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Estimation and mapping of runoff potential under different land use and land cover conditions in the semiarid region of Brazil: a case study in the Riacho da Consulta Watershed, Bahia, Brazil

Estimativa e mapeamento do potencial de escoamento sob diferentes condições de uso e cobertura da terra na região semiárida do brasil: um estudo de caso na bacia hidrográfica do Riacho da Consulta, Bahia, Brasil

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Abstract

The Curve Number method is one of the most widely used methods for estimating run-off potential from rainfall events in watershed. In this study, the Curve Number parameter was estimated, spatialized, analyzed and discussed under different land cover and land use conditions. The study area is the Riacho da Consulta watershed, located in the state of Bahia, Semiarid region of Brazil. Land use and land cover data, slope data and spatial data about pedology of the study area were used. The results showed that the Riacho da Consulta watershed has an average Curve Number of 79, evidencing a watershed with high runoff potential, where areas of very high Curve Number are strongly related to land use and land cover, emphasizing the importance of conservation practices.

Keywords: Curve number. Infiltration. Land cover. Land use. Watershed. Water flows.

Resumo

O método Curve Number é um dos métodos mais usados para estimar o potencial de escoamento de eventos de chuva em bacias hidrográficas. Neste estudo, o parâmetro Curve Number foi estimado, espacializado, analisado e discutido sob diferentes condições de cobertura e uso da terra. A área de estudo é a bacia hidrográfica do Riacho da Consulta, localizada no estado da Bahia, região semiárida do Brasil. Foram usados dados de uso e cobertura da terra, dados de declividade e dados espaciais sobre a pedologia da área de estudo. Os resultados mostraram que a bacia hidrográfica do Riacho da Consulta tem um Curve Number médio de 79, evidenciando uma bacia hidrográfica com alto potencial de escoamento, onde as áreas de Curve Number muito alto estão fortemente relacionadas à cobertura e ao uso da terra, destacando a importância das práticas de conservação.

Palavras-chave: *Curve Number. Infiltração. Fluxos de água. Uso da terra. Cobertura da terra. Bacia hidrográfica.*

Introduction

The knowledge of runoff conditions is of great importance for decision-making in river basins. In the context of global climate change, this knowledge is essential to support and substantiate the formulation and implementation of public policies with an emphasis on the management and conservation of ecosystems (Avanzi; Borges; Carvalho, 2009; Santos; Vajapeyam; Srinivasan, 2007). From this perspective, it can be seen that in both national and international literature, the Curve Number method is one of the most widely used to estimate potential runoff conditions from precipitation events, given the different land cover and land use scenarios, as well as the different types and conditions of land use and cover that characterize landscapes in the regional context (Lal; Mishra; Kumar, 2019).

The Curve Number method, also known in the literature as the Curve Number (CN) Method, was developed and presented by Soil Conservation Service (SCS) of the United States of America (USA) in the 1930s, based on a great need for knowledge of hydrological processes, especially those associated with surface runoff and water storage capacity in small and medium-sized watersheds. In this context, the purpose was precisely to support managers and decision-makers in the conservation of soil and water resources. This method, characterized as being conceptual and empirical, is relatively simple to implement with just one CN parameter, making it the most widely used method for calculating runoff potential based on rainfall events (Araújo Neto *et al.*, 2012; Carvalho; Rodrigues, 2021; Hawkins, 1993; Oliveira *et al.*, 2022).

According to Anjinho *et al.* (2018), the dimensionless parameter CN ranges from 0 to 100, based on the assumption that values close to one hundred (100) represent the boundary conditions of a completely impermeable watershed, in other words, a watershed with an equal and/or practically zero water retention rate. On the other hand, the assumption for values close to zero (0) is that these areas indicate the opposite conditions: a high rate of water retention in the respective watershed, thus representing very permeable watersheds, understood that surface runoff is significantly low, regardless of the amount of accumulated rainfall recorded. Specifically, the methodology it is used to convert the volume of precipitation into the volume of surface runoff by applying the Equation 1 (Rezende; Ribeiro; Mendes, 2018; Soil Conservation Service, 1972):

$$Q = \frac{\left(P - 0{,}2\left(\frac{25400}{CN} - 254\right)\right)^2}{\left(P - 0{,}8\left(\frac{25400}{CN} - 254\right)\right)}$$

Where:

Q – Volume of rainwater runoff (mm)

P – Volume of precipitation (mm)

CN – Curve Number (dimensionless).

