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ORIGINAL ARTICLE

# Comparative study and spatialization of the CN (Curve Number) parameter in the Turvo river basin (RS, Brazil), between 1990, 2006, and 2022

## Estudo comparativo e espacialização do parâmetro CN (Curve Number) na bacia hidrográfica do rio do Turvo (RS, Brasil), entre os anos de 1990, 2006 e 2022

## Estudio comparativo y espacialización del parámetro CN (Curve Number) en la cuenca hidrográfica del río do Turvo (RS, Brasil), entre los años 1990, 2006 y 2022

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## ABSTRACT

This study investigated the use of the Curve Number (CN) methodology to evaluate surface runoff in the Turvo river basin in RS, Brazil, in the years 1990, 2006, and 2022. Using land use and cover data and pedological information, the land use patterns were correlated with the hydrological characteristics of the soils, generating maps that represent the spatial distribution of CN in the periods analyzed. The results showed transformations in land use, with an increase in urban areas of around 260% over the period and a 50% increase in soybean cultivation. Consequently, there was a progressive increase in the CN value over the years, indicating an increase in surface runoff, mainly influenced by the type of soil cover. The results obtained highlight the urgent need for soil and native vegetation conservation actions in the region. The study demonstrates the importance of the CN methodology for assessing hydrological processes

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in river watershed, contributing to understanding human activities' impacts on the hydrological cycle, and developing sustainable water resource management strategies.

**KEYWORDS:** hydrological assessment; surface runoff; water management.

## RESUMO

Este estudo investigou o uso da metodologia Curve Number (CN) para avaliar o escoamento superficial na bacia hidrográfica do rio do Turvo, no Rio Grande do Sul, Brasil, nos anos de 1990, 2006 e 2022. Utilizando dados de uso e cobertura do solo e informações pedológicas, foram correlacionados os padrões de uso da terra com as características hidrológicas dos solos, gerando mapas que representam a distribuição espacial do CN nos períodos analisados. Os resultados evidenciaram transformações no uso da terra, destacando-se o aumento das áreas urbanas em cerca de 260% no período e 50% no cultivo de soja. Consequentemente, houve um avanço progressivo no valor de CN ao longo dos anos, indicando o aumento do escoamento superficial, influenciado principalmente pelo tipo de cobertura do solo. Os resultados obtidos evidenciam a urgência de ações de conservação do solo e da vegetação nativa na região. O estudo demonstra a importância da metodologia CN para a avaliação dos processos hidrológicos em bacias hidrográficas, contribuindo para o entendimento dos impactos das atividades humanas sobre o ciclo hidrológico e para o desenvolvimento de estratégias de gestão sustentável dos recursos hídricos.

**PALAVRAS-CHAVE:** digital tools; interaction and collaboration; teacher training.

## RESUMEN

Este estudio investigó el uso de la metodología del Número de Curva (CN) para evaluar la escorrentía superficial en la cuenca hidrográfica del río Turvo, Rio Grande do Sul, Brasil, en los años 1990, 2006 y 2022. Utilizando datos de uso y cobertura del suelo e información pedológica, se correlacionaron los patrones de uso de la tierra con las características hidrológicas de los suelos, generando mapas que representan la distribución espacial del CN en los períodos analizados. Los resultados evidenciaron transformaciones en el uso de la tierra, destacándose el aumento de las áreas urbanas en aproximadamente 260% y 50% en el cultivo de soja. En consecuencia, hubo un avance progresivo en el valor de CN a lo largo de los años, alcanzando valores medios de 62,16 en 2022, indicando el aumento de la escorrentía superficial, influenciado principalmente por el tipo de cober-

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tura del suelo. Los resultados obtenidos evidencian la urgencia de acciones de conservación del suelo y la vegetación nativa en la región. El estudio demuestra la importancia de la metodología CN para la evaluación de los procesos hidrológicos en cuencas hidrográficas, contribuyendo a la comprensión de los impactos de las actividades humanas sobre el ciclo hidrológico y al desarrollo de estrategias de gestión sostenible de los recursos hídricos.

**PALABRAS CLAVE:** evaluación hidrológica; escorrentía superficial; gestión del agua.

# 1 Introduction

Population growth in recent decades has led to increasing pressure on natural resources, mainly due to the demand for land for cultivation, which can accelerate environmental and water resource degradation. In this context, it is essential to look for ways to minimize these impacts (Lazaretti; Souza, 2019). The continuous development of methods for managing natural resources, such as soil and water, highlights the importance of geoprocessing. This technique, which uses Geographic Information Systems (GIS) to represent spatial phenomena on the computer, plays a crucial role. In addition, as Rocha (2011) points out, river basins are relevant objects of study in this area, given the significant interaction between society and the environment.

