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Analysis of erosion susceptibility through urban scenarios for an expanding area

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ABSTRACT

Urban scenarios can be used by decision makers on matters related to urban expansion, especially when urban areas have socio-environmental problems, such as those resulting from erosion processes. The aim is the analysis of erosion susceptibility with the construction of urban scenarios using the AHP method to assist decision making on urban expansion. Thus, the AHP (Analytical Hierarchical Process) technique was employed to analyze the data collected and a GIS for the spatialization and building of these scenarios. The methodology was developed based on a real case of a Brazilian city located in the state of São Paulo. To validate the methodology, the current scenario of the studied area was constructed and compared with the actual situation of the place. As a conclusion, the study was validated for the applied area and proved to be a tool capable of assisting local governments regarding decision-making processes for urban expansion.

PALAVRAS-CHAVE: Urban Scenarios. Erosion susceptibility. AHP.

1 INTRODUCTION

The planning of future scenarios with a sustainable vision is an effective tool that guides the organization, functioning, and governance of cities (IWANIEC; WIEK, 2014). One of the main advantages of scenario planning is that its building encompasses the union of politics, society, and academia for early decision-making processes based on long-term sustainability (AMER et al., 2013; IWANIEC et al., 2020).

There are two approaches with different views for development of these scenarios. The first one is based on past and predicted conditions for a future random forecast. In the second approach, commonly called backcasting, a future condition is thought for later determination of what would be necessary to achieve it (DREBORG, 1996; IWANIEC; WIEK, 2014).

Regardless of the approach, with the means of achieving a result of better representativeness, the scenarios development must always include a team of researchers, civil society, and government officials from multiple areas (NASSAUER; CORRY, 2004) that are involved in multiple aspects from consultation to co-production (JAHN et al., 2012; LANG et al., 2012; NORSTRÖM et al., 2020).

The building of scenarios can be applied in several areas to assist in the planning of cities. For instance, change of land use concomitantly with the use of water and changes in temperature (IWANIEC et al., 2020). Other application examples would be: change in protein consumption from animal to vegetable in Europe until the year 2030, requiring the allocation of a larger area for agriculture (MANNERS et al., 2020); changes in urban mobility in Turkey until 2035, increasing hikes, the use of bicycles and public transport and, consequently, decreasing the use of private cars (BIYIK, 2019); changes in the fishing system in cities with a fishing-based economy in South Africa (GAMMAGE, 2019).

The application of scenarios can thus contribute to making decisions about the occupation of the physical environment in cities. Occupation – when disordered – can lead to socio-environmental problems such as soil erosion and increase in the vulnerability of the area to mass movements and floods (KOKS et al., 2015) and, consequently, river silting in the urban area. Soil erosion is one of the main socio-environmental problems which worries society due to being responsible for the loss of usable land caused by silting of rivers and, in urban areas, the deterioration of infrastructure (DEVATHA et al., 2015; EL JAZOULI et al., 2017; JAZOULI et al., 2019).

In urban areas, linear water erosion represents the most impact, because besides the loss of significant volumes of soil, it devastates considerable areas and can cause damage in occupied areas, or make the occupation of new areas impossible.

There are several influencing factors in the linear water erosion processes, among them, those related to the surface characteristics (slope steepness, land use, slope length and shape) and to the soil (permeability, texture, and erodibility), the rainfall, and the anthropic intervention (COSTA et al., 2018; EL JAZOULI et al., 2017; PHAM et al., 2018). However, one of the factors with the greatest capacity for accelerating erosion processes is social behavior. Among the anthropic actions are the change of vegetation cover, the improper handling of the soil by agriculture and livestock, and the engineering works poorly planned and/or poorly executed (EZEZIKA; ADETONA, 2011; IPT, 1989).

Among several ways to evaluate the influence of erosive factors, the use of the analytical hierarchical process (AHP) method stands out (ARABAMERI et al., 2018; HALEFOM; TESHOME, 2019; VIJITH; DODGE-WAN, 2019). It is a structured multicriteria analysis technique that assists in making complex decisions involving several elements (SAATY, 1980, 1987). The extrapolation of the data obtained in the GIS platform – in the form of mapping and by the building of scenarios – helps the allocation of resources and decision-making processes regarding preventive or corrective measures that are necessary (HAREGEWEYN et al., 2017).

Thus, this study proposes the use of the AHP method in the analysis of susceptibility through the construction of urban scenarios applied to the study of erosive processes of linear characteristics through the influence factors. The research used data collected in the city of São Manuel, São Paulo, Brazil.

For this reason, first the proposed methodology for the construction of scenarios is described in topic 2. Subsequently, in topic 3, an application of the methodology with data from a city in the center west of the state of São Paulo, Brazil, is conducted. Finally, in topic 4, the construction of the future scenario was confirmed by the evolution of the region with the construction of the planned urban allotments.

2 SCNARIO BUILDING

Figure 1 contains a flowchart divided into three phases that illustrates how to develop the building of scenarios, related to erosion processes for an expanding urban area.

2.1 Phase I - Verification of the need to predict future scenarios for the city

Planning the expansion of a city involves the study of possible future urban scenarios. These scenarios may range from the need for urban expansion to solve a housing deficit problem, to the decrease of problems related to flooding, as well as the prevention or reduction of the occurrence of erosive features. In this phase, groups of people with different interests such as government officials, investors and researchers meet and discuss the need to build the scenarios based on a changing situation in the city.

