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Sediment production susceptibility index in urban area: a case study of Campo Grande – MS, Brazil

Índice de susceptibilidade à produção de sedimentos em áreas urbanas: estudo de caso de Campo Grande – MS, Brasil

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ABSTRACT

Inadequate urban planning has contributed to the sediment production in Urban Hydrographic Micro-basins (UHMs). The present study aims to develop and apply the Sediment Production Susceptibility Index (SPSI) in UHMs from Campo Grande – Mato Grosso do Sul (MS), Brazil, based on the Analysis Hierarchical Process (AHP) and Geographic Information System (GIS) aggregation. The indicators selected for the composition of the SPSI are Soil Class (49%), Average Slope (22%), Vegetation Cover (13%), and Unpaved Streets (16%). It is essentially to jointly analyze indicators from both spheres (natural and anthropogenic) to obtain greater reliability in studies related to sedimentation in urban areas. UHMs undergoing urbanization are more susceptible to sediment production than UHMs that are already densely occupied. SPSI can assist public managers in the urban and environmental planning and in the adoption of preventive measures against the silting of water bodies and obstruction of drainage systems.

Keywords: Soil class; Slope; Vegetation cover; Erosion; AHP.

RESUMO

O planejamento urbano inadequado tem contribuído para a produção de sedimentos em Microbacias Hidrográficas Urbanas (MHUs). O presente estudo tem como objetivo desenvolver e aplicar o Índice de Susceptibilidade à Produção de Sedimentos (ISPS) nas MHUs de Campo Grande – Mato Grosso do Sul (MS), Brasil, a partir da agregação de Análise Hierárquica de Processos (AHP) ao Sistema de Informação Geográfica (SIG). Os indicadores selecionados para composição do ISPS são: Classe de Solo (49%), Declividade média (22%), Cobertura Vegetal (13%) e Ruas Sem Pavimentação (16%). É essencial analisar conjuntamente indicadores de ambas as esferas (natural e antrópica) para obter maior confiabilidade nos estudos relacionados à sedimentação em áreas urbanas. As UHMs em urbanização são mais suscetíveis à produção de sedimentos do que as UHMs já densamente ocupadas. O ISPS pode auxiliar os gestores públicos no planejamento urbano e ambiental e na adoção de medidas preventivas de assoreamento dos corpos hídricos e obstrução dos sistemas de drenagem.

Palavras-chave: Classe de solo; Declividade; Cobertura vegetal; Erosão; AHP.

INTRODUCTION

Soil degradation and reservoir siltation are two of the main environmental, scientific, and engineering challenges (Sotiri et al., 2021). These problems are strongly interconnected with the erosion processes that occur in watersheds (Sotiri et al., 2021). In this context, climate change (increase in extreme precipitation events) combined with disorderly population growth in cities are putting pressure on water and soil systems around the world, especially in developing countries. These changes are favoring the intensification of erosion processes in urban areas and, consequently, the sediment production, transport, and deposition in urban water bodies and overloading drainage systems.

Sediment transport and deposition processes are dynamic and depend on several indicators, such as soil type, slope, vegetation cover, and environmental planning of the area of interest (Peixoto et al., 2021; Franz et al., 2014; Fernández & Vega, 2016; Guerra et al., 2017; Neves et al., 2021). The transport of high concentrations of sediment has several negative impacts, including eutrophication (water pollution), floods (Borrelli et al., 2020), reduction and extinction of aquatic species (Andrietti et al., 2016), siltation, changes in the volume and flow of water, morphological changes in riverbeds and watersheds margins (Zhang et al., 2019) and reduced useful life of retention and detention structures (Krajewski et al., 2024), resulting in environmental, social, and economic damage to society. For this reason, a reliable analysis of the sediment production susceptibility in urban areas has a direct impact on both the quality of the aquatic environment and the hydrological quality of the watershed.

Conventional field methods and techniques for identifying areas susceptible to water erosion and sediment production are expensive, time-consuming, and require extensive data (Efthimiou et al., 2017). A commonly applied method for soil erosion and sediment yield estimation from non-build-up areas is USLE equation or its further modifications (Tsige et al., 2022). An alternative for built-up areas can be a build-up/wash-off model (Bonhomme & Petrucci, 2017) that describes a deposition and flushing of particles from the sealed surface. This approach requires information on rainfall in the study area (Krajewski et al., 2024), needing a reliable and updated database of precipitation. However, the study area of this work lacks this data, as identified by Moraes & Gonçalves (2024). In fact, Moraes & Gonçalves (2024) recommend the strengthening and expansion of programs aimed at the periodic monitoring of hydrological data in Campo Grande – Mato Grosso do Sul (MS), Brazil, since the scarcity of these data represents a barrier to the sustainable management of Urban Hydrographic Micro-basins (UHMs) (Moraes & Gonçalves 2023). Consequently, alternative and simplified methods with lower data requirements are needed (Bueno et al., 2022).

