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Spatial Variability Losses of Soil Watershed Basins for Water Catchment of the Goias State

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ABSTRACT

The changes in land use in Goiás state due to the advancement of agriculture and livestock have caused a major influence on soil losses. This study identified the potential soil loss in the state and alone in 183 watershed basins for water catchment in the state of Goias using the universal soil loss equation (USLE), and their R, K, LS, and CP factors were obtained by geoprocessing tool. The results generated a scenario where most of the area of the state, 77.6%, shows weak erosive sensitivity, 8.5% moderate, and 6.9% erosive susceptibility with high erosive susceptibility. Concerning soil loss of funding basins it was found that twelve basins showed very high class and two in severe erosive susceptibility, 64% of the basins were framed with low and moderate erosive susceptibility. Thus, the use of USLE in conjunction with the Geoprocessing tool was effective in the spatial representation of soil loss, identifying areas most vulnerable to the erosion process, and assisting in proposing priority measures for soil conservation.

Keywords: soil loss; USLE; geoprocessing; sources of funding.

INTRODUCTION

The process of economic globalization and the emerging world economic order have driven a model of appropriation of the natural environment that results in increasing levels of exploitation of natural resources. Constantly developing economic activities have led to transformations in space, with a significant reduction in natural areas. As a result, the environment faces significant negative impacts (Soares and Martins, 2021). According to Saraiva et al. (2019) the dynamics of soil erosion are characterized as a cyclical and balanced process, playing an important role in the transformation of landscape modeling. However, anthropogenic influence due to intensive land use has resulted in continuous changes to the balance of the erosion cycle, intensifying the loss of soil materials.

Research aimed at understanding the factors that condition erosion and, consequently, soil loss in basins, is relevant for the planning and management of water resources, as it helps in the search for measures to mitigate the consequences of sediment production, transportation, and deposition. In this way, the universal soil loss equation (USLE) by Wischmeier and Smith (1978) is a notable example of prognostic modeling for estimating soil loss through erosion and sediment disposal. The USLE is a tool that enables the quantitative assessment of areas with different degrees of susceptibility to erosion, whether in studies applied to the watershed or in soil experiments. Geotechnologies have also played an important role in this context, especially remote sensing and geographic information systems (GIS) (Silva and Luchiari, 2016).

These tools represent crucial resources for studying soil degradation through erosion. As a result, studies focused on the mechanisms of soil degradation by erosion are of significant importance in diagnosing the factors with the greatest erosive potential. These factors can be estimated by applying USLE and geoprocessing in their various applications (Silva and Luchiari, 2016). According to Silva et al. (2021), when carrying out a historical analysis from 1998 to 2018, it was found that the capital of the state of Goias has a reduced vulnerability concerning soil loss, registering average values of approximately 2 $ton \cdot ha^{-1} \cdot year^{-1}$. This situation is a direct result of the conversion of the original vegetation into pastures or agricultural areas, which leads to an increase in soil erosion rates. This process intensifies soil exposure, promoting a notable increase in the speed of surface runoff.

The state of Goias is a region intensely occupied by agriculture and pasture, with a large presence of soils with high erodibility, such as cambisols, neosols, gleysols, and argisols, increasing the risks of degradation of the areas and representing a worrying scenario, which leads to the need for research that seeks to identify vulnerable areas, as a way of prioritizing the specific conservation areas of the basins and the adoption of more restrictive conservation practices.

With this in mind, this study aimed to estimate soil loss by applying the USLE to the entire state of Goias and, in isolation, to 183 water catchment basins in the state, using geoprocessing tools to relate rainfall erosivity to soil erodibility, the relief characteristics, land use and occupation and conservation practices, to better draw up maps classifying the watersheds studied according to their potential for soil loss, thus highlighting those that require priority soil conservation measures.

MATERIALS AND METHODS

Study area

The state of Goias is located in the center-west region of Brazil, with an estimated population of 7,055,228 inhabitants (IBGE, 2022) distributed in 246 municipalities, which are grouped into five large mesoregions, center, south, northwest, north, and east. The state stands out for its population growth, which has increased by approximately 1,053,439 inhabitants compared to 2010 data. Most of the population lives in the Centro Goiania mesoregion, where the city of Goiânia, the state capital, is located. However, population growth also stands out in the regions surrounding Brasília, in the East Goiano mesoregion, and the city of Rio Verde, located in the South Goiano mesoregion (IBGE, 2022). Almost the entire state of Goias, 70% of the area, is part of the Cerrado Biome and three major river basins, the Tocantins-Araguaia, Parana, and São Francisco (ANA, 2020). The Cerrado contributes surface water resources to eight of the 12 hydrographic regions established by the National Water Resources Council (CNRH). This situation places Goias in an important scenario for the distribution of water resources in Brazil.