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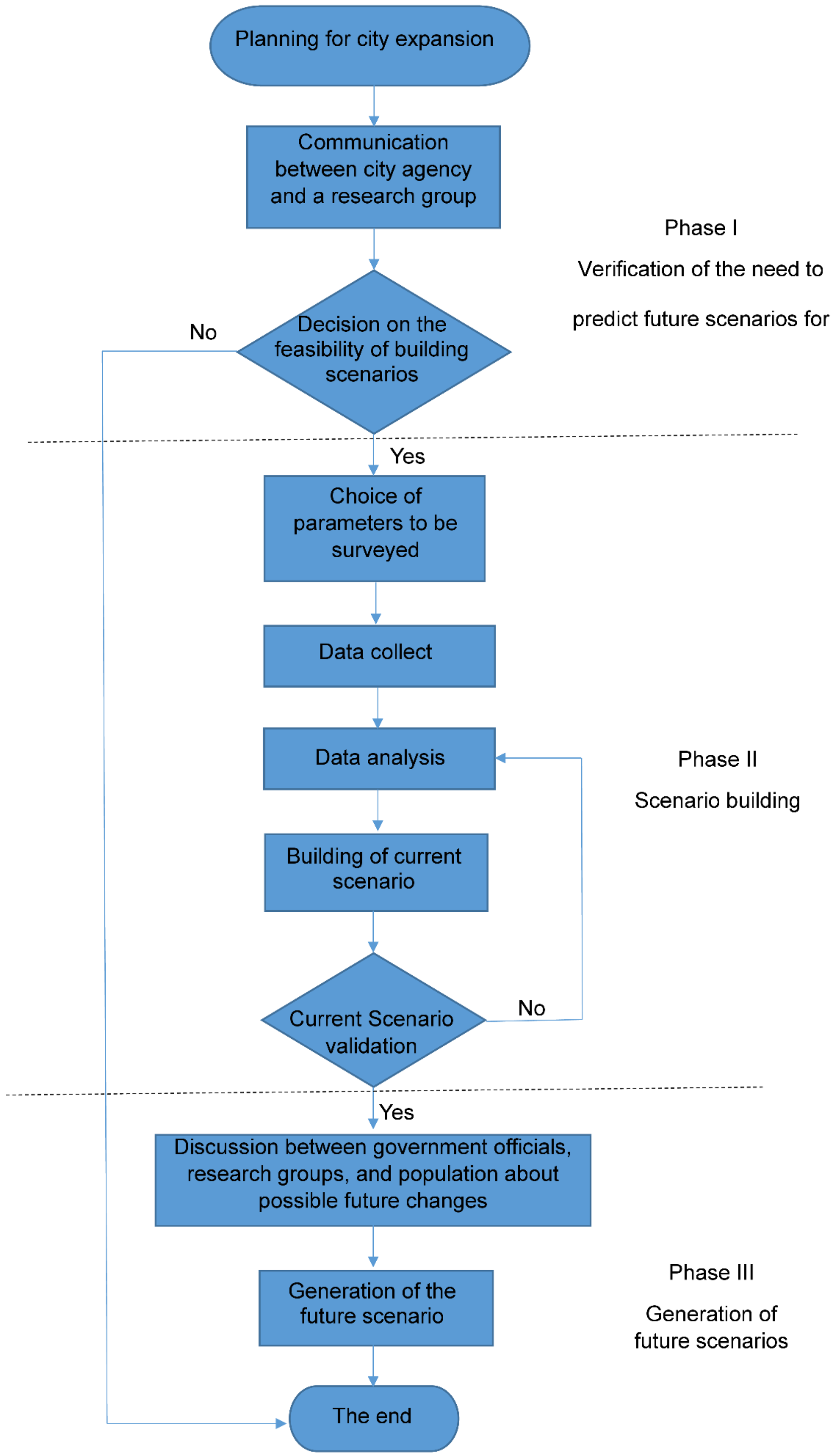
Figure. 1 - Flowchart for building scenarios



2.2 Phase II: Scenario building for assessment of linear water erosion susceptibility

Once the need to build scenarios has been determined – regarding urban linear erosion – it is necessary to determine the factors influencing the erosive features in the study area. These factors vary according to the study location and, most importantly, depends on the availability of data.

To determine the input parameters for the scenario building, it is important that the work team be multidisciplinary, in addition to covering elements of civil society, the research academy, and the local government. Multidisciplinary effort is crucial at this stage since the population is the sphere that closely follows all changes in the region where they live. The local government usually has official data that can contribute to the development of the scenarios and the university has a fundamental role in research, being able to develop all the necessary study, closing the cycle, and contributing to the governance and development of civil society.

Thus, a partnership is proposed, even if informally, so that it is easier to obtain initial data with the local government and a direct contact with society by constant field visits and interviews with residents of the region, to then decide what factors may have influenced erosion processes in the area. Once this is done, the data related to these factors are collected, either by laboratory tests or using open databases available on the internet, to then be spatialized in GIS.

However, it is necessary to analyze the data to determine how much each factor influences the development of erosion processes. In this research, the use of the AHP method is suggested using priority vectors to determine the influence. Thereafter, the judgment matrix can be formed from the fundamental scale developed by Saaty (1987) (Table 1). In this research the construction of the matrix was based on other matrices found in the literature (ALEXAKIS et al., 2013; BASILIO et al., 2019; KACHOURI et al., 2015; LOBÃO et al., 2011; PRADEEP et al., 2015; VULEVIĆ et al., 2015).

Table 1 – The fundamental scale

Intensity of importance on an absolute scale	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between the two adjancent judgments
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, them j has the reciprocal value when compared with i

Source: Adapted from Saaty (1987)

Subsequently, the priority vector of the criteria is calculated. This vector can be understood as the importance each criterion has on the event under study (Arabameri et al. 2018; Mallick et al. 2018; Halefom and Teshome 2019; Vijith and Dodge-Wan 2019). The veracity of the judgment matrix, and consequently the priority vector, can be given by calculating the Consistency Ratio (CR). According to Saaty (1980), CR values below 1.0 represent consistent matrices.

The susceptibility was calculated according to equation 1, where Fi is the value of the influencing factor obtained as a function of spatialization and computed per pixel and wi is the weight obtained by the judgment matrix of the AHP method.

$$Susceptibility = \sum F_i w_i \qquad (1)$$

Then, the algebra of maps in GIS is applied to lead to the spatialization of the current scenario of erosion susceptibility of the study area.

The validation of the method must be made by comparisons between the existing area and the developed map, paying attention to the points where erosive features exist. If the map is validated, i.e., it represents the current state of the area, it can be considered as the current scenario. If this scenario is true, the preparation of the map goes to the third and last stage, otherwise one must return to the stage of analysis of the data, adapting the judgment matrix of the AHP method.

2.3 Phase III: Generation of future scenarios

A discussion among all of those involved professionally and socially should occur, keeping in mind the best actions for possible future alterations.