Pereira et al. (2020) and Albulescu et al. (2022) state that the multi-criteria methodology plays an important role in formulating of susceptibility indexes and aggregating contrasting indicators in environmental studies. In this context, Analysis Hierarchical Process (AHP), developed by Saaty (1977), stands out when carrying out complex environmental studies (Swain et al., 2020; Msaddek et al., 2022), as it seeks to discover and correct logical inconsistencies (Goepel, 2018), minimizing failures and assisting in the decision-making process. AHP has been widely used for mapping of susceptible areas to floods (Ghosh & Kar, 2018; Ramkar & Yadav, 2021; Ikirri et al., 2022; Mudashiru et al., 2022; Moraes & Gonçalves, 2024), soil erosion (Saha et al., 2019; El Haj et al., 2023), and landslides (Hung et al., 2015), being the most acceptable and adaptable method for environmental studies (Kabo-Bah et al., 2021).

Concomitantly, the AHP method is used with geotechnologies to improve decision-making processes. The use of geotechnologies, such as Remote Sensing (RS) and Geographic Information System (GIS), facilitate the obtaining of detailed information at low financial cost in large areas (Msaddek et al., 2022). RS makes it possible to acquire information without the need for direct contact with the study area. GIS allows the creation of a georeferenced database, spatial and temporal analyses and the production of maps that help in the development of management and conservation strategies. In fact, numerous works have been carried out using the combination of AHP and GIS, considered an effective aggregation by Dash & Sar (2020), Pereira et al. (2020), and Ramkar & Yadav (2021).

In Brazil, the study and monitoring of hydro-sedimentological processes are concentrated in the main watercourses and large watersheds, as Santos et al. (2020) in São Paulo and Minas Gerais, Sotiri et al. (2021) in Paraná, Bendito et al. (2023) in Minas Gerais, and Santos et al. (2023) in São Paulo. Some studies are carried out and made available by the National Hydrometeorological Network (RHN), under the coordination of Basic Sanitation and Water National Agency (ANA) and the Brazilian Geological Service (CPRM) (Borella et al., 2022). In general, this continuous monitoring has low spatial coverage and is rare in watersheds with small drainage areas (Borella et al., 2022; Krajewski et al., 2024), mainly in the Midwest Region of the country. These limitations are related to logistics, distance, and/or limited access, that difficult in loco measurements and the installation and maintenance of specific equipment for routine monitoring.

Hence, scientific research related to sediment production susceptibility in urban areas is essential to help solve problems referent to the management and conservation of watersheds that are at risk of environmental degradation (França et al., 2022). In fact, Zhang et al. (2022) state that sediment regulation contributes to the control of hydrological disasters. Therefore, the objective of this work was to develop and apply the Sediment Production Susceptibility Index (SPSI) in UHMs from Campo Grande – MS, Brazil, based on the AHP and GIS aggregation.

METHODOLOGY

Study area

The study areas are the UHMs in the municipality of Campo Grande, capital of the state of Mato Grosso do Sul (MS), Midwest Region of Brazil, as shown in Figure 1. Campo Grande has an area of 8,082.98 km^2, altitude of 500 to 675 meters, gently undulating relief, vegetation of pasture fields and Cerrado, predominant soil class Dark Red Oxisol, and average annual precipitation of 1,570 mm (Campo Grande, 2021). The climate of Campo Grande, according to Koppen's classification, is in the transition range between the humid mesothermal subtype (Cfa) without drought or small drought and the humid tropical subtype (Aw), with a

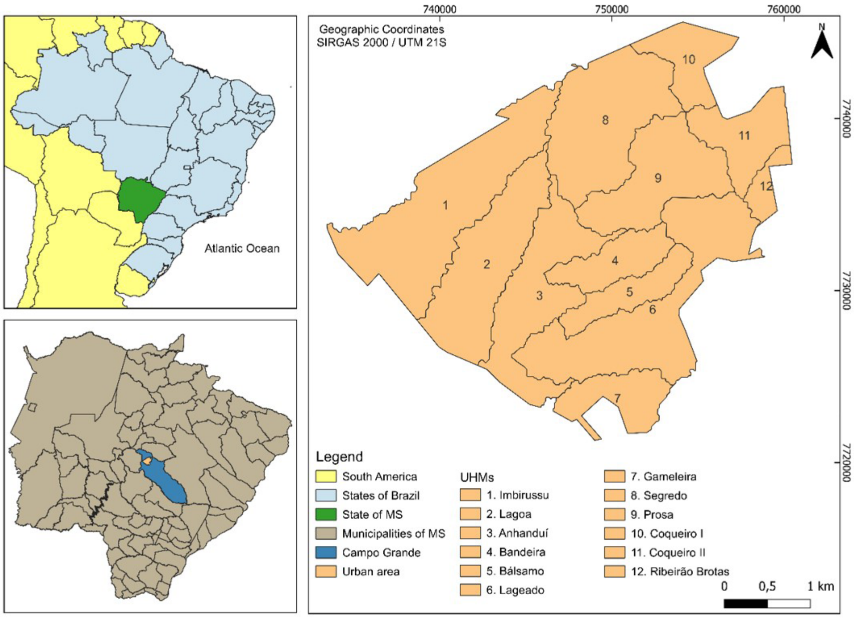

Figure 1. Location of the municipality and UHMs of Campo Grande – MS.

rainy season in summer (December, January, and February) and a dry season in winter (June, July, and August) (Campo Grande, 2021), according to Figure 2.