Given these aspects, the main objective of this study is to estimate and spatialize the values inherent to the CN parameter in different land uses and land cover conditions in a watershed located in the Semiarid Region of Brazil. Specifically, the area defined for the study comprises the Riacho da Consulta watershed (Figure 1). The justification for choosing this area is based on the fact that it is a watershed that has still been studied very little, and that it is a watershed where, although a significant part of it (83%) has natural vegetation cover (Caatinga vegetation), there is a strong occurrence of erosion processes, causing many of its continuous landscapes with natural vegetation cover, gradually, degraded and abandoned (Silva, 2023).

In the Semiarid Region of Brazil, especially in the Caatinga Biogeographic System, scientific studies about the dynamics of water resources, landscapes and the processes that lead to their degradation are extremely relevant to society as a whole, given that environmental degradation in this region of Brazil is one of the main challenges to be overcome. In this perspective, it is important to consider the challenges posed by current and future global climate change scenarios, with a significant increase in areas at high risk of desertification, significant changes in the dynamics of ecosystems and ecosystem services, the impacts on the maintenance of life and biodiversity, on the economy and, consequently, on the way of life and culture, and quality of life of the human beings who inhabit this region that, historically, has lived with various socio-economic challenges.

Methodology

Study area

The study area of this work comprises the Riacho da Consulta watershed. The area is geographically located in the Caatinga Biogeographic System and the Semiarid Climate Region, Northeast Brazil, in the north-central part of the state of Bahia (Figure 1), Chapada Diamantina Complex Ecoregion, in the interior of the municipality of Miguel Calmon, where a significant