The state of Goias has a predominantly tropical climate, characterized by rainy summers and dry winters. The majority of rainfall, around 95%, occurs between the months of October and April, while the period of lowest rainfall is from May to September. Average annual temperatures range from 23 ºC in the far north to 20ºC in the south of the state. During the driest months, such as August and September, it is common to see thermometers marking temperatures of around 34 ºC. The coldest period of the year, which includes June and July, has an average of 12 ºC, with this thermal sensation being more pronounced in the southeastern and southwestern areas of the state (Goias, 2019).

Land use mapping, based on Landsat/TM-5 images taken in 2020, shows that 64.07% of Goias territory is occupied by anthropized areas, 45.28% of which is pastureland, 18.78% agriculture, 32.99% of the territory is covered by remaining vegetation, and 1.40% of Goias territory is covered by urban areas and large bodies of water (IBGE, 2023). Most of this remaining native vegetation is found in the north-east of Goias and there is a great deal of agriculture and pasture in the south of Goias, where few areas are covered by remaining native vegetation. In central Goias, there is little native vegetation, but there are large urbanized areas, agricultural areas, and pastures.

In the east of Goias is the area around the Federal District, where urban occupation is very significant and pastureland predominates, with few areas of agriculture or remaining vegetation. In the north of Goias, the areas occupied by native vegetation stand out, but it is also possible to see extensive areas of pasture. In the northwest of Goias, pasture areas are predominant, with few agricultural areas and very fragmented native vegetation. Figure 1 shows the land use map of the study area.

The main forms of land occupation in Goias, agriculture, and livestock, position the state favorably in terms of its economy. According to Goias (2019), agriculture continues to be the state's main economy, with an approximate production of 22.815 million tons of grain, representing 9.5% of national production. Goias' highly expressive

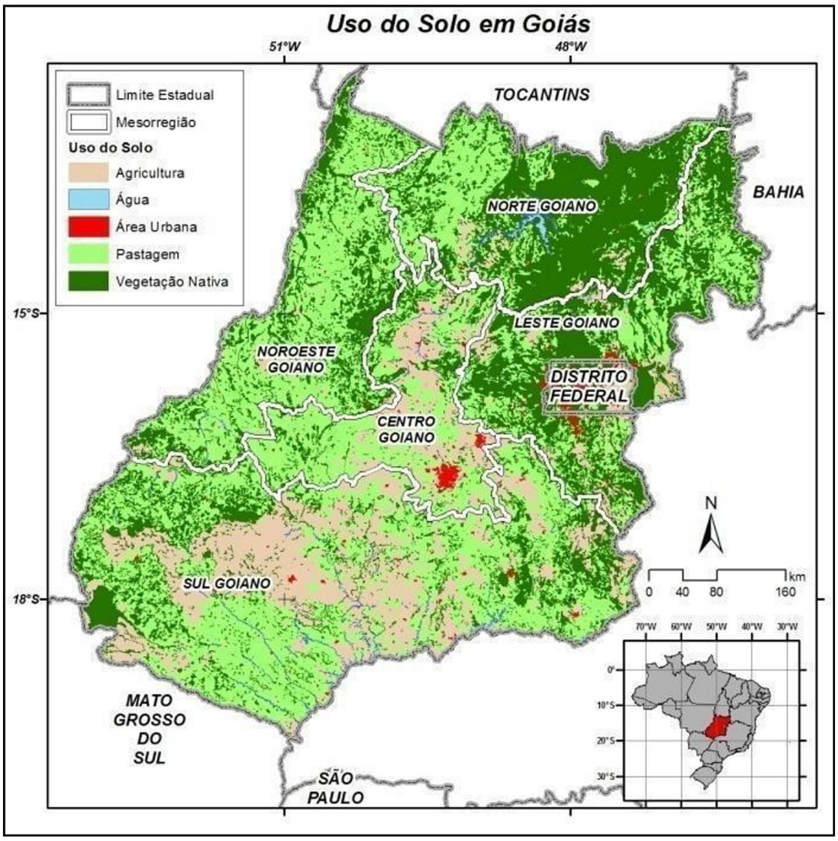

Figure 1. Catchment areas for public water supply in municipalities in the state of Goias

livestock sector places the state among the largest producers in the country. The industrial sector in Goias is diversified, with a focus on food, beverages, pharmaceuticals, mining, and alcohol production, with the state of Goias being the second largest ethanol producer in Brazil.

