Urban road cyclability: indicators for the municipality of Belo Horizonte- MG, Brazil

Ciclabilidade viária urbana: indicadores para o município de Belo Horizonte- MG, Brasil

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ABSTRACT

How people move around in large Brazilian cities reflects a process of production and appropriation of urban space. The transport system is characterised by the increasing rate of individual motorisation and the precariousness of public transport services. The general objective of this paper is to evaluate the level of road cycling in the city of Belo Horizonte/Minas Gerais/Brazil, based on the proposition and analysis of indicators to assess the degree of adequacy of urban roads for bicycle use as a transport mode. The results indicate that many of the roads in Belo Horizonte have good cycling levels. Given its topography and climate, these findings go against commonly held views that consider the municipality inappropriate for cycling as a mode of transport. In reality, Belo Horizonte has a very underused high cycling potential, especially if there were investments to expand the exclusive/preferred road infrastructure.

Keywords: Cyclability. Urban mobility. Active Transport. Non-Motorized Transport.

RESUMO

A maneira como as pessoas se deslocam nas grandes cidades brasileiras é reflexo do complexo processo de produção e apropriação do espaço urbano, que no sistema de transportes se caracteriza pela crescente taxa de motorização individual e na precariedade da prestação de serviços de transportes públicos. O objetivo geral deste paper é avaliar o nível de ciclabilidade viária do município de Belo Horizonte/Minas Gerais/Brasil, tendo como base a proposição e análise de indicadores para avaliar o grau de adequação das vias urbanas ao uso da bicicleta como modo de transporte. De um modo geral, os

resultados obtidos indicam que significativa parcela das vias de Belo Horizonte apresenta bons níveis de ciclabilidade. Esse desempenho costuma contrariar o senso comum que tende a considerar o município, dada sua topografia e clima, como inapropriado ao uso da bicicleta como modo de transporte. Na verdade, Belo Horizonte possui elevado potencial ciclável ainda muito subutilizado, especialmente se existir um investimento na ampliação da infraestrutura viária exclusiva/preferencial.

Palavras-chave: Ciclabilidade. Mobilidade Urbana. Transporte Ativo. Transporte não Motorizado.

1 INTRODUCTION

The movement of goods and people within cities has induced and led to the development of the road system, thus increasing the need for transit and transportation services, as researched by authors such as Barouche (2014), Brazil Vasconcellos (1996), Cardoso (2007), Hansen (1959), Jones (1981), Landis (1994), and Pereira *et al*. (2011). Brazil faces successive failures due to inefficient low-quality public transportation systems, which rely heavily on buses. The legal obligation to execute the National Urban Mobility Policy (PNMU), defined by Law 12,587, January 3, 2012 (BRAZIL, 2012), was an attempt to mitigate the existing deficiencies in the country, mainly due to the prevalence of a model centred on the collective bus system and individual motorised transport. However, as indicated by Vasconcellos (1996), despite the PNMU, it is clear that a lack of willingness to adopt policies less focused on the primacy of motorised urban transport motorisation persists, limiting the space available to new trends that potentially benefit urban mobility more efficiently and sustainably.

The existing financing model of Brazilian public transport is primarily supported by tariff collection. However, 2009 data from the National Association of Urban Transport Companies (ANTU) show that 37 million Brazilians routinely did not use public transport due to their inability to pay the fares. The situation of the Brazilian urban public transport system has been exacerbated by the growth of motorised individual transportation at the expense of public transportation. Barouche (2014) leading to a continual loss of users. Despite the number of resources invested in urban transport systems, problems related to mobility and accessibility have been aggravated by the growth of the vehicle fleet, especially in the country's large urban centres. According to figures from the National Traffic Department of the Ministry of Infrastructure, over 60 million automobiles were on the road in 2023. The increase in congestion overloads the road system and worsens the public transport system. In Belo Horizonte, the fall in the relative participation of intra-urban trips by bus and bicycle confirms the imbalance caused by the historical prioritisation of less sustainable modes (Lessa *et al*., 2019). The last two Origin and Destination Surveys (ODS), produced by the Development Agency of the Metropolitan Region of Belo Horizonte, a governmental entity administered by the State Government of Minas Gerais, indicate that the total of regular daily trips by bus and bicycle shrank from 43.49 and 0.48% to 23.28 and 0.41%, between 2002 and 2012, respectively. In the same period, the share of car trips increased from 23.03 to 30.55%. This increase in car use is mainly due to the migration of public transport users to individual modes of transport, especially cars and motorcycles. Consequently, road congestion is no longer an exclusive problem at peak times.

It is no coincidence that the demand for bicycle use has gradually gained prominence in debates on urban mobility, both in academic and political circles, even if its practical use as a means of transport is still incipient. Several studies, including more recent research (BUEHLER; DILL, 2016; ELIOU *et al*., 2009; FHWA, 2002; GHOLAMIALAM; MATISZIW, 2019; NIELSEN; SKOV-PETERSEN, 2018; RIETVELD; DANIEL, 2004; WAHLGREN, 2011), emphasise that promoting non-motorized transport can be part of a transport planning strategy that includes the objective of reversing urban problems caused by prioritising car use. When used as a practical transportation mode, the bicycle can stimulate greater

social equity by providing the population access to productive activities at a reduced cost while promoting a more physically active lifestyle, thus reducing sedentarism. However, myths regarding the potential use of bicycles in Belo Horizonte persist, including the climate (hot and humid) and topography (there are roads/streets with steep slopes). Regarding the latter, Nobrega (2016) demonstrates this false impression when identifying and mapping the road network's concentrated patterns and high gradients in Belo Horizonte, Minas Gerais.

The result is an incorrect impression that the city is unsuitable for cycling, which is usually accepted as a leisure/sports activity, restricted to certain spaces and specific times, generally at weekends. Given the above, three main issues require further investigation. First, the factors that should be considered to assess the cyclability level. In the case of Belo Horizonte/MG, the pathways with greater or lesser cyclable potential must also be identified. Thirdly, with investment in localized infrastructure, what are the potential road expansion vectors that could encourage the use of bicycles? Considering these issues, this paper aims to evaluate the level of road cyclability in the city of Belo Horizonte/MG, Brazil, based on the proposal and analysis of aggregated and disaggregated indicators to assess how suitable the urban roads are for the use of bicycles as a mode of transport.

2 URBAN CYCLABILITY: CONCEPTS, MEASUREMENT FACTORS, AND ANALYSIS MODELS

"Cyclability" is often perceived as synonymous with "bicycle-friendly." Although both involve a person's ability to move around by bicycle or the prevalence of a cycling-friendly environment, this characterization tends to lead to inaccuracy, and the literature lacks consensus on its definition. For César (2014), for example, cyclability reflects how good or bad a city is for bicycles as a mode of transport. In the same work, this author states that a city may have favourable bicycle use characteristics without a single designated kilometre of cycle paths. Similarly, a city may have several kilometres of cycle paths and low cyclability due to other limiting factors, such as relief. Other authors, such as Dill and Carr (2003), Krenn *et al*. (2015), Silva (2014), Tuner *et al*. (1997), point out that the concept of cyclability extends to the evaluation of the quality of streets focused on bicycle use in an urban area. In general, this assessment considers cyclists' comfort and safety and is not explicitly associated with the existence of appropriate cycling infrastructure.

