Delimitation of ecological corridors in the Metropolitan Region of Belo Horizonte through Analytic Hierarchy Process (AHP) using GIS tools

Delimitação de corredores ecológicos na Região Metropolitana de Belo Horizonte através de Análise Hierárquica (AHP) utilizando ferramentas de SIG

Murilo Mourão de Souza Bahia
Concremat/SP
bahia_murilo@yahoo.com.br

Douglas Sathler dos Reis
Universidade Federal dos Vales do Jequitinhonha e Mucuri/UFVJM
doug.sathler@gmail.com

Rodrigo Affonso de Albuquerque Nóbrega
Universidade Federal de Minas Gerais - IGC/UFMG
raanobrega@ufmg.br

Abstract

Ecological corridors connect habitats, enabling gene flow, biological exchange, and water movement, mitigating fragmentation caused by urban sprawl. This study identifies potential corridors in Belo Horizonte's Metropolitan Region using a geographic model that classifies environmental fragility through natural and anthropogenic factors, combining AHP with GIS. Variables like land use, slope, hydrography, and roads were prioritized for connectivity. The model highlighted corridors in less urbanized zones, linking vegetation fragments to enhance biodiversity. Notably, the proposed corridors aligned with a planned metropolitan highway. Integrating green corridors into the highway project could reduce fragmentation and leverage this potential pathway.

Keywords: Ecological corridor, GIS, Multicriteria Analysis, Lease-cost path, Fragmentation.

Resumo

Corredores ecológicos conectam habitats, facilitando fluxo gênico, troca biológica e movimento da água, mitigando a fragmentação causada pela urbanização. Este estudo mapeou áreas prioritárias para corredores na Região Metropolitana de Belo Horizonte, usando um modelo geográfico baseado em fatores naturais e antrópicos, com AHP e SIG. Variáveis como uso do solo, declividade, hidrografia e malha viária definiram rotas de conectividade. O modelo identificou corredores em zonas menos urbanizadas, ligando fragmentos de vegetação para melhorar biodiversidade. Houve convergência entre os traçados propostos e um projeto de rodovia metropolitana. Sua implementação exige integrar corredores verdes ao anel viário, reduzindo fragmentação e otimizando a conexão ecológica.

Palavras-chave: Corredor ecológico, SIG, Análise multicritério, Trajetória custo-locação, Fragmentação.

1 Introduction

The rapid urbanization, agricultural expansion, and livestock intensification that characterized 20th century Brazil have profoundly impacted natural ecosystems (HERNANDO ET AL., 2017). These anthropogenic pressures have led to extensive environmental fragmentation, particularly in peri-urban regions (PEIXOTO, 2005), with cascading effects on ecological integrity. Habitat degradation has compromised water and soil quality while disrupting critical biological processes, including gene flow among fragmented populations (PRIMACK AND RODRIGUES, 2001; METZGER, 1998). Native vegetation, which plays vital roles in hydrological regulation, nutrient cycling, and climate modulation (CLEMENT AND HO, 2015), has been particularly vulnerable to urban encroachment, with significant consequences for both ecosystem services and human welfare in Brazilian cities (PINA, 2018).

Ecological corridors have emerged as a strategic response to these challenges, offering a means to reconcile conservation objectives with urban development (ROCHA ET AL., 2006). By reconnecting fragmented habitats, these corridors enhance vegetative coverage, mitigate isolation effects, and promote biodiversity conservation (LOUZADA ET AL., 2010). However, stand-alone protected areas prove insufficient for maintaining viable populations; rather, integrated networks of interconnected habitats are required (MARTINS ET AL., 1998). Modern corridor planning increasingly relies on geospatial technologies to evaluate landscape features, including land use patterns, hydrographic networks, and topographic characteristics.

The Belo Horizonte Metropolitan Region (BHMR) presents a compelling case study of these dynamics. The region's 1970s development pattern exacerbated socio-spatial disparities through uneven urban expansion (COSTA AND MENDONÇA, 2012). Subsequent decades witnessed intensifying urban sprawl and ecological fragmentation, particularly following population shifts in the 2000s (COSTA AND MENDONÇA, 2012). These transformations have created an urgent need for innovative connectivity solutions that can support sustainable development.

Recent advances in restoration ecology offer promising, cost-effective approaches to enhance habitat connectivity. Techniques such as fragment densification (XU ET AL., 2024) and avian-mediated regeneration (CHOWFIN AND LESLIE, 2021; BELTRÃO, 2024) leverage natural processes to reduce implementation costs - a critical consideration for resource-constrained municipalities. These nature-based solutions are particularly relevant in the context of major infrastructure projects like the proposed BHMR ring road (SANTOS AND ALVIM, 2022), where strategic planning can mitigate potential fragmentation impacts.

This study contributes to this emerging paradigm by identifying priority areas for ecological restoration along planned transportation corridors. Our integrated approach seeks to balance infrastructure development with conservation objectives, providing a framework for sustainable urban expansion in the BHMR and similar metropolitan regions. Through systematic analysis of landscape connectivity and careful spatial planning, we aim to demonstrate how ecological corridors can be effectively incorporated into large-scale transportation projects.

