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Future Scenarios: Analysis of Susceptible Areas to Floods and Mass Movements

Cenários Futuros: Análise de Áreas Susceptíveis a Inundações e Movimentos De Massas

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Abstract/ Resumo

The cities' migration process, leveraged by the rural exodus, contributed to the triggering of infrastructure problems, basic sanitation, occupation of susceptible areas, among others. In this sense, the proper planning of cities is fundamental to overcome the challenges faced by these urban agglomerations. Given these considerations, this paper aims to determine scenarios of the urban expansion of the city of Novo Hamburgo - RS, from 2015 to 2030. The modeling of Cellular Automata, within the Dynamic EGO software, was applied to analyze the viability of these scenarios concerning areas susceptible to flooding and mass movements in the city. Therefore, the urban spots of 2009 and 2015 were used to calibrate the weights and parameters of the variables used: distance from vegetation areas, distance from the drainage system, distance from the road system, altitude, and declivity. Based

O processo migratório para as cidades, alavancado pelo êxodo rural contribuiu para o desencadeamento de problemas de infraestrutura, saneamento básico, ocupação de áreas susceptíveis, entre outros. Nesse sentido, o adequado planejamento das cidades é fundamental para superar os desafios enfrentados por essas aglomerações urbanas. Perante essas considerações, objetivou-se determinar cenários da expansão urbana da cidade de Novo Hamburgo – RS, no período de 2015 – 2030. Almejando analisar a viabilidade desses cenários frente as áreas susceptíveis a inundações e movimentos de massa no município, aplicou-se a modelagem de Autômatos Celulares, dentro do *software* Dinâmica EGO. Para tanto foram utilizadas as manchas urbanas de 2009 e 2015, afim de calibrar os pesos e parâmetros das variáveis

on the results, the construction of four future prognostic scenarios (2030), were built and then crossed with the susceptibility charts of the Geological Survey of Brazil, in order to identify the expansion against areas susceptible to flooding and mass movements. The results of the 2015 simulation reached similarity values of 0.80. Future scenarios showed a total growth of 3.9% in the study area, mainly concentrated in rural areas, through the expansion of existing spots and the formation of new nuclei. The urban territory composed of medium and high density, and the adjacent areas unfit for occupation, did not allow large expansions of the main urban area, but subtle growth to the south towards the flood areas near the Sinos River is visible; in the northern region, where the terrain reaches high slopes and in the west where a region of wetlands is concentrated. Crossing with susceptibility charts expressed that 7% of predicted expansion areas will occur in areas characterized as highly susceptible to flooding or mass movement. Thus, planning and supervision are the main tools for defining guidelines for an appropriate urbanization process.

Keywords: Urban Expansion; Flood; Mass movements; Simulation of scenarios

JEL Code: R11, R52, R580

utilizadas: distância das áreas de vegetação, distância da rede de drenagem, distância do sistema viário, altitude e declividade. Com base nos resultados se procedeu a construção de quatro cenários de prognósticos futuros (2030), os quais foram cruzados com as cartas de susceptibilidade do Serviço Geológico do Brasil, afim de identificar a expansão frente as áreas susceptíveis a inundações e movimentos de massa. Os resultados da simulação de 2015 alcançaram valores de similaridade de 0,80. Os cenários futuros apresentaram um crescimento total de 3,9 % da área de estudo, concentrado principalmente nas áreas rurais, através da expansão das manchas existentes e da formação de novos núcleos. O território urbano composto por densidade média e alta e as áreas adjacentes impróprias para a ocupação, não possibilitaram grandes expansões da mancha urbana principal, porém é visível um crescimento sutil ao sul em direção as áreas de inundações, próximas ao Rio do Sinos; na região norte, onde o terreno alcança altas declividades e a oeste onde se concentra uma região de áreas úmidas. O cruzamento com as cartas de susceptibilidade expressou que 7% das áreas de expansão previstas no prognóstico ocorrerão em áreas caracterizadas como de alta susceptibilidade a inundações ou movimentos de massa. Assim sendo, o planejamento e a fiscalização são as principais ferramentas para definir diretrizes para um adequado processo de urbanização.

