ENVIRONMENTAL CHANGES DETECTED BY SPACIAL GEOTECHNOLOGIES

Alterações ambientais detectadas por geotecnologias espaciais

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***Abstract**: As global populations grow, demand for food security also rises. As global climate change proceeds, demand for sustainability in said food production also grows. Initiatives that address sustainability in agribusiness can utilize geotechnology to identify losses in environmental quality resulting from methods of food production. The objective of this study is to evaluate the risks of environmental transformations categorized as: savannah, urban, water, forests, exposed soil, cultivation and regrowth in the municipalities of Carazinho, Marau and Passo Fundo, located in southern Brazil, demonstrating the potential of the approach in the Process Analytical Hierarchy (AHP), integrated with Geographic Information Systems (GIS), to determine areas at environmental degradation risk. This study considered parameters of density of rural buildings, soil type, use and slope. The AHP method was used to determine the weights of the parameters, through the following categories: savanna = 0.1; urban = 0.25; water = 0.9; hill = 0.1; exposed soil = 0.4; cultivation = 0.45; and regrowth = 0.5. The results showed that the integrated approach of AHP and GIS in a computerized environment proved itself effective for the mapping and quantification of environmentally degraded areas, attributed to the percentage of exposed soil, with the formation of sedimentary basins in river beds, with a high risk of 2.49%, with 2,680 patches of exposed soil fragments identified, which detracts from the sustainability of agricultural production in the region. This research is fundamentally important as it can be replicated in other regions, making it possible to assess environmental problems in relation to food production areas, aiming to raise the levels of agribusiness on a global scale.*

***Keywords:** Food production; Environmental degradation; Geospatial analysis; Food safety; Global sustainability.*

***Resumo**: Conforme a população mundial cresce, a demanda por segurança alimentar também aumenta. Conforme a mudança climática global procede, a demanda por sustentabilidade nesta produção alimentar também aumenta. Iniciativas que abordam sustentabilidade no agronegócio, podem utilizar geotecnologia para identificar perdas na qualidade ambiental resultantes de métodos de produção alimentícia. O objetivo desse estudo é avaliar os riscos de transformações ambientais categorizados como: savana, urbano, água, florestas, solo exposto, cultivo e rebrota nos municípios de Carazinho, Marau e Passo Fundo, localizados no Sul do Brasil, demonstrando o potencial da abordagem no Processo de Análise Hierárquica (AHP), integrado com Sistemas de Informação Geográfica (GIS), para determinar áreas em risco de degradação ambiental. Esse estudo considera parâmetros de densidade de construções rurais, tipo de solo, uso e declive. O método AHP foi usado para determinar o peso dos parâmetros, através das seguintes categorias: savana = 0,1; urbano = 0,25; água = 0,9; colina = 0,1; solo exposto = 0,4; cultivo = 0,45; e rebrota = 0,5. Os resultados mostraram que a abordagem integrada do AHP e do GIS em um ambiente computadorizado se provou efetiva para o mapeamento e quantificação de áreas ambientalmente degradadas, atribuída à porcentagem de solo exposto, com a formação de bacias sedimentares em leitos de rios, com um alto risco de 2,49%, com 2.680 fragmentos de solo identificados, o que prejudica a sustentabilidade de produção alimentar na região. Essa* *pesquisa é fundamentalmente importante, por poder ser replicada em outras regiões, tornando possível estimar problemas ambientais em relação a áreas de produção alimentar, visando aumentar os níveis de agronegócio em uma escala global.*

Palavras chave: *Produção alimentar; Degradação ambiental; Análise geoespacial; Segurança alimentar; Sustentabilidade global.*

