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SPATIAL MODELING OF THE POTENTIAL FOR URBAN EXPANSION IN MONTES CLAROS – MINAS GERAIS

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Abstract: Population growth has driven horizontal expansion in cities. Urban sprawl when unrestrained can cause several problems in environmental and socioeconomic segments. For medium-sized cities, such as Montes Claros/MG, this is already a fact. Therefore, understanding how expansion occurs spatially in the city is crucial for urban planning, especially regarding urban land use planning. Therefore, a simplified mapping of classes with potential for urban expansion for Montes Claros was elaborated and linear regression models were applied to understand which variables explained the distribution of these classes. Three classes were obtained: area with urban potential, area with potential for expansion, area not suitable for expansion. The area with urban potential was explained by the variable's residents, water, income, unoccupied, occupied, vegetation, and altitude, and obtained an R^2 of 0.89 (p-value < 0.05). While the class area with expansion potential was explained by the variables not occupied, vegetation, and altitude (R^2 = 0.93 and p-value < 0.05). The unsuitable area was explained by altitude and relief (R^2 = 0.84 and p-value < 0.05). Socioeconomic and physical variables explained the spatial distribution of potential classes for urban expansion in Montes Claros. This methodology presents itself as a crucial tool for urban planning.
Keywords: Modeling; Linear Regression; Geoprocessing; Middle City.

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MODELAGEM ESPACIAL DO POTENCIAL À EXPANSÃO URBANA EM MONTES CLAROS – MINAS GERAIS

Resumo: O crescimento populacional tem impulsionado a expansão territorial nas cidades. A expansão urbana pode ocasionar diversos problemas nos segmentos ambientais e socioeconômicos. Para as cidades médias, a exemplo Montes Claros/MG, isso já é um fato. Portanto, o entendimento de como a expansão ocorre espacialmente na cidade é crucial para o planejamento urbano, sobretudo quanto o ordenamento do uso do solo urbano. Por isso, elaborou-se um mapeamento simplificado de classes com potencial à expansão urbana para Montes Claros e aplicou-se modelos de regressão linear para entender quais variáveis explicaram a distribuição dessas classes. Dessa forma, foram obtidas três classes: área com potencial urbano, área com potencial de expansão, área não adequada para expansão. A área com potencial urbano foi explicada pelas variáveis moradores, água, renda, não ocupado, ocupado, vegetação e altitude, e obteve R^2 de 0.89 (p-value < 0.05). A classe área com potencial de expansão foi explicada pelas variáveis não ocupado, vegetação e altitude (R^2 = 0.93 e p-value < 0.05). A área não adequada foi explicada por altitude e relevo (R^2 = 0.84 e p-value < 0.05). Variáveis socioeconômicas e físicas explicaram a distribuição espacial das classes potenciais à expansão urbana em Montes Claros. Essa metodologia apresenta-se como suporte ferramenta crucial para o planejamento urbano da cidade de Montes Claros.
Palavras-Chave: Modelagem; Regressão Linear; Geoprocessamento; Cidade Média.

MODELACIÓN ESPACIAL DEL POTENCIAL DE EXPANSIÓN URBANA EN MONTES CLAROS – MINAS GERAIS

Resumen: El crecimiento de la población ha impulsado la expansión horizontal en las ciudades. La expansión urbana sin control puede causar varios problemas en los segmentos ambientales y socioeconómicos. Para ciudades de tamaño mediano, como Montes Claros/MG, esto ya es un hecho. Por lo tanto, comprender cómo ocurre la expansión espacialmente en la ciudad es crucial para la planificación urbana, especialmente en lo que respecta a la planificación del uso del suelo urbano. Por lo tanto, se elaboró un mapeo simplificado de clases con potencial de expansión urbana para Montes Claros y se aplicaron modelos de regresión lineal para entender qué variables explicaban la distribución de estas clases. Se obtuvieron tres clases: área con potencial urbano, área con potencial de expansión y área no adecuada para la expansión. El área con potencial urbano fue explicada por las variables residentes, agua, ingresos, desocupados, ocupados, vegetación y altitud, y obtuvo un R^2 de 0.89 (valor p < 0.05). Mientras que el área con potencial de expansión fue explicada por las variables desocupados, vegetación y altitud (R^2 = 0.93 y valor p < 0.05). El área no adecuada para la expansión fue explicada por la altitud y el relieve (R^2 = 0.84 y valor p < 0.05). Las variables socioeconómicas y físicas explicaron la distribución espacial de las clases potenciales para la expansión urbana en Montes Claros. Esta metodología se presenta como una herramienta crucial para la planificación urbana
Palabras clave: Modelado; Regresión Lineal; Geoprocesamiento; ciudades de tamaño mediano.