Palavras-chave: Expansão Urbana; Inundações; Movimentos de massa; Simulação de cenários

Código JEL: R11, R52, R580

1. INTRODUCTION

The increase in the number of cities and their growth were not only due to demographic development caused by population growth as a whole but also to rural exodus and migrations from smaller to larger cities. The migration process to large and medium-sized cities, mostly by young people, and people with low incomes and education, in search of better financial and living conditions, can cause problems for the receiving cities of these immigrants. “Santos (1989)”. Thus, the proper planning of cities is fundamental to overcome the challenges faced by these urban agglomerations. Rapid economic and social changes require methodology and technical resources that not only contribute to the understanding of the phenomenon of agglomerations in the world but also define alternatives and paths that allow the construction of sustainable cities “Buarque and Lima (2005)”.

However, this planning is not always achieved, causing the emergence and increase of urban areas in odd places, causing problems for the city and the population living in urban agglomerations in areas of slopes subject to mass movement or areas susceptible to flooding. Given this, accurate knowledge of the conditions of each community is essential for the success of proper planning, and it is, therefore,

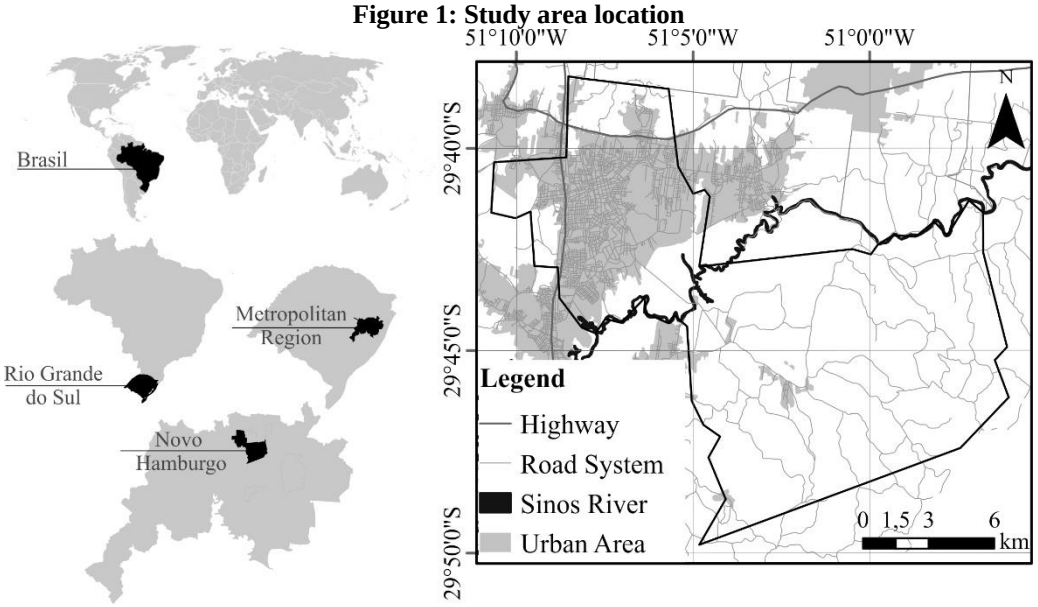
necessary to collect variables that represent the actual conditions of each location, where these will be beacon sources for determining a quantitative scenario, and as input data for determining future scenarios. In this sense, this work aims to identify situations of the urban expansion of the city of Novo Hamburgo - RS, from 2015 to 2030, taking into consideration the variables, land use and occupation, drainage network, road system, and digital model of elevation, aiming to analyze the viability of these scenarios in the face of areas susceptible to flooding and mass movements in the city, in order to help the proper urban environmental planning.

2. METHODS

2.1 Study Area

The city of Novo Hamburgo is located in the metropolitan area of the state of Rio Grande do Sul, Brazil (Figure 1). Situated between 29 ° 29 'to 29 ° 45' S and 51 ° 04 'to 51 ° 08' O, it has approximately 238,940 inhabitants distributed over an area of 224 km² (IBGE, 2010).

Figure 1: Study area location



Novo Hamburgo has been marked by the industrialization of the leather footwear sector since the late nineteenth century "Schütz (1992)". This process leveraged an intense migratory action, with people coming from many parts of the countryside looking for jobs and a better quality of life. Urban planning and infrastructure did not follow this process leading to irregular settlements, which intensified in the 1990s when there was an intense crisis, which attacked the leading economy of the city: the leather-footwear industry. This situation resulted in unemployment and bankruptcy of various industries, accentuating environmental problems from the occupation of irregular areas "Riegel and Quevedo (2015)". Novo Hamburgo was chosen as a case study because it is a medium-sized city located in a metropolitan region that has undergone an accelerated urbanization process. This fact, associated with the crisis, resulted in irregular occupations that settled in areas subject to flooding and mass movements.