Alternatively, Eliou, Galanis, and Proios (2009); Gholamialam and Matisziw (2019); Kirner and Sanches (2011); Nordström and Manum (2015), and Wahlgren (2011) evaluate cyclability according to existing cycling infrastructure in a given location. Thus, the definition of cyclability implies the extent to which the cycling network provides for appropriate bicycle use. This definition is also close to the Bicycle Level of Service (BLOS), used by Botma (1995), Dixon (1996), Jensen (2007), Petrisch *et al*. (2007), and the Highway Capacity Manual (2010), which only consider factors related to local cycling infrastructure and ignore other factors such as relief, climate, and socioeconomic aspects. Despite adopting a similar approach, Grigory (2008), Lowry *et al*. (2012), and Nielsen and Skov-Petersen (2018) consider that cyclability is also an assessment of the ability and efficiency of the cycling network to connect to essential destinations. Therefore, they consider the quality and distances of the journeys.

The quality of the infrastructure can also interpret cyclability and serves as a measure of cyclists' access to desired destinations. In this sense, cyclability refers to cyclists' inherent ease of performing their regular trips. In other words, cyclability refers to the "friendliness" of a place for bicycle users in terms of comfort and safety. Therefore, environmental factors such as relief, climate, land-use diversity, and factors related to cyclists' safety and comfort, like infrastructure provision, preferential treatment for bicycles, and parking availability, should be considered essential. In general, based on the literature consulted, discussions on cyclability examine bicycle mobility based on the European and, to a lesser extent, North American and Asian realities, as demonstrated by, for example, Buehler and Dill (2016), Forester (1993), Fuller *et al*. (2013), Manum *et al*. (2017), Nordström and Manum

(2015). Factors such as spatial structure have also had an evident impact on bicycles as a mode of transport. In the Brazilian case, public policies aimed at the movement of people in large urban centres have historically been formulated primarily to serve individual motorized transport (BAROUCHE, 2014; CARDOSO, 2007; VASCONCELLOS, 2011; VILLAÇA, 1998). Therefore, a different approach to the concept is required, adapted to the local reality, marked by a high level of inequality and inadequate planning and management. Likewise, identifying the factors contributing to cycling is a fundamental step in guiding methodological procedures and constructing models and methods to estimate local cyclability. Therefore, the following section briefly reviews the literature on the factors, be they environmental, social, or even structural (dedicated lanes, separators/flow barriers, for example), which are considered determinants in the choice of the bicycle as a mode of transport.

2.1 FACTORS AND VARIABLES INFLUENCING THE USE OF THE BICYCLE AS A MODE OF TRANSPORT

According to the *Federal Highway Administration* (FHWA, 2002), a division of the United States Department of Transportation, an individual's decision to use a non-motorized mode of transport is a complex process with three main conditions. The first is the individual's perception of their initial needs. Depending on the reason for their journey, they will assess whether the alternative mode can carry out their trip. Their perception of the bicycle's ability to adequately carry out a shopping or work trip is quite instructive. Secondly, they consider the trip's characteristics, such as whether the planned route has preferential bicycle lanes or favourable climatic conditions. Routes with preferential treatment can encourage bicycle use because they offer cyclists more comfort and safety, while good weather conditions do not discourage the city dweller from using alternative transport modes. Finally, the third condition considers the characteristics of the destination. Factors include accessibility to a given location, facilities such as bicycle racks, and the risk of theft or depredation (FHWA, 1992).

These conditions cover several factors that individuals consider before starting their bike trip. The FHWA suggested categorising these factors into two groups: subjective and objective. Subjective factors relate to each individual's unique characteristics, which can only be identified by research with the target audience. Cultural perspective, physical condition, daily habits, appreciation of physical activities, and feeling safe in traffic are examples of subjective factors. The objective factors consider both the environmental characteristics of a given place (climate and relief) and the characteristics of the infrastructure (adequate infrastructure for bicycles). For Pezzuto and Sanches (2004), the factors presented by FHWA are 1) Subjective: Travel length; Traffic safety; Convenience; Travel cost; Value attributed to time; Valuing of physical exercise; Physical conditions; Family circumstances; Daily habits; Attitudes of social values; and Social acceptability. 2) Objective: Environmental characteristics (Climate and Topography); Infrastructure characteristics; Adequate bicycle infrastructure; Accessibility and continuity of routes; and Transport alternatives.

Other authors have a similar perspective to Sener *et al*. (2009) and classify the factors that influence bicycle use into three categories: 1) Demographic, such as age, sex, race, vehicle ownership, and family income; 2) Attitudes and perceptions, such as the perception of safety and protection, perception of time vs cost, and attitudes regarding the practice of physical activities; 3) Characteristics of the region, bicycle-related infrastructure and amenities, such as land use, environmental factors, the existence of parking lots, and the provision of showers and lockers in the workplace, among others. Wahlgren (2011) proposes organizing environmental, traffic, and social factors. The first set includes the cycle network, green areas, attractiveness, route, relief, stops, and distance. The second category covers factors that vary over time, such as pollution, noise, traffic flow, car speed, cyclist speed, and road congestion. The latter group comprises factors representing the relationship between pedestrians, drivers, and cyclists.