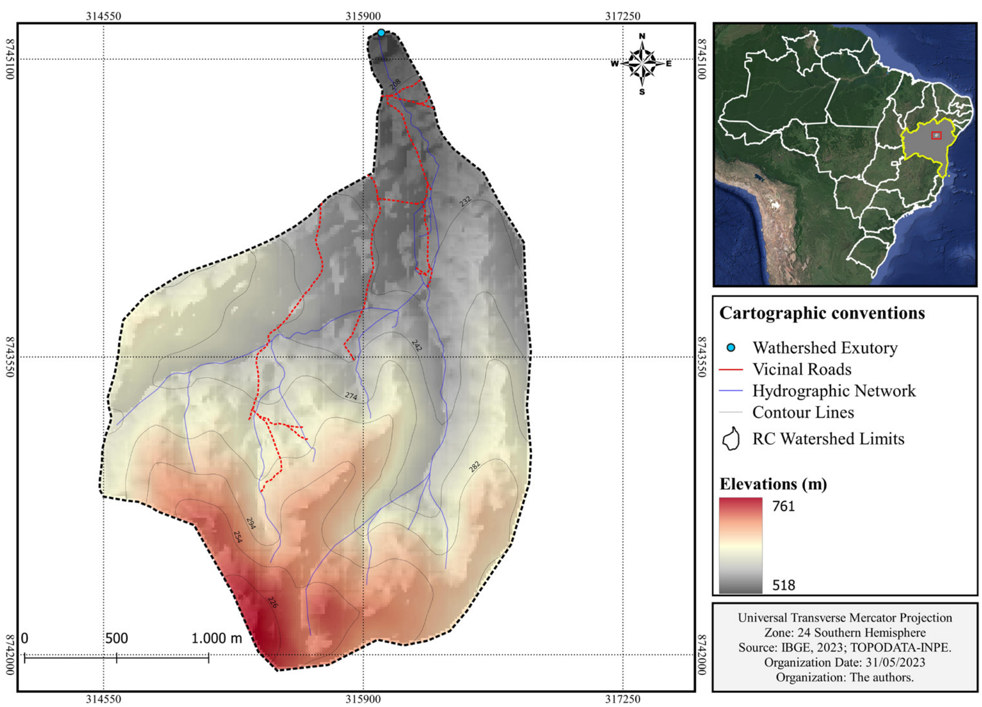

Figure 1 – Situation map of Riacho da Consulta watershed.
Source: The authors.

part of the inhabitants (10.409 inhabitants, 39.3%) live in the rural area, and one of their main socio-economic activities is raising cattle, goats and sheep, as well as other activities related to food production and marketing (Instituto Brasileiro de Geografia e Estatística, 2022). The Riacho da Consulta watershed covers an area of approximately 445 hectares and has an average altitude of around 624m, with an altimetric range of 243m. The lowest altimetric levels are 518m, especially in the north-central part of the area, where there are areas of marshland and low waters; while the highest altitudes are above 761m, occurring from the southern part of the watershed (Figure 1), in areas with predominantly undulating and strongly undulating terrain, to the southwest.

The average slope observed in the study area, measured as a percentage, is 16.1%, showing the occurrence of undulating reliefs. From the Pedology perspective, the study area is characterized by the predominance of Latossolos Vermelhos, comprising around 350.0 Ha of the total area of the watershed; followed by Neossolos Regolíticos, 38.0 Ha; Neossolos Flúvicos, 30.0 Ha; Neossolos Quartezarênicos, 25.0 Ha; and Organossolos Háplicos, 2.0 Ha. Regarding climatic conditions, the average annual rainfall and temperature in the region where the study area is located are 107.78mm and 26.9°C, respectively, showing a region where rainfall volumes are not very significant, as observed in most of the municipalities located in the Semiarid Region of Brazil.

Theoretical and methodological approach

With regard to the theoretical and methodological framework of this study, it should be noted that the spatial data used was acquired as follows: the data relating to the pedology that occurs in the study area was collected and specialized by Silva (2023), by successive in loco activities; the Digital Elevation Model data was acquired in the website TOPODATA – Geomorphometric Database of Brazil, within the scope of the National Institute for Space Research (INPE), with a spatial resolution of 30m; the land use and land cover data was acquired using Digital Image Processing (DIP) from high spatial resolution (10m) satellites, specifically, images from the Multispectral Instrument (MSI) sensor system on board the Sentinel 2. The delimitation of the Riacho da Consulta watershed and the extraction of its respective hydrographic network took place using the environment Geographic Information System (GIS), using the software QGIs, version 3.22 Biatowieza.

The CN methodology, developed and presented by Soil Conservation Service, classifies soils into four (4) large groups, according to their infiltration capacity and production of surface runoff, classified as A, B, C or D, representing an increase in runoff in the same order (Anjinho *et al.*, 2018). The classification of the hydrological groups inherent to the soils that occur in the study area followed the guidelines described in Sartori, Lombardi Neto and Genovez (2005), where soils belonging to hydrological group A include very deep soils (> 200cm), with a high infiltration rate and resistance and tolerance to erosion, porous soils with a low textural gradient (<1.20), medium texture, for the most part, including well-drained soils, or excessively drained soils. In the specific case of the study area, it is observed that the latter group is mainly associated with water bodies.

Soils belonging to group B, in turn, are deep soils (100 to 200cm), with a moderate in-filtration rate, resistance and tolerance to erosion, moderately porous soils with a textural gradient varying between 1.20 and 1.50, sandy texture throughout the profile or medium texture. Group C soils are described as being deep (100 to 200cm) or shallow (50 to 100cm), with a low infiltration rate and low resistance to erosion. These are soils with a textural gradient greater than 1.50, mainly associated with low activity clay (Tb). Finally, soils of group D are soils with a very low infiltration rate, offering very little resistance to erosion, shallow soils (<50cm), shallow soils associated with abrupt textural changes, clayey soils associated with high activity clay (Ta), mostly organic soils.