The first procedure consisted of an applied modeling, using a Cellular Automata model developed by "Soares-Filho et al. (2001)" within the Dinamica EGO software. For this purpose the 2009 Urban Spot "Riegel and Quevedo (2015)" was used; the 2015 Riegel (2019) Land Use and Occupation Map; besides the maps of the drainage network and road system developed by the "Project Monalisa (2005)"; and the "Aster Gdem (2011)" Digital Elevation Model. Compatibility was performed in ArcGIS software, with a spatial resolution of 30x30m, georeferenced to the UTM coordinate system, and SIRGAS 2000 datum. In the same software,

distance maps of areas composed by vegetation, ways (streets, roads), and the drainage system were built, in addition to the slope and altitude map. On the other hand, in the software Dynamics EGO, the five variables were unified in a single file called Cube raster. At the same time, the transition matrix between 2009 and 2015 was created, which consists of creating a cross-tabulation between two maps.

Subsequently, the variables that were initially in continuous form were reclassified at predetermined intervals. For each interval, a weight of evidence was calculated. These values determined whether the thematic variable had influence or not for urban spot transition. Thus, when there are negative weights, it means that the characteristic disfavored the occurrence of transition; positive weights tend to favor it; and weights equal to zero do not represent any kind of influence "Trentin and Freitas (2010)". The results also underwent statistical analysis based on Cramer indices (V) and Joint Information Uncertainty (U), to evaluate the spatial dependence between the variables.

Finally, the simulation of the 2015 period was performed using the 2009 spot, the transition matrix, the raster cube, and the weights of evidence, as well as incorporating two types of transition algorithms: the expander function, which is linked to the expansion of existing urban areas; and the "patcher" function (spot forming), referring to the formation of new urban spots "Soares et al. (2009)", "Rossetti (2011)" and "Silva et al. (2017) ". Validation was performed by analyzing the fuzzy similarity "Zadeh (1975)" between the simulated map and the 2015 spot. The method uses multiple windows and a constant decay function "Soares-Filho et al. (2009)", the results range from 0 to 1, and the closer to 1 the greater the similarity between the maps. Based on the parameters and weights used in the 2015 simulation, the execution of the model for future forecasts, considering the 15 years (2030) was proceeded. In all, 4 prediction scenarios were run based on the possible probabilities.

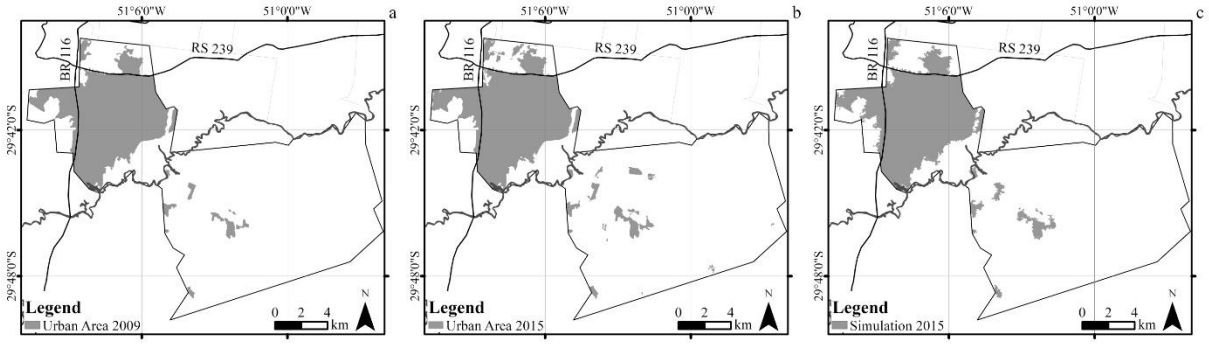
After that, the susceptibility charts of the Brazilian Geological Survey "CPRM (2015)" referring to mass movements and flooding of Novo Hamburgo city (Projection UTM and Datum SIRGAS 2000) were used. According to "CPRM (2015)," the charts were built based on bibliographic research and the inventory of the records, resulting in a preliminary chart of the susceptible areas. Based on the preliminary step, a field check was performed, followed by a GIS analysis, associated with the database.