Within the study of natural resources, soil moisture is one of the fundamental points to be considered when analyzing soil and water. The exchange of water and energy between the earth's surface and the atmosphere contributes water vapor to the atmosphere through evaporation in bare soil or evapotranspiration from vegetation, helping in the process of rain formation (Bogena *et al*., 2015; Corradini, 2014). Therefore, this information is an essential tool for assisting in flood forecasts, landslides, and irrigation management (Brocca *et al*., 2017; Uber *et al*., 2018).

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Another important factor is infiltration, which is the process by which water passes through the soil surface. From the level of infiltration, surface runoff and other factors within the hydrological cycle arise, which can cause undesirable processes such as erosion and flooding (Rodrigues; Pruski, 2019). It is important to know the infiltration rate of water in the soil, which is fundamental for implementing measures aimed at soil conservation and designing effective irrigation and drainage systems. In addition, such data contributes significantly to a broader understanding of the subject, as Paixão *et al*. (2004) discussed.

Runoff, in turn, is a hydrological process that can have a high degree of temporal and spatial variability and can be described as the movement of water over the soil surface. It is a complex process that considers certain characteristics such as land use and management, soil type, topography and lithology (Lemma *et al*., 2018; Zhang *et al*., 2018).

The growing need to understand hydrological processes in small watersheds has led to the development of various tools, such as the Curve Number (CN) method. The CN method was developed in the 1930s by the US Natural Resources Conservation Service (NRCS, 2009). It is a simple tool that can help researchers and managers to conserve soil and water resources by estimating runoff rates in river basins using hydrological data (Carvalho; Rodrigues, 2021).

The CN method was created to investigate and evaluate surface runoff in river basins, with the aim of providing more precise information on erosion processes and soil degradation. This approach is essential for an in-depth understanding of hydrological phenomena and their implications for the sustainable management of water resources. At the beginning of its implementation, the CN method was developed to provide an effective tool for estimating surface water losses and soil erosion, aiming to contribute to the proper management and planning of water and environmental resources. Pioneering studies carried out in the 1930s and 1940s collected infiltration data

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in several watersheds in the United States (USDA-NRCS, 2016; Hawkins *et al*., 2009), laying the conceptual and empirical foundations for the method. With its simple approach, characterized by a single CN parameter, the CN method then became the most widely adopted tool for calculating runoff based on rainfall events (Lal; Mishra; Kumar, 2019).

In this context, this study aimed to carry out a comparative and spatial analysis of the CN parameter in the Turvo River Basin (TRB), in the state of Rio Grande do Sul, Brazil, over the years 1990, 2006 and 2022. The aim was to understand the temporal variations of this parameter and its implications for the hydrological processes of the region, as well as to provide subsidies for the planning and management of water resources, especially with regard to the conservation of soil and water resources. The main research questions include: How have CN values changed in the TRB? What are the implications of these changes for water resource management? What strategies can be recommended to mitigate the negative impacts identified?

# 2 Material and Methods

## 2.1 Study area

The study area is located in the Turvo River Basin (TRB). It covers an area of approximately 1,298 km$^2$ and belongs to the Uruguay River hydrographic region. It is located in the northwest of the state of Rio Grande do Sul, comprising the municipalities of Três Passos, Tenente Portela, Miraguaí, Bom Progresso, Braga, Redentora, Campo Novo, Coronel Bicaco, Santo Augusto and Palmeira das Missões, between the geographical coordinates 27°36'57"S / 53°76'52"O and 27°97'51"S / 53°63'17"O (Figure 1).

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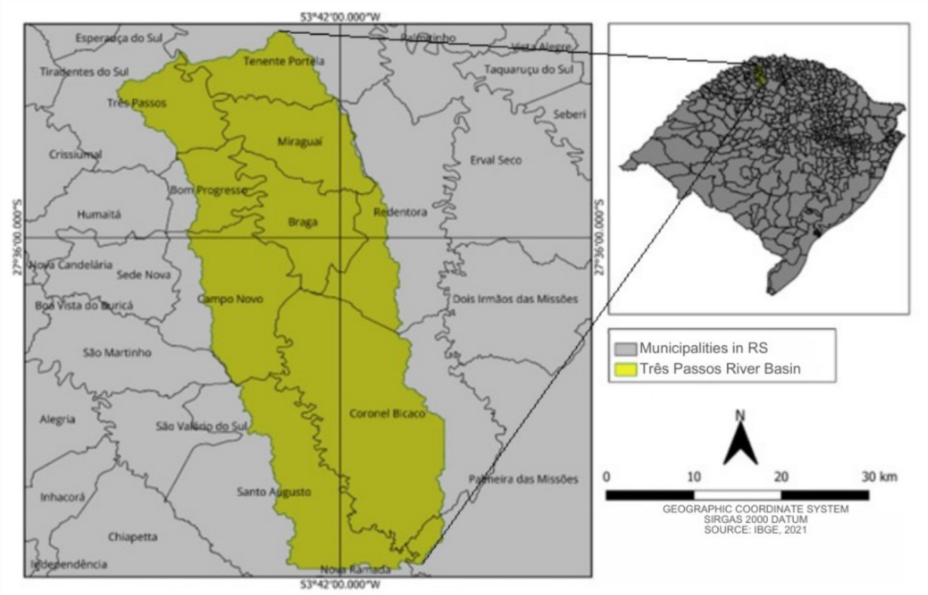
FIGURE 1 - Location of the Turvo river basin, RS, Brazil.




