the areas of SB1 and SB9, should receive special attention, given their high potential for generating surface runoff, as evidenced by the CN values. In the case of SB6, the contribution of surface runoff from these surfaces with low infiltration rates becomes even greater since its extension represented around 11.1% of the total area of the sub-basin in 2022. It should be considered that the trend of land use is relatively continuous expansion, which indicates that impacts will also grow continuously, if measures are not taken to control them (AMORIM and PIROLI, 2023).

With the increase in soil moisture, moving towards a condition in which it is saturated or near saturation at the onset of rainfall, the runoff depth tends to increase (SONG and WANG, 2019); in this scenario, the CN values are modified to adapt to the new moisture condition (ARCIII, resulting in CNIII). The CNIII values and the resulting runoff depth, for the years 1992 and 2022, are shown in Figure 9. The minimum CN value increased from 30 (ARCII) to roughly 50 (ARCIII); thus, the runoff also increased for the entire Rio Pardo basin, with a predominance of classes above 60 mm for a rainfall of 130 mm. In urban areas, for example, values increased from 88.32–101.35 mm (ARCII) to 109.6–116.6 mm (ARCIII).

The NRCS-CN method estimates the amount of precipitation that is converted into surface runoff, based on CN values; however, the choice of these values can change this estimate (Faouzi et al., 2022). In this study, unique tabulated values were used for each hydrologic soil-cover complex, disregarding (for example) the hydrological condition of each LULC, as well as variations in cover treatment in annual crop areas, according to the documentation provided by the USDA (USDA, 2004a). This simplification was performed since such characteristics are not available in the LULC database. Furthermore, other uncertainties in the estimates lie in the default value of the initial abstraction equal to 0.2, which may not be suitable for some situations (Lal et al., 2016). Valle Junior et al. (2019) observed, for a river basin in Brazil, that in most precipitation events, the values were below 0.2, suggesting a value of 0.05 for the location analyzed. For the Rio Novo basin, the default value was used since the available CN tables were developed for this condition.

Despite the simplifications adopted, through the NRCS-CN method used in a GIS environment, it was possible to verify changes in surface runoff behavior, given the changes in LULC between the years 1992 and 2022, in the Rio Novo basin, as well as in the sub-basins used in order to discretize the area. This indicates locations with increases in CN values and consequently in surface runoff.

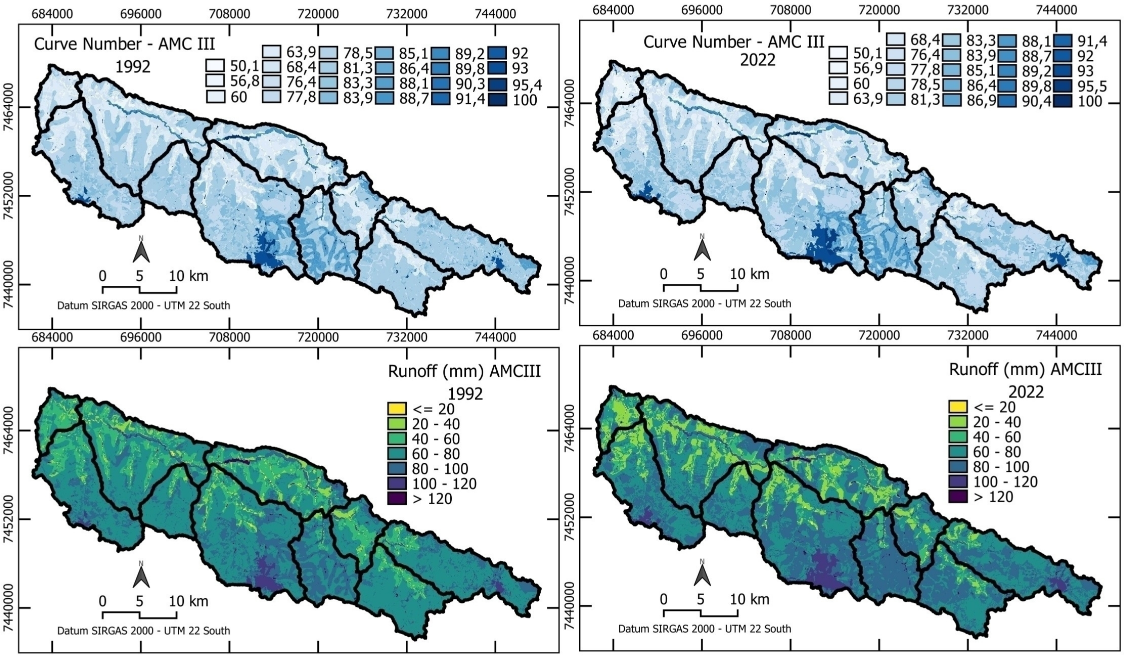

Figure 9 - Curve Number values and surface runoff depth, considering the antecedent runoff condition III and a rainfall of 130 mm for 1992 and 2022.

CONCLUSION

This study evaluated LULC between the years 1992 and 2022 and its consequences on the behavior of surface runoff in the Rio Novo basin. Using the Curve Number method (NRCS-CN), it was possible to identify the locations with the greatest potential for generating surface runoff, as well as estimate its quantity depending on a given volume of rainfall. The results indicated that a large portion of the basin underwent changes in LULC over this 30-year period, with a reduction in pasture and an increase in annual crops and sugarcane cultivation, as well as an increase in urban areas in some of the sub-basins. In part of the basin, the changes in LULC were unfavorable, from the viewpoint of soil and water conservation, since — with an increase in CN values — the potential for generating surface runoff tends to increase, thereby resulting in damage to the soil and water resources in the basin. Due to the urbanization process, there was an increase in soil sealing in three sub-basins, indicating that both in rural and urban areas, given the increase in CN values, it is essential to adopt conservation techniques in order to reduce surface runoff and increase water infiltration. Accordingly, adopting the NRCS-CN method in a GIS environment proved to be useful for defining critical areas regarding surface runoff, being a tool for sustainable planning in the Rio Novo basin, or in other ungauged catchments in Brazil or around the world.

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