Finally, the expansion areas foreseen in the four built scenarios were crossed with the areas characterized as high susceptibility to floods and mass movements, to identify the worst scenario given the occupation of these regions.

3. RESULTS

In 2009, the urban area of Novo Hamburgo corresponded to 4,941.54 ha (22.26%). In 2015 the spot reached 5,301.81 ha (23.88%), a growth of 1.62%. Figure 2 shows the spots for 2009 and 2015, as well as the result of the 2015 simulation. Thus, the highest concentration of growth occurred in the rural area of the city as a result of a highly consolidated urban territory with few growth options next to the main spot, due to the existence of Environmental Protection Areas (EPA), Permanent Protection Areas (PPA), susceptible areas and wetlands in the adjacent regions.

Figure 2: (a) Urban area 2009; (b) Urban area 2015; (c) Simulated urban area 2015



The demographic data in the last censuses show a small variation in relation to the population ratio from 236.193 inhabitants in 2000 to 238.940 inhabitants in 2010, that is, an increase of 2.747 inhabitants in 10 years. The percentage of growth of 1.16% (or geometric average rate of 0.13% p.a.) in this period is relatively lower than in the previous decade (1991-2000), which registered an increase of 14.84% (or 1.55% p.a.). However, the number of households, which in 2000 was 71.085, increased to 80.409 in 2010, which represents an increase of 13.11% "Riegel et al. (2017)". This growth reflects the expansion of the urban perimeter, which was largely consolidated in the rural area and the bordering regions of the main urban spot.

Regarding the similarity between the maps, Table 1 presents the values obtained through the fuzzy similarity technique and constant decay function in five window sizes. In this case, the variations were 0.36 to 0.80, which represents a satisfactory index when compared to similar works: "Ferrari (2008)", obtained a variation between 0.44 to 0.84) analyzing the changes of the ground cover of the Terra da Quarta Colônia (RS) , between 2002 and 2008; "Rossetti (2011)" obtained similarity indices between 0.34 and 0.71 in a 9x9 window analyzing changes in urban land use in Rio Claro (SP) in 1972, 1988 and 2006; Kawashima et al. (2016) ", obtained values between 0.48 to 0.78 analyzing changes in the landscape of the Baixada Santista (SP) port region between 2005 and 2013.

Table 1: Similarity Fuzzy

Simulation Period	Windows (pixels)	Minimun	Maximun
2009 - 2015	3 x 3	0.36	0.41
	5 x 5	0.44	0.56
	7 x 7	0.51	0.67
	9 x 9	0.56	0.75
	11 x 11	0.60	0.80

Figure 3 shows the four possible scenarios for the 2030 simulation. In general, growth is concentrated in rural areas through the expansion of existing spots and the formation of new nuclei. The projected increase was 3.9% (875 hectares) of the total area of the city, reaching 6,168.6 ha (27.78%). The formation of new nuclei always occurred in the rural area, far from the occupied points, being identified five new spots in the first scenario. The territory composed of medium and high density in the urban region, and the surrounding areas unfit for occupation, does not allow new occupations or large expansions. The subtle expansion to the south, where humid areas and near the Sinos River are concentrated is visible; to the north, where areas with high slope are located; and to the west where wetlands are also situated. This process raises concerns about planning and inspection in environments unsuitable for occupancies such as EPA, PPA, and hazardous areas. The rural area also needs eminent care, given the local environmental heritage, which focuses on crops and field areas, which may be affected by the lack of infrastructure mainly related to the basic sanitation aspects of residents living in these regions.

The "CPRM (2015)" susceptibility charts are shown in Figures 4. The areas characterized as high susceptibility to flooding (Figure 4a) correspond to 11.48% of the total area of the city and are concentrated near the Rio do Sinos, along imposing streams and wetlands. The areas characterized as highly susceptible to mass movements (Figure 4b) correspond to 3.3% of the total area and are located in the city extremities, to the north of RS 239 highway, and the east and south of the rural area.