Source: the authors (2024).

The predominant climate in the TRB region is classified as Cfa according to Köppen, a humid temperate climate with hot summers. The average annual rainfall is approximately 1,800 millimeters. Average annual temperatures are around 20°C, with seasonal variations of around 10°C. In July, the coldest month, average temperatures are slightly above 10°C. Frosts occur in the region from May and continue until September (SPERS, 2020).

The soils that predominate in the TRB are mainly Latosols. This soil is characterized by low to medium slope, absence of stones, well-defined A, B, and C horizons, high fertility, and water retention capacity, making it suitable for agricultural activities. Eutrophic Cambissolos Háplicos Ta are also present, with strongly undulating or mountainous reliefs and no humic A surface horizon. These soils have variable natural fertility, limited by the steep relief, shallow depth and presence of stones in the soil, which can influence their ability to support different crops or agricultural activities.

According to Prado (2005), soils classified as Latosols have less water availability, even in cases where they have a lot of clay. Their internal drainage is very pronounced, meaning that they have high infiltration rates. On the other hand, in Cambisols, water availability varies according to depth and the presence of mica and silt content.

## 2.2 Spatial data collection

The spatial data used in this study was obtained as follows: the pedology data was acquired from the Brazilian Agricultural Research Corporation - Embrapa; the Digital Elevation Model (DEM) (SRTM) was obtained from the TOPODATA geomorphometric data platform provided by the National Institute for Space Research (INPE); the land use and land cover data was acquired from the Annual Mapping of Land Use and Land Cover in Brazil Project (MapBiomas), for the years 1990, 2006 and 2022.

## 2.3 Technical procedures

The Turvo River Basin (TRB) boundaries were defined using data from the Digital Elevation Model (DEM) provided by the SRTM. These boundaries were demarcated using QGIS software version 3.28.2 - Hannover, using the hydrological terrain analysis tools available in the System for Automated Geoscientific Analyses (SAGA GIS).

The NRCS-CN methodology classifies soils into four hydrological groups (A, B, C, or D), considering factors such as precipitation, surface runoff, and infiltration. This classification is based on similar physical characteristics of soils in the same climatic region, such as layer depth, water percolation rate, texture, structure, and expansion when saturated. These characteristics influence surface runoff patterns, as Anjinho *et al*. (2018) reported.

Chart 1 shows the hydrological classification of soils made by Sartori, Lombardi Neto, and Genovez (2005), who adapt the SCS methodology to Brazilian soils.

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CHART 1 - Hydrological soil classification for Brazilian conditions.

| GROUP | FEATURES | SOIL TYPES |
|---|---|---|
| A | Very deep soils (> 200 cm), with a high infiltration rate and resistance and tolerance to erosion, porous soils with a low textural gradient (< 1.20), medium texture, well-drained or excessively drained soils. | Yellow Latosol, Yellow Red Latosol, and Red Latosol, both with a clayey or very clayey texture and high macro porosity; Yellow Latosol and Yellow Red Latosol, both with a medium texture but with a non-sandy surface horizon. |
| B | Deep soils (100 to 200 cm), with a moderate infiltration rate and resistance and tolerance to erosion, porous soils with a textural gradient varying between 1.20 and 1.50, sandy texture throughout the profile or medium texture. | Yellow Latosol and Yellow Red Latosol, both medium--textured but with a sandy surface horizon; Bruno Latosol; Red Nitosol; Quartzarenic Neosol; Red or Yellow Red Argisols with a sandy/medium, medium/clay, clay/clay or clay/very clay texture that do not show abrupt textural changes. |
| C | Deep (100 to 200 cm) or shallow (50 to 100 cm) soils, with a low infiltration rate and low resistance to erosion, are soils with a textural gradient greater than 1.50, associated with low activity clay (Tb). | Shallow Argissolo, but not showing abrupt textural change or Red Argissolo, Yellow Red Argissolo and Yellow Argissolo, both deep and showing abrupt textural change; medium-textured Cambissolo and humic or humic cambis-solo, but with physical characteristics similar to Latosols (latosolic); Ferrocarbic Spodosol; Fluvic Neosol. |
| D | Soils with a very low infiltration rate offering very little resis-tance to erosion, shallow soils (< 50 cm), shallow soils associated with abrupt textural changes, clayey soils associated with high activity clay (Ta), organic soils | Litholic Neosol; Organosol; Gleissolo; Chernossolo; Planossolo; Vertissolo; Alissolo; Luvissolo; Plintossolo; mangrove soils; rock outcrops; Cambissolos that do not fall into group C; Yellow Red Argissolo and Yellow Argissolo, both shallow and associated with abrupt textural change. |