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Introduction

Population growth in urban centers is a consequence, mainly of the migratory process, that is, the displacement to cities in search of services and opportunities that are developed in these spaces (BRAGA; ALVES, 2020). Currently, more than 54% of the world's population lives in urban areas (TERFA et al., 2019), and it is projected that by 2050, about 68% of the global population will reside in cities (UNITED NATIONS, 2016). To accommodate the rapid population increase, the physical growth of the urban area is expected, which translates into expansion of peripheral areas of the city, which are altered and, depending on the dynamics of cities, present new formats and multiple uses (RIBEIRO et al., 2020). However, urban sprawl, when unrestrained, leads to problems on environmental and socioeconomic axes, such as urban heat islands, air pollution, decreased biodiversity, loss of green areas and increased traffic, low infrastructure, and inadequate provision of services to urban (MISHRA, 2019; CHIDI; MAGAR; MAGAR, 2021; IMAITOR-UKU et al., 2021)

Cities in Brazil, of different sizes, had substantial changes in their physical extensions in the face of the urban growth process (BATISTA et al., 2021). Medium-sized cities are clear examples, mainly because of their importance in the context of the Brazilian urban network (PAULA, 2019). In the context of medium-sized cities, Montes Claros (located in the north of the state of Minas Gerais), represents well the behavior of urban growth, since studies show that in the last decades its physical composition

has extended substantially (BOLAY, 2016). However, although there are studies that prove the growth/expansion of the city of Montes Claros (LEITE, 2006; LAURENTINO et al., 2020), to date, there are no records of works that include mapping the expansion potential of Montes Claros, as well as the explanation of these classes based on physical and socioeconomic variables. It is known that physical and socioeconomic factors are decisive in the direction of urban expansion, as they serve for environmental planning, quality of urban life, interventions, and standards that are developed in cities (BRAGA; ALVES, 2020; RIBEIRO et al., 2020). Therefore, considering the importance of the city of Montes Claros in the regional scenario, with about 400,000 inhabitants, the economic and service center of a vast region of the state of Minas Gerais (FRANÇA; SOARES, 2007) understanding their patterns of urban expansion becomes essential, especially for urban management and planning.

Monitoring the potential for urban expansion, considering variables that limit or facilitate it, must provide spatially explicit information, and for that, GIS (Geographic Information System) techniques are essential tools, especially considering their ability to represent the geographic space in an environment. computing in an agile and feasible way (MELIANI, 2019). Many studies have used these tools to map classes of potential for urban expansion (OLIVEIRA, 2014; FILHO; GONÇALVES, 2015; RIBEIRO, 2020). However, most of these studies did not aim to understand which variables explain each potential class. However, this is essential, as it can provide quantitative information on the spatial patterns of expansion, especially relating to the city's environmental and socioeconomic conditions. Therefore, the use of statistical techniques can help in studies with this scope, for example, multiple linear regression models, as they allow the entry of a set of predictor variables to explain the patterns observed in a dependent variable (DIAS et al., 2016) as the potential classes for urban expansion.