In addition to the physical-structural, chemical and biological properties inherent to the soils that occur and characterize the landscape of a given region, citing the example of the area under study, as well as its relationship with the layout of the relief (slope); the coverage and use of the land and its respective spatial-temporal dynamics, also exerts a strong influence on its protection and potential for infiltration and/or surface runoff, having a direct repercussion on surface runoff (Botelho, 1999). In this sense, the land cover and land use data are the results of supervised classification of Sentinel 2 images, as mentioned above, dating from April and September 2021, with a Kappa coefficient of 0.92 and 0.93 for these months respectively.

It is important relevant to describe that the data describing the slope of the study area has also been incorporated into this analysis of runoff potential. According to Villela e Mattos (1975), the slope of the land it is strongly related to the occurrence of erosion processes, as it is a factor that has a direct influence on the speed at which water moves through surface run-off. In this sense, the different aspects related to physical-environmental factors in the context of the study area help to understand the environmental characteristics that characterize the respective watershed, as well as corroborating the understanding of the dynamics of land cover and land use, especially the latter. For example, Silva (2023) emphasizes that areas mapped as bare soil in the context of Riacho da Consulta watershed are strategically prioritized for the implementation of sustainable and conservationist practices, considering that these areas are the most vulnerable to desertification.

Results and Discussion

On Figure 2 it is presented the maps for altitude, slope, land use and land cover, and the different soil classes that occur in the context of the study area, Riacho da Consulta watershed. With specific regard to pedology, five (5) soil classes can be observed throughout the Riacho da Consulta watershed: Latossolos Vermelhos and Neossolos Flúvicos, both classified in hydrological group B, totaling approximately 380 hectares, 85% of the watershed's total area; Organossolos Háplicos, classified in hydrological group C, comprising around 1.84 hectares, 0.4% of the study area; Neossolos Regolíticos and Neossolos Quartzarênicos, falling into hydrological group D, occupying around 62.73 hectares, 14.6% of the total area of the Riacho da Consulta watershed.

The most part (78.6%) of the study area is characterized, pedologically, by the occurrence of: Latossolos Vermelhos, well-developed, deep and drained soils; Neossolos Regolíticos (8.6%), especially in the north and west, these soils are poorly developed, sandy in texture and highly erodible; followed by the Neossolos Flúvicos (6.8%), associated mainly with valley bottoms and intermittent streams, areas that have moderate and/or high availability of water in the soil profile for a large part of the year, contributing to groundwater levels, not by chance, since the presence of typical and/or common species in the dense phytophysiognomies of the Caatinga is common; Neossolos Quartizarênicos (5.5%), these soils are also poorly developed and sandy; and finally the Organossolos Háplicos (0.4%), occurring in the form of a discontinuous patch in the extreme north of the study area, associated with the floodplain area.

The mapping of land use and land cover (Figure 2) shows the different aspects inherent to natural and anthropogenic factors on a landscape scale in the Riacho da Consulta watershed. Land cover conditions are evidenced by the occurrence of the different phytophysiognomies characteristic of the Caatinga's natural vegetation cover. Specifically considering the Dense Caatinga phytophysiognomies, which comprise only 5.1% of the watershed's total area, it can be