The division of a higher order watershed into hydrographic micro-basins facilitates the identification and control of environmental problems related to sediment production and the establishment of priorities for the mitigation of these problems. It allows to expand the detail of the data in the region of interest (Pinto et al., 2016). Therefore, the urban area of Campo Grande was divided into twelve UHMs based on the elevation digital model image (SRTM3-S21-W55-v2) of the study area available at United States Geological Survey (2022) and with the support of Quantum Geographic Information System software (QGIS, 2022).

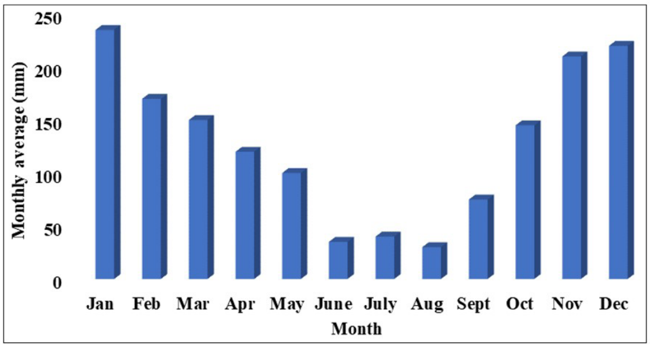

Figure 2. Average monthly precipitation of Campo Grande – MS, Brazil (Instituto Nacional de Pesquisas Espaciais, 2024b).

Development of the SPSI

The development of SPSI consisted of six stages: i. selection of indicators, ii. Standardization of indicators, iii. Weighting of indicators, iv. Consistency of indicators, v. formulation of the index and vi. application of the index. Methodology and steps like those adopted by Macedo et al. (2018), Singh & Bhakar (2021), Mudashiru et al. (2022) and Ikirri et al. (2022) in the development of its hydrological indexes and maps. Figure 3 presents the flowchart referring to the methodology adopted.

Selection of indicators

The selection of indicators for the composition of the SPSI was carried out through a literature review (Luz et al., 2015; Carvalho, 2017; Queiroz, 2017; Caldas et al., 2019; Agra & Andrade, 2021; Borella et al., 2022; Aires et al., 2022; Bueno et al., 2022; Mushtaq et al., 2023). Indicators with potential to interfere with sediment production in urban areas, accessible and with reference values were prioritized (Singh & Bhakar, 2021). It is worth noting that there is no consensus regarding the number of indicators necessary to generate a susceptibility index and map for hydrological and hydro-sedimentological studies, since this depends on factors such as local data availability, geographic location and climate of the study area and importance of the indicator (Yagoub et al., 2020).

The indicators selected for the composition of the SPSI were: Soil Class (SC), Average Slope (Sa), Vegetation Cover (VC), and Unpaved Streets (US) in the UHMs. Indicators that are easy to measure, available in municipal, state, or national databases and preferably quantitative. Table 1 shows the acquisition source, type of data and software/method used to calculate the indicators.

Standardization of indicators

The results for each indicator were standardized to remove the influence of different measurement units (Macedo et al.,

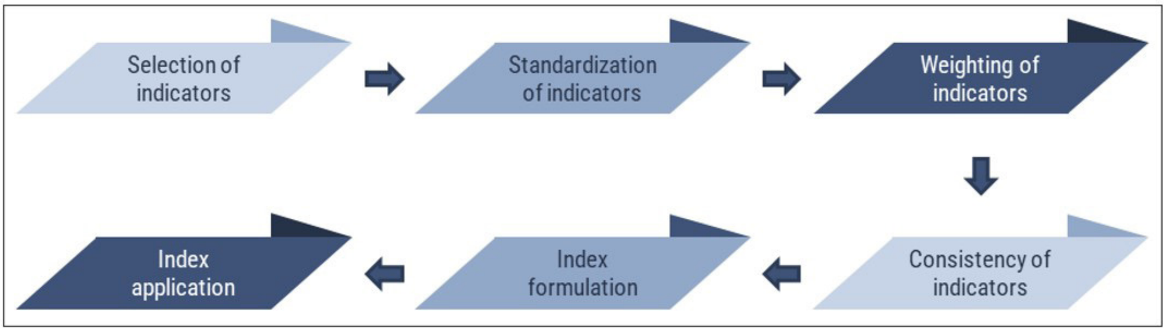

Figure 3. Flowchart for development of the SPSI.