Resumen: *A medida que la población mundial crece, la demanda de seguridad alimentaria también aumenta. A medida que avanza el cambio climático global, la demanda de sostenibilidad en la producción de alimentos también aumenta. Las iniciativas que abordan la sostenibilidad en el agronegocio, pueden utilizar la geotecnología para identificar pérdidas en la calidad ambiental resultantes de métodos de producción alimentaria. El objetivo de este estudio es evaluar los riesgos de transformaciones ambientales categorizados como: sabana, urbano, agua, bosques, suelo expuesto, cultivo y rebrota en los municipios de Carazinho, Marau y Passo Fundo, demostrando el potencial del enfoque en el Proceso de Análisis Jerárquico (AHP), integrado con Sistemas de Información Geográfica (SIG), para determinar áreas en riesgo de degradación ambiental. Este estudio considera parámetros de densidad de construcciones rurales, tipo de suelo, uso y pendiente. El método AHP fue utilizado para determinar el peso de los parámetros, a través de las siguientes categorías: sabana = 0,1; urbano = 0,25; agua = 0,9; colina = 0,1; suelo expuesto = 0,4; cultivo = 0,45; y rebrota = 0,5. Los resultados mostraron que el enfoque integrado de AHP y GIS en un entorno computadorizado demostró ser efectivo para el mapeo y cuantificación de áreas ambientalmente degradadas, atribuidas al porcentaje de suelo expuesto, con la formación de cuencas sedimentarias en con un alto riesgo de 2,49%, con 2.680 fragmentos de suelo identificados, lo que perjudica la sostenibilidad de la producción alimentaria en la región. Esta investigación es fundamentalmente importante, por poder ser replicada en otras regiones, haciendo posible estimar problemas ambientales en relación a áreas de producción alimentaria, con el objetivo de aumentar los niveles de agroindustria a escala global.*

Palabras clave: *Producción de alimentos; Degradación ambiental; Análisis geoespacial; Seguridad alimentaria; Sostenibilidad global.*

1. Introduction

Global population growth is fueling the demand for both quantity and quality of food. Additionally, sustainability factors in agricultural production are in high demand (KÖNINGER *ET AL*., 2021). Expanding countries such as China increasingly need to secure new sources of water and arable land for agricultural production in order to guarantee production of the amount of food needed to meet the needs of their population (ZHANG *ET AL*., 2018).

The current methods of food production require attention and renewed interest, as the degradation caused by conventional agricultural practices become costly to undo (RUSSO *ET AL*., 2021). Recent efforts include approaches aiming to develop and implement alternative forms of sustainable agriculture (SKAF *ET AL*., 2019).

A Brazilian study in the municipality of Boa Vista, in Paraíba State, sought to map and analyze areas with different levels of risk of environmental degradation, based on a multicriteria analysis and remote sensing images through the use of LANDSAT-5 and SRTM. The parameters analyzed were land use, soil type, slope, housing and water bodies (FALCÃO, 2013). Their findings demonstrated efficient applicability of remote sensing geotechnologies.

Another study performed in Ardabil Province in northwest Iran mapped the suitability of land for barley production (SEYEDMOHAMMADI *ET AL*., 2019). This study used criteria such as soil depth, slope, climactic characteristics, pH, electrical conductivity, exchangeable sodium percentage, equivalent calcium carbonate and gypsum content; the results made it possible to both correct environmental damage and increase food production (SEYEDMOHAMMADI *ET AL*., 2019).

This study analyzes an agricultural production region in southern Brazil which has a Regional Development Council established as a forum for promoting sustainable policies and actions for regional development (SOCIOECONOMIC ATLAS, 2022), and is characterized by the predominant production of soybean and corn commodities. The authors' goal was to analyze the level of environmental risk present in a given area through remote sensing, to spatially verify locations with elevated risk of degradation.

Practical initiatives, as well as the United Nations' (UN) Sustainable Development Goals (SDGs) through SDGs 1, SDGs 2 and SDGs 12 both present and analyze data regarding production systems for food. There remains the need for expert insights, in order to bring a valid approach to sustainability assessments (PASHAEI *ET AL*., 2017). Several aspects are considered crucial for labeling global agribusiness sustainable, especially the evaluation of production systems through remote sensing methodologies.

The objective of this study is to evaluate the risks of environmental transformation and degradation in areas categorized as savannah, urban, water, forests, exposed soil, cultivation and regrowth in and around the municipalities of Carazinho, Marau and Passo Fundo, located in southern Brazil, demonstrating the potential of the approach in the Process Analytical Hierarchy (AHP), integrated within Geographic Information Systems (GIS) in the determination of areas with high risk of environmental degradation.