Figure 3: Simulation 2030: (a) Scenario 1; (b) Scenario 2; (c) Scenario 3; (d) Scenario 4

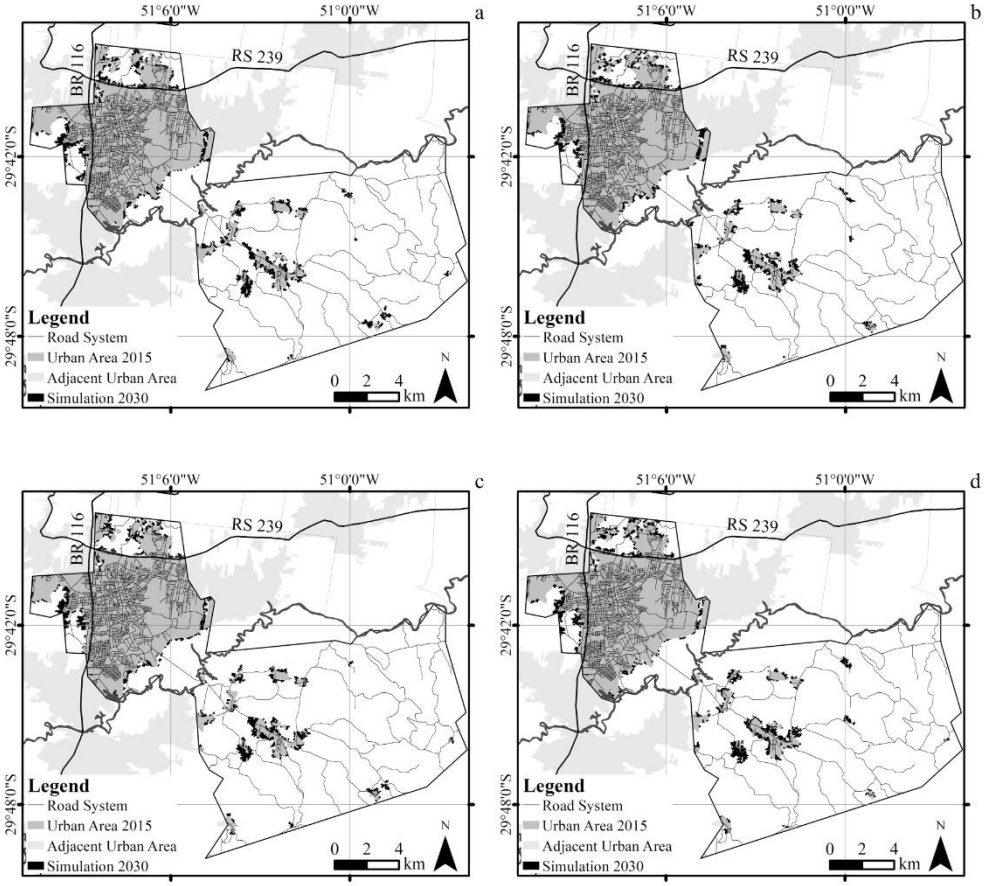
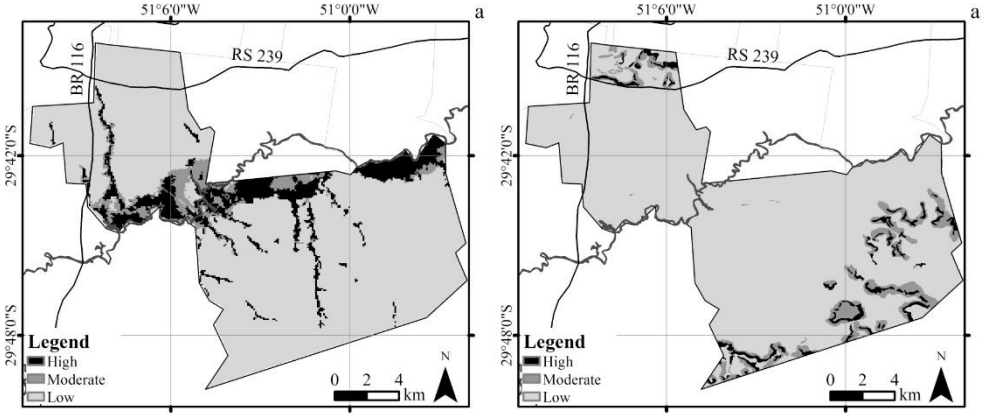


Figure 4: (a) Flooding and susceptibility chart; (b) Mass movements and susceptibility chart



Source: "CPRM (2015)"