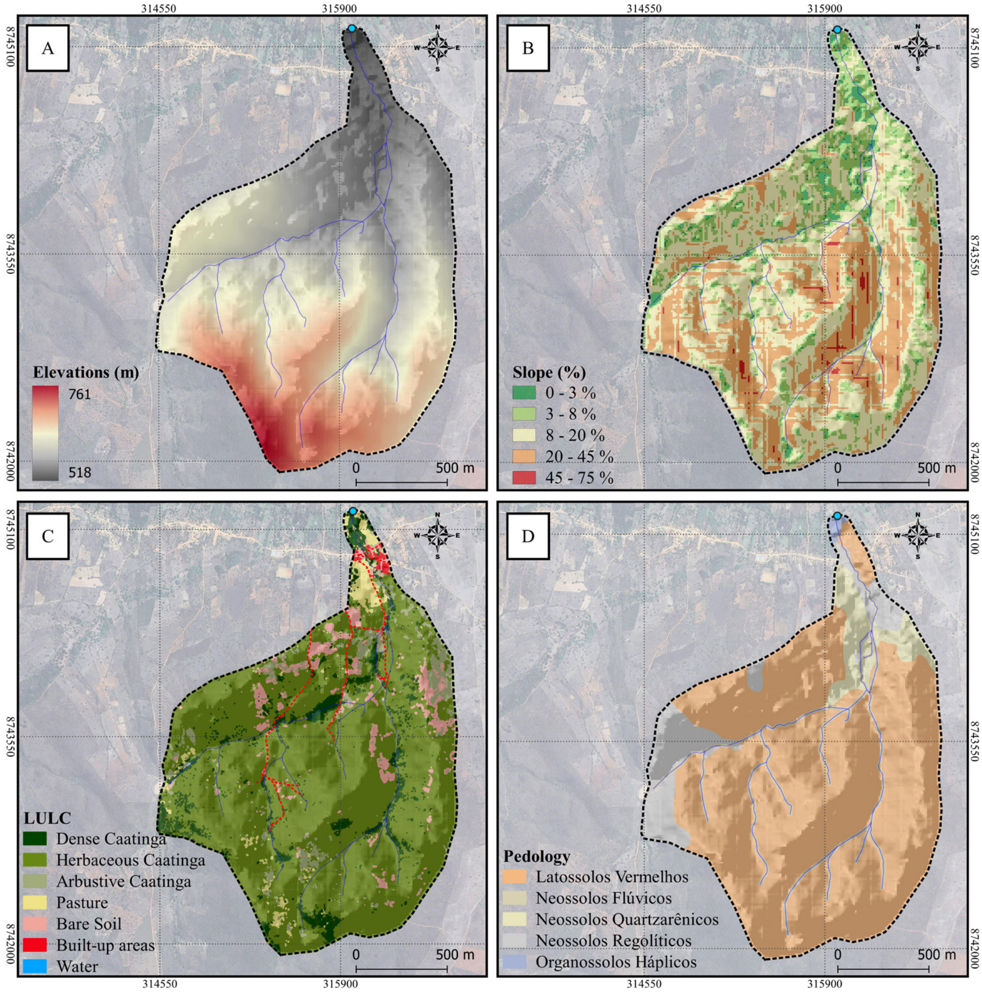

Figure 2 – A) Hipsometic, B) slope, C) land use and land cover, D) Pedology in the Riacho da Consulta watershed.
Source: The authors.

seen that these are mostly associated with valley bottom areas, occurring mainly in the central portion of the watershed, areas whose hypsometric classes vary between 518 and 609 meters in altitude, where one can also observe the fragmentation of continuous landscapes with natural vegetation for land use by pastureland.

Areas covered by Caatinga Herbaceous and Caatinga Arbustive phytophysiognomies occupy around 84.0% and 4.3%, respectively, of the watershed, with the latter (Caatinga Arbustive phytophysiognomies) contrasting most with areas of exposed soil, which comprise 3.4% of the study area, mainly associated with Latossolos on gently undulating reliefs. From the terrain slope map in the context of the study area, it can be seen that the average slope observed is 16.1%, characterizing undulating reliefs. On Figure 3 it is presented the spatialization of CN in the study area. As can be seen, areas with high CN values predominate, showing a watershed with high runoff potential and low infiltration capacity.