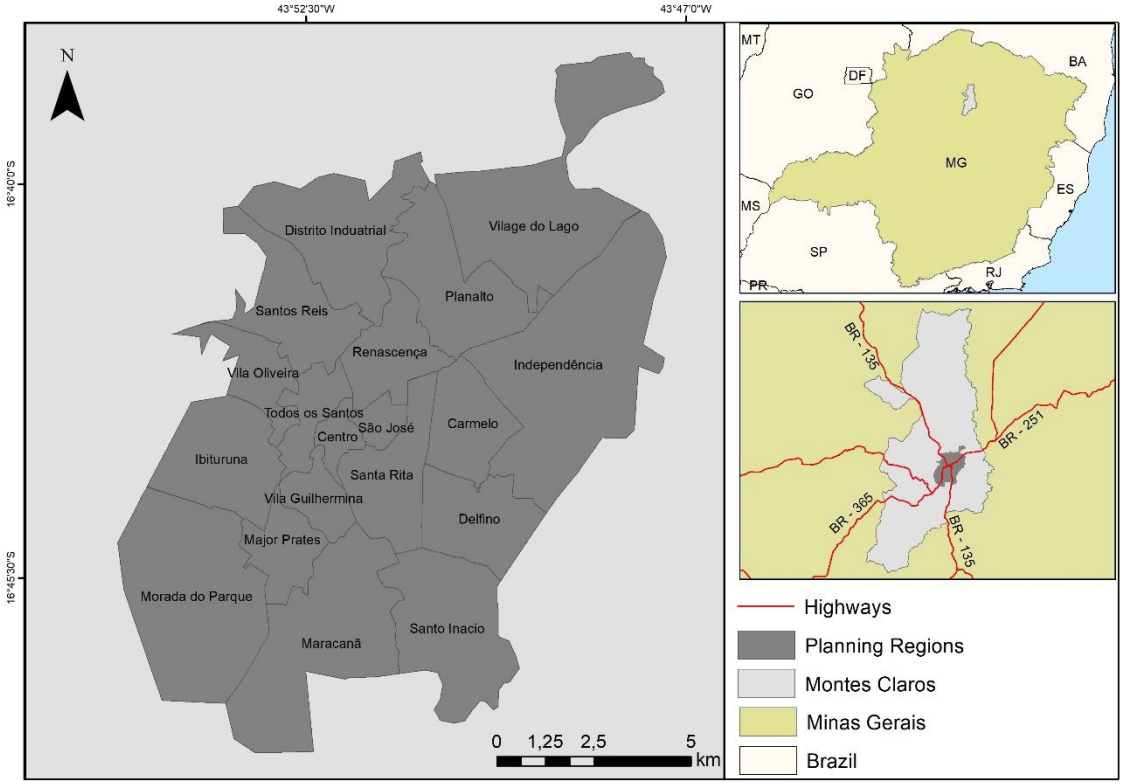
The objective of this work was to elaborate a simplified model to identify areas of urban expansion and understand which variables explained how classes mapped to the city of Montes Claros. For this purpose, GIS methods and linear models are used.

Materials and methods

Study area

The study area is located in the north of the state of Minas Gerais, notably in the Intermediate and Immediate regions of Montes Claros (IBGE, 2017) (Figure 1). Montes Claros in 2010 had a population of 361,915 inhabitants, of which 95.17% are located in urban areas and 4.83% in rural areas. It is estimated that in 2021 Montes Claros had 417,478 inhabitants (IBGE, 2021), an increase of 15% in 21 years.

Figure 1 - Urban Area of Montes Claros – MG



Source: The authors, 2022.

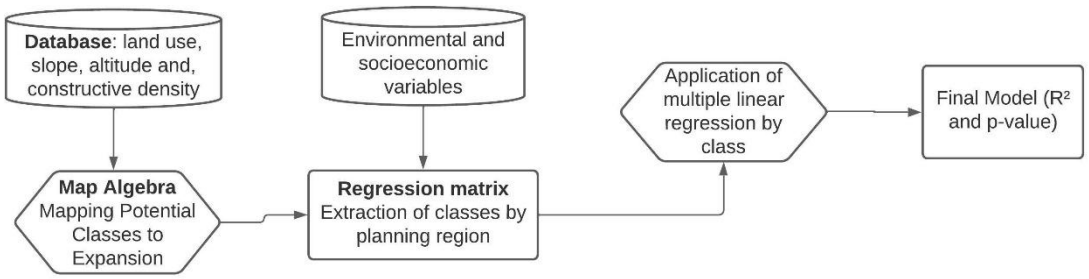
Since 2016, after municipal decree No. 3,393, the urban division of planning regions was carried out, developed, and applied for the purposes of urban organization and management, which aims at the environmental and social quality of its citizens (LEITE, 2006; PMMC, 2016). Thus, this regionalization was used for the development of this research.