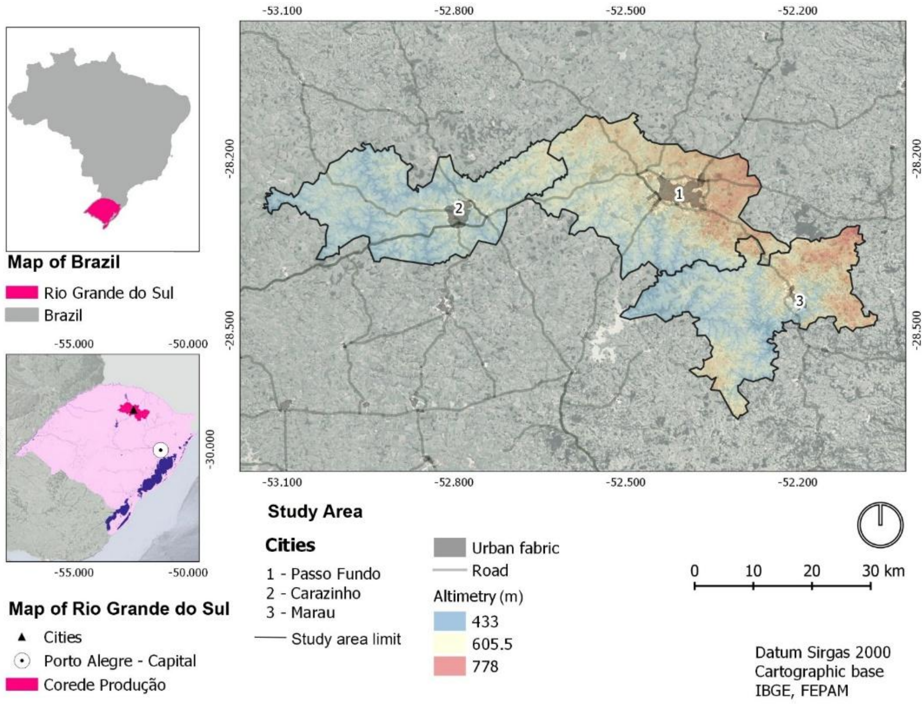
Regarding sustainability, there are negative factors related to food security, unique from region to region. These factors include pollution, soil degradation, waste, transportation challenges, greenhouse gas emissions, and food loss (NCHANJI AND LUTOMIA, 2021). The proposed investigation will be able to contribute to the reflections on the habits of humanity in relation to food production, as well as analyzing data and decision-making techniques that require attention to environmental degradation on a global scale.

2. **Material and methods**

2.1 *Study area*

The study areas comprise the municipalities of Carazinho, Marau and Passo Fundo, located in the state of Rio Grande do Sul, in southern Brazil. Their territorial area combined totals 6,003 km², and are located at latitude 28º 15' 46" S and longitude 52º 24' 24" W (Figure 1) (IBGE, 2022).

Figure 1: Location of the area of study



Source: Elaborated by the authors

This area is known as the Missões Plateau, and is characterized by a very homogeneous relief composed of soft, rounded hills regionally known as "coxilhas" underlain by latosols (FERNARDES *ET AL*., 2021; IBGE, 2022). The three municipalities studied have two characteristic vegetation types comprised of Savannah and Mixed Ombrophilous Forest (MARONI *ET AL*., 2021; IBGE, 2022).

The area's hottest month, January, ranges from 18.0° C to 26.5° C on average. The coldest month, July, varies from 9.5° C to 15.8° C on average (EMBRAPA, 2022). Average annual rainfall varies from more than 1,100 mm to less than 2,500 mm. The area typically experiences between 79 and 140 days of rain per year (EMBRAPA, 2022). These three municipalities are the most representative ones from COREDE Produção (Regional Council for Production Development) (BERNARDES *ET AL*., 2021). Land use is characterized by the cultivation of soybeans, corn and wheat on a massive scale.

COREDE Produção is integrated into 21 municipalities, providing support for planning decisions for regional development in a systematic way (BERNARDES *ET AL*., 2021). The main importance of this study is an interconnected strategy, considering the SDGs for the strengthening of environmental and social sustainability, mitigating environmental impacts related to agricultural production areas (PROVIN *ET AL*., 2021).