Source: Sartori; Lombardi Neto; Genovez (2005).

As can be seen in Chart 1, group A soils have high saturated hydraulic conductivity and a deep water table, while group D soils are classified as having low saturated hydraulic conductivity and a shallow water table. The USDA-NRCS (1986) establishes the infiltration rate as the rate at which water enters the soil, influenced by surface conditions, while the transmission rate is the rate at which water moves through the soil. The transmission rate is higher in group A soils, which have better infiltration conditions, and the transmission rate is lower in group D soils, which have worse infiltration conditions.

## 2.4 Determining the Curve Number - CN

The CN values for the watershed were spatialized by integrating the 1990, 2006 and 2022 land use maps with the hydrological groups map, using QGIS

3.28.2 - Hannover software. This integration made it possible to establish CN values for different types of land cover in the basin. For this purpose, the values established by the United States Soil Conservation Service (SCS, 1972) were adopted.

According to the methodology described by the SCS (1972), the values assigned to the dimensionless parameter CN range from 0 to 100. Values close to 100 indicate a limit condition of completely impermeable basins, with a water retention rate of zero. On the other hand, values close to zero suggest a high water retention rate, characterizing highly permeable basins, in which there is no surface runoff, regardless of the amount of accumulated rainfall (Anjinho *et al*., 2018).

Using QGIS tools, automated estimation of CN values was carried out for each region of the TRB. This process involved applying geoprocessing functions to integrate soil and land use data, resulting in a spatialized map of CN values (Oliveira *et al.*, 2011; D'Asaro; Grillone, 2012; Rezende; Ribeiro; Mendes, 2018; Lal; Mishra; Kumar, 2019; Ballardin *et al*., 2023).

# 3 Results and Discussion

The TRB area is made up of four soil classes (Figure 2). The most representative classes in the basin studied are Latossolo Vermelho, classified in hydrological group C, followed by Cambissolos Háplicos, in hydrological group A (Figure 2).

The data showed that more than 90% of the area falls into hydrological group C (Figure 2, Table 1), which is characterized by soils with a low infiltration rate and low resistance to erosion (Sartori; Lombardi Neto; Genovez, 2005).

The areas, with the respective percentages, of each type of soil are described in Table 1.

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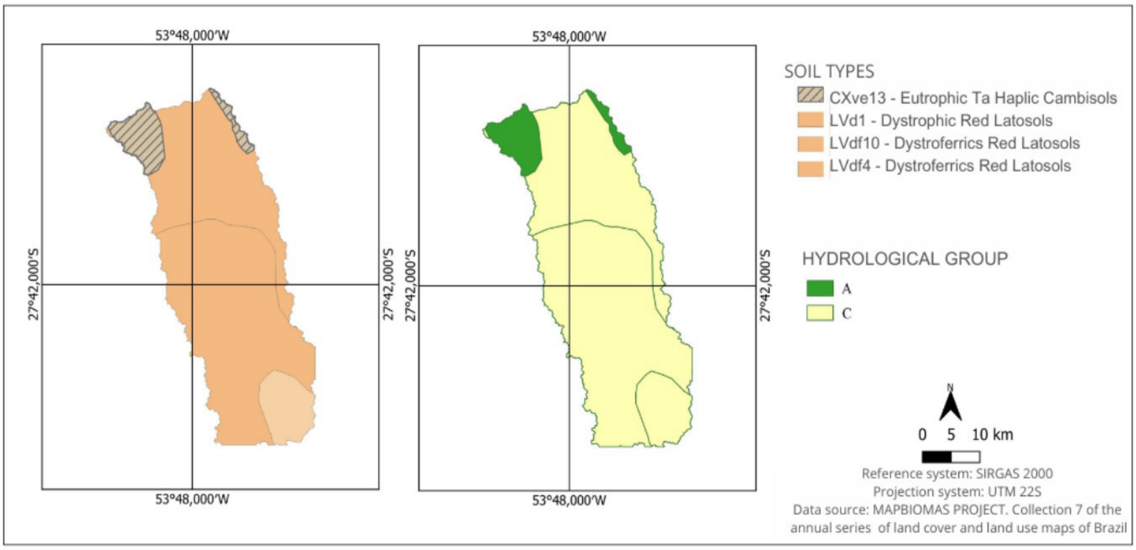
FIGURE 2 - Soil types and hydrological groups in the Turvo river basin, RS, Brazil




Source: the authors (2024).