Rietveld and Daniel (2004) also believe that bicycle use is related to personal characteristics, such as income, age group, gender, and activity patterns, which can predict this choice. Local government initiatives, the quality of the bicycle network, and the general costs of other modes of transport directly influence what the authors call "widespread bicycle costs" (Figure 1). Rather than focusing only on monetary value, these costs consider diverse factors. Namely: 1) Travel time depends on the cities' spatial structure and the adequacy of the cycling infrastructure; 2) Physical capacity and comfort refer to the layout and quality of the roads destined for bicycle use, the user's physical fitness, and the relief and climatic conditions; 3) Road safety refers to the risk of being involved in accidents with motorized transport modes; 4) Risk of theft and robbery: results from the quality of the push-bike and the distance travelled on the routes, that is, the better the bicycle, the greater the probability of theft or robbery on longer and more frequent trips; 5) Monetary cost of the bicycle includes the costs of acquisition, maintenance, and parking. The "widespread costs of motorized modes of transport" are noteworthy as the difference between the costs will influence whether the bicycle is used.
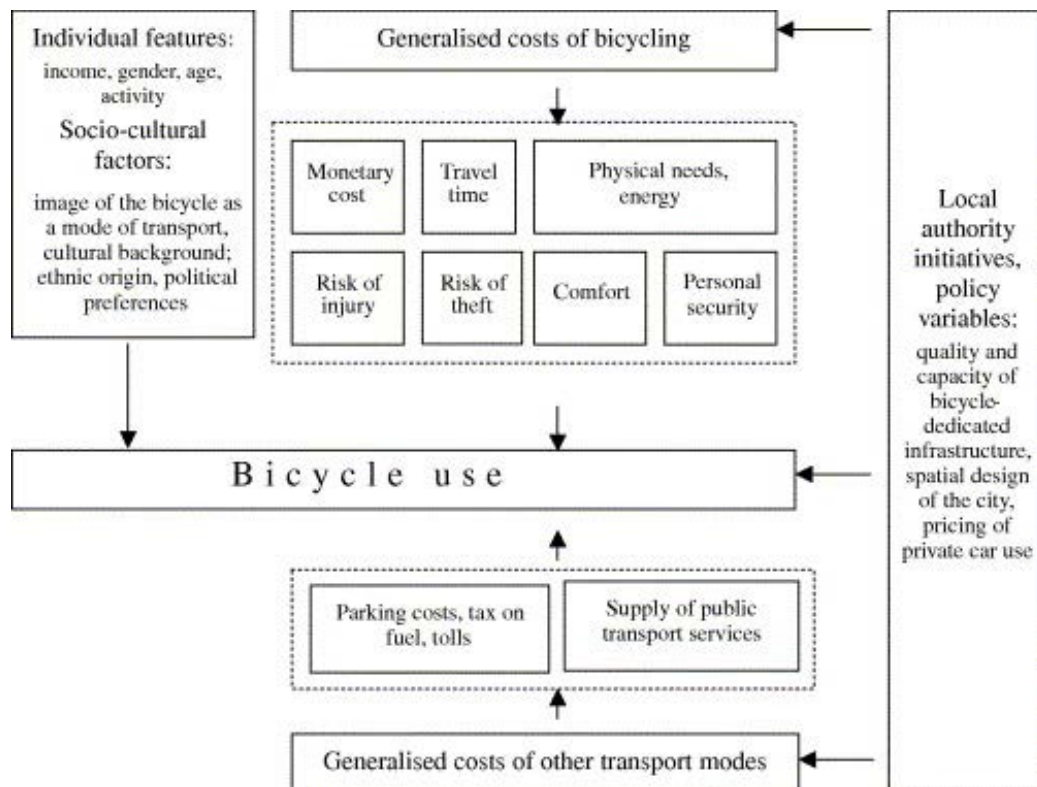
Figure 1 | General picture of the factors and variables that influence bicycle use

Source: Extracted from Rietveld and Daniel (2004).

Table 1 shows the primary factors and variables used to characterise cyclability in the cities analysed by Rietveld and Daniel (2004). Their results indicate that in cities with high population density, the contribution of bicycle trips to the total number of trips is reduced by more than 8%. Similarly, in places with a proportionally larger young population, bicycle use increases by 4%. On the other hand, increased participation of voters of the Liberal Party is associated with less cycle travel. In locations with higher education and vocational training, there is an increase of 7.4%. In a hilly city, the reduction in bicycle use can reach 74%. An additional car per capita reduces the share of travel by 26%. Politically speaking, the index shows a positive correlation between local government initiatives and bicycle use. The final two factors related to the outcomes of implemented local policy show that bicycle use is reduced by 0.05% when there is a gain of one percentage point of people dissatisfied.

Table 1 | Cyclability analysis factors and variables in cities in the Netherlands

Factors	Variables
Characteristics of the city	Demographic density
	Concentration of human activities
	Proportion of young people
	Presence of university and technical school
	Proportion of Liberal Party voters
	Proportion of foreigners
	Income increases of the population.
	Number of cars per capita
	Terrain
Political Efforts	Bicycle infrastructure
	Frequency of stops at intersections
	Availability and parking costs
	Frequency of obstacles
	Pavement quality
	Speed (percentage of rides where the bike is faster than the car)
Political consequences	Security Level
	Degree of satisfaction

Source: Adapted from Rietveld and Daniel (2004).

Other studies on the relationship between factors/variables and bicycle use have similar results to Rietveld and Daniel (2004). Ashley and Banister (1989), Axhausen and Smith (1986), Forester (1993), Lott *et al*. (1977), Ortuzar *et al*. (2000), Pucher and Buehler (2008), and Sorton and Walsh (1994) state that motor vehicle ownership, income, the presence of higher education facilities, user age, distance and duration of travel, topography, and cycling infrastructure are factors that undoubtedly affect bicycle use in urban areas. Although less frequent than European studies, research in Brazil on bicycle use and the assessment of cyclability also raise factors that may or may not encourage their use. Prodivelo and Sanches' (2010) research aimed to identify the factors that determine the choice of this mode of transport and evaluate individuals' perceptions of cycling. To this end, they applied an attitude survey to 447 cyclists and non-cyclists in the cities of São Carlos, Rio Claro, and São Paulo.

The analysis of this survey indicates that the factors with the most significant positive response among the interviewees are those that establish cycling as a cheap and healthy form of transport. Regarding the limitations of bicycle use, 67% of the interviewees stated that they would cycle more often if there were more bicycle infrastructure. Lack of security was considered an impediment by 56% of respondents. César (2014), for example, interviewed 2,925 people from all over Brazil to assess the cyclability of Brazilian cities. In the questionnaire, cyclists evaluated the following factors: relief, climate, physical barriers, city size and diversity of land use, pollution, integration with public transport, road conditions, security, personal safety, continuity of cycling infrastructure, linearity, safety and comfort, local culture, and urban mobility management.

2.2 MODELS AND METHODS FOR ASSESSING URBAN CYCLABILITY

Three main models/methods are used to analyse urban cyclability. The first is based on Bicycle Suitability, the second is estimated by cyclists' behaviour and the Spatial Syntax, and the last uses Multicriteria Analysis. In bicycle suitability models, several attributes of a given linear section of road receive a certain number of points combined to calculate a score qualifying the segment in a spectrum

from desirable to undesirable. Thus, it is possible to determine the most suitable bicycle routes. The models are generally distinguished by the attributes selected, the points system, and their distribution. Notably, each model's authors provided theoretical and empirical findings that support the associated values and indicate the inclusion or exclusion of specific attributes.

Bicycle suitability models are applied according to the levels of tension, suitability, and capacity of roads. According to Turner *et al*. (1997), the level of tension is a simple concept that incorporates the three most intuitive stress factors experienced by cyclists in urban traffic, namely: traffic volume, lane width, and motor vehicle speed. In this regard, Sorton and Walsh (1994) argue that cyclists avoid certain places in a city, for example, to escape the harassment of heavy traffic and the unease of travelling on narrow streets with a large volume of motor vehicles. Thus, Sorton and Walsh developed a model using the Bicycle Stress Level (BSL) metric, quantifying this stress in urban and suburban streets in Madison, Wisconsin, USA. The BSL is applied by dividing the streets into segments according to their intersections and then stipulating the criteria to quantify the three factors individually. The follow-ups are classified after the values have been entered (SORTON; WALSH, 1994).