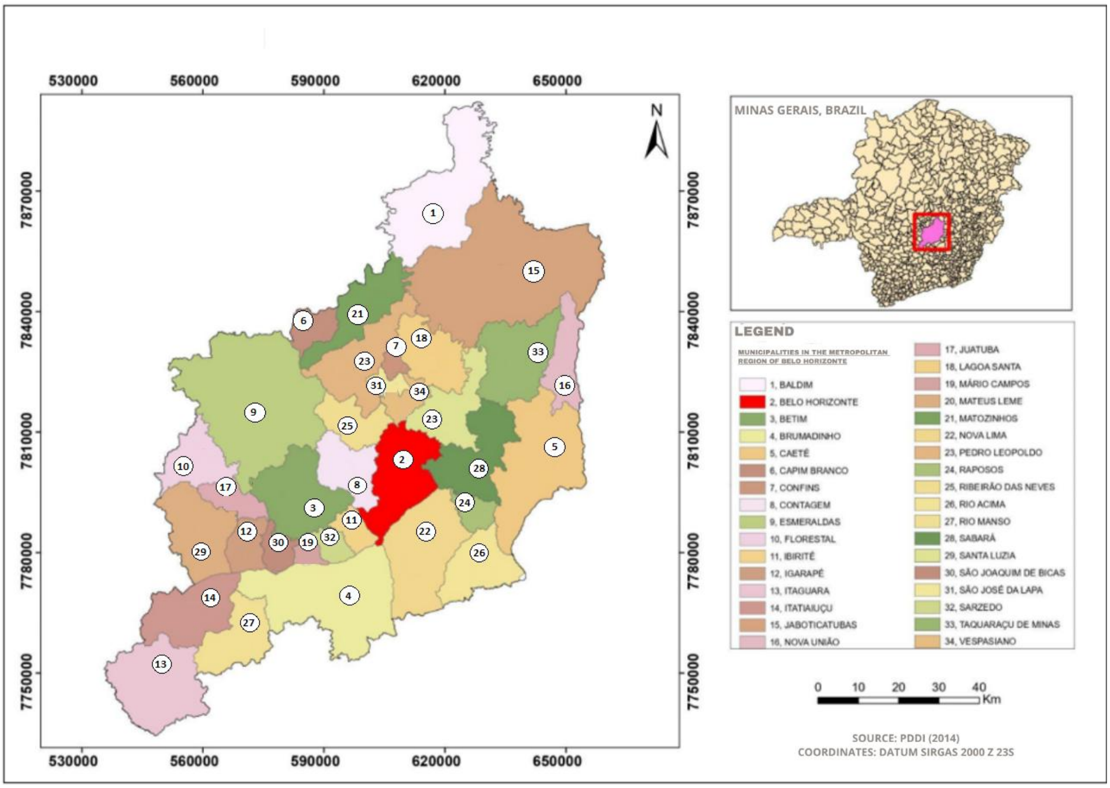
2 Methodological Approaches

2.1 Study Area

The BHMR is Brazil's third most populous urban area, covering 9,467 km² in central-western Minas Gerais. With 5.9 million residents across 34 municipalities (IBGE, 2022), population density is highest in Belo Horizonte 2,530,701 inhabitants) and its immediate neighbors such as Contagem (673,849), Betim (450,024), Ribeirão das Neves (341,415), Nova Lima (97,378) and, Sabará (137,877). The BHMR represents a biodiverse transition zone between Atlantic Forest and Cerrado biomes (SILVA ET AL., 2023). Rapid urbanization has intensified landscape fragmentation, particularly in the densely populated center-south region

ISSN 2237-549X

Figure 1. Municipalities of our study area: the Belo Horizonte Metropolitan Region



2.2 Multi-criteria decision making and GIS

Multi-criteria decision analysis requires evaluating variables with different weights, particularly for spatial problems (OSBORNE & RUBINSTEIN, 1994). The Analytic Hierarchy Process (AHP) (SAATY, 1990) addresses this challenge by systematically weighting variables, reducing subjective bias in decision-making.

To initiate this study, we developed a spatial database incorporating land use, roads, hydrography, and slope variables. Following Louzada et al. (2010), we applied AHP-weighted criteria within a Least-Cost Path analysis (SAATY, 1990) to optimize ecological

2.2.1 Database preparation

The geographical modeling process involves the initial processing of each individual thematic map, enabling subsequent joint analysis. All vector files were converted to raster (road network and hydrography) using ArcGIS tools (Spatial Analyst Tools - Density - Kernel Density). Additionally, straightforward conversions of land use and slope information were executed, facilitating the conversion of data into raster format.

Chart 1: Data Sources and Methods of Extracting Variables Used in the Delimitation of Ecological Corridors in the BHMR

Data	Source	Date	Extraction
Landuse	INPE - National Institute for Space Research EMBRAPA M. Demuzere et al., Global Map of Local climate zones.	2013 2013 2022	Extraction made from data provided by the "Global Map of Local Climate Zones" (LCZ), with a spatial resolution of 100m, derived from several observation datasets and specialized LCZ class labels. Extra mining class was extracted from data from INPE (2013) and EMBRAPA (2013), prepared by the EA-UFMG Geoprocessing Laboratory.
Hydrography	ANA - National Water Agency.	2017	Delimitation of the Metropolitan Region of Belo Horizonte and ordering of sections using the Sthrsler Methodology.
Slope	CPRM – Brazilian Geological Servisse.	2013	A mosaic was created using satellite images taken from sheets SE-23 and SF-23. The mosaic was classified according to the references (Flat 0 to 3%, Gentle wavy 3 to 8%, Wavy 8 to 20%, Strong wavy 20 to 45%, Mountainous 25 to 75% and Steep >75%).
Road Network	DNIT – National Department of Infrastructure and Transport. IBGE – Brazilian Institute of Geography and Statistics.	2018, 2022 2021	The road network data was extracted from sources from DNIT (2018, 2022) and IBGE (2021), compiled and processed by the EA-UFMG Geoprocessing Laboratory. Due to the high level of information in the data, each layer was characterized according to its functional hierarchy of the road system.