The municipality is located in an area of Cerrado stricto sensu vegetation, Seasonal Deciduous Forest, with a semi-humid hot tropical climate (ALMEIDA et al., 2020). The relief elevations are concentrated between 579 and 916m, with a maximum slope of 54.42%.

Technical and Operational Procedures

To carry out the work, the following steps were performed: i) a database was built with the variables for mapping the potential classes for expansion; ii) then map algebra was applied to obtain the classes; iii) next, socioeconomic and environmental variables were obtained to explain the distribution of potential classes; iv) then, multiple linear regression models were applied to obtain statistical responses (ie, R^2 and p-value) for the explanation of potential classes.

Figure 2 - Operational steps followed in the methodological framework.



The mapping of potential classes was carried out through environmental variables, such as slope, altitude, land use, and constructive density. These variables were chosen because they are responsible for the spatial organization in the urban environment.

To obtain the slope and hypsometry, the Digital Elevation Model (DEM – SRTM) was used, with a spatial resolution of 30 meters. Processing was performed using ArcGIS software, version 10.3. They were applied to fill and slope tools, to correct the imperfections and generate the slope. For the use and land cover, it was developed from an image of the Landsat 8 satellite (OLI sensor), in orbit and point 218/072 of the year 2020. For the mapping, the supervised classification was applied through MaxVer (maximum likelihood), which resulted in the following classes: occupied area, water, vegetation, and no vegetation cover. While the constructive density was obtained through the kernel function and was generated from the points referring to the buildings of the city of Montes Claros-MG, provided by the municipal government.

All variables obtained were spatially compatible, that is, interpolated by the bilinear method for 30 meters of resolution. Subsequently, the urban land use potential was developed based on the following equation:

$$\frac{(\text{Slope} + \text{Altitude} + \text{Land Use and cover} + \text{Constructive Density})}{4}$$

From this operation, the classes Area with Urban Potential were obtained; Area with Expansion Potential and, Area Not Suitable for Expansion.

Statistical analysis

In order to describe the influence of socioeconomic and environmental variables on the classes of potential for urban expansion, a simple multiple linear regression model was applied. The urban potential classes were established as the dependent variable (y). For that, the areas (km²) of each class were obtained for the limits of the Montes Claros planning regions (n = 19). To explain the classes of potential, we set up a database with 7 predictor variables, among them: residents, water, income, unoccupied, occupied, vegetation, and altitude. The predictor variables (x) were also obtained for each planning region; in the case of land use classes, the area in km² was extracted, while for the other variables, their representation units were followed.