The level of road adequacy is determined by a more varied range of models that consider traffic volume, the width of the carriageway, the speed limit for motor vehicles, the condition of the paving, and the location of the cycling infrastructure as characteristics making roads more or less suitable for bicycle use. As pointed out by Turner *et al*. (1997), these models have the advantage of limited input variables but do not incorporate hypothetical factors that could affect the use of bicycles. In this regard, Davis (1987) developed the Bicycle Safety Index Rating (BSIR) to provide a mathematical model that indexes the stipulated safety values to the roads' physical characteristics. The BSIR comprises the Road Segment Index (RSI), which evaluates individual segments of the roads, and the Intersection Evaluation Index (IEI), which examines intersections between road sections. The indexes use the following input variables: Average daily traffic volume per lane; Speed limit of motorised vehicles; Lane width; Paving factor (pavement condition or presence of drainage utility holes); Location factor (parking and conversion lanes, gradient, declivity, continuity of cycling paths and adjacent land use); and Signaling/intersections. Another metric used to determine road suitability is the Interaction Hazard Score (IHS), developed by Landis (1994) to assess the suitability of roads for cycling in American urban areas such as Birmingham, Alabama. Like the BSIR, the IHS also uses factors related to cyclist safety; however, it unifies all the factors in a single general indicator. Landis developed questionnaires based on cyclists' perceptions to adjust the values and calibrate the models. In addition to the factors BSIR uses, the HIS includes the volume of heavy vehicles.

The metric used to measure track capacity is the Bicycle Level of Service (Blos), which Lowry (2012) views as the most current and frequent analysis. Studies such as those by Dowling (2008), Gholamialam and Matisziw (2019), Grigory (2018), Manum *et al*. (2017), and Szyszkowicz (2018) use or mention Botma (1995) and Dixon's (1996) Blos. The Blos is considered state-of-the-art in assessing cyclability and was developed to complement the Highway Capacity Manual (HCM) or Road Capacity Manual for non-motorized travel (LOWRY, 2012). Lowry (2012) also proposes that the Blos' calculation weighs ten factors that influence bicycle use: 1) the width of the road for motor vehicles; 2) width of cycle paths; 3) width of cycle lanes; 4) proportion of parking lots for motor vehicles; 5) volume of traffic; 6) speed of vehicles; 7) the percentage of heavy vehicles; 8) paving condition; 9) presence of obstacles; and 10) proportion of roads with preferential treatment for bicycles. These factors are combined in a nonlinear equation designed to produce a numerical score representing cyclists' perceptions of comfort and safety.

Despite showing some functionality in their research context, the models presented have significant deficiencies. The metrics do not consider attributes unrelated to road infrastructure, such as topography, landscape quality, and demographics. According to Tralhão and Ribeiro (2014), cyclists deviate from the shortest route mainly to avoid areas of rugged relief. Secondly, as previously stated, metrics such as Blos can only be applied on routes with preferential bicycle treatment. Finally, the methods were developed

in the USA, which raises uncertainties about their applicability to Belo Horizonte. Unlike the proposals based on classical methods, models estimated by cyclists' behaviour and Spatial Syntax provide alternative techniques that are also effective in evaluating cyclability. Cyclability can also be measured and evaluated based on the geometric characteristics of urban space, such as road linearity and the angles between intersections. When related to cyclability or walkability, spatial syntax can be very helpful. Pereira *et al*. (2011) suggest that since urban configuration spatially affects the displacement pattern of people and vehicles through the city, it is possible to predict which roads will be used the most. Manum *et al*. (2017) and Nordström and Manum (2015) applied spatial syntax to model the cyclability of Oslo, Norway, and Gothenburg, Sweden, demonstrating that the angular minimisation of intersections is essential for route choice. According to the authors, in addition to intersections, the number of stops (signalling) and relief most influenced the speed and time of bicycle trips.

Multicriteria Analysis models have also proved to be appropriate in delineating cyclable roads and routes, as highlighted by Carvalho (2016), Gholamialam and Matiszaw (2019), Rybarczyk and Wu (2010) and Silva (2014). Satisfactory results in its application in urban mobility planning is a factor that has weighed heavily in its selection. One advantage of multicriteria analysis is that it can be easily associated with a GIS. In this regard, Malczewski (2006) justifies that although GISs and multicriteria decision methods are two distinct research areas, urban planning problems can benefit from combining their techniques and procedures. Compared to other methods, multicriteria analysis is also advantageous as it does not distinguish the data's origin, whether an in-loco primary source or secondary information from government management bodies. It is noteworthy that secondary data fully supports the methodology proposed in this research, guaranteeing its remote applicability without sending an investigative team to the field. This method was selected after analyzing the options.

It is essential to highlight that multicriteria analysis is a mathematical method that allows different alternatives (or scenarios) to be compared to direct decision-makers to a weighted choice, as Jordão and Pereira (2006) pointed out. It is not a coincidence that its use is expanding in environmental quality, sustainability, and transport planning studies (SILVA, 2014). According to Gonçalves (2007), multicriteria analysis can be performed in the GIS environment using one of the two procedures listed below. 1) Boolean overlap: the restrictive criteria are supported by classification methodologies called Boolean computer science (true, false, binary, or bivalent). In this case, there is no weighting of the inputs by their level of importance; 2) Fuzzy logic: the values of the variables' logical criteria can be any real number between 0, corresponding to the false value, and 1, corresponding to the true value. The values can also arise from applying weights to obtain a weighted average; thus, subjective decision-making decreases and is commonly used to standardise certain factors (FOLLETO, 2016; NUNES, 2018)
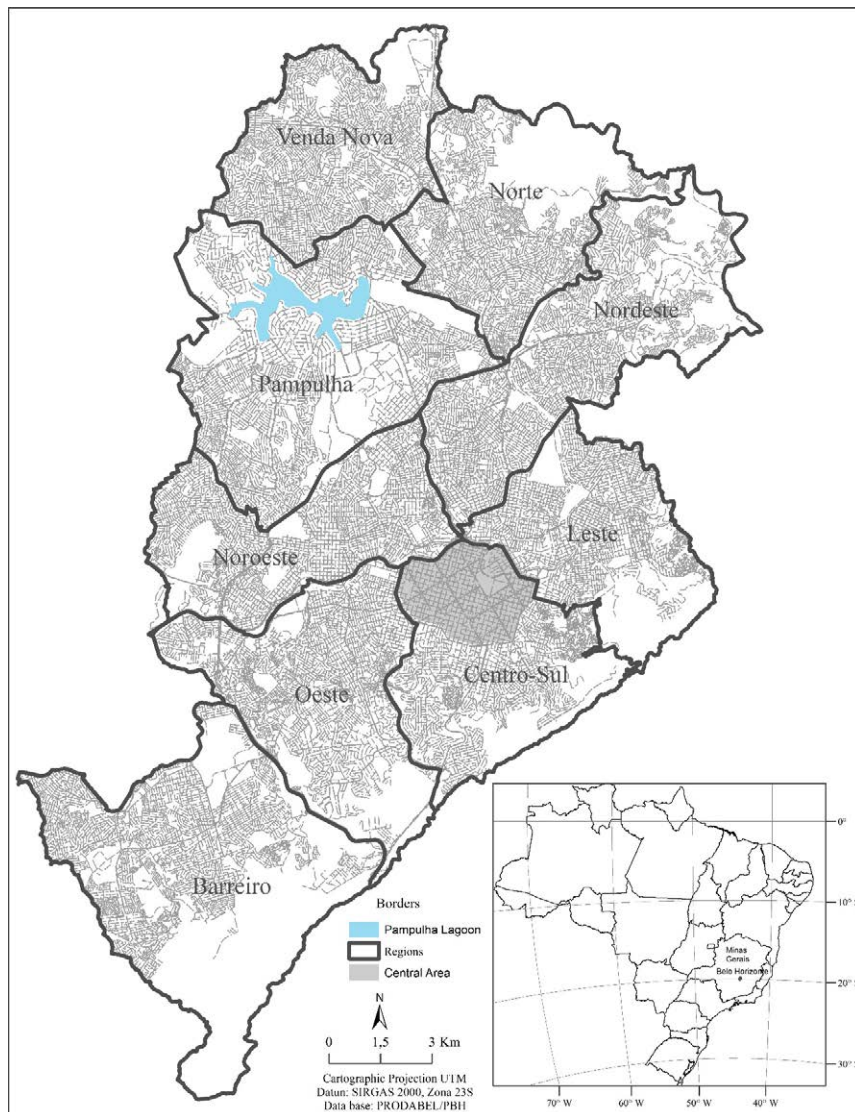
3 METHODOLOGICAL PROCEDURES USED: SPATIAL UNITS, VARIABLES, AND PROPOSED INDICATORS