Source: INPE (2013), EMBRAPA (2013), Demuzere et al. (2022), ANA (2017), CPRM (2013), DNIT (2018; 2022) and IBGE (2021).

2.2.2 Defining Costs

Assigning costs to the layers of selected data and their corresponding categories enables the application of diverse interactions between the layers, a process known as "map algebra" (DeMers, 2002). Preceding the generation of comparison matrices for each variable's factors, it was necessary in this study to reclassify the images, ensuring they conform to the same analysis interval.

According to Louzada et al. (2010), the costs ranges from 1 to 100, contingent on the suitability within each distinct category. Consequently, areas most conducive to accommodating ecological corridor implementation incur lower costs. Conversely, areas where the establishment of ecological corridors is unviable, given the requisite construction of connectivity lines, bear the highest possible implementation costs. This technique facilitates the identification of suitable regions for ecological corridor implementation, mandating its application before deploying the AHP model for conducting map algebra. Chart 2 presents the delineation of costs for each variable utilized in this investigation.

Chart 2: Definition of Costs by Land Use Type and Adopted Justifications.

Use of the soil	Costs	Justification
1) Compact Highrise	100	Considering them as barriers to the passage of Ecological Corridors, receiving extreme costs. The acquisition of areas for this implementation would be very complex. Represented by the most urban areas with a dense mix of buildings, few or no trees, and mostly paved ground cover.
2) Compact Midrise	100	
3) Compact Lowrise	100	
4) Open Highrise	90	Still representing a barrier to the passage of Ecological Corridors, it presents a smaller arrangement of buildings and an abundance of permeable earth cover, low plants and trees.
5) Open Midrise	90	
6) Open Lowrise	80	It presents a much lower arrangement of buildings with an abundance of permeable land, with a greater presence of plants and trees.
7) Lightweight Lowrise	75	Dense mix of low-rise buildings, little vegetation present and mostly compacted earth cover, there is a certain opening to introduce vegetation.
8) Large Lowrise	100	Open arrangement of large buildings, with no or little vegetation present. The ground cover is mostly paved, considering it a barrier to ECs.
9) Sparsely Built	50	Open arrangement of small buildings, in a natural environment, with a large abundance of permeable earth cover inducing the partial creation of ECs.
10) Heavy Industry	100	Industrial. The main ground cover is paved and compacted, high induction construction materials such as metal, steel and concrete. Unfavorable for the creation of ECs.
11) Dense Trees	1	Densely wooded landscape of deciduous and evergreen trees. The soil cover is permeable, and these are important areas for ecological corridors.
12) Scattered Trees	20	Areas with a wooded landscape, with evergreen trees, with mainly permeable land cover. These are areas of natural forests, tree cultivation or large urban parks or protected areas.
13) Bush, scrub	20	

14) Low Plants	25	Landscape areas of small crops, natural pasture or urban parks. Points of extreme importance for buffer zones and connection between dense vegetation.
15) Bare Rock or Paved	25	These zones were represented in the Metropolitan Region of Belo Horizonte by landscapes composed of rock, present with greater emphasis in Serra do Curral. They are favorable for implementing ECs.
16) Bare Soil or Sand	20	Landscape with little vegetation, but due to the small amount in the Metropolitan Region of Belo Horizonte, they can be incorporated into adjacent areas to favor the implementation of corridors.
17) Water	1	Open areas of water bodies, in lakes, rivers or small bodies of water, favor the implementation of ECs.
18) Mining	100	Active mining area or in the process of being closed. Unfavorable area for the creation of ECs.
HYDROGRAPHY (Density Weighted)	Costs	Justification
0,064913213 – 2,565783205	90	Extremely low
2,565783206 – 3,885686812	75	Low
3,885686813 – 4,962450281	50	Average
4,962450282 – 6,108682361	25	High
6,108682362 – 8,922161102	1	Extremely high
Road Network	Costs	Justification
0 – 61,14653703	1	Extremely low
61,14653704 – 232,3568407	25	Low
232,3568408 – 489,1722963	50	Average
489,1722964 – 776,5610203	80	High

776,5610204 – 1.559.236694	100	Extremely high
Slope	Costs	Justification
Flat 0 – 3%	90	Plan - Ecological recovery is not recommended - suitable for mechanical agriculture.
Smooth Wavy 3 – 8%	75	Smooth Wavy.
Wavy 8 – 20%	75	Wavy - Moderately suitable for ecological recovery.
Wavy Fort 20 – 45%	50	Wavy Fort - Suitable for ecological recovery.
Mountainous 45 – 75%	25	Mountainous - Very suitable for ecological recovery.
Escarpment > 75%	01	Mountainous - Very suitable for ecological recovery.

2.2.3 Multicriteria Analysis and Map Algebra

The AHP method was employed to standardize variables, analyze weightings, and generate the cost surface. The initial phase of determining values for the comparison matrices represented the most critical step in the entire ecological corridor delineation process. At this stage, each characteristic's level of significance was established. Etherington (2016) suggests that establishing hierarchies between socio-environmental information, especially concerning the movement of organisms and populations, is challenging. Decisions in such cases are guided by local characteristics, expert insights, and relevant literature. The paired comparison matrix was specified as illustrated in Chart 3.