TABLE 1 - Soil types, with their respective areas and percentages, in the Turvo river basin, RS, Brazil.

| Soil types* | Area km$^2$ | % |
|---|---|---|
| LVd - Dystrophic Red Latosols | 102,16 | 8% |
| LVdf10 - Dystroferrics Red Latosols | 427,46 | 33% |
| LVdf4 - Dystroferrics Red latosols | 676,93 | 52% |
| CXve – Eutrophic Ta Haplic Cambisols | 91,51 | 7% |
| Total | 1298,05 | - |

*Where: LVd - Dystrophic Red Latosols; LVdf10 - Dystrophic Red Latosols + Eutrophic Red Nitosols + Eutrophic Haplic Nitosols; LVdf4 - Dystrophic Red Latosols + Eutrophic Red Nitosols; CXve - Eutrophic Ta Haplic Cambisols + Eutrophic Lithic Neosols + Eutrophic Red Nitosols.

Source: the authors (2024).

The changes in land use and land cover classes and the percentage differences in land use by period can be seen in Figures 3 and 4, respectively. The evolution of land use and occupation in the TRB over the years can be seen in Figure 5.

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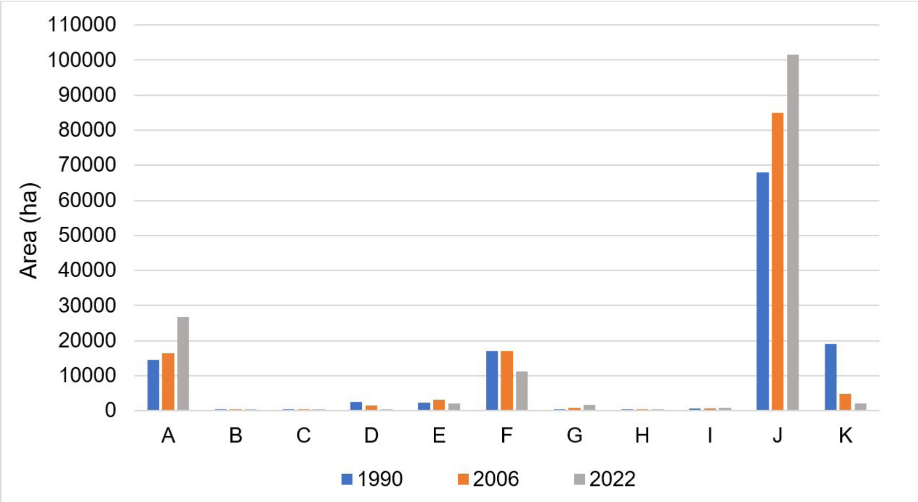
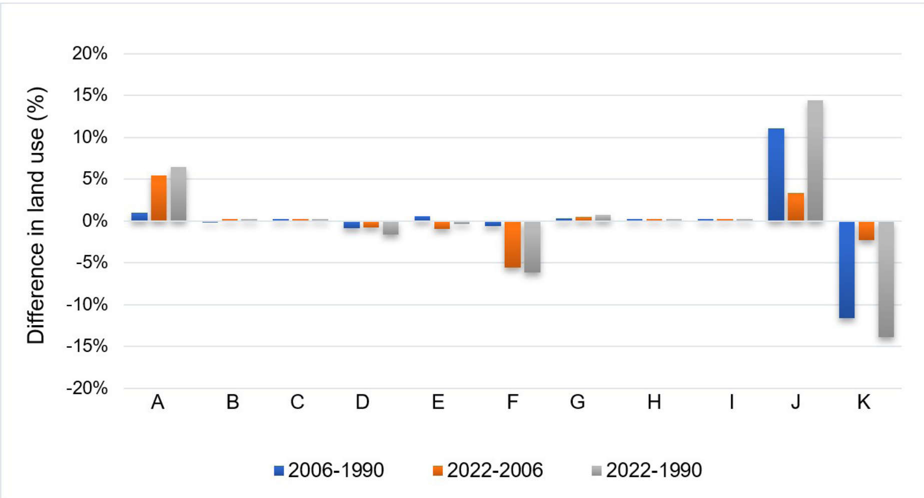
FIGURE 3 - Land use and cover classes in the Turvo river basin, RS, Brazil.