Given this study's purposes, the urban roads of Belo Horizonte, in the central portion of the state of Minas Gerais/Brazil, were used as spatial analysis units (Figure 2) based on the vector base of the municipal road network, created and updated by the Belo Horizonte City Hall's Data Processing Company (Prodabel/PBH). In total, this network is approximately 4,962.5 km long, represented by 52,178 georeferenced vectors, which represent spatial analysis units organised in a database with their respective non-graphical attributes (values in each variable), distributed according to Belo Horizonte's ten Administrative Regions, as shown in Figure 2. The methodological procedures used can be divided into three main stages: 1) variable selection, 2) measurement weighting, and 3) proposition of indicators (disaggregated and the ICV), as depicted in Figure 3. In addition to processing and treating data, the first stage involved the selection of the variables used in this proposal based on the literature review. The selected variables were classified according to the following factors: 1) those concerning the road's general characteristics (Road System); 2) those that identify the presence and characteristics of bicycle infrastructure (Road Infrastructure); and 3) those that characterise the environment where the road

is inserted (Environment). As the subject has no legal or technical normative aspects, variables were selected based on the reflections in the consulted bibliography. The availability of secondary data for analysis was considered since there was no data production by direct research or fieldwork. Seven variables consistent with the local reality were selected to compose the proposed methodology and in line with data availability. It is important to emphasise that data availability for secondary analysis tends to be one of the main limiting aspects of selecting variables.

The variables were weighed using factors obtained through the Delphi Method, a prediction technique designed to provide advanced knowledge of the probability of future events, using the request and systematic collection of expert opinions on a given subject. According to Wright and Giovinazzo (2000), it was initially developed in the 1950s by Rand Corporation/USA to obtain specialist consensus on technological forecasts. In general, the Delphi Method can be defined as an interactive activity designed to bring together the opinions of a group of experts to obtain consensus. It is based on a group communication process to allow individuals to deal with and explore complex problems. In addition to seeking consensus, studies based on this method propose to predict the future based on collecting qualitative/quantitative information based on the knowledge of a specific group of individuals specialised in the topic in question.

Figure 2 | Road network of Belo Horizonte/Minas Gerais/Brazil
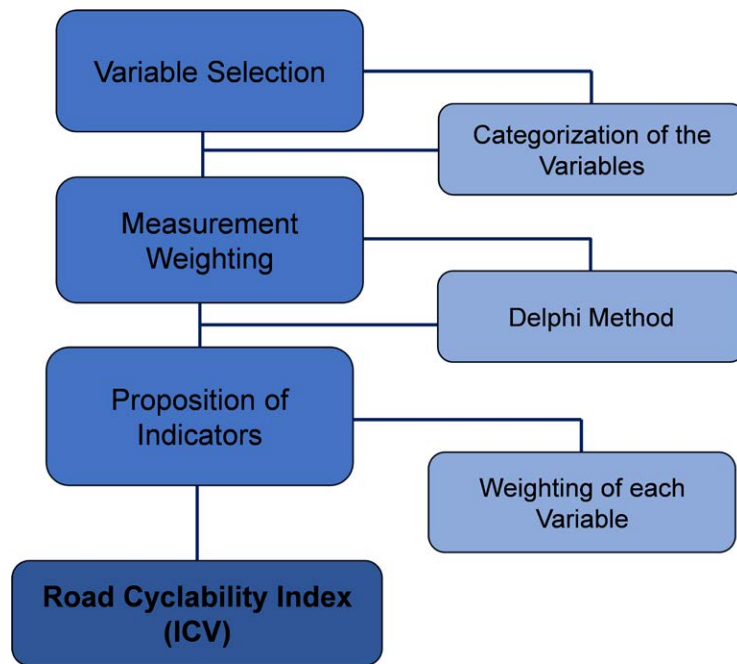
Source: Prodabel/PBH cartographic base (2020).

Figure 3 | Methodological Procedures

Source: não tem no documento

In this research, the Delphi method was used to support the definition of the weighting coefficients of the manipulated variables, thus applying the method to obtain coefficients/weights based on the choice of a multidisciplinary group of specialists who are cognizant of the phenomenon and the spatial reality where it is located. Given the established purposes, the selection of specialists aims at a multidisciplinary group with knowledge of the study area for a combined assessment of the road cyclability factors. Those involved represent the municipal public administration, university professors specialising in urban mobility and transport, Ph.D. students in transport, and private sector analysts focused on urban planning. The analysis of the experts' evaluations verified that the variables with the highest scores match those most relevant in the literature analysed. For example, the "Preferential treatment for bicycles" variable concentrated most evaluations in scores 9 and 10. Next was the variable "Efficiency of public lighting," whose evaluation average scored 8.5.

After three rounds of assigning scores, disaggregated and aggregated indicators were proposed, resulting from the combined factors' scores. Equation 1 represents the operation.

$$P = \frac{A}{\mu} \qquad\qquad \text{Equation 1}$$

wherein:

P = Weighting of each Variable;

A= Evaluation

μ= Average of the evaluations of all factors.