Table 3: AHP paired comparison matrix

	Landuse	Hydrology	Transportation Network	Slope
Landuse	1	2	3	4
Hydrology	½	1	3	2
Transportation Network	1/3	1/3	1	3
Slope	1/4	1/2	1/3	1

Source: Authors, adapted from Saaty (1987).

In this study, land use presented the greatest weight of influence (46.00%), due to the intrinsic relationships between different spaces, especially those that match natural forests and the presence of urban areas. From the point of view of land use, Forman and

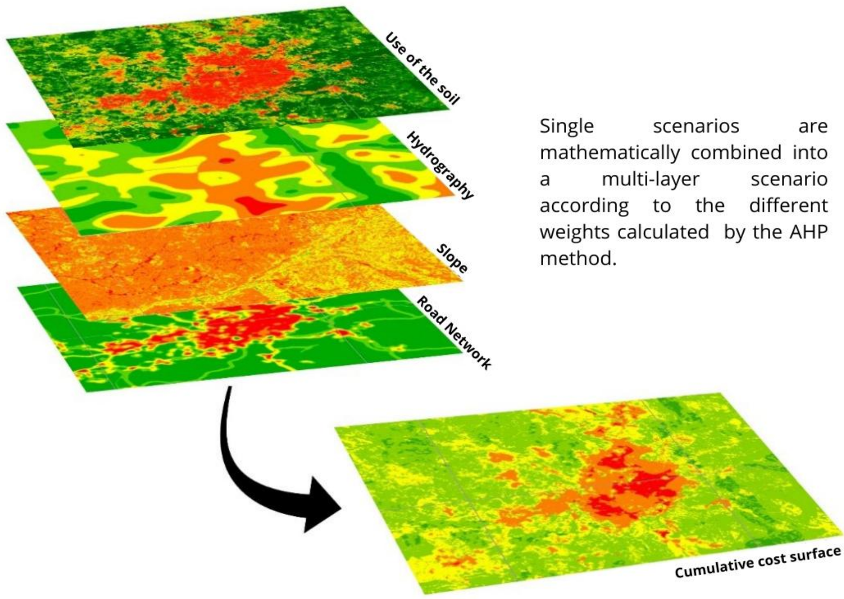
Gordron (1986) define that the essential standards for maintaining an ecologically viable landscape are: 1) the presence of natural vegetation that can offer habitat for species; 2) connectivity between these vegetation points through ecological corridors, which must be large enough to provide habitat inside; 3) natural hydrological processes that can maintain the quality, quantity and timing of water downstream.

Hydrography has the second greatest influence (26.00%) on the delimitation of BHMR ecological corridors, since the presence of watercourses is highly relevant for the balance of the environment. Hydrological behavior arises mainly from the variability of climatic processes and land use. The restoration of riparian forests as part of the strategy for implementing ecological corridors can bring benefits to the metropolitan population, such as the recovery of rivers and degraded areas by increasing water availability.

The road network received a weight of 18.00%. The highest road flow was recorded in areas with the highest human occupation in BHMR. Furthermore, there are important access highways and also the busiest urban traffic corridor in Belo Horizonte. Highways, historically, catalyzed the process of environmental fragmentation in the BHMR, creating obstacles to the creation of areas of environmental connectivity. Finally, the slope received a weight equivalent to 10.00%, being strongly associated with the different morphological domains of the BHMR. Despite the lower weight, the coverage of this aspect throughout the entire portion of the territory (unlike roads that are located in specific areas) makes this variable extremely relevant for the analysis and definition of the layout of ecological corridors. Furthermore, it is worth highlighting that areas with high slopes are considered areas of permanent conservation by legislation.

In order to ascertain whether the attained results meet acceptable criteria, it is essential to compute the consistency index, as elucidated by Saaty (1990), wherein the derived value must not exceed 0.10. The calculated index for the influence weight of the designated variables stood at 0.084, demonstrating the coherence of the judgments made within this study. The distinct scenarios for each variable, previously computed, are amalgamated into a unified scenario utilizing the Map Algebra technique within the framework of GIS. Each scenario was treated as raster data, and the reclassified classification values are determined based on the corresponding weight obtained from the intra-scenario comparison via the AHP method. Figure 2 visually presents the amalgamation of layers to compose the cumulative cost surface, achieved through map algebra.

Figure 2. Map algebra for the production of a cumulative cost surface.