Once the guidelines have been defined, it will be possible to adapt the maps of the influencing factors, thus generating the new scenarios that could help the decision makers establish which ideal scenario should be adopted.

3 APPLICATION OF THE METHODOLOGY

For applying the methodology, it was key defining a suitable study area. So, the urban area of the São Manuel was chosen. The city is located in the State of São Paulo, Brazil, UTM coordinates: Zone 22S, E 749,454.27m, N 7,483,893.98m and average altitude of 700 meters (Figure. 2). The average temperature of the city is 20.8 °C, with an average annual precipitation of 1,465mm, which means the city has a high-altitude tropical climate with dry winters and rainy summers. These climatic conditions provide the occurrence of water erosion.

The urban area of the city is located on sandstones of the Adamantina Formation and on basalts of the Serra Geral Formation, which are covered by an association of Dark-Red Latosol, Red-Yellow Latosol, Purple Soil and Argisols (RIDENTE JR *et al.*, 2001). According to the erosion risk letter developed by Ridente Jr et al. (2001), the urban area of the city has a middle and high risk of susceptibility to water erosion.

In the urban area, there are nine existing water erosive features that have been cataloged to compose the City Basic Sanitation Plan (SECRETARIA DE ESTADO DE SANEMANETO E RECURSOS HÍDRICOS, 2017). Pascoto (2020) classified these erosive features by visiting the locations indicated in the Plan. During visits, the urban drainage system, the urban road system, a possible outcrop of the water table and the vegetation surrounding the features were analyzed. It was also necessary to interview residents of the region of features, for classification purposes. The interviews were designed to figure out the possible causes and of when each feature began developing.

Figure. 2 - Study area localization

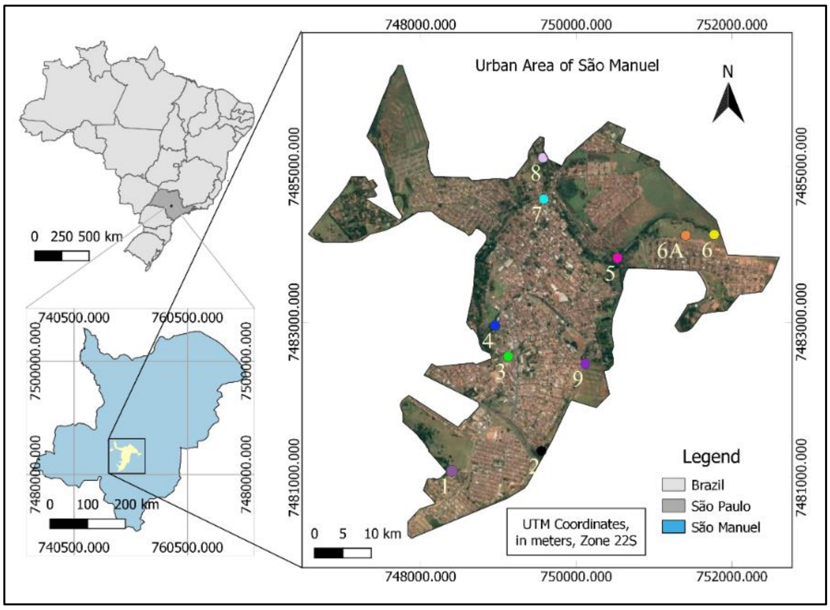


Table 1 shows the classification of these features. Of the nine existing features, it was impossible to classify one (feature 3) because the feature was already recovered at the time of classification. However, although Pascoto (2020) classifies feature 6 as a stabilized gully erosion, one of its branches is active due to a rupture in the drainage system piping in the neighborhoods around the feature (PASCOTO *et al.*, 2020), therefore, this branch was named as feature 6A to study it separately from feature 6. Thus, 3 features were classified as active gullies (features 1, 2 and 6B), two as stabilized gullies (features 4 and 6), one active ravine (feature 9) and one recovered ravine (feature 5), as well as two margin features (features 7 and 8) and one unclassified (feature 3).

Table 1 – Classification of features according to Pascoto (2020)

Feature	Classification	Feature	Classification	Feature	Classification
1	Active gully	5	Recovered ravine	7	Margin erosion
2	Active gully	6	Stabilized gully	8	Margin erosion
3	No Classification	6B	Active gully	9	Active ravine
4	Stabilized gully				

3.1 Verification of the need to predict future scenarios for the city (Phase I)

This topic comprised Phase I of Figure 1. By informal conversations with the population and with real estate investors, it was noted that the city had a housing deficit, which can be confirmed by the provisions of the document that makes up the Bases for the São Paulo Housing Plan, where the region in which the chosen city is located has the need for the construction of more than 1.1 million houses (GOVERNO DO ESTADO DE SÃO PAULO, 2012).

Furthermore, the choice was made due to the city experiencing the pressure of real estate development and, consequently, needing a study on possible areas of urban expansion, considering the changes that this expansion could bring to the area in relation to the risk of triggering erosive processes. As a result, the need to build different scenarios arose, including the application of changes in the land use of certain areas of interest in the real estate market to analyze the best expansion options when related to the risk of developing erosive processes.

3.2 Scnario building (Phase II)

This step comprises Phase II of Figure 1. Here it was discussed how the parameters were selected, the data collection and the data analysis using the AHP method was explained. Finally, the actual scenario was constructed, analyzed and validated.

3.2.1 Parameters to be surveyed

The parameters that influence water erosion processes are the subject of many studies (ALAGNA ET AL., 2019; COSTA ET AL., 2018; DA SILVA ET AL., 2019; DE PLOEY, 1981; JIONGXIN, 1996; MORGAN, 1983; SANTOS ET AL., 2011; SIMONETTI ET AL., 2018; SINGH, KHERA, 2009; VEZZANI, MIELNICZUK, 2011). considerable part of these studies were based on the parameters that constitute the universal soil loss equation (USLE). Thus, according to the decision makers of the municipality, the choice was based on the parameters of the USLE, due to the ease of collecting the parameters in the region: land use, average slope of the watershed, soil texture, permeability and soil erodibility (Pascoto et al. 2020a).

3.2.2 Data collect

To quantify the influencing factors, Pascoto (2020) collected deformed and undisturbed samples at 0.60 m depth in the headcut of each erosive feature in the urban area and spatialized the results of the analysis.