The water supply system in the state is operated in part by the State Sanitation Company (SANEAGO), and in part by the municipalities themselves. Around 84.53% of the total population of Goias has access to water supply services, while the population that has access to sewage services totals 74.99% (Instituto Água E Saneamento, 2021). All 183 watersheds studied in this work are SANEAGO public supply watersheds, which supply 177 municipalities. The areas of the basins vary from 0.075km, as in the case of the catchment that supplies the municipality of Adelândia, to 12,129.26 km², the basin that supplies the municipality of Caçu.

Study area

The watersheds were delimited in this work using the ArcGIS 10.1 computer program and adopting the coordinates of the water catchment points as the basins' headwaters. Soil losses were estimated using the USLE proposed by Wischmeier and Smith (1978) (Equation 1).

$$A = R \times K \times LS \times CP \tag{1}$$

where: A – average annual soil loss rate ($t \cdot ha^{-1} \cdot year^{-1}$); R – rainfall erosivity factor ($MJ \cdot mm \cdot ha \cdot h^{-1} \cdot year^{-1}$); K – soil erodibility factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$); LS – topographic factor (dimensionless); C – crop management factor (dimensionless); P – conservation supporting practice factor (dimensionless).

There are currently several models for estimating soil loss, of which the universal soil loss equation (USLE) is one of the oldest and most widely used. There are models derived from the USLE such as the revised universal soil loss equation (RUSLE) and the modified universal soil loss equation (MUSLE). Although these models are more accurate, they also require more detailed input variables. As this study is for the entire state of Goiás, intending to produce qualitative mapping, and as there are no variables with the necessary detail to use the RUSLE or MUSLE models, we opted for the USLE model. In addition, (Djoukbala, et. al., 2019) obtained relatively similar values when comparing the three models applied in Wadi Gazouana North-West of Algeria.

To apply the universal soil loss equation (USLE) using a geographic information system, it is necessary to organize a geographic database with altimetric data, rainfall data, soil data, land use and cover data, and data on conservation practices. The altimetry dataset was produced under the Topodata project by the National Institute for Space Research (Valeriano and Rossetti, 2011). Using an altimetry dataset from the Shuttle Radar Topography Mission (SRTM) project, with a spatial detail of 90 meters, the Topodata project applied geostatistical techniques, producing an altimetry dataset with a spatial refinement of 30 meters. According to (Monari; Segantine and Silva, 2022) the Topodata dataset has quality compatible with the 1:100,000 scale, which is appropriate for regional analysis. These data were selected through a process of eliminating spurious data (depressions or protrusions), using the filling algorithm, which detects the points of depressions and protrusions, and then calculates an average value, based on values neighboring the spurious point (Planchon and Darboux, 2001).

USLE for estimating soil loss using geotechnical tools

The precipitation erosivity (R) value for the watersheds studied was calculated using continuous records of the historical rainfall series (millimeters·per·day^{-1}) provided by the Tropical Rainfall Measuring Mission (TRMM). This is satisfactory in terms of reliability (Nobrega et al., 2008). It is applicable in studies aimed at hydrological purposes, especially in Brazil (Collischon et al., 2007; Nobrega et al., 2008). Erosivity is obtained by applying Equations 2 and 3.

$$R = \sum_{i=1}^{12} = EI_{30i} \tag{2}$$

So:

$$EI_{30i} = 67{,}3555\left(\frac{r^2}{P}\right)^{0{,}85} \tag{3}$$

where: $EI30$ – monthly average of the erosivity index; r – monthly average rainfall; P – average annual rainfall; i – index of months; R – erosivity.

Estimates of daily accumulated rainfall were obtained for the year 2012 with a resolution of 0.25 × 0.25 degrees. The K soil erodibility values were obtained using data from the literature proposed by Silva and Alvares (2005), as shown in Table 1. The authors of this research compiled information from various scientific papers to structure a database and determine the average values (arithmetic means) of erodibility for each soil class.v The ramp length factor (LS) was determined by processing the altimetry data obtained from the Topodata/INPE project, using the Moore and Burch (1986) model proposed by Shiferaw (2011) and Silva (2014), using Equation 4.

$$LS = \left(\frac{accumulated\ flow\ x\ cell\ size}{22{,}13}\right)^{0{,}4} \times \times \left(\frac{sin(declivity)}{0{,}0896}\right)^{1{,}3} \tag{4}$$

To determine the use and occupation of the land in the basins, we used the map of land use and vegetation cover of the state of Goias, drawn up under the MapBiomas initiative, based on the processing of Landsat/TM-5 images from 2011. According to (Souza et al., 2020), this mapping has a global accuracy of 83.19%. The methodology proposed by Baptista (2003) was then applied, in which the land use and occupation classes are correlated with the integrated C and P factors, becoming CP. In the land use and occupation map, the classes were associated with CP values predetermined in the methodology adopted by Baptista (2003) (Table 2).