Table 2 shows the results of the importance coefficients of the variables, which served as the basis for the proposed Road Cyclability Index (ICV). It is an aggregate indicator that summarises the performance of all factors and variables. The sum of the scores of the attributes of the pathways was given, whose weights were fixed by the Delphi Method (Equation 2). Overall, the road segments with the highest results have the best conditions for bicycle use. However, the adequacy and distribution of these

results into classes, understood here as "Very Low," "Low," "High," and "Very High" cyclability, required the use of a specific classification method.

$$ICV = \sum_{n=1}^{7}(D_n P_n)^2 \qquad\qquad \text{Equation 2}$$

where:

ICV= Road Cyclability Index;

D= Performance of track attributes;

P= Weighting in each Variable.

A quantiles classification method was used to the detriment of an arbitrary categorisation for mapping purposes. This method creates intervals to equate the distribution, organising them into classes with similar frequencies. As four classes were opted for, the distribution is approximately 25% per class to ensure that each class interval has approximately the same number of values and that the change between the intervals is reasonably consistent. The variables were also classified according to their level of performance for a disaggregated analysis. There are two ways to establish these levels. The first, configuring variables with non-Boolean attributes, inputs performance levels based on a grade or concept. The higher this grade or concept, the better the attribute's performance in the reality in question. The second method arranges the variables with Boolean attributes. In line with the characteristics of a cyclability study, the attribution of performance levels to Boolean attributes starts from the condition of "adequate" or "inadequate." As each factor has specific features closely associated with the reality in which the attribute is inserted, each variable should be evaluated individually to ensure that it receives the most appropriate treatment when assigning performance levels. Thus, the definition of the score varies according to how each attribute relates to the analysed space. In this research, the performance level of each variable varies from 0 (inadequate), 1 (partially adequate), 2 (adequate), and 3 (ideal), as detailed in Figure 4, which discriminates according to the selected factor[2].

Table 2 | Weighting coefficients of the variables used – Delphi method

Factors	Variables	Coefficient
Road System	Typology (V1)	1,026
	Width (V2)	0.939
	Paving (V3)	0.927
Road Infrastructure	Preferred treatment (V4)	1.310
	Hierarchy (V5)	1.242
	Lighting efficiency (V6)	1,156
Environment	Longitudinal slope (V7)	1.001

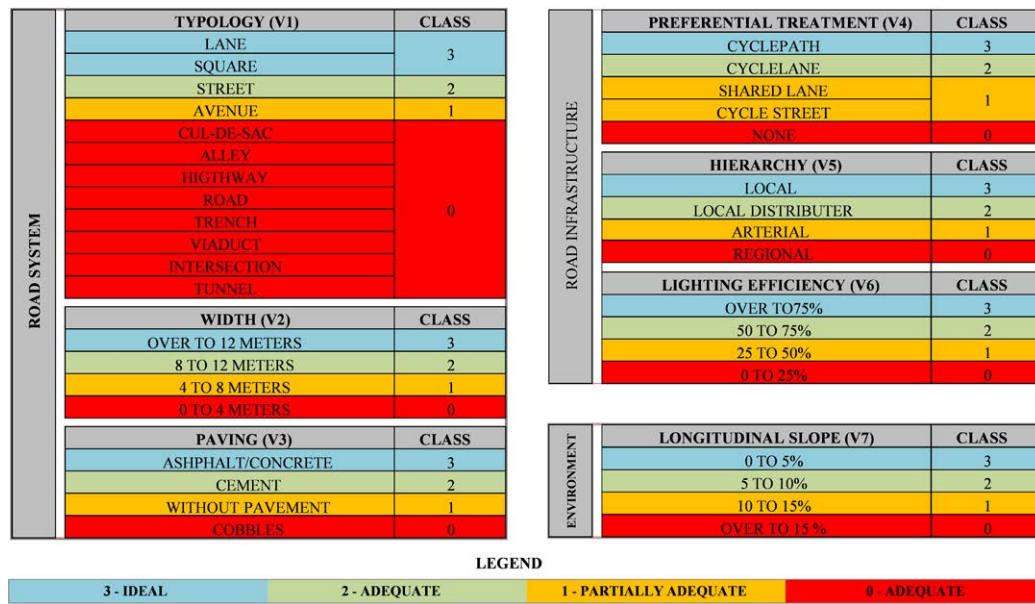*Source: Developed by the author.*

Figure 4 | Categorization of the variables used, according to selected factors and performance level

Source: Developed by the author.

# 4 CYCLABILITY LEVELS IN BELO HORIZONTE/MG: DESCRIPTION AND ANALYSIS OF THE RESULTS

Notably, there is no clearly defined spatial pattern in Belo Horizonte; thus, it was not possible to define contiguous areas intensely restrictive or appropriate to bicycles as a means of transport. However, as observed and inferred from Figure 5, roads with higher cyclability levels are prevalent in the Pampulha, Centro-Sul, and Venda Nova regions compared to other regions. It is no coincidence that these regions have the most extensive road networks with preferential bicycle treatment. It should also be noted that the Central-South and Pampulha Regions house the higher-income population (FONSECA *et al*., 2017), including higher construction standards, wider roads, and large areas for public leisure, such as the lagoon and public parks where people from around the city gather for physical/sports activities.

The logic of spatial distribution coincides with the different territory use patterns. The road segments with the lowest cycling potential are spatially associated with recently occupied areas, such as the most peripheral areas of the North and Northeast regions. Furthermore, this also applies to sections with steeper inclines, such as those in the south/southeast portion of the municipality, bordered by the Serra do Curral uplands. The precariousness of the available physical infrastructure is striking in the areas associated with shantytowns and favelas. There is a lack of pathways with the higher performance levels required for cyclability. Frequently, routes are hilly alleys, many lacking good paving and efficient public services, such as lighting.

Although roads with preferential treatment for bicycles are expected to have a higher level of cyclability, the proposed methodology revealed several examples of roads with cycling infrastructure where this was not the case. Even though the conditions for bicycle use as a mode of transport are not limited to the available cycling infrastructure, it is clear that the proper implementation of a bicycle transport infrastructure is not inconsequential and directly results in an increase in the perception of comfort and safety for cyclists. However, an inadequate implementation may imply a failure to fulfil the potential to stimulate suitable bicycle transport. Viola *et al*. (2019) use the logistic regression statistical method to propose a model to estimate the potential use of bicycles as a means of transportation in Belo Horizonte. In general, the results, particularly in the city's central region, confirmed the possibilities of