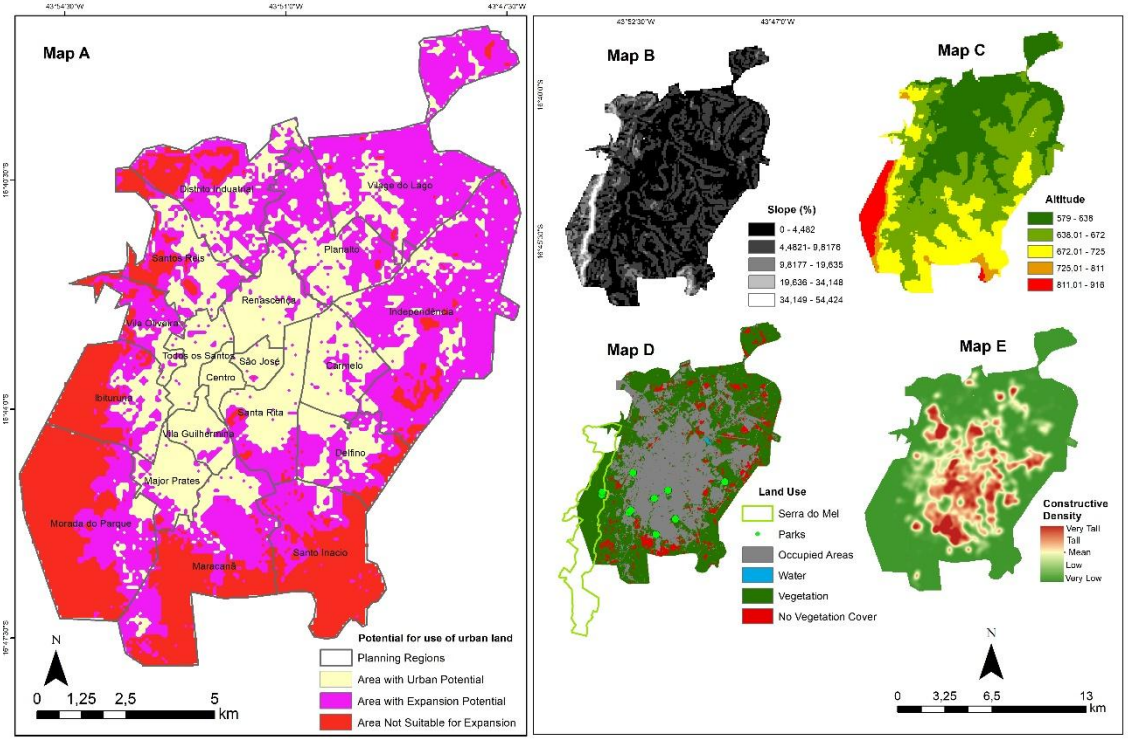
After extracting the values of the variables by the limits of the planning regions, three regression matrices were obtained (with variables y~x). These matrices were inserted into the R software and the stepwise procedure was applied. Initially, a regression model was fitted (fitted) with all predictor variables. Subsequently, the F test (with significance < 0.05) was applied to assess the significance of the variables inserted in the model. The final model was obtained with the most significant variables ($p < 0.05$) in the first model and was chosen based on the Akaike criterion (AIC) (SAKAMOTO; ISHIGURO; KITAGAWA, 1986). This procedure was applied to each class of expansion potential (n = 3).

Results

Environmental Provisions and Land Use Potential of Montes Claros - MG

The Class of Area with Urban Potential is predominantly located in the central region of the city, where the relief is flat (between 0 and 9.81% of slope (Figure 3B) and altitude of up to 672 meters, corresponding to the busiest area of the city. This is the class with the highest concentration of build density (Figure 3E).The Area with Expansion Potential is the class that presents characteristics conducive to being expanded, concentrated in the north and east directions (slope from 0 to 9.81% and altitude of up to 672 meters, a little occupied region). In this class, the constructive density varies from low to very low. The Area Not Suitable for Expansion class, located southwest and south of the urban area, corresponds to the region of the city with more accentuated relief (slope between 9.81 and 54.42% and altitude up to 916 meters). This class has the highest concentration of vegetation and parks in the city, in addition to Serra do Mel, which is protected by law.

Figure 3 - A) Potential for use of urban land; B) Slope; C) Altitude; D) Land use; E) Constructive Density.



Explanation of the distribution of potential classes to urban expansion

In the model for the Area with Urban Potential class (Table 1), all the variables entered were significant for the model ($p < 0.05$), and explained 89% of the distribution of this class. The Area with Expansion Potential (Table 2) obtained R^2 equal to 0.93, and only the unoccupied variables, vegetation, and altitude showed significance to represent the class, therefore, the model excluded the other variables ($p > 0.05$). The Area Not Suitable for Expansion (Table 3), the vegetation and altitude variables, explained 84% of this class.