2.2 Analysis parameters used in this study

Table 1. Equations applied in this study.

Number	Equation	Description
1	$A = (D_r - x_{min})/(x_{max} - x_{min})$	A - linear normalized value
		D_r - raster data

		x_{min} – lower raster value x_{max} - higher raster value
2	$w_{ij} = 1/d_{ij}^{k}$	w_{ij} - weight of sample j at point i of the grid K - distance exponent d_{ij} - distance value from sample j to grid point i
3	$\hat{\lambda}_R = \sum_{i=1}^{n} \frac{1}{R^2} k\left(\frac{p - p_i}{R}\right)$	K - phenomenon smoothing property R - adopted radius p_i - points that contribute to the result p - central point n - number of events observed
4	A= $[D/W_n]$	A - auto vector D - matrix row sum Wn - sum of the matrix general
5	$P = [D * W_n/W_n]$	D – matrix row sum Wn – sum of the matrix general P - vector product
6	$B = P/A$	B - Eigenvalue P – vector product A - auto vector
7	$B_m = [D * W_n/W_n]$	Bm - average auto value D - matrix row sum Wn - sum of the matrix general
8	$CI = \{(B_m - n)/(n - 1)\}$	CI - consistency index Bm - average auto value n- number of criteria
9	$CR = CI/RI$	CR - consistency ratio CI - consistency index RI - random index

Source: Adapted from Saaty (1990), Saaty (1994), Saaty and Shang (2011), Falcão (2013), Maroni *et al*. (2021).

The parameters taken into account were: soil type, land use, slope and density of rural buildings. For the generated parameters, thematic maps were constructed in raster files, linearly normalized, according to Equation 1, where the values range from zero (0) to one (1) (Table 1) (SAATY, 1990; SAATY, 1994; SAATY AND SHANG, 2011; MARONI *ET AL*., 2021).

The land use map of the study area was constructed using a false-color visualization mosaic, according to the Landsat TM-8 satellite characteristic, dated March 17, 2020, using the RGB654 composition bands. This stage of thematic classification was carried out in a supervised manner (FAUVEL *ET AL*., 2015), using the Dzetsaka tool in a QGIS environment, version 3.10, adopting the Gaussian model. The objects resulting from these classifications were two files in raster format (tif.), later treated with the Sieve tool in the QGIS environment (2022).

The AHP method provides for each class a certain risk weight, for which the following categories/weights were predetermined: savanna / 0.1; urban / 0.25; water / 0.9; hill / 0.1; exposed soil / 0.4; cultivation / 0.45; and regrowth / 0.5. These weights were measured in the studies by FALCÃO (2013). For altimetry analysis, raster images from the Shuttle Radar Topography Mission (SRTM) program were used with a spatial resolution of 30m, obtained from the USGS Earth Explorer, and the altimetry quotas were obtained (TSENG *ET AL*., 2017). Thus, considering the terrain slope analysis, where slope SRTM raster image was used in a QGIS environment, to generate a raster mosaic, where slope was classified in percentage (index).

The types of soil were obtained from the geosciences system of the Geological Service of Brazil, and the material presents the classification of the soil based on EMBRAPA PARAMETERS (2022). The AHP method predicts a certain risk weight for each class, for which the following categories/weights were pre-determined: Podzolic Dark Red alic / 0.33; Intermediate Bruno Latosol to Halic Purple Latosol = 0.23; Dystrophic Purple Latosol = 0.20; Intermediate Structured Bruna Earth to Dark Red Podzolic = 0.43; and Alic Humic Dark Red Latosol = 0.26 (FALCÃO, 2013).

Rural buildings were surveyed to determine density by means of a point with the locations, using the QGIS software. The radius used was 5000 m and the spatial resolution adopted was 30x30m (POTAPOV *ET AL*., 2019). The shapefile of points was used to generate a color map, necessary to estimate the point intensity of a process in a region and compose a surface whose value is proportional to the intensity of the sample per unit of analyzed area (MARONI *ET AL*., 2021).

2.3 Determining the weight assigned to the AHP in a computational environment

The Analytic Hierarchy Process (AHP) is a multi-criteria decision approach consisting of determining weights for parameters to be assigned to variables, seeking a greater interpretation of data, structured in objectives, criteria, sub-criteria and alternatives (ELVIS *ET AL*., 2022).