bicycle usage and indicated the positive potential for migration from other modes of transportation, especially motorised individual modes.
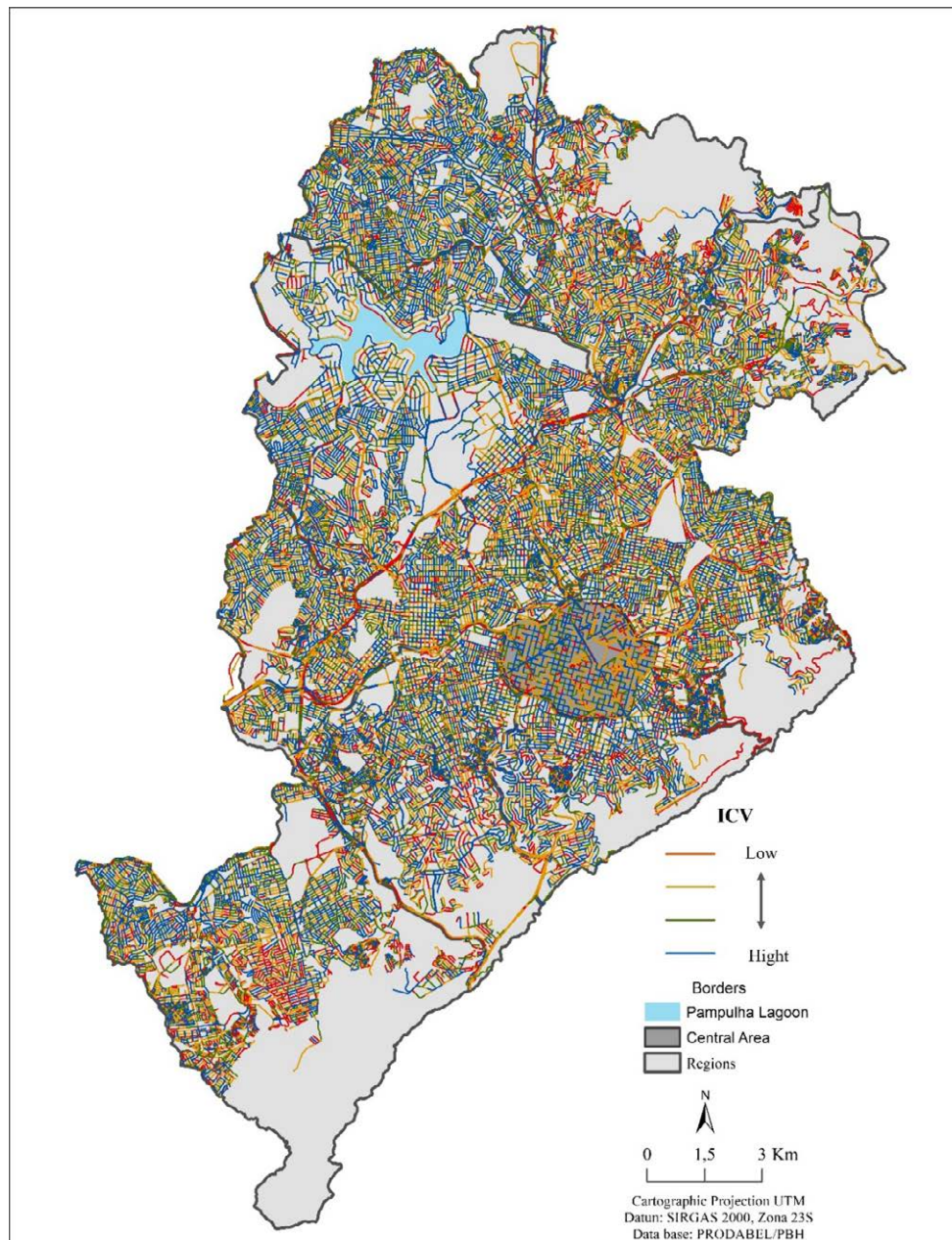

Figure 5 | Road Cyclability Index in the municipality of Belo Horizonte/MG

Source: Developed by the author.

A disaggregated analysis of the results, broken down according to the performance level of each variable (Figure 6), indicates a more favourable situation for bicycle use in the variables road paving (V3) and lighting efficiency (V6). The ideal pathway condition for these two variables corresponded to 89.6% and 85.6%, respectively. The high scores in the variables hierarchy (V5) and road slope (V7) are also noteworthy. In both, the roads' cyclability level exceeds 70%. Declivity also merits highlighting since the myth that the city is unsuitable for cycling is still common, given the supposed prevalence of very steep roads, which does not represent reality. The level of suitability is only reduced in the eastern portions of the Central-South and Eastern Regions, where the Serra da Curral's escarpments form more significant obstacles to bicycle use. The results are less favourable when the preferential treatment

variable (V4) distribution is observed. In this case, 98.1% of the routes were considered inadequate. By superimposing the vectors referring to those routes considered adequate/ideal on the preferential treatment network (bicycle paths/bicycle lanes) in Belo Horizonte, it is possible to identify possible lines of expansion/integration for cycling. In principle, these areas should be considered priorities for public infrastructure investment.
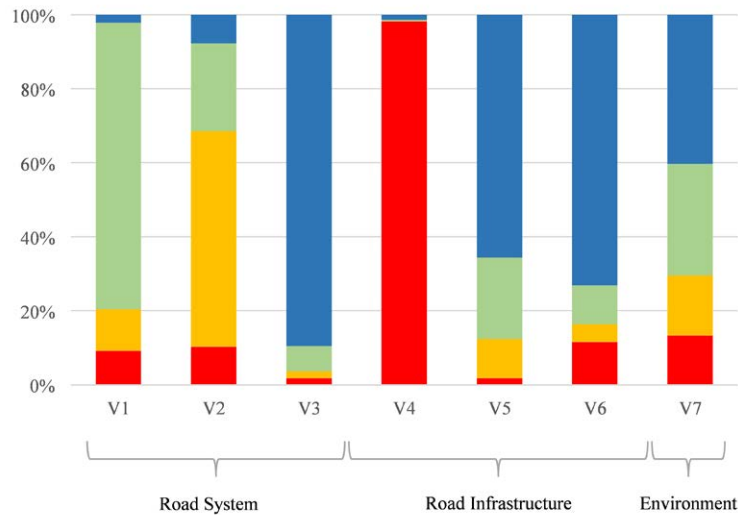
Performane Level (km)				
Variáveis	Inadequado	Parcialmente Adequado	Adequado	Ideal
V1	4.805	5.839	40.431	1.109
V2	5.336	30.435	12.397	4.016
V3	960	941	3.535	46.748
V4	51.210	34	239	701
V5	954	5.503	11.504	34.223
V6	6.027	2.521	5.465	38.171
V7	6.948	8.487	15.725	21.024

Figure 6 | Distribution by Road Cyclability Index variables in the municipality of Belo Horizonte/MG