Table 1- Statistical summary of multiple linear regression and F-test for the class Area with Urban Potential

Source	Estimate	Std. Error	AIC	F Value	P value
Model			-105.3		
(Intercept)	2041	333,10			
Residents	0,00	0,00	-102.257	3.347	< 0.05
Water	1330	606,90	-100.423	4.801	< 0.05
Income	0,00	0,00	-99.708	5.407	< 0.05
Unoccupied	-134,20	53,44	-98.694	6.307	< 0.05
Occupied	87,93	25,28	-93.206	12.102	< 0.05
Vegetation	25,48	7,27	-93.055	12.287	< 0.05
Altitude	-3,18	0,53	-79.613	36.243	< 0.05

AIC = Akaike Information Criterion, F = F-test, p = significance level. F = 12.42; R^2 = 0.89; and $p < 0.05$.

Table 2 - Statistical summary of multiple linear regression and F-test for the class Area with Expansion Potential

Source	Estimate	Std. Error	AIC	F Value	P value
Model			-77.2		
(Intercept)	2.587701	0.676692			
Unoccupied	0.382551	0.079495	-61.466	23.158	< 0.05
Vegetation	0.045700	0.012527	-67.138	13.309	< 0.05
Altitude	-0.003965	0.001044	-66.403	14.425	< 0.05

AIC = Akaike Information Criterion, F = Ftest, p significance level. F = 71.42; R^2 = 0.93; and $p < 0.05$.

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Table 3 - Statistical summary of multiple linear regression and F-test for the class Area Not Suitable for Expansion

Source	Estimate	Std. Error	AIC	F Value	P value
Model			-74.170		
(Intercept)	-4.757207	0.702638			
Vegetation	0.023638	0.007671	-67.317	9.496	< 0.05
Altitude	0.007381	0.001085	-50.342	46.299	< 0.05

AIC = Akaike Information Criterion, F = Ftest, p = significance level. F = 42.77; R^2 = 0.84; and p < 0.05.

Discussion

The Class of areas with Urban Potential corresponds to the downtown and adjacent regions, where there is the highest concentration of trade and service activities that are developed in Montes Claros. (FRANÇA; SOARES, 2007). Due to the diversity of activities, this class presents greater urban complexity, therefore, the linear regression model used all the variables that were inserted to justify this class. An example of this was the "residents" variable, which shows that the central regions of the urban perimeter have the highest density of inhabitants (AMORIM et al., 2020) consequently, it has a greater concentration of buildings and occupied areas. These factors imply changes in use and landscape, mainly causing the reduction of vegetation, which is suppressed by buildings and the paving of roads (FEITOSA et al., 2011).

Flattened relief reduces the risk of landslides or physical instability (MARQUES et al., 2018) which enhances urban occupation in this class. The absence of water bodies in the central regions favors their occupation, as there is no need to comply with environmental legislation aimed at water resources (GARCIA; LONGO, 2020). The income variable reinforces that this class serves an occupied, urbanized, and also commercial area, with the largest movement of capital in Montes Claros (FRANÇA; SOARES, 2007) . This class has outstanding characteristics of being the commercial center of Montes Claros, with the availability of numerous services, transport, health and, leisure (BRANDÃO; SILVA, 2016) which directly influences the appreciation of the price of land and properties. With the growth of the urban area, empty spaces appeared in the central regions, which have no use or social function (LEITE, 2006). These spaces are explored by the real estate market until there is a better time to sell or apply a new function (CARMONA; MORAIS BOMTEMPO, 2020). However, the reactivation of these spaces can bring positive aspects to the population when new uses are applied, such as health centers, leisure areas, or even social housing that sheltered the population in street conditions (FREITAS; NEGRÃO, 2014).

The Class of Area with Expansion Potential, concentrated in the north and east directions, had 93% of its distribution justified by the variables not occupied, vegetation and altitude. This region is sparsely inhabited compared to the central regions of the city, so there are still many spaces that have not been occupied (LAURENTINO et al., 2020). Thus, the urbanization process did not change the entire land use of this class, therefore, it still maintains extensive areas of vegetated land. However, replacing vegetation with urban uses in this region would not violate environmental laws, as it does not correspond to a conservation area (LEITE; BATISTA; CLEMENTE, 2010), justifying its potential for expansion. The low altitude of the relief contributes to the process of urban expansion in this class since the relief does not have spatial impedance (MARQUES et al., 2018).