In agreement with another studies (Silva, 2023), who points out that the Riacho da Consulta watershed is highly susceptible to erosion and that the areas with a predominance of undulating (8-20%), strongly undulating (20-45%) and mountainous (45-75%) terrain comprise areas with restricted use by human activities and need to be effectively earmarked for the conservation of fauna and flora in the context of the study area; Figure 3 shows that the areas used for human

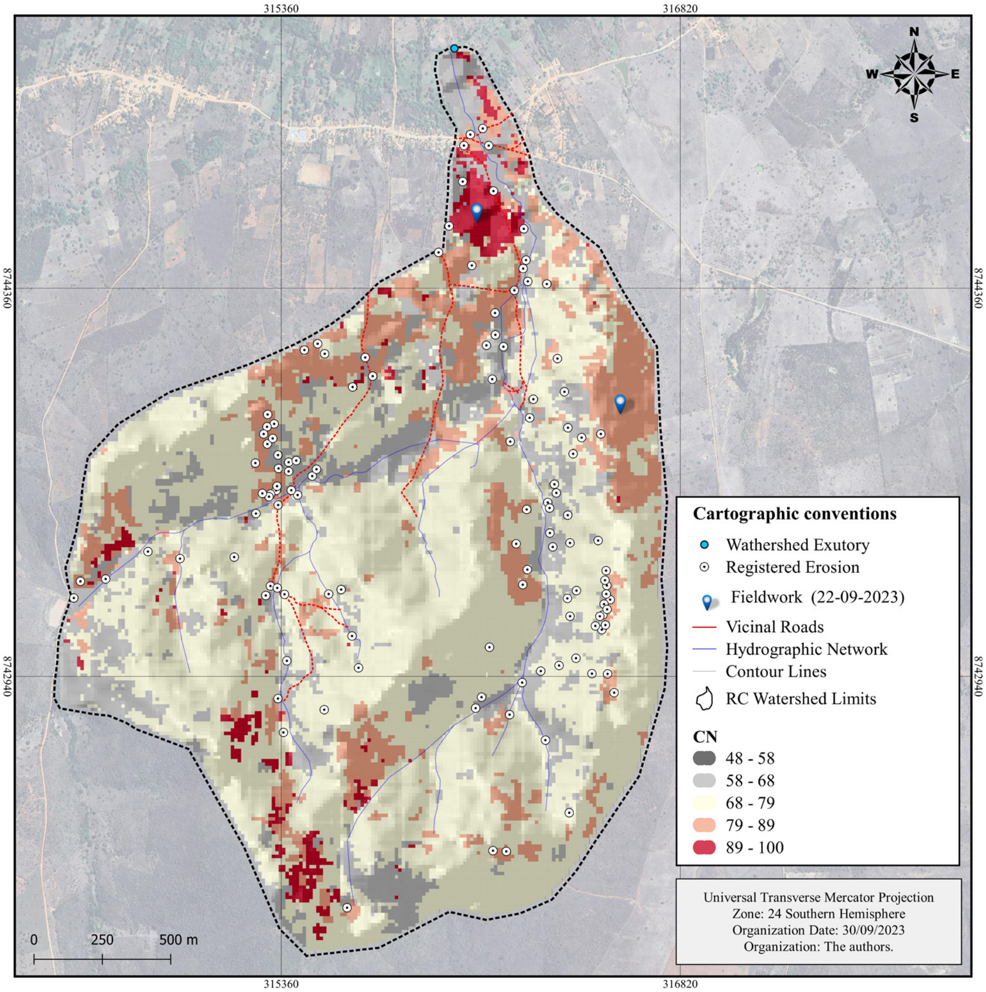

Figure 3 – Curve Nuber spatialization in the Riacho da Consulta watershed.
Source: The authors.

activities are slightly associated with areas with high runoff potential, demonstrating the potential impacts of a possible increase in these areas on water resources in the Riacho da Consulta watershed.