Table 1. Erodibility values for major soil groups

Major soil groups	Erodibility (ton·h·MJ^{-1}·mm)$^{-1}$
Argisols	0.01990
Cambisols	0.0182
Chernosols	0.0104
Spodosols	0.0248
Gleissols	0.0279
Latosols	0.0043
Neosols	0.0127
Nitosols	0.0091
Organosols	0.0124
Planosols	0.0134

Source: Silva and Alvares (2005).

USLE calculation

All the USLE factors were mapped for the entire geographical area of the state of Goias, thus producing maps of erosivity (R factor), soil erodibility (K factor), slope length (LS factor), and land use and occupation classes, combined with conservation practices (CP factor). These maps were digitally stored in a matrix structure, with a spatial

Table 2. CP values for land use and occupation classes

Land use and occupation	CP
Consolidated urban space	0.0
Agriculture	0.12
Pasture	0.055
Cerrado	0.0007
Seasonal Forest	0.00004
Sandbank	1.0

Source: Baptista (2003).

Table 3. Erosive susceptibility based on USLE

Erosive susceptibility	$ton{\cdot}ha^{-1}{\cdot}year^{-1}$
Weak	0–5
Moderate	5–10
High	10–20
Very high	20–40
Severe	40–80
Very Severe	> 80

Source: Perovic et al. (2013).

resolution of 30 meters. Then, using computer map algebra tools, all the components of the USLE were multiplied, resulting in a soil loss map for the entire state of Goias, in which each cell, with a spatial resolution of 30 meters, has a soil loss value calculated. Subsequently, through zonal operations, the area of each delineated watershed was integrated with the soil loss map for the state of Goias, obtaining an average value for each of the 183 watersheds studied, from which maps were drawn up using coloring within the set of watersheds. The values obtained were classified according to the levels of susceptibility to erosion proposed by Perovic et al, (2013), as can be seen in Table 3, which also made it possible to evaluate the results obtained for soil loss with susceptibility to erosion.

RESULTS

The first result obtained was a map of the water catchment areas in the state of Goias, for which SANEAGO is responsible for water treatment and municipal public supply. There are 183 catchments, several of which overlap (Figure 2). In all, the catchment areas occupy a significant