Table 1. Source of acquisition, type of data, and software/method adopted to calculate the indicator.

Indicator	Source/Type of data	Software or method
SC	City hall/Vector	QGIS (2022)
Sa	SRTM3-S21-W55-v2 image with 3-arc spatial resolution from the digital elevation model (United States Geological Survey, 2022)/Raster	QGIS (2022)
VC	CBERS - 4A image with spatial resolution of 2 meters (Instituto Nacional de Pesquisas Espaciais, 2024a)/Raster	Semi-supervised classification dzetsaka plugin in QGIS (2022)
US	City hall/Vector	QGIS (2022)

Table 2. Proposal of susceptibility classes and values to sediment production based on soil class.

Soil class	Values	Reference
Urban area, Haplic gleisol and Histosols	1	Carolino de Sá (2004); Luz et al. (2015); Agra & Andrade (2021) and Bueno et al. (2022)
Dystrophic red oxisol, Dystrophic yellow oxisol, Dystrophic red-yellow oxisol and Dystrophic red nitisol	2	Queiroz (2017); Agra & Andrade (2021); Bueno et al. (2022) and França et al. (2022)
Planosols, Plinthosol; Luvisol and Podzols	3	Luz et al. (2015) and Aires et al. (2022)
Arenosol and Cambisol	4	Queiroz (2017); Agra & Andrade (2021); Bueno et al. (2022)
Leptsol; Regosol and Fluvisol	5	Carolino de Sá (2004); Queiroz (2017); Luz et al. (2015); Aires et al. (2022); Bueno et al. (2022) and França et al. (2022)

Table 3. Proposal of classes and values of susceptibility to sediment production according to the average slope and percentages of vegetation cover and unpaved streets in urban hydrographic micro-basins.

Indicators/Values	1	2	3	4	5
Sa (%)	< 1.00	1.01 - 2.00	2.01 - 3.00	3.01 - 4.00	> 4.00
VC (%)	> 35	25 - 35	15 - 24	05 - 14	< 05
US (%)	< 10	10 - 20	21 - 30	31 - 40	> 40

Source: Slope adapted from Pittelkow (2013) and Luz et al. (2015). Vegetation Cover adapted from Rueda (2010).

2018). The indicator results were divided into 5 ordinal classes (intervals), which were assigned values 1, 2, 3, 4, and 5, with 1 being less susceptible and 5 more susceptible to sediment production in UHMs, as shown in Tables 2 and 3, based on a bibliographic survey mentioned in the tables and analysis of the characteristics of each indicator in relation to susceptibility to sediment production (sediment detachment and transport). Figures 4, 5, 6 and 7 show the classifications of the SC, Sa, VC and US indicators, respectively, in the UHMs of Campo Grande – MS.

Weighting of indicators

To analyze the susceptibility of urban areas to sediment production, it is worth highlighting those different indicators have distinct importance in the composition of an index (Mosavi et al., 2020). The weighting of indicators was carried out using the AHP method (Saaty, 1977), which is a multi-criteria decision-making technique widely applied in environmental studies to distinguish the importance of indicators (Swain et al., 2020; Ramkar & Yadav,

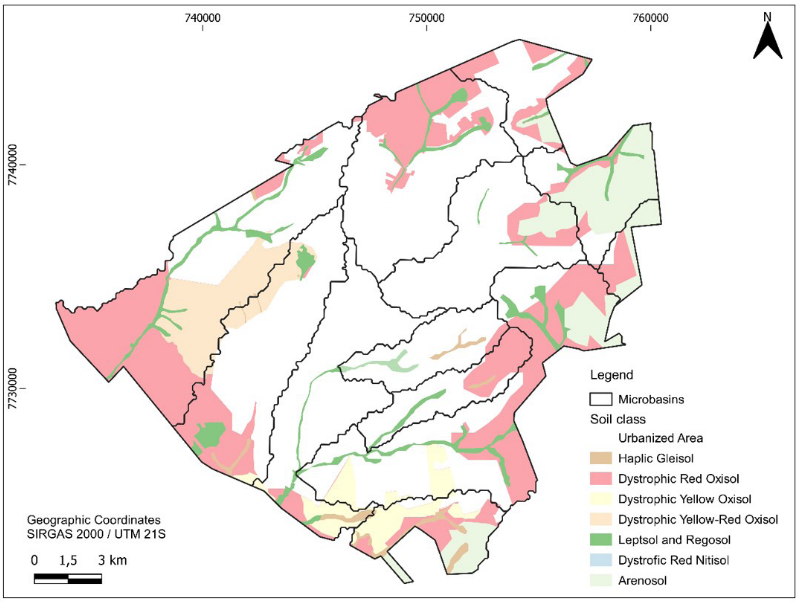

Figure 4. Soil class of UHMs in Campo Grande – MS.
Source: Adapted from PLANURB (Campo Grande, 2021).