Table 2 presents the scale, where 1 indicates equal importance, while 9 indicates that one factor is absolutely more important than another (SAATY, 1980; AWAD AND JUNG, 2022).

Table 2. AHP importance scale for comparison pair.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Little importance of one over the other	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its mastery demonstrated in practice
9	Absolute importance	Evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocal	If activity i has one of the above numbers assigned to it when compared to activity j, then j has the reciprocal value when compared to i. The reciprocals of 1 to 9 (1/1 and 1/9) show that one is less important than the other.	

Source: Adapted from Saaty (1980), Awad and Jung (2022).

The AHP method calculates a Consistency Ratio (CR) by comparing the Consistency Index (CI) of the matrix, with the consistency index of a random matrix, called the Random Index (RI) (SAATY, 1980; AWAD AND JUNG, 2022), according to Table 3. The next step is weighting the data. It consists of: (a) calculation of the eigenvector; (b) determining the Cross product; (c) calculation of the Eigenvalue; (d) calculation of the average lambda; (e) calculation of the consistency index (CI) and (f) determining the Consistency Ratio (CR). When the matrix has complete consistency, IC = 0, the higher the CI, the worse the matrix consistency. When CR is less than 0.10, the matrix shows reasonable consistency. Thus, the weight results could be accepted when the CR is satisfactory (SAATY, 1980; AWAD AND JUNG, 2022).

Table 3. Random index as a function of the number of criteria (n) in the matrix.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: Adapted from Saaty (1980), Awad and Jung (2022).

The environmental degradation risk map was developed utilizing QGIS software version 3.10 (QGIS, 2022) with 30 m spatial resolution. The weights derived from the AHP model were assigned to each parameter studied. The created raster was categorized into 5 classes of equal intervals (MARONI *ET AL.*, 2021).

3. Results and discussion

3.1 Geoanalysis of the studied region, with application of the AHP method

The sustainable food production on a global scale is of concern due to the depletion of natural resources in areas of intense agricultural production (WUNDERLICH AND MARTINEZ, 2018). With an ever-growing population, increases the need of growing agricultural production systems (XU *ET AL.*, 2019). Sustainability based intensification of areas can promote food security and economic development in many regions by gaining knowledge about environmental impacts (MICHALEK, 2022).

This study utilized an environmental degradation risk map determined by the AHP method (SEYEDMOHAMMADI *ET AL.*, 2019; ZHANG *ET AL.*, 2021). Through Table 4, it’s observable the variables Eigenvector indices (W), such as: land use, which was 0.62, the type of soil, 0.21, the slope, 0.11 and the buildings, 0.06. The weights were used in QGIS (2022) through the raster calculator tool.

Table 4. Application of parameters and weights for the AHP method applied to the criteria of land use, soil type, and density of buildings.

Criteria	Use of the soil	Soil type	Slope	Buildings	Sum lines	Auto vector (W)	Vector product	Lambda Eigenvalue