The results of the joint granulometry tests (NBR 7181/2016) provided the sand fraction maps and clay fraction. When analyzing the composition of both maps, it is possible to infer that the studied soil is typically sandy, varying between 73% sand and 18% clay in the composition of feature 4 and 88.5% sand and 6% clay in feature 6A.

The determination of soil erodibility used the methodology of Nogami and Villibor (1979) adapted by Pejon (1992). This methodology uses the water absorption and immersion water loss tests. The water absorption test consists of measuring how much water a specimen, previously dried in the air, absorbs in regular periods of time until it reaches saturation (approximately 1 hour). The immersion loss test consists of quantifying the percentage of soil loosened in 24 hours due to immersion of the undisturbed soil sample in water. From the results of these two tests, the erodibility of the material is calculated by dividing the absorption index multiplied by 40 by the loss index by immersion. If the erodibility (E) result is a number less than 1, the material is classified as high erodibility; if the erodibility (E) is greater than 1, it is considered as low erodibility. To facilitate the observation of these results, Pascoto et al. (2020a) plotted the index of absorption x loss by immersion, and plot the limit proposed by Pejon (1992). In this graph, it is possible to notice that features 1, 6, and 6A were classified as high erodibility (E less than 1), and the others, features 2, 3, 4, 5, 7, 8 and 9 showed low erodibility (E greater than 1).

The permeability data (NBR 13292/2021 and NBR 14545/2021) presented by Pascoto et al. (2020a) shows that the features presented a great variability in the order of magnitude of this parameter. They ranged from 10^{-3}cm/s to 10^{-6}cm/s. However, they were considered acceptable considering the values estimated by the literature for the granulometric curve of each point.

For the mean slope parameter of the feature contribution area, Pascoto et al. (2020a) developed a slope map using topographic maps from INPE (National Institute for Space Research), on a scale of 1: 10,000. In the chart of Pascoto et al. (2020a) , it was noted that there is a small area with a slope between 12.1% and 20% with most of the city in the range of 3.1% to 6%. Among the erosive features analyzed, the slope varied between 2.1% (feature 8) and 7.5% (feature 1).

The land use classification was based on satellite images from Google Earth (PASCOTO et al. 2020a). The areas were then classified and measured according to the one proposed by Costa et al. (2018). Thus, one feature is in riparian forest (feature 1), two in a reforestation area (features 2 and 4), three in a residential area (features 5, 6A and 9), two in water glasses (feature 7 and 8), and two in the pasture area (features 3 and 6).

3.2.3 Data analysis using the AHP method

The Analytical Hierarchical Process (AHP) method was used to analyze all the maps developed by Pascoto et al. (2020a),. This method uses pairwise comparisons to prioritize criteria and assist people in making complex decisions, where decision makers do not need to provide a numerical judgment. They make a qualitative assessment by defining the intensity of the importance of each judgment (Table 1). (SAATY, 1980, 1987).

Erro! Fonte de referência não encontrada. shows the judgment matrix of the influencing factors, with the last column showing the weights obtained after the pairwise comparison of the variables. In descending order, the highest weight obtained was for land use (0.393), followed by fractions of clay and sand (0.200 each), slope (0.129), and permeability and erodibility (0.039 each). The judgment matrix was considered satisfactory since consistency rate (CR) obtained was 0.045, below then 1 (SAATY, 1980).

Table 3 – AHP judgment matrix, weights, and consistency rate (CR)

Variables	Declivity	Sand	Clay	Permeability	Erodibility	Land Use	Weights
Declivity	1	1/3	1/3	5	5	1/3	0,129
Sand	3	1	1	5	5	1/3	0,200
Clay	3	1	1	5	5	1/3	0,200
Permeability	1/5	1/5	1/5	1	1	1/7	0,039
Erodibility	1/5	1/5	1/5	1	1	1/7	0,039
Land use	3	3	3	7	7	1	0,393
Consistency ratio (CR): 0,045							

Having defined the weights of each factor influencing erosive processes using the AHP method, an equation (1) was generated. This equation can describe the current scenario of susceptibility to the development of linear erosive features since the parameters surveyed explained only these features, with the influencing factors (F) given by: $F_{land\ use}$, F_{sand}, F_{clay}, $F_{declivity}$, $F_{permeability}$ e $F_{erodibility}$.

$$Susceptibility = (F_{land\ use} * 0{,}393) + (F_{sand} * 0{,}200) + (F_{clay} * 0{,}200) + (F_{declivity} * 0{,}129) + (F_{permeability} * 0{,}039) + (F_{erodibility} * 0{,}039) \quad (2)$$

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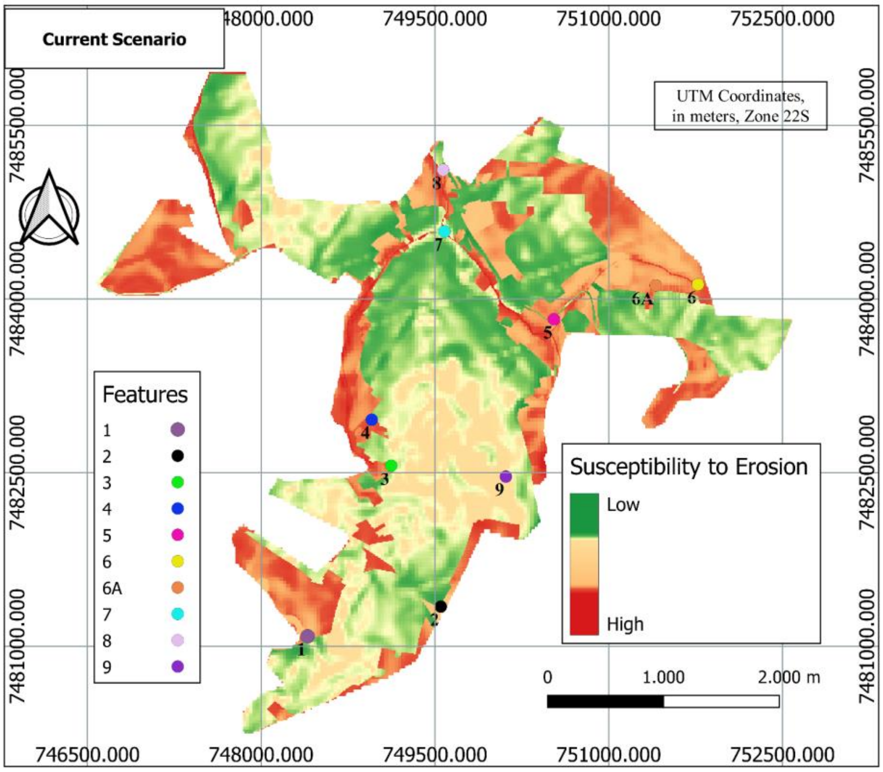
The values of each of these factors was determined in two different ways. For land use, sand, clay, permeability and erodibility the parameter value was taken from each pixel of interest. For slope gradient, the average slope gradient was calculated.