The northern and eastern regions of Montes Claros offer the best physical conditions for expansion, however, the social and urban characteristics present complex points, as well as distance and mobility, unavailability of urban facilities, parks, and green areas (FRANÇA; BARBOSA, 2019). Due to these reasons, the land value in the Urban Expansion Potential class is low (BARCELLA; MELAZZO, 2022). In this way, these lands were destined for the construction of properties financed by social housing programs, such as Minha Casa Minha Vida (FRANÇA; BARBOSA, 2019). The properties have a low constructive standard produced on a large scale and in places with precarious environmental conditions (DIAS; BEDIN; FIGUEIREDO;, 2021). Due to the low cost, these projects are developed by construction companies, who follow the rules of real estate capital and see the possibility of profit (FAUSTINO; ROYER, 2021).

The resident population in the class with urban growth potential corresponds to the population with the lowest per capita income in the city of Montes Claros (FRANÇA, 2020). Therefore, residents face social difficulties such as low schooling, unemployment, and violence (COSTA; SILVA FREITAS, 2021). Thus, these factors interfere with the installation and investments in trades and services that can promote the urban development of the region. Still, the existing residential standards and lack of urban services and environmental amenities influence the devaluation of this class, especially from the point of view of real estate agents (BARCELLA; MELAZZO, 2022).

To explain the distribution of the Area Not Suitable for Expansion class, only two variables were used by the model, that is, vegetation and altitude. This class corresponds to the concentration of variability in the relief of the urban area of Montes Claros, with the presence of steep areas and steep slopes (LAURENTINO et al., 2020). Thus, the relief of this region is unsuitable for the occurrence of the urbanization process (MARQUES et al., 2018) . Vegetation is an outstanding use of the Not Suitable for Expansion class, mainly due to the presence of parks, springs, and environmental protection areas, especially Serra do Mel, listed in 2016, by decree n° 3,477.29. Therefore, the physical and environmental conditions of this class make it difficult for growth to occur in the southwest and south of the city. This class includes areas of springs, rivers, and Cerrado vegetation, especially the phytophysiognomy of the Seasonal Deciduous Forest (Mata Seca), present in steep areas and slopes, which are protected by Law No. 12,651, of May 25, 2012 (GALVÃO, 2018). In this way, urban evolution in this sense can cause losses in biodiversity and environmental imbalance (FURTADO et al., 2020). However, the presence of green and the existing environmental amenities in this region is seen by real estate agents as positive aspects in the appreciation of the price of land (BARCELLA; MELAZZO, 2022) associated with good access roads and the availability of urban services. Therefore, the class that offers greater environmental and urban comfort in Montes Claros is intended for the population that has the highest financial condition (ALMEIDA et al., 2020).

Conclusions

The results achieved showed that the class with potential for expansion, in the north and east of Montes Claros, present physical conditions conducive to urban expansion, without breaching environmental standards. On the other hand, the class is restricted to growth has relief and areas of permanent protection that restrict urban evolution. The central region, referring to the class with potential, has the highest urban occupation and constructive density, however, it can still offer new functions for society, with the adoption of new uses in its idle spaces.

The multiple linear regression models used as a tool to explain each mapped class showed that the six variables (residents, water, income, unoccupied, occupied, vegetation, and altitude) included in the model were necessary to explain 89% of the use of the class with urban potential. The class with potential for urban expansion had 93% of its use justified by the variables not occupied, altitude, and vegetation. Finally, in the class that does not have expansion potential, the model used the altitude and vegetation variables to explain 84% of the use.

This model can help in urban planning and management, as it points to areas with better environmental, social, and economic conditions for the growth of the city. With this, the public power will be able to guide the planning of the urban territory and promote the sustainable and balanced growth of the city.

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