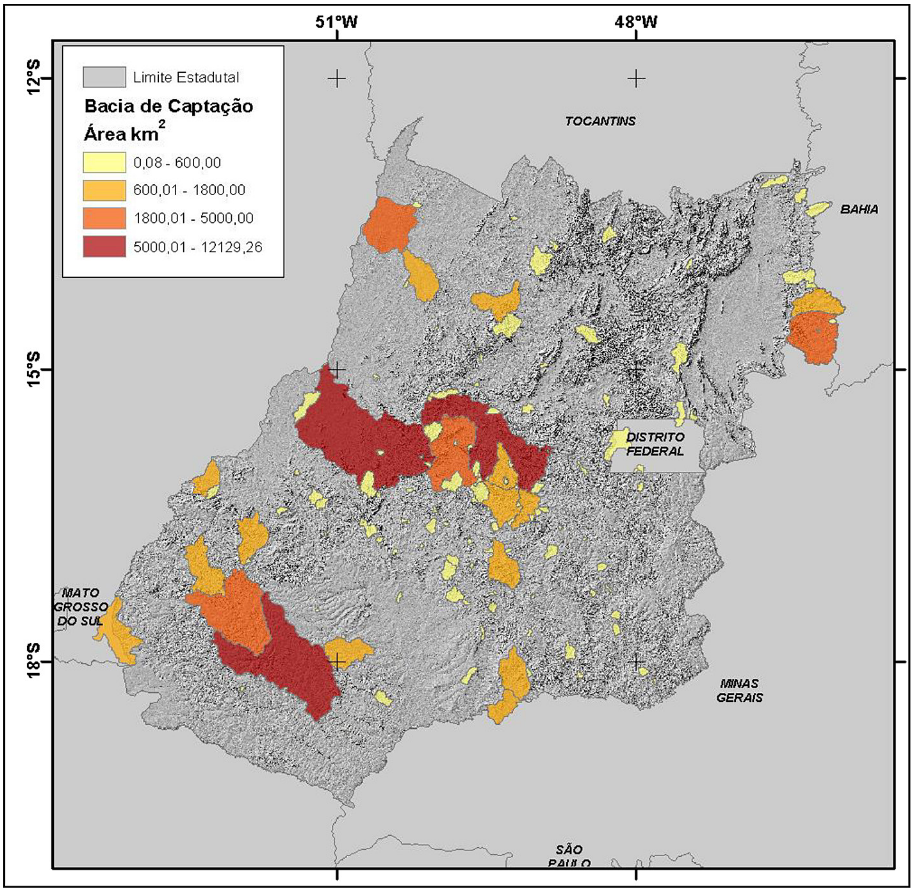

Figure 2. Catchment areas for public water supply in municipalities in the state of Goias

area of the state of Goias, 64,071.75 km^2, or 18.8% of the state's area. Many catchments occupy areas in several municipalities.

The heterogeneity of catchment areas is one of their characteristics, ranging from a few to many square kilometers. In general, the size of the catchment is related to the location of the catchment point, which has been adopted as the outlet in the process of delimiting the catchments. After delimiting the catchments, the R, K, LS, and CP factors used in the USLE were mapped (Figure 2).

The erosivity mapping (Figure 3a) showed that the northwestern part of the state of Goias has the highest rainfall rates, while the southeastern and northeastern parts have the lowest erosivity. Due to the predominantly low-declivity terrain throughout the state, the greatest ramp lengths identified are in the northern part of Goias and the region surrounding the Federal District, with significant portions of land in the northwest, northeast, and south of the state where ramp lengths are practically zero (Figure 3b). Concerning soil cover and conservation practices (CP), the highest values found (Figure 3c) coincide with areas occupied by agriculture (red color), followed by pasture areas (orange color), then areas covered with native vegetation (light green color), and finally zero values were found in urbanized areas and water bodies (dark green color). This study showed that several of the water catchment areas in Goias, especially those located in the southern and central portions of the state, have been under intense anthropogenic pressure as a result of farming activities and urbanization. As shown in the land use mapping that was included in the universal soil loss equation.

The soil erodibility map (Figure 3d) shows that there are significant portions of the state of Goias where cambisols, neosols, gleissols, and argisols predominate, with the highest erodibility values, which are shown on the maps in orange and red. On the other hand, planosols, latosols, and plinthosols, in green, are the soils with the lowest erodibility values. By multiplying the mappings of the USLE factors, the susceptibility to erosion of the state of Goias was mapped, as shown in Figure 4. Most of the area of the state