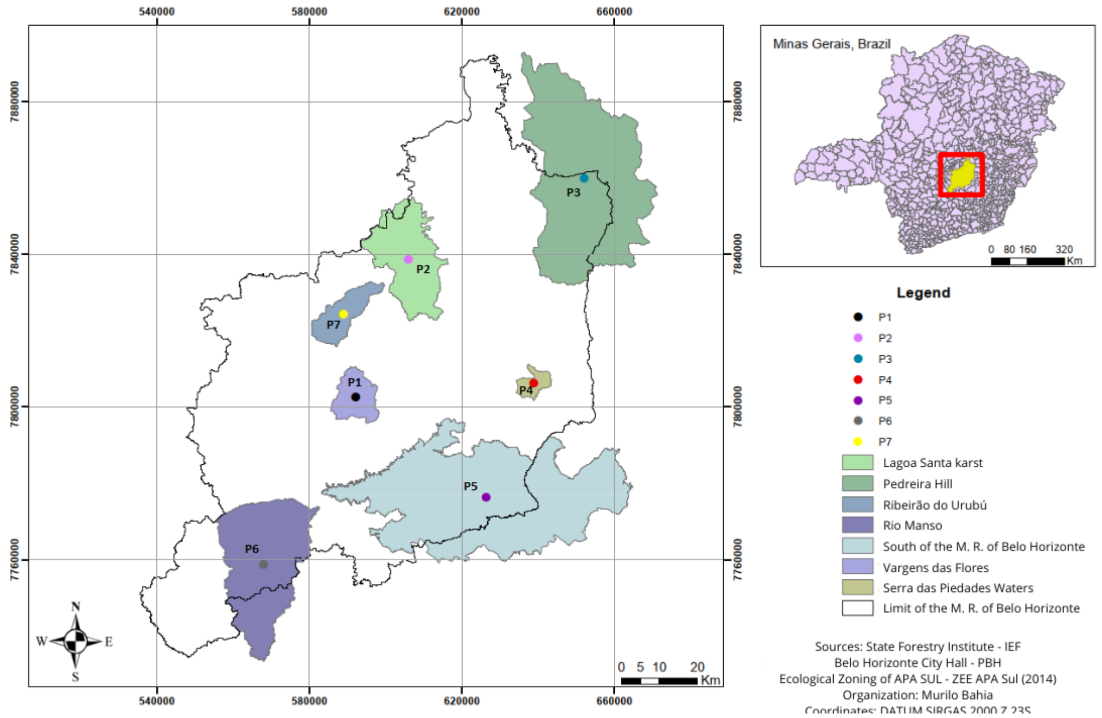
2.2.4 Least-cost Path

In geography, the conceptual understanding is that closer objects exhibit a higher level of connectivity. According to Tobler (1970), "everything is related to everything else, but near things are more related than distant things." This idea finds extensive application in quantifying diverse geographical processes, including those in ecological systems. Nevertheless, in certain systems, this proximity relationship does not strictly adhere to the order of Euclidean distances and necessitates an alternative calculation method (ETHERINGTON, 2016).

To delineate the connectivity routes between the points, we conducted the Least-Cost Path technique. The values of each pixel within the cost surface denote the distance cost per unit pixel attributed to traversing various segments of the terrain. In essence, each pixel of the cost surface map bears a distinct value, prompting the software to generate a path representing the minimum accumulated cost along the route, calculated as the product of the cost and the distance covered. This process entails the computation of two elements for each specific point: the Cost Distance and the BackLink. The cost distance indicates the effort relative to the originating point: the steeper the incline, the higher the cost incurred along the path. The BackLink denotes the direction with respect to the path, encompassing all eight feasible cardinal points from one cell to the subsequent one. Ultimately, to establish the most cost-effective paths between a selected point and any other point on the map, the integration of the cost distance, backlink, and destination origin is imperative. Irrespective of the route taken, the elevation change remains constant (Etherington, 2016). In this study, we create a 500-meter-wide buffer was created for each connectivity line, as the data derived from this study is insufficient to precisely ascertain the optimal width of the pertinent corridors.

The selection of points of interest used to connect the ecological corridors took into account the conservation units within the Metropolitan Region, the extent of the vegetation patches, and the spatial distribution of these patches across the territory. The chosen units encompassed the Karst of Lagoa Santa (APA), Morro da Pedreira (APA), Rio Manso (APE), SUL BHMR (APA), Vargem das Flores (APA), Águas da Serra da Piedade (APA), and Ribeirão do Urubu (ON FOOT). In order to establish the least costly connectivity paths between the conservation units, the centroids of the designated areas were considered as the connecting points, as shown in the Figure 3.