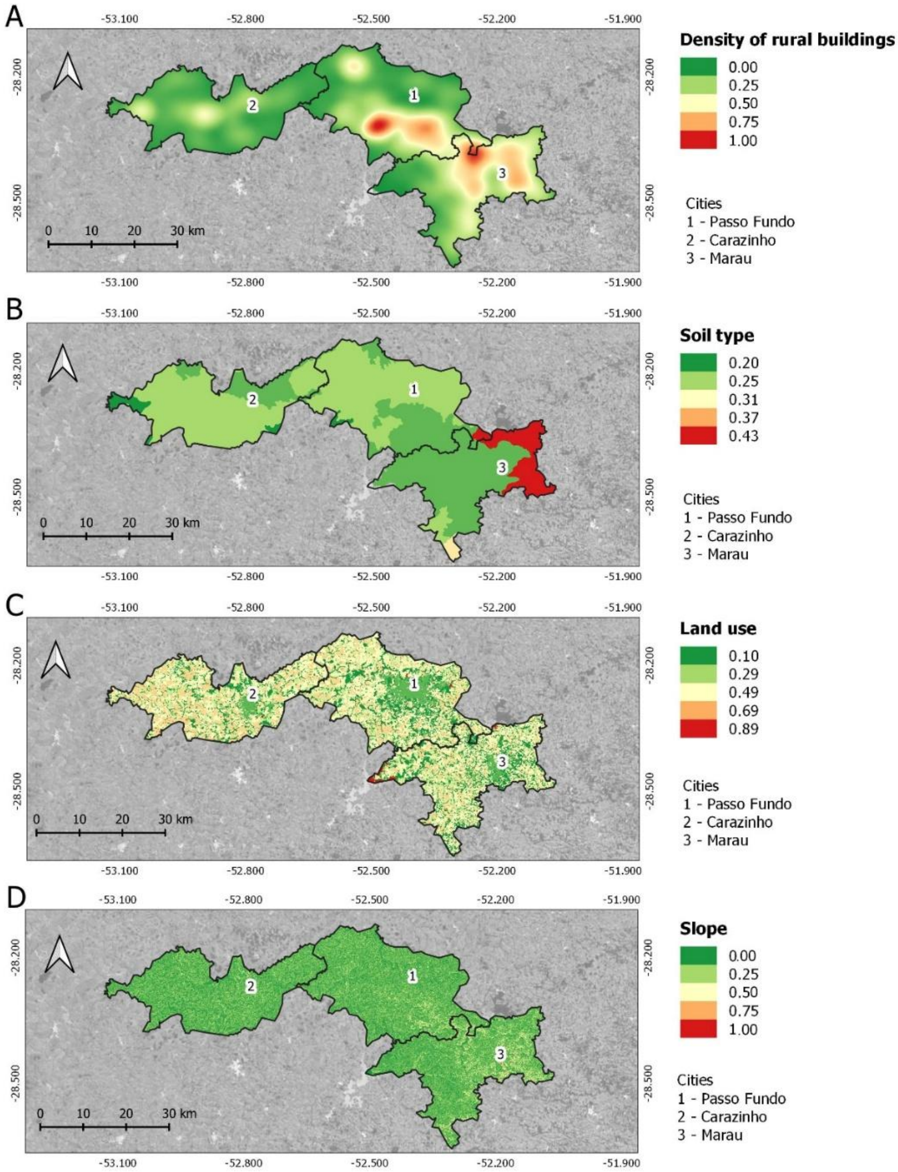
Use of the soil	1	5	7	8	21.00	0.62	2.89	4.64
Soil type	0.20	1	2	4	7.20	0.21	0.77	3.63
Slope	0.14	0.50	1	2	3.64	0.11	0.41	3.84
Buildings	0.13	0.25	0.50	1	1.88	0.06	0.24	4.33
Consistency Ratio (CR) 0.042; Consistency Index (CI) 0.0376; Maximum Lambda (L_{max}) 4.113.								

Figure 2A presents risk factors referring to the density of rural buildings. It is assumed the concentration of buildings is related to human actions and the possibility of intensifying environmental impacts. These buildings enhance the scope of the agro-industrial production of animals (ZHOU, 2022).

Figure 2B shows risk factors related to the type of soil, considering criteria such as depth, porosity, drainage, agricultural production, chemical fertility level, resistance, erosion and texture gradient. The risk is very low for: Dystrophic Purple Latosol with a factor of 0.20; Intermediate Bruno Latosol for Alic Purple Latosol with a factor of 0.23; and Dark Red Humic Alic Latosol with a factor of 0.26. The Dark Red Alic Podzolic soil has a factor of 0.33 and is considered moderate. Intermediate structured Terra Bruna soil to Dark Red Podzolic with a factor of 0.43 is considered the greatest risk (MEINEN AND ROBINSON, 2021).

Figure 2C presents risk factors related to land use. Values ranging from 0.1 to 0.29 are considered very low risk, and are related to the uses assigned to savanna (0.1), urban (0.25) and forest (0.1). The range of 0.31 is considered moderate in areas with vegetative cover intended for cultivation. Ranges above 0.37 are related to exposed soil (0.4) and regrowth (0.5) (Figure 2D). The use of water presents a risk factor of 0.9, and are characterized as areas with lower altimetry, sometimes dammed. For UWACU *ET AL*. (2021), the damming of water becomes important and necessary for the maintenance of drainage basins and hydrographic microbasins, but they usually present problems from silting, concentration of effluents, pesticides, and variations in water turbidity.