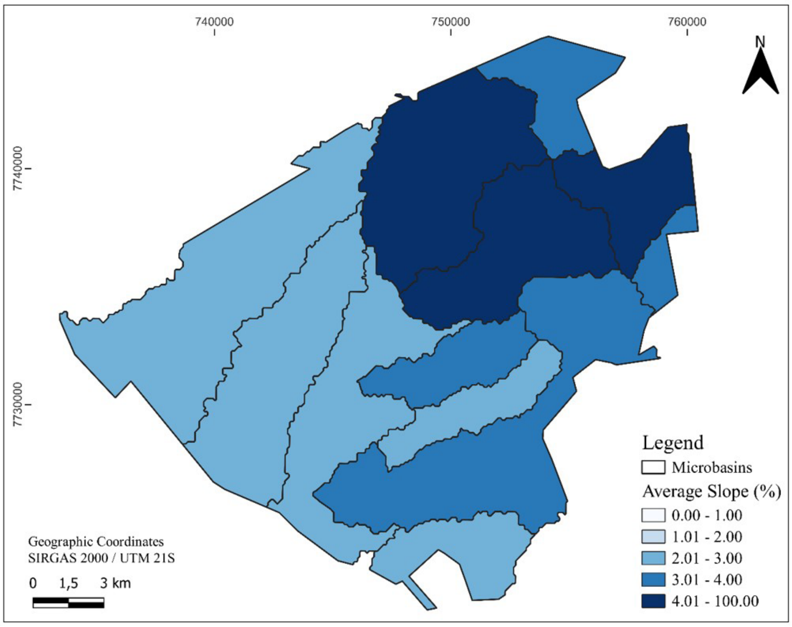

Figure 5. Average slope of UHMs in Campo Grande – MS.

2021; Singh & Bhakar, 2021; Ikirri et al., 2022; Mudashiru et al., 2022; Zhang et al., 2022; Bueno et al., 2022; Mushtaq et al., 2023). The indicators were compared in pairs in a matrix, so that each interaction was assigned a degree of importance, as proposed by Saaty (1977) and shown in Table S1 available in Supplementary Material.

Consistency of indicators

The consistency ratio (CR) was calculated from Equation 1, for the final weights assigned to the indicators, to verify that CR < 0.10, showing consistency between the results obtained (Saaty, 1977). That is, if A were more important than B, and B more important than C, then C could not be more important than A. This calculation procedure aims to minimize possible errors in the attribution of importance degrees (Swain et al., 2020).

$$CR = \frac{CI}{IR} \tag{1}$$

where IR is a fixed value, referring to the size of the matrix and defined by Saaty (1977).

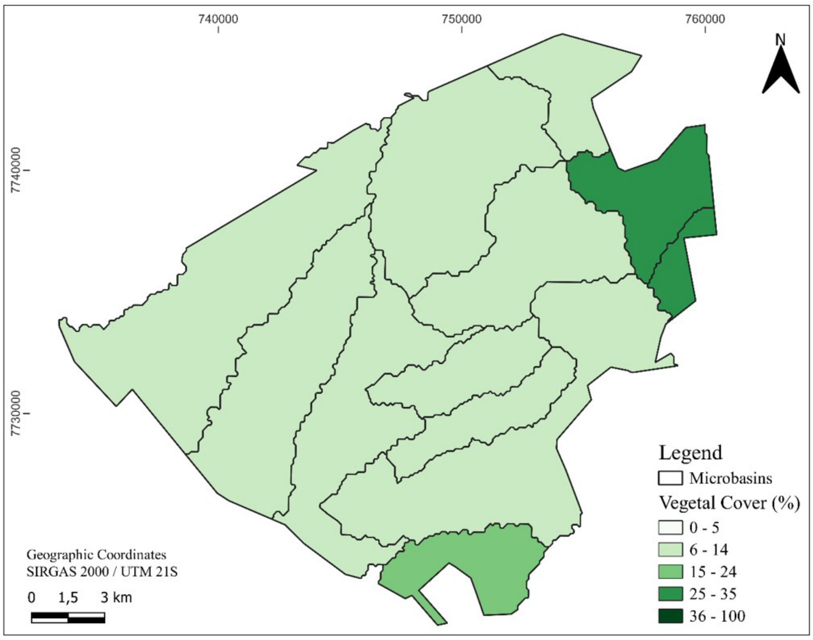

Figure 6. Vegetation cover of UHMs in Campo Grande – MS.