Where: A = Forest Formation, B = Forestry, C = Wetland and marshland, D = Grassland Formation, E = Pasture, F = Mosaic of Uses, G = Urbanized Area, H = Other Unvegetated Areas, I = River, Lake and Ocean, J = Soybeans and K = Other Temporary Crops
Source: the authors (2024).

In general, the results show that land use has been transformed by anthropogenic activities, especially the increase in urban areas and, more significantly, the expansion of soya plantations in the region (Figures 3, 4 and 5). These results can also be seen in the analysis of the percentage difference in land use over the periods analyzed (Figure 4).

FIGURE 4 - Difference in land use by period, in the Turvo river basin, RS, Brazil.




Where: A = Forest Formation, B = Forestry, C = Wetland and marshland, D = Grassland Formation, E = Pasture, F = Mosaic of Uses, G = Urbanized Area, H = Other Unvegetated Areas, I = River, Lake and Ocean, J = Soybeans and K = Other Temporary Crops
Source: the authors (2024).

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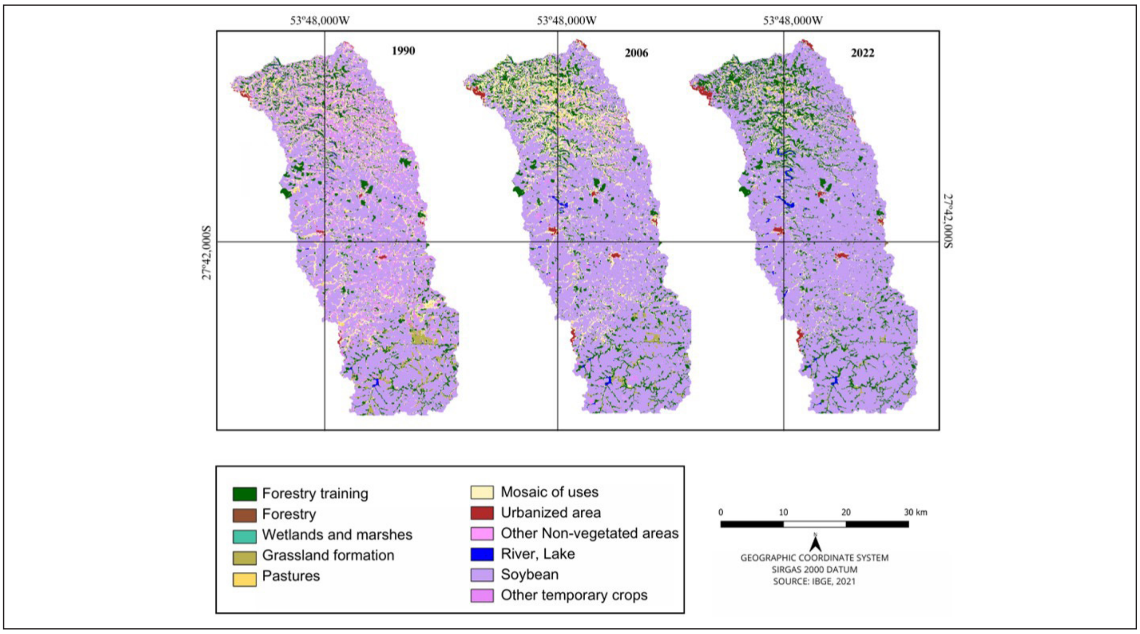
The areas occupied by soya peaked in the period from 1990 to 2006, with an increase of around 25% in the area planted, corresponding to 66% of the total area of the basin (Figure 5). Growth continued in the following period (2006 to 2022), when there was a 19% increase in the area under soya cultivation. In total, the area devoted to soybean cultivation grew by almost 50% when comparing 1990 and 2022. In this year, the area occupied by soybeans reached close to 69% of the total area of the TRB.

There was also an increase in the use classes for forestry and urbanized areas (Figures 3, 4 and 5). In relation to forestry, it was possible to observe a 12% increase in its occupied area between 1990 and 2006, and a 62% increase between 2006 and 2022, corresponding to 18% of the basin's total area. This can be explained by the changes to the Forest Code, which took place in 2008 and which, according to Igari and Pivello (2011), now require rural properties to be environmentally regularized so that producers can access rural credit. With this increase in enforcement of the requirements arising from the Forest Code, there has been a progressive increase in forest areas, as can be seen in Figure 5.

FIGURE 5 - Land use and occupation in the Turvo river basin (RS, Brazil) in the periods 1990, 2006 and 2022.




Source: the authors (2024).

Urbanized areas, which occupied around 460 ha in 1990, rose to 884 ha in 2006, increasing their area of occupation by 92%. In 2022, the total area was 1663 ha, which corresponds to an 88% increase in urbanized areas. The total increase from 1990 to 2022 was around 260%, demonstrating the advance of urbanization in the basin region (Figure 5).