3.2.4 Building of current scenario

The current scenario was built with the survey and results obtained by Pascoto (2020). With the aid of GIS map algebra, the current susceptibility scenario for the development of linear erosive processes was generated (Figure. 3) using equation (1) in the raster calculator of the QGis 3.4.14 program.

Figure. 3 - Current scenario of susceptibility to the development of linear erosive features



3.2.5 Current Scenario validation

All features are located in the areas most susceptible to erosion. The only exception is feature 9, which is located in an intermediate region of susceptibility. Feature 9 was the only one classified as active ravine, according to Pascoto (2020). The remainder rainfall erosions were classified as gullies. The main difference between the classification in ravines or gullies took into account the size of the feature and the water table outcrop. Thus, the classification of feature 9 in the current scenario as intermediate susceptibility is related to a type of erosion feature of lesser proportion and that, therefore, did not reach and probably will not reach the water table.

These facts were proven with the observation of the erosion feature region, which points to smaller declivities in relation to the other features and to specific anthropic action, indicating the presence of a rain gallery; however, it is inefficient as shown in Table 1. This analysis corroborates the validation of the current scenario of susceptibility to the development of linear erosive features.

In addition, it is noted that urbanized areas with high waterproofing due to the paving of the streets are the places with the lowest susceptibility rates, whereas the more distant places, closer to the periphery of the city, are the ones with the highest fees. This can be explained due to the fact that these areas are generally the transition between the waterproofed soil of the city and the permeable soil of the rural area.

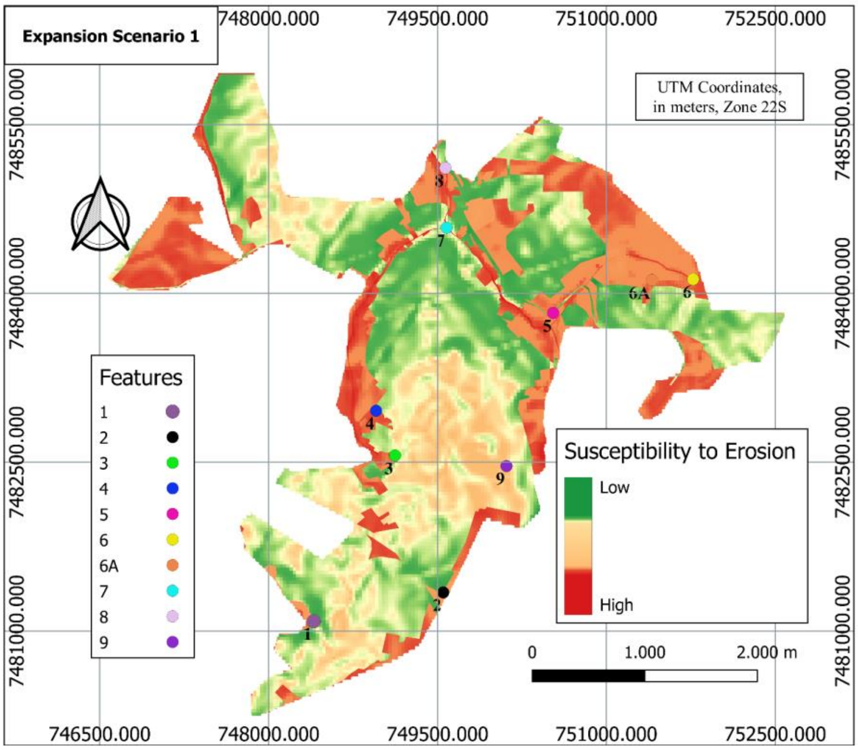
Places where there is concentrated of the flow through the street indicate the need for the adoption of works to dissipate energy from the runoff, in addition to periodic maintenance throughout the drainage system of the city, corroborating the study by Pascoto et al. (2020b).

3.3 Generation of future scenarios

With the current scenario validated, it was possible to create a future scenario with a supposed urban expansion. As a result of discussion concerning government officials, investors, research groups, and population about possible future changes, the choice of expansion over the southwest region was motivated by the possible future implementation of two urban allotments, totaling 600 house plots.

The future scenario generated (Figure. 4) showed three spots of high erosion susceptibility in the southwest region, indicating to investors possible spots that could present problems related to linear water erosion and, thus, indicating possible places where studying the implementation of works to dissipate energy from concentrated surface runoff – such as hydraulic ladders or the use of gabions – would be interesting. It is also possible to suggest a study of neighborhood interference and propose compensatory measures for the approval of the project.