Figure 2. Chosen areas and Centroids



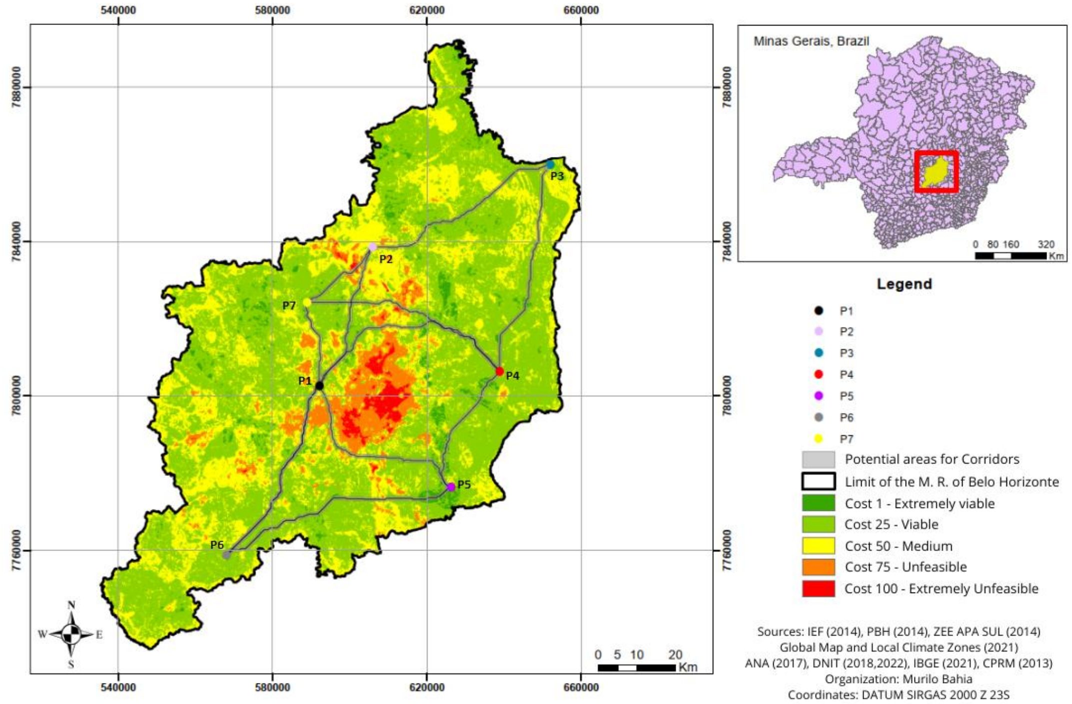
3. Results and Discussion

The modeling generated seven connection lines among the selected conservation units. Figure 4 illustrates the paths of least cost, showing the layout of connectivity lines based on the selected weightings. The corridors that connect P6-P5, P3-P4, and P2-P3 presented "linear" layouts, as the cost surfaces in these regions are more favorable to the

ISSN 2237-549X

implementation of connectivity lines, given the absence of built-up regions and the lower density of road networks. However, due to the length of these corridors, the morphology and specificities of the region, it would be ideal to divide this extensive corridor into multiple connection strips using small fragments as buffer zones. According to Ferriti (2013) and Góes (2015), the distance between fragments can make it difficult to exchange individuals and the arrangement of a long corridor throughout the environment influences the level of exchange and the flow of species.

Figure 3. Potential Map for implementing Ecological Corridors in the Metropolitan Region of Belo Horizonte



In contrast, in the corridors that connect P1-P2, P1-P4, P1-P5 and P2-P7, there are very resistant spatial elements that create challenges for the layout of ecological corridors. As a result, the model generated curvilinear lines by tracing corridors in relatively unfavorable regions. In areas where there is a tendency to strong human pressure, the ecological structure becomes even more important for the balance of the region (HERZOG, 2010; LOUV, 2008; MCDONALD ET AL., 2018). According to Herzog (2010), Louv (2008) and McDonald et al. (2018), the route, when located close to areas with greater urban density, can bring benefits to the population, such as improving water and air quality, increasing the availability of leisure areas and a reduction in respiratory diseases.

While our methodology provides an immediate foundation for environmental policy design in the BHMR, future studies should refine corridors width specifications. The current 500-meter standardized buffer—adopted from Arimono (2012) for habitat loss analysis—serves as a provisional measure. However, optimal widths may vary spatially; certain sections could benefit from expanded corridors to [1] Enhance habitat diversity and area, [2] Mitigate edge effects, and [3] Incorporate protective buffers. Notably, CONAMA (1996) guidelines recommend corridor widths of at least 100 meters or 10% of total length, suggesting potential adjustments to our design. Subsequent research should integrate these regulatory standards with site-specific ecological assessments to optimize connectivity.

Considering our results, a thorough analysis of the P4-P1 corridor (Figure 5) is necessary, which may have a very relevant function for the East-West connection through areas of strong urban density in the BHMR. Its route coincides with the North and West loop of the future construction of the metropolitan ring road, as seen in detail in Figure 5. The Metropolitan ring road should bypass the entire Northern and West portion of the continuous urban area of the BHMR, relieving the traffic flow on the Ring Road and facilitating the passage and flow of people and goods through the region.

The proposed northern loop's proximity to the ecologically sensitive Lagoa Santa Karst Area (Point 2) has raised environmental concerns. While the ring road will inevitably alter existing spatial patterns marked by urban challenges (PEREIRA AND CALDEIRA, 2011), our analysis confirms this route offers the only viable ecological connection between key BHMR regions. We recommend integrating an ecological corridor along the highway to prevent environmental fragmentation, implementing protective policies against informal settlements, and creating a continuous green infrastructure for regional ecological balance. This "green line" approach would mitigate impacts and enhance metropolitan quality of life.

The creation of green highways must be considered in metropolitan planning. The creation of tunnels for species crossing is already a reality in several cities in Canada, as exposed by McDonald and Cassady (2004), where they tested the effectiveness with which rodents used crossing structures built along the Trans-Canada Highway, through studies of the effect of size, coverage and different types of corridors, such as underground and overhead passages.

In Brazil, there are examples of ecological highways that were created incorporating concepts of sustainability and green practices. We can mention the BR-290 (connects greater Porto Alegre to the coast of Rio Grande do Sul), Anchieta-Imigrantes (connects the capital of São Paulo with Baixada Santos) and Rodovia do Sol (connects Vitória to Guarapari). These roads incorporated many mitigation strategies, as follows: 1) the creation of tunnels with greater spacing between pillars to avoid cutting down part of the forests; 2) appropriation of degraded areas to host construction sites; 3) installation of sewage treatment stations; 4) and the creation of "faunoducts" (Ecological corridors), to transport fauna between specific points (an initiative that even received the Ford Motor Company Award for Environmental Conservation in 2006). The changes that may occur in this region tend to modify the structure of land use in the locality and can increase the environmental and socio-spatial fragmentation in the northern BHMR. Therefore, technical studies considering the design of an ecological corridor in this area must conducted by the authorities involved in this ring road project.