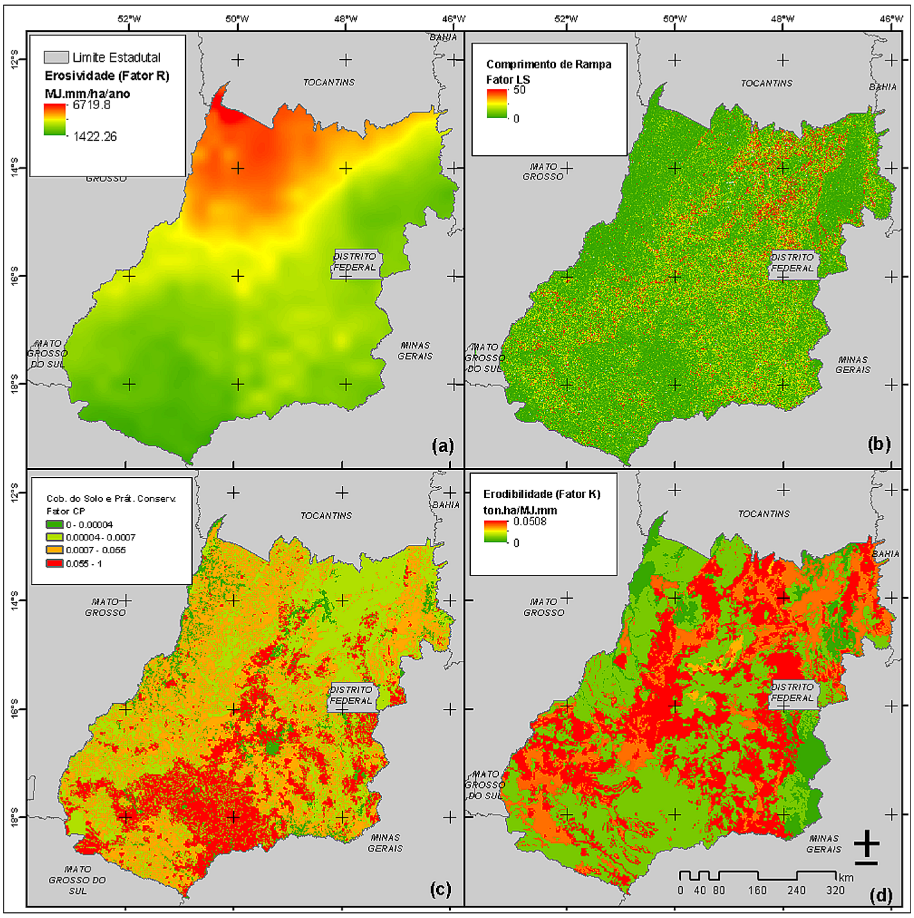

Figure 3. Mapping of the factors used to calculate the USLE, (a) erosivity, (b) slope length, (c) cover and conservation practices, and (d) soil erodibility