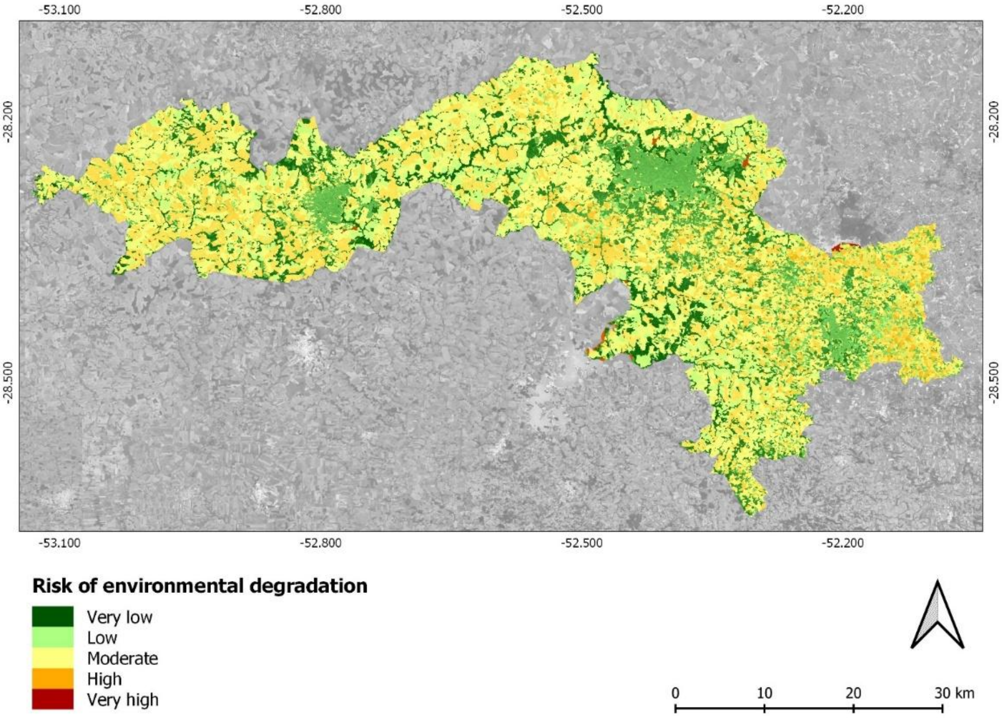
Figure 2: Risk factors related to different causes



Source: Elaborated by the authors

Figure 3 displays a map of environmental degradation represented from four parameters analyzed and weighted by the AHP method, demonstrating that the greatest potential for risk categorized as "very high" are related to dams. This is related to two issues, the first refers to the use of exposed soil, increasing the inefficiency of the grain production system, causing losses in the production process. The management styles adopted by these farmers at some point leaves the land without vegetative cover, leading to possible impacts such as soil erosion, silting of water resources and loss of soil productivity (DAL MORO *ET AL*., 2021). The environmental system sometimes does not support certain cultivation techniques, causing erosion, soil movement and areas with lack of nutrients.

Figure 3: Risk of environmental degradation



Source: Elaborated by the authors

The eastern zone of Marau consists of the intermediate structure Dark Red Podzolic soil type, with an average depth of 150 cm and moderate drainage, demanding special attention. Furthermore, the integrated systems of farming and livestock utilized in this area reduces the amount of fertilizers needed. AHP soil modeling provides the likely zones of soil erosion and assists in land and soil management (ZHANG *ET AL*., 2021).