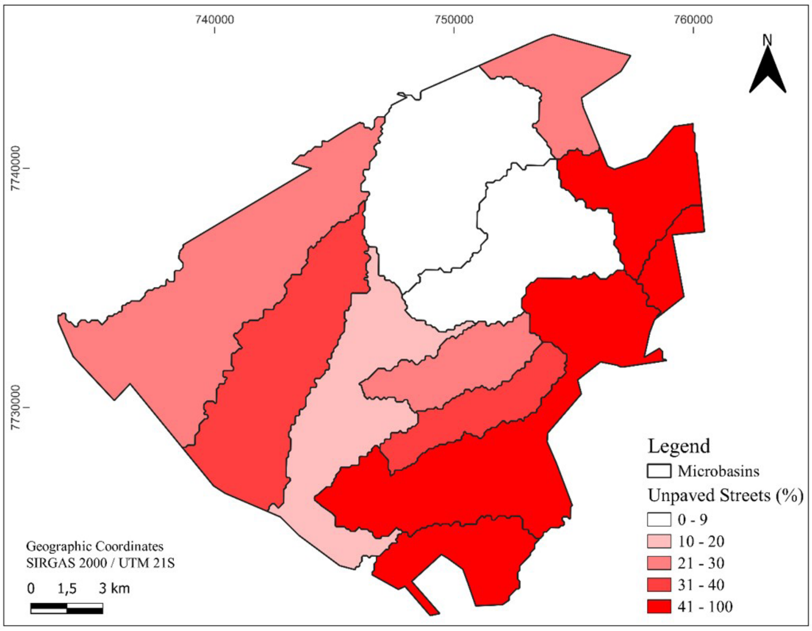

Figure 7. Unpaved streets in the UHMs of Campo Grande – MS.

The CI is the Consistency Index determined from Equation 2:

$$CI = \frac{(\ \text{máx} - n)}{(1 - n)} \quad (2)$$

where $\lambda_{máx}$ is the largest or main eigenvalue of the variable matrix and n is the order of the matrix.

Index formulation

Based on the weights obtained for each indicator by AHP, the SPSI was formulated according to Equation 3. It is worth mentioning that the experts/decision makers in this study have doctorates and experience in the areas of environmental, civil, and agronomic engineering and know well the study area. All analysis

Table 4. Sediment Production Susceptibility Classes according to the SPSI result.

Susceptibility class	SPSI
Very low	1.00 to 1.74
Low	1.75 to 2.49
Moderate	2.50 to 3.24
High	3.25 to 4.24
Very high	4.25 to 5.00

reached the satisfactory limit for the consistency ratio in obtaining the weights of the indicators for the composition of the SPSI.

$$SPSI = \sum_{i=1}^{n} Pi.Vi \quad (3)$$

where SPSI = Sediment Production Susceptibility Index; Pi = weight of i indicator; Vi = value of i indicator.

Index application

The SPSI was applied to the UHMs of Campo Grande - MS, to classify them as very high, high, moderate, low, or very low susceptibility to sediment production. Table 4 presents the intervals of SPSI results that refer to each susceptibility class.

RESULTS AND DISCUSSION

Equation 4 represents the SPSI with the respective weights of the indicators generated by AHP. The SC (49%) and Sa (22%) indicators are the most significant for evaluating susceptibility to sediment production, corroborating Bueno et al. (2022), followed by US (16%) and VC (13%). Although the US indicator was given lower weight, its high results are associated with the UHMs highly susceptible to sediment production in this study.

$$SPSI = 0.49 \times \sum_{i=1}^{n} \left(Wi \times \frac{ASCi}{At} \right) + 0.22 \times VSa + 0.13 \times VVC + 0.16 \times VUS \quad (4)$$

where SPSI = Sediment Production Susceptibility Index; Wi = Value referring to Soil Class i; ASC = Area referring to Soil Class i in the UHM (km^2); At = Total area of the UHM (km^2); VSa = Value referring to the average slope in the UHM; VVC = Value referring to the Vegetation Cover in the UHM; VUS = Value referring to the Unpaved Streets in the UHM.

Mushtaq et al. (2023) highlight that the surface runoff velocity and the infiltration rate of rainwater depend on the angle of inclination of the study area. High runoff velocity in areas with steep slopes increases the erosion rate compared to lower angle slopes (Pittelkow, 2013; Kachouri et al., 2015; Queiroz, 2017; Agra & Andrade, 2021; Neves et al., 2021; Aires et al., 2022), and consequently increases susceptibility to sediment production (Neves et al., 2021; Aires et al., 2022; Mushtaq et al., 2023).

Concomitantly, susceptibility to soil erosion and sediment production is also related to the SC of the region (Mushtaq et al., 2023), being directly regulated by characteristics such as texture, organic matter content, original material, porosity, structure and potential of infiltration (Blanco & Lal, 2023). According to Carvalho (2017), SC is the most significant indicator for the occurrence of erosive processes and silting in UHMs. Carolino de Sá (2004) says that sandy soils are more susceptible to erosion, as their particles are easily disaggregated by the action of rain. While clayey soils, when they have good permeability, are more resistant to erosion, as more fertile soils, because they provide better plant development, protecting them from erosion processes.