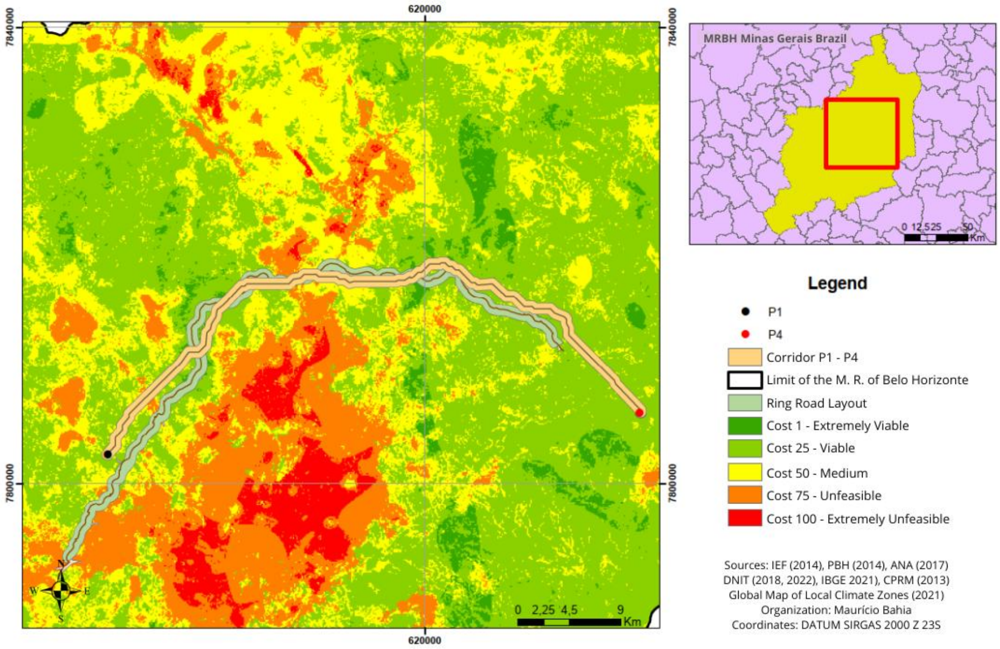
The use of the AHP method, based on the Least Cost Path and Map Algebra tools, demonstrated that the use of different variables and criteria allows for a more accurate understanding of the socio-environmental reality. According to Figueiredo et al. (2006), choosing areas and actions to protect biodiversity is a complex activity, as it is based on decision-making, which must balance the demands of societies for the use of natural resources with the need for environmental protection. This study is effective in indicating areas relevant to the structural connectivity of ecological corridors, connecting natural areas or preserved portions of the territory. Figure 4 shows that there are significant opportunities in the region for the implementation of connectivity lines.

The proposal presented in this article may face implementation challenges due to the high cost associated with establishing ecological corridors in RMBH. Alternative strategies that promote the natural regeneration of areas may support the restoration of connectivity between habitats (XU et al., 2024; CHOWFIN AND LESLIE, 2021). The suggested model enhances the impact of nature regeneration policies, positively influencing the cost-benefit ratio of the resources invested. In addition, the participation of social groups seeking environment justice and balanced landscapes is relevant during the design and the construction of this road ring. Promoting interconnection between habitats in a way that is harmonious with different land uses, encouraging the creation of better environmental conditions in BHMR municipalities, will bring benefits to

ISSN 2237-549X

ecosystems and all metropolitan citizens. The involvement of public authorities, companies and organized civil society is essential for projects of this magnitude.

Figure 5. Corridos P1-P4 overlaid to BHMR Cost Surface Map



4. Conclusions

This study successfully implemented a GIS-based multi-criteria approach to identify ecological corridors in the BHMR, demonstrating its effectiveness at the metropolitan scale. The methodology integrated key environmental variables to optimize connectivity between fragmented habitats, resulting in the delineation of 11 distinct corridors. These corridors fall into two categories: (1) relatively linear pathways in less disturbed areas, facilitating efficient inter-fragment connectivity, and (2) more sinuous routes in urban-proximate zones, reflecting greater anthropogenic constraints.

Notably, one primary corridor connecting the eastern and western BHMR aligns with the planned metropolitan ring road route. This spatial convergence underscores the critical value of geospatial analysis in environmental planning, particularly for mitigating the ecological impacts of major infrastructure projects. Our findings emphasize the need for evidence-based policy frameworks that integrate ecological connectivity considerations into urban development strategies. The study establishes a replicable framework for corridor planning in metropolitan regions, highlighting the importance of environmental assessments for sustainable urban expansion. Future research should focus on refining corridor width parameters and monitoring the ecological efficacy of implemented connections

References

ARIMONO O. A. S. 2012. Identificação de Corredores Ecológicos entre as Unidades de Conservação de Proteção Integral do Distrito Federal e Análise do Impacto da Dinâmica do Uso da Terra no Habitat do Mamífero Tapirus Terrestris. Monografia de Conclusão de Curso de Especialização, Brasília.

CLEMENT M. T., CHI G., HO H.C. 2015. Urbanization and land-use change: A human Ecology of deforestation across the United States, 2001-2006. Sociol. Inq. 85(4):628–653. doi: 10.1111/soin.12097.

CONAMA - Conselho Nacional do Meio Ambiente. 1996. Dispõe sobre os corredores de vegetação entre remanescentes como área de trânsito para a fauna. Resolução n. 09, de 24 de outubro de 1996. Diário Oficial da União, n. 217, p. 23070.