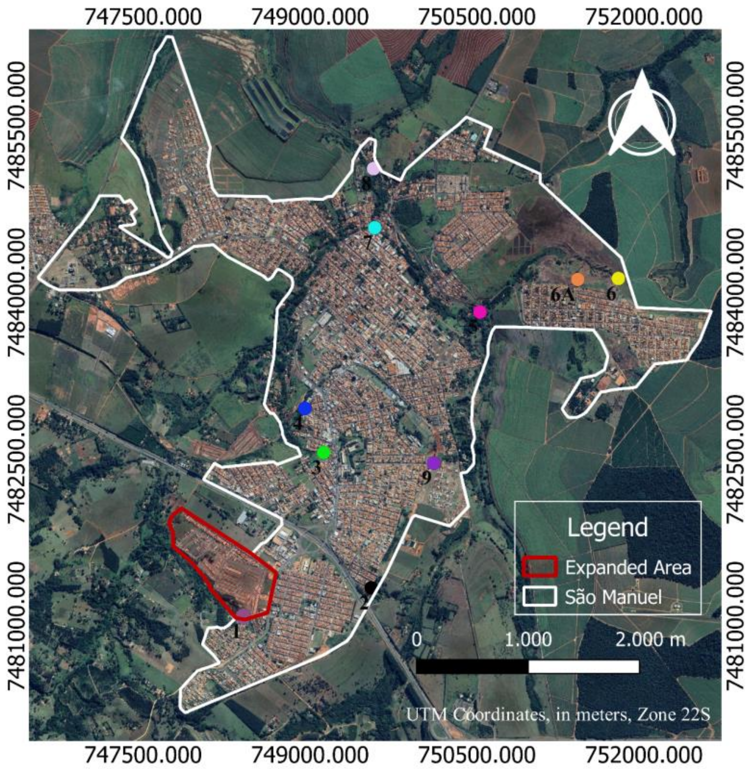
Figure. 4 - Future scenario of susceptibility to the development of linear erosive features with a possible urban expansion in the southwest region



4 IMPLEMENTATION OF THE FUTURE SCENARIO

The plots started to be implemented in 2019 and the first houses were built in 2021. The research was conducted before implementation began, and it was possible to evaluate the effect on erosion susceptibility, validating the future scenario generated in the study. Thus, site visits were conducted and no new erosive features were found in the area, corroborating the result found in the development of the future scenario (Figure 5).

Figure. 5 - Implantation of the future scenario in southwest region



5 CONCLUSIONS

The building of the scenarios to assess the erosion susceptibility must consider – among other factors – the physical environment through the survey of parameters capable of representing natural processes. The use of this methodology is effective for the functioning and governance of cities due to the success obtained with the application in several areas, such as changing land use, water use, urban mobility, among others.

In the studied area, the analysis of the results of the factors influencing the erosive processes indicated the priority of the land use factor, followed by soil texture, slope, and permeability with erodibility. The definition of the priority of factors by the AHP method, regardless of the order obtained, proves the efficiency of the use of future scenarios as a tool for managing territories that will face urban expansion. This study indicated the land use factor as the highest priority, indicating the need for decision making to mitigate this interference. Therefore, the careful quantification of the factors is crucial to ensure the success of application and guarantee the priority of the factors in a more precise way, providing the generation of scenarios more consistent with reality.

The methodology proved to be effective in small and medium-sized cities in Brazil, with similar physical environment conditions, as its validation and application to a real case proved the importance for understanding the behavior of the urban area when expanded upon in relation to susceptibility to the developing erosive processes. These scenarios enable the planning of future anthropic actions, which are necessary to avoid or mitigate existing social and environmental problems in areas susceptible to the development of linear erosive features.

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REFERENCES

ALAGNA, V.; BAGARELLO, V.; DI PRIMA, S.; GUAITOLI, F.; IOVINO, M.; KEESSTRA, S.; CERDÀ, A. Using Beerkan experiments to estimate hydraulic conductivity of a crusted loamy soil in a Mediterranean vineyard. **Journal of Hydrology and Hydromechanics**, [s. l.], v. 67, n. 2, p. 191–200, 2019.

ALEXAKIS, D. D.; HADJIMITSIS, D. G.; AGAPIOU, A. Integrated use of remote sensing, GIS and precipitation data for the assessment of soil erosion rate in the catchment area of "Yialias" in Cyprus. **Atmospheric Research**, [s. l.], v. 131, p. 108–124, 2013. Disponível em: <http://dx.doi.org/10.1016/j.atmosres.2013.02.013>

AMER, M.; DAIM, T. U.; JETTER, A. A review of scenario planning. **Futures**, [s. l.], v. 46, p. 23–40, 2013. Disponível em: <http://dx.doi.org/10.1016/j.futures.2012.10.003>

ARABAMERI, A.; REZAEI, K.; POURGHASEMI, H. R.; LEE, S.; YAMANI, M. GIS-based gully erosion susceptibility mapping: a comparison among three data-driven models and AHP knowledge-based technique. **Environmental Earth Sciences**, [s. l.], v. 77, n. 17, p. 1–22, 2018. Disponível em: <http://dx.doi.org/10.1007/s12665-018-7808-5>

BASILIO, T. C. C.; FUJIMOTO, J. T.; LOPES, T.; ASCIUTTI, G. A. M.; LORANDI, R.; DE LOLLO, J. A. Influência da Forma das Encostas na Suscetibilidade à Erosão na Bacia Hidrográfica do Rio Claro (Santa Rita do Passa Quatro, SP). **Revista Brasileira de Cartografia**, [s. l.], v. 71, n. 1, p. 233–252, 2019.

BIYIK, C. Developing urban transport in Turkey with greater consideration for sustainability. **Preprint**, [s. l.], n. April, 2019. Disponível em: <https://www.preprints.org/manuscript/201904.0198>

COSTA, C. W.; LORANDI, R.; DE LOLLO, J. A.; IMANI, M.; DUPAS, F. A. Surface runoff and accelerated erosion in a peri-urban wellhead area in southeastern Brazil. **Environmental Earth Sciences**, [s. l.], v. 77, n. 5, p. 1–18, 2018. Disponível em: <https://doi.org/10.1007/s12665-018-7366-x>

DA SILVA, A. M.; MORADI, E.; RODRIGO-COMINO, J.; CERDÀ, A. Spatial variability of soil roughness in persimmon plantations: A new combined ISUM (improved stock unearthing method) approach. **Ecological Indicators**, [s. l.], v. 106, n. June, p. 105528, 2019. Disponível em: <https://doi.org/10.1016/j.ecolind.2019.105528>

DE PLOEY, L. Crusting and time-dependent rainwash mechanisms on loamy soil. **RPC Morgan,** [s. l.], p. 139–152, 1981.

DEVATHA, C. P.; DESHPANDE, V.; RENUKAPRASAD, M. S. Estimation of Soil loss Using USLE Model for Kulhan Watershed, Chattisgarh- A Case Study. **Aquatic Procedia**, [s. l.], v. 4, n. Icwrcoe, p. 1429–1436, 2015.