Vegetation is a natural protection of the soil against the impact of raindrops, contributing to greater water infiltration (Romshoo et al., 2012; Queiroz, 2017; Baloque & Capoane, 2021) and controlling erosive processes (Hepp & Gonçalves Júnior, 2015). According to Zhang et al. (2022), the initial process of silting up of water bodies is soil erosion, caused mainly by the kinetic force of raindrops, which disaggregate and transport soil particles to watercourses. In general, VC is inversely proportional to soil erosion (Mushtaq et al., 2023) and has a direct influence on the amount of organic matter in the soil, as well as on the decrease in water velocity during surface runoff. Kachouri et al. (2015) state that the extent to which soil can be eroded is controlled by the proportion of VC existing in an area.

Finally, US, that is, dirt streets, contribute enormously to the loss of soil through erosion, accelerating the silting process of water bodies in urban areas (Pittelkow, 2013; Baloque & Capoane, 2021). In general, this occurs because most of this type of access is built without engineering design, poorly meeting local needs (Baloque & Capoane, 2021) and may contain drainage failures and inadequate street location.

Figure 8 shows the susceptibility classes to sediment production of each UHM based on the application of SPSI in Campo Grande - MS. High susceptibilities to sediment production occur mainly in UHMs that have higher percentages of US and Sa, as well as soils more susceptible to detachment and transport of particles (Leptsols, Regosols and Arenosols) and lower percentages of impermeable areas (UHMs 11 and 12), characteristics like those identified by Mushtaq et al. (2023). It is possible to infer that UHMs in the process of occupation are more susceptible to sediment production than densely occupied UHMs (Ferreira & Alves Sobrinho, 2020), because they have more areas with exposed soil (empty land and unpaved streets, for example) (Franz et al., 2014). This reinforces the importance of environmental planning in the urbanization process of municipalities, as highlighted by Ferreira & Alves Sobrinho (2020).

UHMs classified as low susceptibility are characterized by lower percentages of US and higher percentages of soils less susceptible to detachment and transport of particles (Dystrophic Red Oxisol and Dystrophic Yellow Oxisol) and impermeable areas (UHMs 3, 4, 8 and 9), as found by Bueno et al. (2022). That is, densely occupied UHMs are less susceptible to sediment production. However, these UHMs must receive periodic monitoring, since upstream UHMs can generate sediments, being carried to downstream UHMs and causing serious problems with silting of water bodies and obstruction of the drainage system present on the mostly paved roads.

UHMs 1, 2, 5, 6, 7 and 10 show moderate susceptibility to sediment production, even containing higher percentages of Sa and US compared to the others in some cases. These UHMs

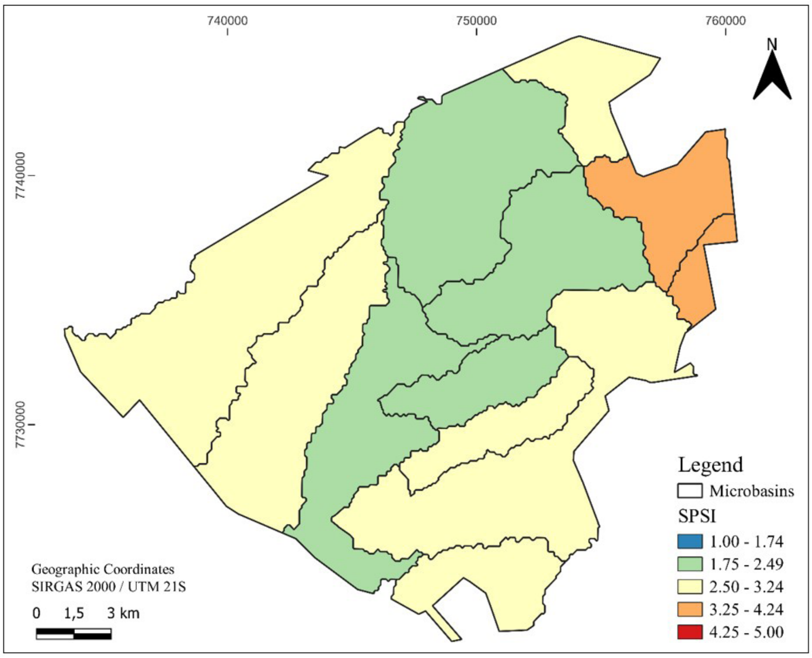

Figure 8. Susceptibility classes to sediment production in the UHMs of Campo Grande – MS from the SPSI.

are mostly composed of soils that are less susceptible to the detachment and transport of particles (Dystrophic Red Oxisol and Dystrophic Red-Yellow Oxisol). This condition brings a certain dynamic balance in relation to the erosive potential of moderate UHMs, since the high susceptibility of the Sa and US indicators is mitigated by the pedological characteristics of the region, as observed by Bueno et al. (2022) in a study carried out in the state of São Paulo in Brazil.

The SPSI developed in this work can be used by planners, engineers and public policy makers to identify UHMs that require more attention from public authorities. This allows for safer and more sustainable urban development (Mudashiru et al., 2022), especially with current climate change and a significant increase in extreme hydrological disasters. In fact, Bui et al. (2019) concluded that approximately 200 million people are affected annually by floods, while global economic losses are estimated at around 60 billion dollars per year due to hydrological disasters (Janizadeh et al., 2019).