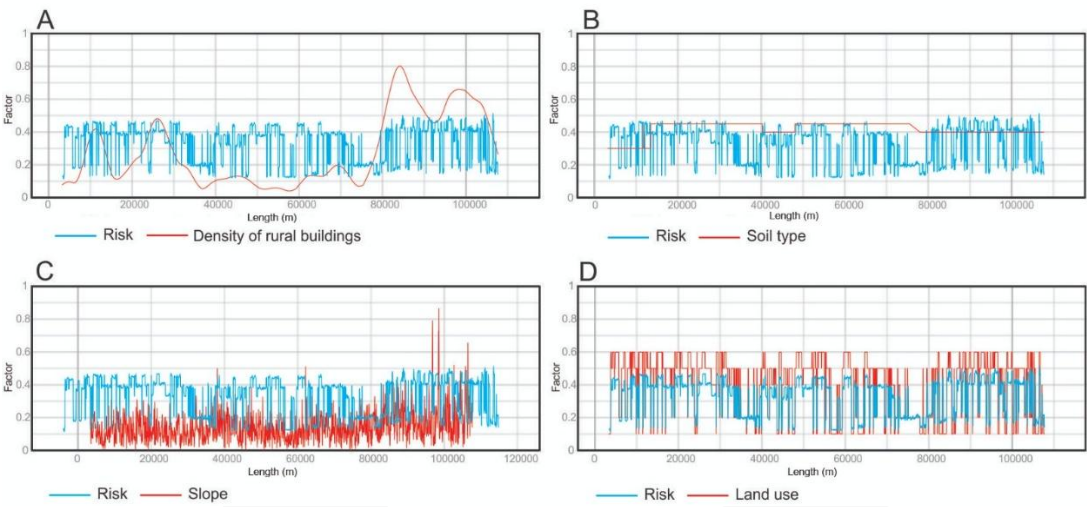
Table 5. Environmental degradation risk classes, area and number of spots.

Class	**Land cover (ha)**	**% Land cover**	**Number of Patches**
Very low	575.47	27.14	2,874
Low	235.12	11.42	3,857
Moderate	1,191.00	57.84	1,636
High	51.27	2.49	2,680
Very high	5.96	0.28	91
Total	**2,058.85**	**100**	**11,138**

Table 5 presents the magnitude and comparison between the risk classes of environmental degradation in the area. 57.84% of the total area is at moderate risk. Part of this impact is related to the acquisition date of the Landsat 8 satellite image, which was acquired in the second week of March. Therefore, the cultivated areas are quite significant in this period. 2.49% of the study area is classified as high risk. For WOLF *ET AL*. (2021), there is a high percentage of exposed soil, demonstrating local weaknesses and the emergence of other environmental degradation, such as the formation of sedimentary basins in river beds.

The longitudinal histogram generated in this study represents the exposed areas with a map of environmental degradation risk. The criterion applied in the AHP method to the building density parameter corresponded to 0.06, considering small changes in water resources (Figure 4A). In Figure 4B, the soil type parameter presents a similar behavior, showing that the criterion used by the AHP method of 0.26 was adequate. Figure 4C demonstrates the relationship between the slope parameter and risk, demonstrating that the 0.11 criterion applied by the AHP method caused little change in the histogram. Figure 4D presents the land use parameter, where a weight of 0.62 was applied, demonstrating that there was a great influence on the representation of risk.

Figure 4: Longitudinal histogram of environmental degradation risk of exposed areas



Source: Elaborated by the authors

There is a need for research to support local and global food security (DAL MORO AND BRANDLI, 2020). Through a precise analysis in productive areas, it was possible to assess possible degradation and encourage decision-making, as well as to present factors that contemplate food security and the Sustainable Development Goals (SDGs) outlined by the UN.

4. Conclusion

Evaluating the risks of environmental degradation in this area, this study demonstrates the potential of the integrated AHP and GIS approach in determining areas with high risk of environmental degradation. It was possible to significantly observe the increase in production in a sustainable way, as well as the fulfillment of the UN's SDGs.

One of humanity's greatest challenges is the need to facilitate the sustainable production of food. The importance of synergy between production systems and agribusiness chains is observed. Grain production systems coupled with livestock, poultry and swine production can facilitate the cycling of nutrients and reuse of waste. Zones identified by the study as having a high risk of environmental degradation should adopt less intensive management systems.

The interactions between both methods used proved to be efficient in environmental analysis. The authors suggest this replication in other regions for future work. Also, more study is needed in the construction of public policies that favor sustainable production and food security while working with existing production systems. Public policies that enhance the use of geotechnologies sensitive to regional differences present greater equity in the distribution of public resources allocated to agricultural production.

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