As can be seen in Figure 3, the average NC observed for the entire study area was 79, showing that the Riacho da Consulta watershed has high runoff conditions. Specifically, it can be seen that the predominance of areas with high CV values occurs spatially throughout the watershed, mainly in its northern and northeastern and southwestern portions, respectively. As shown in Figure 3, from fieldwork carried out on September 22nd (09) of the year 2023, Figure 4 shows a record of the landscape in an area with high runoff potential, located in the northeastern portion of the study area.

As can be seen (Figure 4), this is an area in an advanced stage of soil degradation (Latossolo Vermelho), located in the interfluve to the northeast of the watershed. Although this area has these conditions, it is important to note that, during the dry season (July to November), it is often used for grazing by livestock farmers, due to the fact that pasture areas in the region are practically exhausted by this time. It is important to understand that, this practice further accelerates the process of soil degradation in these areas and, as Silva (2023) proposes, these areas are more suitable, from a land use perspective, for biodiversity conservation.

Figure 4 – Recording the landscape in an area with high runoff potential in the Riacho da Consulta wa-tershed.
Source: The authors (2023).

Figure 5, which is also the result of fieldwork carried out on September 22nd (09) 2023, shows a second record of the landscape in another area that also showed high runoff potential, located in the northern portion of the Riacho da Consulta watershed. Similarly to what was observed in Figure 4, the landscape in question (Figure 5) shows that land use is geared towards farming activities, with degraded pastures and a predominant presence of species commonly found in environments covered with Arbustive Caatinga.

Figure 5 – Recording the landscape in an area with very high runoff potential in the Riacho da Consulta watershed.
Source: The authors (2023).

The preferential corridors commonly seen in cattle (Figure 5), goat and sheep grazing areas can be seen, highlighting the process of soil compaction, a process which directly limits the infiltration of rainwater and increases the potential for surface runoff. Soil compaction is an easily identified process in cultivated pasturelands and is quickly related to the practice of overgrazing, highlighting the lack of good management practices, which in the short, medium and long term can lead to the degradation of these areas. Thus, in both landscapes visited through fieldwork, comprising areas with high runoff potential, human interventions in ecosystems were identified. As mentioned above, neglecting good management practices where these activities take place can jeopardize the ecosystem balance of the watershed.

Conclusion

By estimating and spatializing the values inherent in the CN parameter, an analysis was carried out of the potential runoff conditions in the Riacho da Consulta watershed, considering different land cover and land use conditions. The average CN value observed for the entire watershed was 79, showing that the potential for surface runoff in the Riacho da Consulta watershed is high.

On the other hand, it shows that the Riacho da Consulta watershed has significant restrictions in terms of water infiltration into the soil, which can trigger other processes that impact the soil, water resources, biodiversity, ecosystem services and the culture of the inhabitants who have historically had links with the area. Furthermore, it is understood that the absence of conservation practices in the watershed can accentuate the challenges related to erosion processes, for example, with the consequent loss of soil and silting up of its water resources.

About the potential for surface runoff in relation to the dynamics of land use and land cover conditions, this study showed that land use areas have higher CN values than land cover areas, thus demonstrating a high potential for surface runoff in the former and a low potential for surface runoff in the latter, even though the conditions and properties of the soils in the areas where the latter occur are not favorable to infiltration. In this sense, it is important to carry out fieldwork to validate the results and, above all, the processes that help to understand and explain the high runoff potential in the study area.

It also highlights the importance of implementing conservation practices in the context of the Riacho da Consulta watershed and, above all, practices aimed at proper soil management, especially in areas used for grazing activities. It is hoped that future studies will contribute to soil loss in the Riacho da Consulta watershed. Similarly, other studies should investigate the importance of forest fragments for the implementation of an ecological corridor in the context of the watershed in question.

The results found, presented and discussed within the scope of this study can support the formulation and implementation of public policies with an emphasis on conservation practices in the context of the area under study, for example, supporting the definition of areas of restricted use by human activities in the Riacho da Consulta watershed.

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