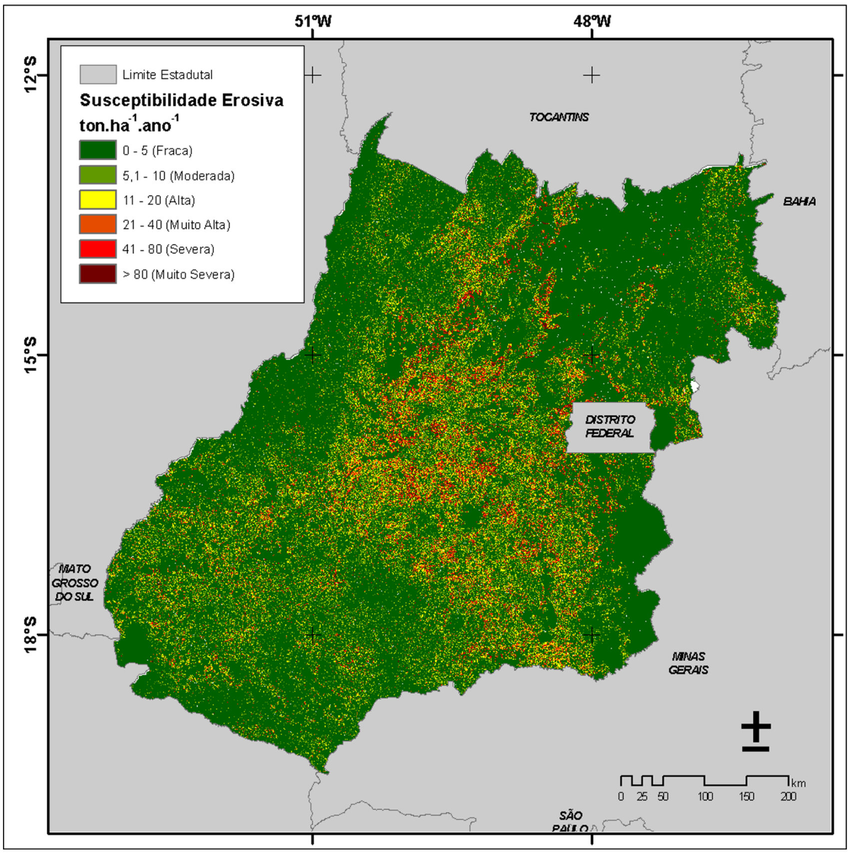

Figure 4. Map of erosion susceptibility in Goiás

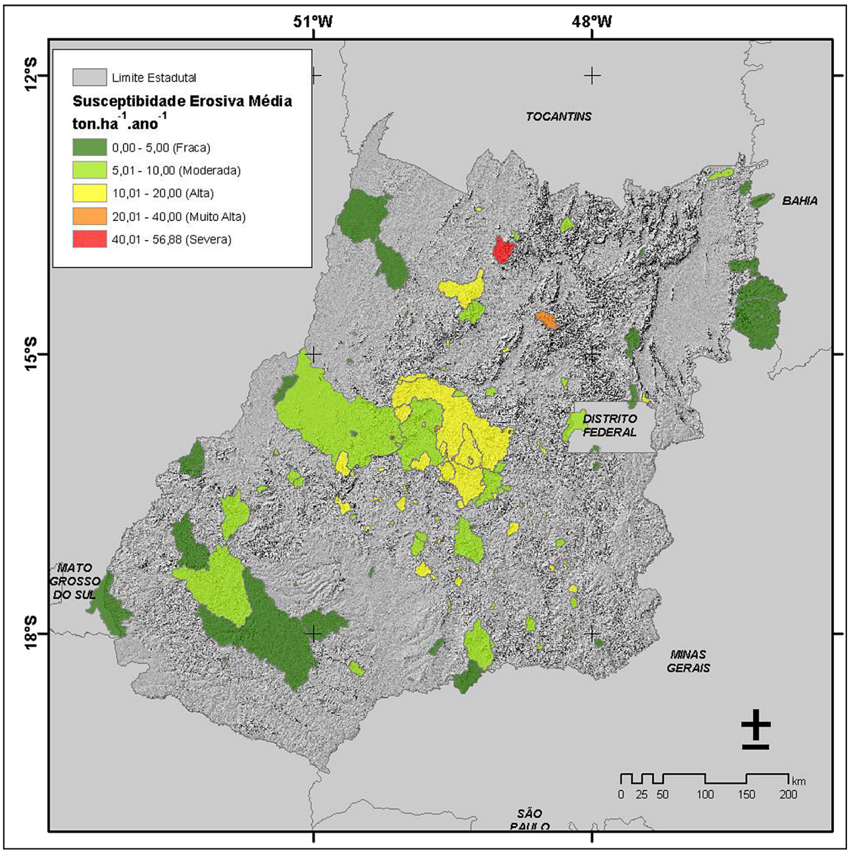

Figure 5. Average erosion susceptibility of catchments

of Goias, 77.58% of the area, according to the application of the USLE, has a soil loss of less than or equal to 5 ton·ha^{-1}·year^{-1}, therefore with low erosion susceptibility. In the case of moderate erosion susceptibility, where soil loss can vary from 5 to 10 ton·ha^{-1}·year^{-1}, only 8.5% of the state's area falls into this category. Places with soil loss of between 10 and 20 tons·ha^{-1}·year^{-1}, with high erosion susceptibility, total 6.91% of the area of the state of Goias. Only 4.31% of the area of the state of Goias has soil loss ranging from 20 to 40 tons·ha^{-1}·year^{-1}, with very high erosion susceptibility, followed by areas with severe erosion susceptibility (between 40 and 80 tons·ha^{-1}·year^{-1}), occupying 1.92% of the area of the state, and the rest of the area of the state of Goias, 0.76%, with very severe erosion susceptibility, with soil loss exceeding 80 tons·ha^{-1}·year^{-1}. Through a zonal analysis between the map of water catchment areas (Figure 5) and the map resulting from the USLE (Figure 5), the average soil loss in each water catchment area in Goias was calculated, which is shown in Figure 2 according to the classification of erosion susceptibility proposed by Perovic et al. (2013). As the zonal analysis was applied individually to each of the catchments, the fact that some of them had spatial overlaps did not affect the final results.

DISCUSSION

The results obtained in this study showed that most of the catchments had low and moderate erosion susceptibility, which is closely related to the low-slope terrain throughout the state. In the catchments with high and very high erosion susceptibility, the determining factors were slope length (LS) together with soil erodibility (K), which play important roles in the soil erosion process, as identified in the work by Perovic et al. (2013). Table 4 shows the municipalities divided according to the average erosive susceptibility of their catchments. It can be seen that 62 municipalities in Goias have a low susceptibility to erosion and 49 municipalities have catchments with a moderate susceptibility to erosion. Considering the catchments with high susceptibility to erosion, showing significant amounts of soil loss per hectare during the year, 56 municipalities were found to be supplied by water abstracted from catchments a situation that deserves greater care. The municipality of Goiânia is supplied by water collected and treated from the Samambaia stream and João Leite stream basins, which are moderately susceptible to erosion, and from the Meia Ponte river basin, which is highly susceptible to erosion. Still, more worryingly, Table

Table 4. Municipalities are categorized according to the classification of the average erosion susceptibility of their catchment area for public water supply