DREBORG, K. H. Essence of backcasting. **Futures**, [s. l.], v. 28, n. 9, p. 813–828, 1996.

EL JAZOULI, A.; BARAKAT, A.; GHAFIRI, A.; EL MOUTAKI, S.; ETTAQY, A.; KHELLOUK, R. Soil erosion modeled with USLE, GIS, and remote sensing: a case study of Ikkour watershed in Middle Atlas (Morocco). **Geoscience Letters**, [s. l.], v. 4, n. 1, 2017.

EZEZIKA, O. C.; ADETONA, O. Resolving the gully erosion problem in Southeastern Nigeria: Innovation through public awareness and community-based approaches. **Journal of Soil Science and Environmental Management**, [s. l.], v. 2, n. 10, p. 286–291, 2011. Disponível em: <http://www.academicjournals.org/JSSEM>

GAMMAGE, L. C. **Development of a scnario-based approach for responding to change in fishery systems: A case study in the small- scale fisheries of South Africa's Southern Cape**. 2019. University of Cape Town, [s. l.], 2019.

GOVERNO DO ESTADO DE SÃO PAULO, ... **Bases para o Plano Estadual de Habitação de São Paulo**, 2012.

HALEFOM, A.; TESHOME, A. Modelling and mapping of erosion potentiality watersheds using AHP and GIS technique: a case study of Alamata Watershed, South Tigray, Ethiopia. **Modeling Earth Systems and Environment**, [s. l.], v. 5, n. 3, p. 819–831, 2019. Disponível em: <http://dx.doi.org/10.1007/s40808-018-00568-6>

HAREGEWEYN, N.; TSUNEKAWA, A.; POESEN, J.; TSUBO, M.; MESHESHA, D. T.; FENTA, A. A.; NYSSEN, J.; ADGO, E. Comprehensive assessment of soil erosion risk for better land use planning in river basins: Case study of the Upper Blue Nile River. **Science of the Total Environment**, [s. l.], v. 574, p. 95–108, 2017. Disponível em: <http://dx.doi.org/10.1016/j.scitotenv.2016.09.019>

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. IBGE. **Cidades e Estados**. 2022. Disponível em: <https://www.ibge.gov.br/cidades-e-estados/sp/sao-manuel.html>. Acesso em: 14 dez. 2022.

IPT, I. de P. T. **Consolidação do projeto orientação para o controle à erosão no Estado de São Paulo**, IPT, 1989.

IWANIEC, D. M.; COOK, E. M.; DAVIDSON, M. J.; BERBÉS-BLÁZQUEZ, M.; GEORGESCU, M.; KRAYENHOFF, E. S.; MIDDEL, A.; SAMPSON, D. A.; GRIMM, N. B. The co-production of sustainable future scenarios. **Landscape and Urban Planning**, [s. l.], v. 197, n. December 2019, p. 103744, 2020. Disponível em: <https://doi.org/10.1016/j.landurbplan.2020.103744>

IWANIEC, D.; WIEK, A. Advancing Sustainability Visioning Practice in Planning—The General Plan Update in Phoenix, Arizona. **Planning Practice and Research**, [s. l.], v. 29, n. 5, p. 543–568, 2014.

JAHN, T.; BERGMANN, M.; KEIL, F. Transdisciplinarity: Between mainstreaming and marginalization. **Ecological Economics**, [s. l.], v. 79, p. 1–10, 2012. Disponível em: <http://dx.doi.org/10.1016/j.ecolecon.2012.04.017>

JAZOULI, A. El; BARAKAT, A.; KHELLOUK, R.; RAIS, J.; BAGHDADI, M. El. Remote sensing and GIS techniques for prediction of land use land cover change effects on soil erosion in the high basin of the Oum Er Rbia River (Morocco). **Remote Sensing Applications: Society and Environment**, [s. l.], v. 13, p. 361–374, 2019. Disponível em: <https://doi.org/10.1016/j.rsase.2018.12.004>

JIONGXIN, X. Benggang erosion: The influencing factors. **Catena**, [s. l.], v. 27, n. 3–4, p. 249–263, 1996.

KACHOURI, S.; ACHOUR, H.; ABIDA, H.; BOUAZIZ, S. Soil erosion hazard mapping using Analytic Hierarchy Process and logistic regression: a case study of Haffouz watershed, central Tunisia. **Arabian Journal of Geosciences**, [s. l.], v. 8, n. 6, p. 4257–4268, 2015.

KOKS, E. E.; JONGMAN, B.; HUSBY, T. G.; BOTZEN, W. J. W. Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. **Environmental Science and Policy**, [s. l.], v. 47, p. 42–52, 2015. Disponível em: <http://dx.doi.org/10.1016/j.envsci.2014.10.013>

LANG, D. J.; WIEK, A.; BERGMANN, M.; STAUFFACHER, M.; MARTENS, P.; MOLL, P.; SWILLING, M.; THOMAS, C. J. Transdisciplinary research in sustainability science: Practice, principles, and challenges. **Sustainability Science**, [s. l.], v. 7, n. SUPPL. 1, p. 25–43, 2012.

LOBÃO, J. S. B.; FRANCA-ROCHA, W. de J. S. Da; SILVA, A. B. Da. GEOPROCESSAMENTO NA MODELAGEM DA VULNERABILIDADE NATURAL À EROSÃO NO MUNICÍPIO DE MORRO DO CHAPÉU-BA Geoprocessing in Modeling Vulnerability to Natural Erosion in the City of Morro do Universidade Estadual de Feira de Santana – UEFS Universidade Estadual. **Revista Brasileira de Cartografia**, [s. l.], v. 63, n. 1, p. 101–114, 2011. Disponível em: <http://www.lsie.unb.br/rbc/index.php/rbc/article/viewFile/362/354>

MANNERS, R.; BLANCO-GUTIÉRREZ, I.; VARELA-ORTEGA, C.; TARQUIS, A. M. Transitioning European protein-rich food consumption and production towards more sustainable patterns-Strategies and policy suggestions. **Sustainability (Switzerland)**, [s. l.], v. 12, n. 5, 2020.

MORGAN, R. P. C. The non-idenpendence of rainfall erosivity and soil erodibility. **Earth Surface Processes and Landforms**, [s. l.], v. 8, p. 323–338, 1983.