On the other hand, there was a reduction in the areas of grassland and in those areas used for temporary crops (Figures 3 and 4). Comparing the years 1990 and 2022, it was found that temporary crops and grasslands lost around 89% and 78% of their total area, respectively (Figure 5).

Similarly, the areas known as mosaics of use, where it is not possible to distinguish between pasture and agriculture, represented around 13% of the total in 1990, falling by 34% from 2006 to 2022. In 2022, these regions corresponded to 7% of the total area of the TRB (Figure 5).

It was observed that pasture formations saw an increase of around 37% in the area occupied between 1990 and 2006. When comparing the years 2006 and 2022, there was a 33% reduction, resulting in a 7% drop in the area occupied between 1990 and 2022 (Figure 4).

It is possible that soybean cultivation replaced the areas previously used for grassland, temporary crops and mosaic uses, which were reduced over the period (Figures 3, 4 and 5).

Curve number values changed significantly in the TRB in the years 1990, 2006 and 2022 (Figure 6). For example, in 1990, CN values were relatively low (below 63), indicating a predominantly permeable basin, with greater soil infiltration capacity and lower runoff rates (Hawkins, 1993; Woodward *et al*., 2003; Usda-Nrcs, 2004; Hawkins *et al*., 2009). In 2006, there was an increase in the area with CN greater than 77. Finally, in 2022 around 22.54% of the basin's area had CN values greater than 77 (Figure 6), which reflects changes in land use and occupation in the region.

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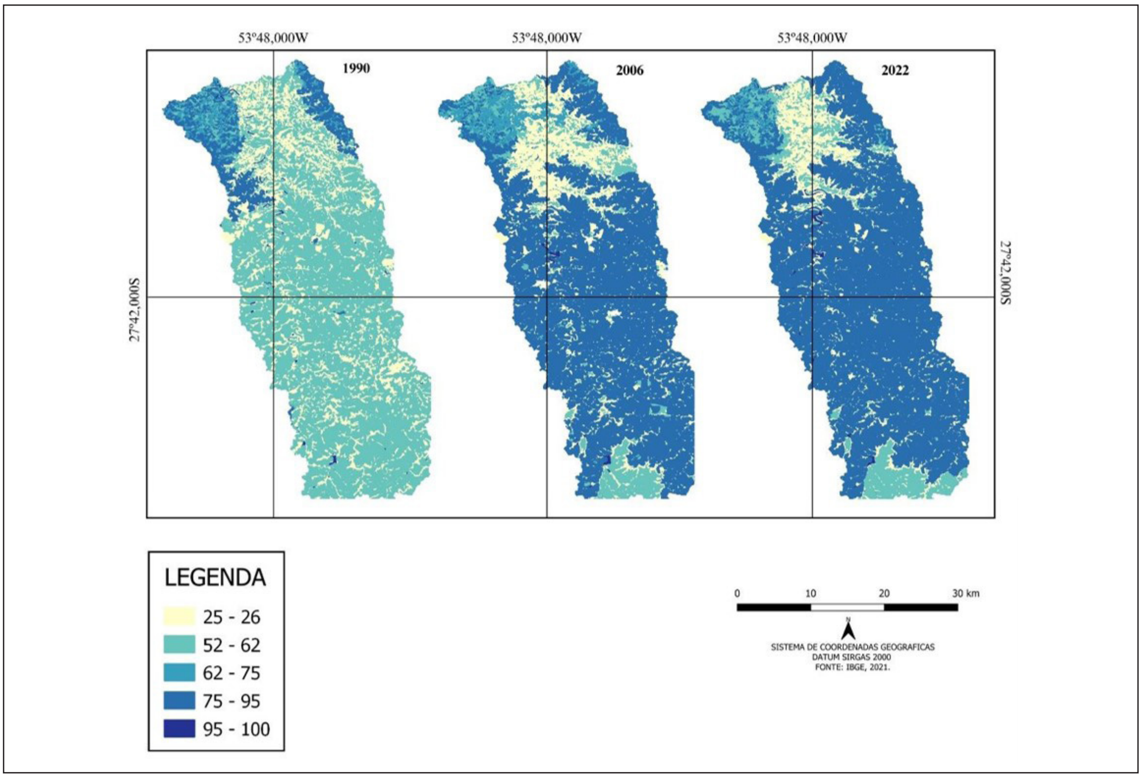
Table 2 shows the increase in CN values in the TRB over the years, as well as their respective areas.

FIGURE 6 - CN parameter in the Turvo River Basin (RS, Brasil) in 1990, 2006 and 2022.