In the context of global climate change, the relationship between extreme precipitation events and surface runoff is increasingly complex (Ren et al., 2023). Understanding surface runoff changes helps to scientifically formulate flood control strategies and improve regional water resources regulation capabilities (Ren et al., 2023). Therefore, the SPSI can assist in this process, as it can identify the UHMs most susceptible to the production of sediments and consequently, with greater potential for interference with the surface runoff of rainwater in urban areas, due to obstruction of the drainage system and reduction of useful volume of retention and detention structures.

AHP and GIS aggregation is an efficient methodology for approaches like this study, since the necessary data are easily accessible in public collections, contributing to their low cost. However, the methodology adopted in this work presents a limitation regarding the temporal analysis of the data. The SC and Sa indicators, although highly relevant for sediment production, do not show temporal change, reducing the magnitude of possible changes in SPSI results over time (Bueno et al., 2022). On the other hand, the VC and US indicators are extremely volatile over the years.

Furthermore, França et al. (2022) emphasize that incorporating more indicators into a hydrological index makes the results more consistent with the local reality. In fact, an advantage of the methodology applied in this study is its flexibility (França et al., 2022). According to Bueno et al. (2022), several physical and social indicators can be selected according to their relevance for composing the index, increasing the reliability of its integrated analysis.

Hence, it is advisable to strengthen and expand periodic monitoring programs for data relating to land use/occupation and urban infrastructure in the study area, to increase the number of indicators pertinent to the index and keep them always updated. At the same time, the scarcity of these data represents a barrier to sustainable management and hydro-sedimentological studies of UHMs that suffer from problems of high sediment production, and consequently, obstruction of the drainage system causing severe urban floods (Yadav & Mangukiya, 2021), mainly in developing countries (Costache et al., 2022). Therefore, the public database may constitute a limitation about the specificities of a study area (Bueno et al., 2022).

Moreover, it is necessary to encourage a program that aims to reduce the area of exposed soil in the region, to minimize sediment production. Dixon et al. (2016) highlight that the restoration of watercourse banks significantly contributes to the reduction of stormwater discharge peaks in watersheds, and consequently, reduces the detachment and transport of sediments.

Finally, SPSI can be applied in any region of the world, but due to the spatial variability of important indicators for particle detachment and transport, mapping susceptibility to sediment production is quite regional. Therefore, the selection and standardization of indicators used in the composition of the SPSI can be modified based on the specific characteristics of the area of interest, to allow the efficient application of the methodology of this work. Consequently, when replicated in another study area with characteristics different from Campo Grande - MS, the weights of the SPSI indicators depend on the analyses carried out by local decision makers. According to Mudashiru et al. (2022), this can be a disadvantage, because depends on the degree of uncertainty and knowledge of decision makers, so monitoring the CR limit is essential for the analysis of all experts.

For this reason, a second limitation of the multi-criteria method used in this work is related to the decision-making process, which requires a certain number of paired comparisons by experts based on the number of indicators used (Mudashiru et al., 2022), being characterized due to uncertainty based on the subjectivity of decision makers (Ikirri et al., 2022). Finally, it is recommended to validate the SPSI using field data. However, it is worth highlighting that as systematic surveys on soil erosion and sediment transportation are still rare in Brazil (Santos et al., 2023), the low availability of this data hampers SPSI validation. In this context, Sotiri et al. (2021) concluded that the use of reservoirs as validation points represents a good opportunity for this type of index developed, because the reservoirs almost entirely collect the sediment that arrives from the micro-basin. Furthermore, the authors say that measurements of sediment stock in reservoirs are often easier to perform than conventional monitoring of continuous sediment flow, which produces a high sampling effort and also needs to deal with large errors due to high variability in river stretches.

CONCLUSIONS

The objective of this study was to develop the SPSI and apply it to UHMs in the city of Campo Grande – MS, Brazil. The indicators selected to compose the SPSI are: SC (49%), Sa (22%), VC (13%), and US (16%). Sediment production in UHMs is influenced both by natural characteristics (soil and slope) and by human actions (deforestation, construction of roads without technical studies, and disorderly growth of cities). Therefore, it is essentially to jointly analyze indicators from both spheres (natural and anthropogenic) to obtain greater reliability in studies related to sedimentation in urban areas.

UHMs undergoing urbanization are more susceptible to sediment production than UHMs that are already densely occupied. AHP and GIS integration is a simple alternative for dealing with complex problems involving contrasting indicators over a large area. Finally, applying SPSI in UHMs can help public managers in the urban and environmental planning of cities and in the adoption of preventive measures against silting of water bodies and obstruction of drainage systems, alleviating environmental, social, and economic problems for the population and public authority.

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SUPPLEMENTARY MATERIAL

Table S1. Degree of importance of the relationships between the analysed elements (Saaty, 1977).

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