NASSAUER, J. I.; CORRY, R. Using Normative Scenarios in Landscape Ecology. **Landscape Ecology**, [s. l.], v. 19, n. 1, p. 343–356, 2004.

NOGAMI, J. S.; VILLIBOR, D. F. Soil characterization of mapping units for highway purposes in a tropical area. **Bulletin of the International Association of Engineering Geology - Bulletin de l'Association Internationale de Géologie de l'Ingénieur**, [s. l.], v. 19, n. 1, p. 196–199, 1979.

NORSTRÖM, A. V.; CVITANOVIC, C.; LÖF, M. F.; WEST, S.; WYBORN, C.; BALVANERA, P.; BEDNAREK, A. T.; BENNETT, E. M.; BIGGS, R.; DE BREMOND, A.; CAMPBELL, B. M.; CANADELL, J. G.; CARPENTER, S. R.; FOLKE, C.; FULTON, E. A.; GAFFNEY, O.; GELCICH, S.; JOUFFRAY, J. B.; LEACH, M.; LE TISSIER, M.; MARTÍN-LÓPEZ, B.; LOUDER, E.; LOUTRE, M. F.; MEADOW, A. M.; NAGENDRA, H.; PAYNE, D.; PETERSON, G. D.; REYERS, B.; SCHOLES, R.; SPERANZA, C. I.; SPIERENBURG, M.; STAFFORD-SMITH, M.; TENGÖ, M.; VAN DER HEL, S.; VAN PUTTEN, I.; ÖSTERBLOM, H. Principles for knowledge co-production in sustainability research. **Nature Sustainability**, [s. l.], v. 3, n. 3, p. 182–190, 2020.

PASCOTO, T. V. **Análise fatorial e de componentes principais aplicadas ao estudo dos fatores influenciadores de processos erosivos**. 2020. Universidade Estadual Paulista, [s. l.], 2020.

PASCOTO, T. V.; FUREGATTI, S. A.; PEIXOTO, A. S. P. Consideration of land luse in the evaluation of erosive process in gully erosion. **Revista Eletronica em Gestão, Educação e Tecnologia Ambiental**, [s. l.], v. 24, 2020. a.

PASCOTO, T. V.; FUREGATTI, S. A.; PEIXOTO, A. S. P. Avaliação do fator erodibilidade nos processos erosivos , na cidade de São Manuel / SP. **XX Congresso Brasilieiro de Mecânica dos Solos e Engenharia Geotécnica**, [s. l.], 2020. b.

PEJON, O. J. **Mapeamento geotécnico da folha de Piracicaba - SP (Escala 1:100.000): Estudo de aspectos metodológicos, de caracterização e de apresentação dos atributos - Volume I**. 1992. Universidade de São Paulo, São Carlos, 1992.

PHAM, T. G.; DEGENER, J.; KAPPAS, M. Integrated universal soil loss equation (USLE) and Geographical Information System (GIS) for soil erosion estimation in A Sap basin: Central Vietnam. **International Soil and Water Conservation Research**, [s. l.], v. 6, n. 2, p. 99–110, 2018. Disponível em: <http://dx.doi.org/10.1016/j.iswcr.2018.01.001>

PRADEEP, G. S.; KRISHNAN, M. V. N.; VIJITH, H. Identification of critical soil erosion prone areas and annual average soil loss in an upland agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. **Arabian Journal of Geosciences**, [s. l.], v. 8, n. 6, p. 3697–3711, 2015.

RIDENTE JR, J. L.; CANIL, K.; ALMEIDA, M. C. J.; MONTEIRO, M. C.; TECNOL, P. ANÁLISE DA EROSÃO NO MUNICÍPIO DE SÃO MANUEL , SP. [s. l.], p. 1–8, 2001.

SAATY, R. W. **The Analytic Hierarchy Process**. New York: McGraw-Hill, 1980.

SAATY, R. W. The analytic hierarchy process-what it is and how it is used. **Mathematical Modelling**, [s. l.], v. 9, n. 3–5, p. 161–176, 1987.

SANTOS, D. C. dos.; PILLON, C. N.; FLORES, C. A.; LIMA, C. L. R. De; CARDOSO, E.; M. C., PERERIA, B. F.; MANGRICH, A. A. Agregação e frações físicas da matéria orgânica de um Argissolo Vermelho sob sistemas de uso no bioma Pampa. **Revista Brasileira de Ciência do Solo**, [s. l.], v. 35, p. 1735–1744, 2011.

SECRETARIA DE ESTADO DE SANEMANETO E RECURSOS HÍDRICOS. **Plano Municipal de Saneamento de São Manuel**, 2017.

SIMONETTI, V. C.; SILVA, D. C. C.; OLIVEIRA, R. A.; SABONARO, D. Z.; ROSA, A. H. Análise da suscetibilidade do solo a processos erosivos do parque natural municipal corredores de biodiversidade (PNMCBIO) de Sorocaba (SP). **RA'E GA - O Espaco Geografico em Analise**, [s. l.], v. 44, p. 169–180, 2018.

SINGH, M. J.; KHERA, K. L. Nomographic estimation and evaluation of soil erodibility under simulated and natural rainfall conditions. **Land Degradation e Development**, [s. l.], v. 20, p. 471–480, 2009.

VEZZANI, F. M.; MIELNICZUK, J. Agregação e estoque de carbono em Argissolo submetido a diferentes práticas de manejo agrícola. **Revista Brasileira de Ciência do Solo**, [s. l.], v. 35, p. 213–223, 2011.

VIJITH, H.; DODGE-WAN, D. Modelling terrain erosion susceptibility of logged and regenerated forested region in northern Borneo through the Analytical Hierarchy Process (AHP) and GIS techniques. **Geoenvironmental Disasters**, [s. l.], v. 6, n. 1, 2019.

VULEVIĆ, T.; DRAGOVIĆ, N.; KOSTADINOV, S.; SIMIĆ, S. B.; MILOVANOVIĆ, I. Prioritization of soil erosion vulnerable areas using multi-criteria analysis methods. **Polish Journal of Environmental Studies**, [s. l.], v. 24, n. 1, p. 317–323, 2015.