Source: Developed by the author.
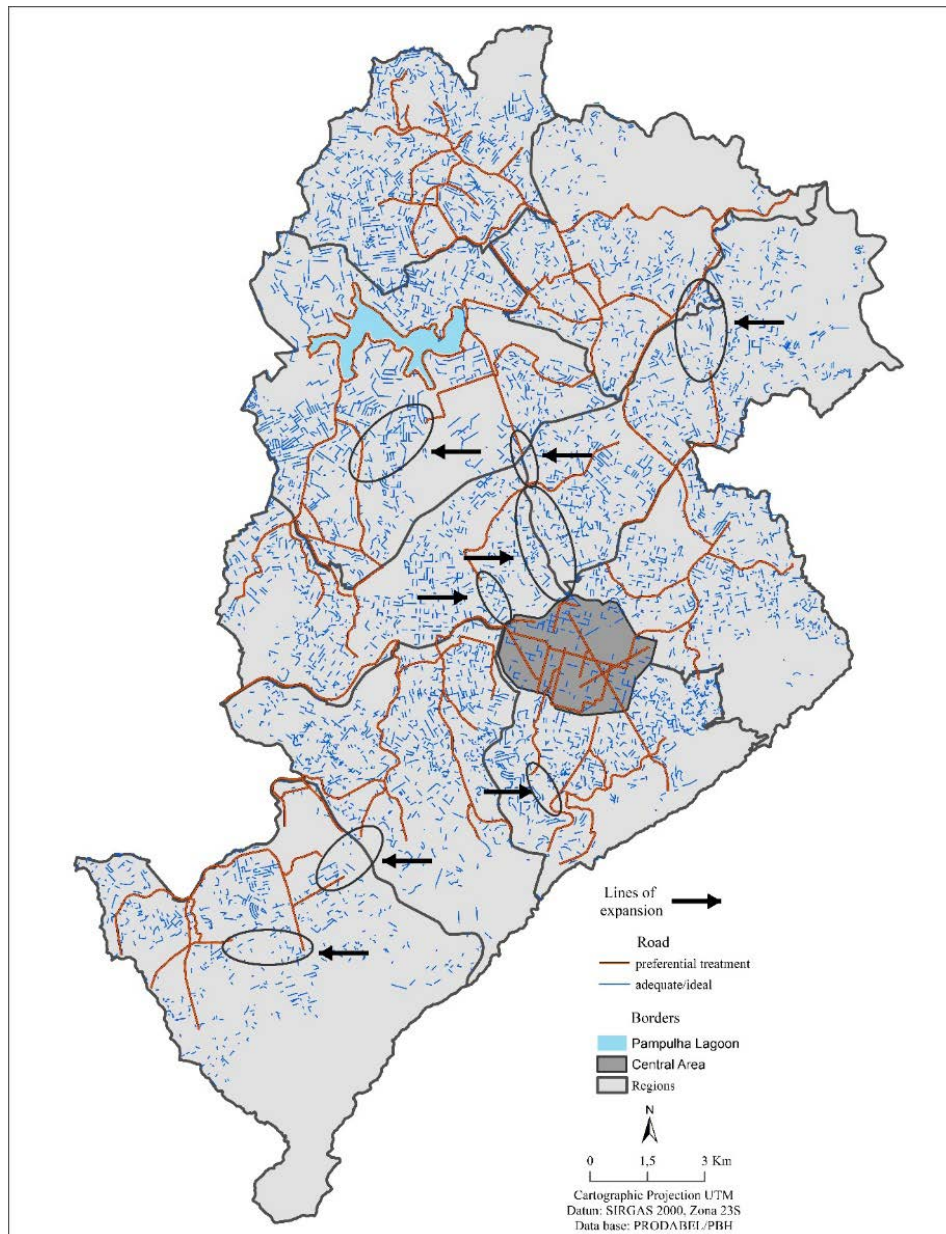
Figure 7 | Road Cyclability Index in the municipality of Belo Horizonte/MG

Source: Developed by the author.

5 FINAL CONSIDERATIONS

After establishing a methodological approach inherent to its purpose, this study estimated the road cyclability level in Belo Horizonte and offered parameters capable of supporting the design of sustainable public transport policies. As it is based on active systems, it applies to the reality of other large Brazilian cities, marked by the high concentration of individual motorised transport. Further theoretical and conceptual progress is required, as this contribution reinforces the need for alternatives to the monolithic view of the city of automobiles and vehicle flow. As described throughout the work, cyclability is an underexplored and relatively recent academic concept. In Brazil, studies of active transportation directly associated with mobility and sustainable accessibility are still infrequent. Thus, this work proposes techniques and methodologies offering cyclability indicators that foster a broader discussion on improving public urban management and planning policies and inducing increasingly sustainable urban mobility.

Overall, the results suggest that a significant portion of the roads in Belo Horizonte (approximately 44.3% of the road extension) have good levels of cyclability. This data contradicts the common-sense view that, given its topography and climate, the municipality is unsuitable for using bicycles as a mode of transport. Belo Horizonte has a very underutilised high cyclable potential, especially if there is an investment in expanding the exclusive/preferred road infrastructure, which is still very incipient in its urban fabric. Moreover, a brief comparison of the spatial distribution of the results shows a substantial imbalance in the availability of accessible cycling systems, with an intense concentration in the Pampulha, Centro-Sul, and Venda Nova regions. On the other hand, the eastern and northern regions had the lowest CVI levels. These units are spatially associated with areas of recent occupation, such as the most peripheral areas of the North region, and areas of steep longitudinal slopes, such as in the East. The results also indicate that the inadequate deployment of cycling infrastructure may result from the failure to exploit the potential to promote adequate bicycle transport. The roads with cycling infrastructure with the most favourable performance levels are enlightening examples.

Even with reservations and careful interpretation, the results and the methodology proposed through the indicators presented can support municipal governments and bodies linked to public transport policies, which have recently tried to increase municipal bicycle use. The cycling routes in Belo Horizonte mentioned above result from these efforts (BELO HORIZONTE, 2018). They are a set of actions under the responsibility of the municipal administration, aiming to meet the aspirations of cyclist organisations and manage the demand for bicycle transportation by creating attractive routes for cycling. Thus, a tool capable of measuring road cyclability levels is an essential input in the execution of the project. At the same time, using indicators that assess the level of cyclability can foster the appropriate targeting of public investments to priority areas and routes, manage demand to increase the number of trips, and establish a balance in the amount of travel generated by modes of transport.

Other paths for future research on cyclability can be recommended, such as studies investigating whether the cyclable routes proposed and implemented by municipal authorities align with local cyclability. Furthermore, other analyses based on primary data, such as ODS 2002 and 2012, would enable confrontations validating the results achieved here. An example could be the simulation of routes from the origins and destinations of trips by the mode in question. In reality, every motorised journey starts with an active mode of transport, such as walking and potentially cycling. Thus, research that helps to encourage bicycle use associated with motorised modes of transport is essential for the understanding and diffusion of bicycles as an effective mode of transport.

NOTES

1| This article is a result of the master's thesis "The Bicycle and Urban Mobility: the effects of the diffusion of the cycle path network on bicycle commuting in Belo Horizonte/MG," defended within the scope of the Graduate Program in Analysis and Modeling of Environmental Systems at IGC/UFMG

2| It is noteworthy that the method used to evaluate performance can be based on interpretations with a certain degree of arbitrariness. However, when recognized in the cited literature, the interpretations suggest the norms/standards used in the aforementioned reference works.

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