COSTA H. S. M., MENDONÇA J. G. 2012. Novidades e permanências na produção do espaço da metrópole: um olhar a partir de Belo Horizonte. In: Oliveira FL., Costa HSM., Cardoso AL, Vainer CB. (orgs.) Grandes projetos metropolitanos: Rio de Janeiro e Belo Horizonte. Rio de Janeiro: Letra Capital Editora.

DEMERS M. N. 2002. GIS modeling in raster. New York: John Wiley.

DEMUZERE M. et al. 2022. A global map of local climate to support earth system modelling and urban-scale environmental science. Earth System Science Data, 14(8): 3835-3873.

ETHERINGTON T. 2016. Least-Cost Modelling and Landscape Ecology: Concepts, Applications, and Opportunities. Curr Landscape Ecol Rep 1:40-53.

FERRETTI O. 2013. Os espaços de natureza protegida na Ilha de Santa Catarina, Brasil. Tese de doutorado, Universidade Federal de Santa Catarina, Centro de Filosofia e Ciências Humanas, Curso de Geografia, Florianópolis, SC.

FIGUEIREDO W. M. B., SILVA J. M. C., SOUZA M. A. 2006. Biogeografia e a conservação da biodiversidade. In: Rocha CFD et al. Biologia da Conservação: Essências. São Carlos: Rima.

GODRON M. 1986. Landscape ecology. New York: John Wiley and Sons.

GÓES T. L. 2015. Ecologia da paisagem da planície entre mares na Ilha de Santa Catarina: Conectividade entre fragmentos de vegetação através de corredores ecológicos. Dissertação de mestrado, Universidade Federal de Santa Catarina, Programa de Pós-Graduação em Geografia, Florianópolis, SC.

HERNANDO A., Velázquez J, Valbuena R, Legrand M, Gárcia AA. 2017. Influence of the resolution of forest cover maps in evaluating fragmentation and connectivity to assess habitat conservation status. Ecological Indicators, 79: 295-302.

LOUV R. 2008. Last child in the woods: saving our children from nature-deficit disorder. New York: Algonquin Books.

LOUZADA FLRO, SANTOS AR, SILVA AG, COELHO ALN, EUGENIO FC, SAITO NS, PELUZIO TMO, TULER TO, TEBALDI ALC, GARCIA GO. 2010. *Delimitação de corredores ecológicos no ArcGIS 9.3.* Louzada FLRO, Santos AR, Silva AG (orgs.). Alegre, Espírito Santo (ES), Brasil.

MARTINS AKE, SARTORI NA, MENEZES IC, BRITES RS, SOARES VP. 1998. Metodologia para Indicação de Corredores Ecológicos por Meio de um Sistema de Informações Geográficas. Anais, IX Simpósio Brasileiro de Sensoriamento Remoto, Santos, Brasil, 11-18 setembro de 1998, INPE, p. 611-620.

MCDONALD W, CASSADY ST. Clair C. 2004. The effects of artificial and natural barriers on movement of small mammals in Banff National Park, Canada. Oikos, 105(2): 397-407.

METZGER JP. 1998. Landscape ecology approach in the preservation and rehabilitation of riparian forest areas in S.E. Brazil. In: CHAVÉZ, Salinas; MIDDLETON, John (Org.). Landscape Ecology as a Tool for Sustainable Development in Latin America: International Association for Landscape Ecology.

OSBORNE MJ, RUBINSTEIN A. 1994. A course in game theory. MIT press.

PEIXOTO MCD. 2005. Expansão urbana e proteção ambiental: um estudo a partir do caso de Nova Lima /MG. XI Encontro Nacional da Associação Nacional de Pós-Graduação e Pesquisa em Planejamento Urbano e Regional - ANPUR, Salvador.

PEREIRA RG, CALDEIRA AB. 2011. Impactos antrópicos no patrimônio natural e cultural do Vetor Norte da Região Metropolitana de Belo Horizonte (BHMR). Revista de Biologia e Ciências da Terra, 11(1): 22-31.

PINA GF. 2018. Análise multicritério na identificação de áreas para a recuperação ecológica no plano de manejo ambiental municipal. Dissertação de mestrado, Universidade Estadual Paulista, Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal.

PRIMACK RB, RODRIGUES E. 2001. Biologia da conservação. Londrina.

RICHARDS P, Pellegrina H, Vanwey L, Spera S. 2015. Soybean Development: The Impact of a Decade of Agricultural Change on Urban and Economic Growth in Mato Grosso, Brazil. PLoS ONE 10(4).

ROCHA CFD et al. 2006. Corredores ecológicos e Conservação da Biodiversidade: Um Estudo de Caso na Mata Atlântica. In: Rocha CFD et al. Biologia da conservação: essências. São Carlos: Rima.

SAATY RW. 1987. The analytic hierarchy process—what it is and how it is used. Mathematical modelling, 9(3-5):161–176.

SAATY, TL. 1990. How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research 48: 9−26.

SANTOS M, Alvim A. 2022. A regional Venda Nova (BH) e o processo de reestruturação urbana do vetor norte da região metropolitana de Belo Horizonte (BHMR\MG). Estudos Geográficos: Revista Eletrônica de Geografia.

SILVA, RVM., Cherem, LFS., Salgado, AAR. 2023. Mapeamento das Áreas de Conflito, Conservação e Tensão da APA Sul RMBH, Minas Gerais, Brasil. *Revista Geografias*, *19*(1), 20–34.

TOBLER, WR. 1970. A computer movie simulating urban growth in the Detroit region. Economic Geography, 46: 234-240.