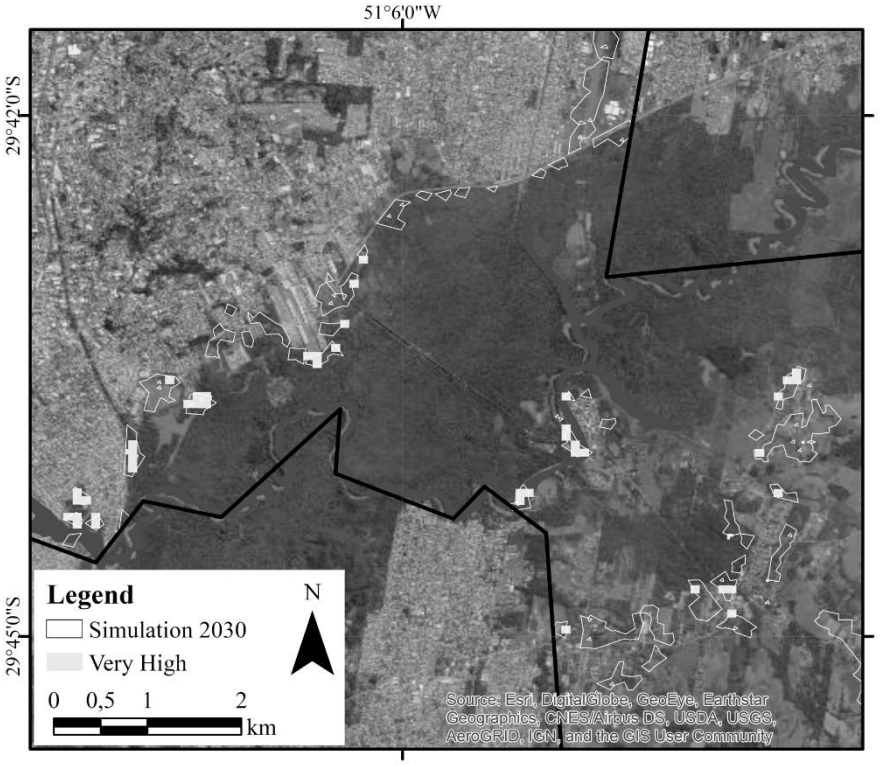
As predicted, by 2030, the urban city growth will correspond to approximately 875 hectares, an increase of 3.9% of the study area in relation to the total area of the city. Despite the existence of a large rural area that allows this expansion, care is needed with the transition use and occupation of the land, aiming to minimize the effects of urbanization, such as the increase of risk areas that are already a reality in the city. Thus, Table 2 presents the four prognostic scenarios and the percentage of areas that coincide with the zones defined as high susceptibility by the CPRM, in which it is observed that the worst scenario for the occupation of susceptible areas is the first for floods and the second for mass movements.

Table 2: Similarity between prognostic scenarios

	Mass Movements		Floods	
	%	Area (Hectare)	%	Area (Hectare)
Scenario 1	4.68	53.81	0.80	9.19
Scenario 2	6.58	75.65	0.75	8.59
Scenario 3	4.51	51.90	0.72	8.23
Scenario 4	5.78	66.46	0.79	9.07