Municipalities supplied by catchments with low susceptibility to erosion
Abadia de Goias, Acreúna, Adelândia, Alto Paraíso, Alvorada do Norte, Amorinópolis, Aparecida de Goiânia, Aragarças, Araguapaz, Bom Jardim de Goias, Bom Jesus de Goias, Britania, Buritinópolis, Cachoeira Alta, Cachoeira Dourada, Caçú, Caiapônia, Campo Alegre, Catalão, Cavalcante, Cidade Ocidental, Cocalzinho, Cristalina, Crixás, Damianópolis, Divinópolis de Goias, Doverlândia, Goiatuba, Iaciara, Inaciolândia, Israelândia, Itapirapuã, Itarumã, Jandaia, Jussara, Luiz Alves, Luziânia, Mambaí, Maurilândia, Monte Alegre de Goias, Montividiu, Mozarlândia, Mundo Novo de Goias, Nova Crixás, Novo Gama, Ouvidor, Pilar de Goias, Pirenópolis, Planaltina, Portelândia, Posse, Rio Verde, Santa Bárbara de Goias, Santa Helena de Goias, Santa Rita do Araguaia, São Domingos, São João da Aliança, São José dos Bandeirantes, São Miguel do Araguaia, Serranópolis, Terezina de Goias and Três Ranchos.
Municipalities supplied by catchments with moderate susceptibility to erosion
Água Limpa, Aloândia, Anápolis, Aragoiânia, Arenópolis, Aruanã, Aurilândia, Buriti Alegre, Caldazinha, Campestre de Goias, Campos Belos, Cezarina, Corumbá, Cromínia, Cumarí, Diorama, Formoso, Goianápolis, Goianésia, Goiânia, Goias, Guapó, Indiara, Ipameri, Iporá, Itumbiara, Jataí, Jauapací, Joviânia, Leopoldo de Bulhões, Marzagão, Minaçú, Montes Claros de Goias, Morrinhos, Nova Glória, Orizona, Padre Bernardo, Palmeiras de Goias, Palminópolis, Piracanjuba, Piranhas de Goias, Professor Jamil, Quirinópolis, Rianápolis, Santa Tereza, Santo Antônio do Descoberto, Silvania, Uruaçú and Uruana.
Municipalities supplied by catchments with high susceptibility to erosion
Alexânia, Americano do Brasil, Anicuns, Araçú, Barro Alto, Bela Vista, Brazabrantes, Campo Verde, Carmo do Rio Verde, Ceres, Rialma, Córrego do Ouro, Damolândia, Edealina, Edéia, Estrela do Norte, Fazenda Nova, Firminópolis, Formosa, Goiânia, Goias, Heitoraí, Hidrolândia, Inhumas, Itaberaí, Itaguarí, Itapuranga, Itauçú, Jaraguá, Moiporá, Morro Agudo de Goias, Nerópolis, Petrolina de Goias, Pontalina, Porangatu, Rubiataba, Sanclerlândia, São Francisco de Goias, São João da Paraúna, São Luis de Montes Belos, Terezópolis, Trindade, Turvânia, Urutaí, Varjão and Vianópolis.
Municipalities supplied by catchments with very high susceptibility to erosion
Avelinópolis, Bonfinópolis, Campo Limpo, Caturaí, Niquelândia, Interlândia, Itaguarú, Ouro Verde, Santa Rosa de Goias and Taquaral de Goias.
Municipalities supplied by catchments with severe erosion susceptibility
Santa Tereza de Goias and Goias.

4 shows that in Goias, 10 municipalities are collecting water from river basins with very high erosion susceptibility, and the municipalities of Santa Tereza de Goias and Cidade de Goias (Pedro Ludovico stream) are supplied by catchments with severe erosion susceptibility. This situation is directly influenced by the relief, with high ramp length values, combined with a highly erodible soil type. It is important to mention that the municipality of Goias has two other catchments, one with moderate erosive susceptibility and the other with high erosive susceptibility, both located on the Bacalhau stream.

CONCLUSIONS

This work has led to the conclusion that the application of the USLE model, together with geoprocessing tools, is of substantial importance for mapping the erosion susceptibility of watersheds where drinking water catchments are located, thus contributing to conservation planning and the immediate control of the most critical areas. Using the methodology employed, it was found that most of the catchments in the state of Goias have low and moderate erosion susceptibility, which is related to the relief and low slope in these areas. A small group showed very high and severe erosion susceptibility, such as the Meia Ponte river basin, one of the main water sources for Goiânia, the state capital, which is in the high erosion susceptibility class. Therefore, the basins in these classes need immediate attention from the point of view of soil conservation on the part of the municipalities when managing their water supply basins.

In these cases, the adoption of soil conservation practices, the instruction of rural landowners in the proper use of the soil, and the development of support and incentive programs for environmental conservation are important tools in the process of protecting these supply sources.Currently, there are growing concerns about the effects of climate change, which are becoming increasingly frequent in the Cerrado biome. Therefore, it is recommended that further studies be carried out considering the occurrence of extreme events, especially with a focus on increased rainfall intensity.

Given this scenario, it is recommended that legislation be established to regulate the use and occupation of land in catchment basins, as this is an instrument that enables the preservation of these springs, as well as the maintenance of water quality and quantity.

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