Source: the authors (2024).

TABLE 2 - Variation of CN classes by area and percentage in the Turvo River Basin (RS, Brasil).

| CN classes | Areas (km²/%) 1990 | % | 2006 | % | 2022 | % | Change (km²) 1990-2006 | 2006-2022 |
|---|---|---|---|---|---|---|---|---|
| < 26 | 178,04 | 10,46% | 183,94 | 5,17% | 109,89 | 2,76% | 5,89 | -74,05 |
| 26 - 56 | 172,01 | 10,10% | 182,45 | 5,13% | 262,63 | 6,59% | 10,44 | 80,18 |
| 57-62 | 1238,28 | 72,72% | 2370,67 | 66,62% | 2673,50 | 67,05% | 1132,39 | 302,83 |
| 63- 77 | 24,90 | 1,46% | 41,38 | 1,16% | 42,93 | 1,08% | 16,48 | 1,56 |
| > 77 | 89,59 | 5,26% | 780,11 | 21,92% | 898,63 | 22,54% | 690,52 | 118,52 |
| CN Medium | 48,57 | | 49,21 | | 62,16 | | - | |

Source: the authors (2024).

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The results obtained indicate that the expansion of anthropogenic activities has resulted in an increase in CN values in the TRB (Figure 6), affecting the infiltration process over the years. This may be a reflection of the increase in impermeable areas resulting from the expansion of urbanization and agricultural crops, where the soil is compacted by the intensive use of large machinery and equipment. This means that part of the rainwater does not infiltrate the soil, increasing surface runoff, which can cause soil erosion problems.

As Carvalho and Rodrigues (2021) point out, the CN method is an important tool for estimating runoff rates in river basins using hydrological data. In this study, the areas with CN values higher than 77 are those occupied by urbanized areas, as well as regions where there is a combination of land use (pasture and crops). In these regions, the predominant soil is Cambissolo Háplicos Ta Eutróficos, which is characterized by steep relief, shallow depth and the occurrence of rocks (Marques *et al*. 2007). These characteristics combined make these areas very susceptible to erosion and with reduced infiltration capacity (Rios, 2011). Another important factor to consider is the significant increase in urbanization in the basin region in recent decades, which favours surface runoff processes and reduced infiltration in these areas (Medonça, 2009; Nascimento; Carvalho; Costa, 2017).

Changes in CN values have several implications for water resource management in the TRB, such as increased surface runoff. This is because as CN values increase, the infiltration capacity of the soil decreases, resulting in greater volumes of surface runoff (Oliveira *et al*. 2016). This can lead to a greater frequency and intensity of flooding, especially during heavy rainfall events. In addition, the decrease in soil infiltration reduces aquifer recharge, which can affect the availability of groundwater for human and agricultural supply (Piroli, 2015).

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Finally, there is also a reduction in water quality, since the increase in surface runoff can carry pollutants, nutrients and sediments into water bodies, which can have an impact on both the environment and public health (Barrett *et al*. 1998; Souza, 2012).

Some strategies can be adopted to mitigate the negative impacts associated with the increase in CN values in the TRB, such as: a) adopting practices such as terracing, contour planting and the use of cover crops can help reduce soil erosion and increase water infiltration; b) actions such as promoting the preservation and restoration of forested areas can improve water infiltration, reduce surface runoff and increase aquifer recharge; c) the implementation of green infrastructure, such as rain gardens, permeable sidewalks and water retention zones, can also help manage surface runoff and improve water infiltration; d) adopting an integrated management approach that considers the interactions between land use, water management and environmental conservation, with a view to developing more sustainable policies and practices for the watershed; e) promoting education and awareness programs for farmers, urban dwellers and policymakers can raise awareness about the importance of soil and water conservation; and f) establishing a system of continuous monitoring of CN values, land use and water quality to help evaluate the effectiveness of the management measures implemented and adjust strategies as necessary.

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# 4 Final Considerations

In the years 1990, 2006 and 2022 there was a progressive increase in CN values in the TRB, which is reflected in a reduction in soil permeability and an increase in surface water runoff.

The identification of the areas with the greatest potential for significant surface runoff demonstrates the urgency of soil and vegetation conservation actions in the region, especially in the face of advancing urbanization and soybean cultivation.

The results obtained have direct implications for territorial planning and water resource management, providing crucial information to mitigate the risks of erosion and surface runoff.

It also highlights the fundamental role of the CN methodology as an effective tool for assessing the impacts of human activities on hydrological processes in river basins.

For future research, we suggest continuing to monitor changes in soil cover and water quality, as well as evaluating the effectiveness of the conservation measures implemented. These results could provide input for the development of sustainable water resource management strategies in the Rio do Turvo region.

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