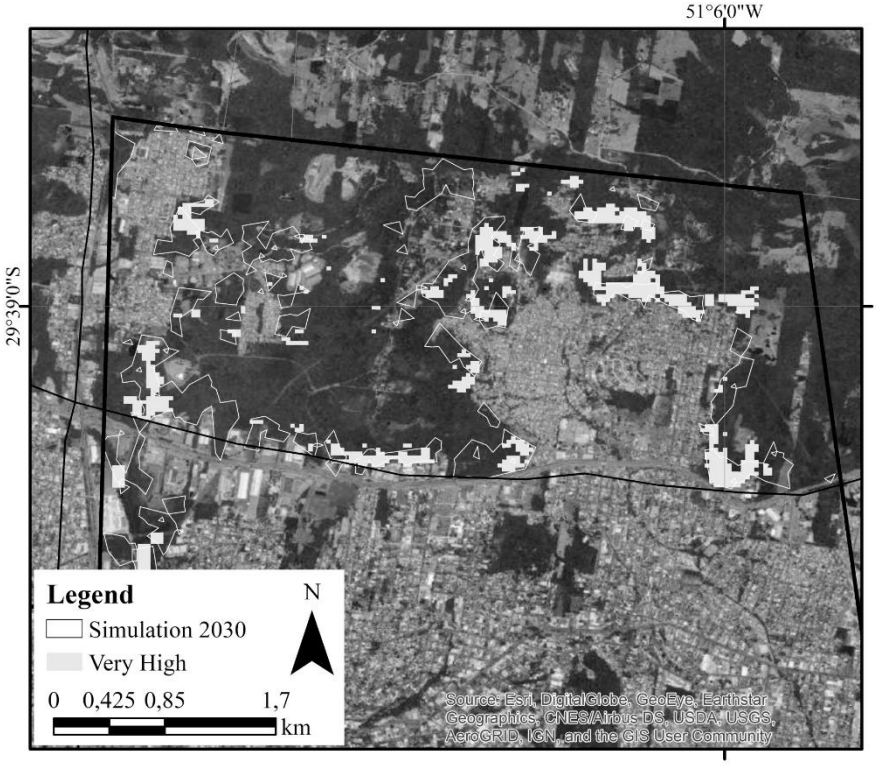
Figure 5 shows the transition region between the urban and rural areas, in which the Sinos River stands out. Polygons referring to scenario 1 is in white and spots highly susceptible to flood, occupied by the simulation of urban sprawl, are in red. In this case, despite the low percentage of areas characterized as highly vulnerable, they stand out in particular regions, especially in areas adjacent to irregular communities. In the rural area, there is also evidence of inadequate occupation of susceptibility areas near the Sinos River and wetlands.

Figure 5: Detail of flood areas concomitant with 2030 prognostic scenarios



Concerning mass movements, the area of most concern is the region north of the RS-239 highway, highlighted in Figure 6, which presents Scenario 2, along with the areas with high susceptibility. Besides being characterized as susceptible to mass movements, these areas are also considered APP, which has a certain occupation restriction due to low occupancy and utilization rates, imposed by the Master Plan of the City "Novo Hamburgo (2010)". In some parts of this region, there is also PPA where occupation is not allowed "Brazil (2012)". However, the inclusion of susceptibility spots in the Master Plan and the total occupancy restriction is the first step to restrain the impact on these steep sloping areas. On the other hand, they are also regions inhabited by irregularity, so frequent inspection is another possibility to inhibit occupation and avoid damage.

Figure 6: Detail of mass movement areas concomitant with 2030 prognostic scenarios



Concerning planning in unoccupied areas, aware of the imminent risk in many parts of the city, expansion over susceptible areas is not acceptable. The displacement of the population that currently occupies flood areas or susceptible to mass movements to more salubrious environments is almost impossible in a territory such as the city of Novo Hamburgo, where several regions live annually with this type of disaster. Thus, it is necessary to create a prevention plan to protect these areas. Therefore, the percentage of expansion over susceptible areas should be null, corresponding to proper planning and inspection.

4. CONCLUSION

Territorial planning consists of understanding a particular region, based on the attributes of visualization and space awareness, considering the spatial dynamics. Thus, this work applied modeling methods, aiming to establish results that allow information to be crossed and, consequently, to help urban planning, to reduce the impacts on the environment and society.

The simulation process obtained adequate similarity indexes, reaching over 0,80. The proposed methodology allowed to establish four prognostic scenarios for 2030, taking as a case study the city of Novo Hamburgo-RS. The modeling showed that the areas far from the main urban area, located in the rural area of the city, will be the most required ones for the new occupations. In the urban region, the growth of the existing spot is also evident. Yet, due to the lack of suitable areas for occupation, it is perceived imposition of expansion in areas susceptible to flooding and mass movements, besides preservation and bathing areas, establishing the aggravation of old problems in the region. The simulation model performed allowed us to understand that urban expansion is dynamic and heterogeneous without growth patterns. Therefore, prognostic scenarios longer than 15 years are not feasible, since the variables that influence the expansion advance change over the years.

The final analysis of the work established the relationships between the expansion areas and the susceptibility charts built by the CPRM. Thus, it has been estimated that around 7% of the areas to be occupied are susceptible to mass movements or floods, that is, they characterize a risk to the population if they are to be inhabited. Thus, it is emphasized the need for inspection of these areas, to control illegal progress and allow sustainable use of the soil and a better quality of life for people.

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