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Bicycle parking allocation and its equity implications: The case of Bogota, Colombia

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ABSTRACT

Bicycles are a sustainable alternative for urban mobility; however, their usage depends mainly on safety, convenience, and infrastructure availability, which have been widely studied. However, most studies have overlooked the importance of bicycle parking facilities in the network-planning process. In this work we aim to draw attention to the importance of including bicycle parking (BP) facilities in a well-thought-out bicycle infrastructure planning process highlighting the detrimental effects of not doing so for transportation equity, using Bogotá, Colombia, as a case study, where bicycle trips have multiplied in the last few years, reaching a 6.6 % modal share in 2019. To this end, we present a geospatial analysis and machine learning approach to assess the network coverage of bicycle parking spots. Additionally, we compared the city's bicycle trip patterns and applied a survey to know the perception of users (n = 397). The results show that the current distribution of bicycle parking in the city does not favour equity, given that it is not in line with the origin and destination of bicycle trips. This could widen socio-territorial inequity by affecting accessibility to bicycle use for daily commutes. To the best of our knowledge, this study presents the first assessment of the impact of parking distribution on the planning of bicycle infrastructure in the Global South.

1. Introduction

Cycling has been promoted as an excellent transportation mode because of its several benefits to the environment, health, and decongestion of roads. However, concerns regarding equity in bicycle infrastructure distribution have arisen, given that most infrastructure investment is still allocated to private cars, without considering or prioritising sustainable infrastructure modes (Arellana et al., 2020; Gössling, 2016).

A lack of bicycle infrastructure can deter individuals from cycling. Research has demonstrated a direct correlation between the availability of cycling infrastructure and an increase in cycling demand (Félix et al., 2020), with cycle lane availability and design being key factors studied (Buehler and Pucher, 2012; Dill and Gliebe, 2008; Dill and Voros, 2007; Krizek et al., 2007; Moudon et al., 2005). However, cycle lanes alone have been found to be insufficient in encouraging bicycle use (Dill and Carr, 2003). Other infrastructure-related factors, such as bicycle parking availability (Heinen and Buehler, 2019; Wardman et al., 2007) should also be considered as they impact both current and potential cyclists, which is often overlooked in practical application.

Numerous urban planning challenges have arisen due to the increasing popularity of bicycles, such as the scarcity of parking spaces in London in 2015 and the need for commuters in the United States to bring their bicycles to work (Van der Spek and Scheltema, 2015). To address this issue, cities like Philadelphia, United States, and Edmonton, Canada, have increased the availability of bicycle parking facilities (Hunt and Abraham, 2007; Noland and Kunreuther, 1995). Scholars have emphasized the importance of bicycle parking availability in influencing commuters' decisions to use bicycles as a mode of transportation (Epperson, 1994; Hull and O'Holleran, 2014; Noland and Kunreuther, 1995; Pucher and Buehler, 2008). Additionally, the strategic placement of bicycle parks can encourage or discourage cycling by shaping travel patterns (Heinen and Buehler, 2019).

Providing sufficient BP is crucial to ensure accessibility for all population sectors, as inadequate transportation services can lead to inequity and socio-economic exclusion (Blanco et al., 2014). Improving

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accessibility for poor individuals, who often rely on transit and other affordable modes, should be a priority to promote transportation equity (Pereira et al., 2019). Enhancing bicycle parking availability can help achieve this goal by increasing the number of cyclists (Yuan et al., 2017).

In the global south, there is a lack of studies on the correlation between BP infrastructure placement and its impact on transportation equity. This is noteworthy considering that the risk of damage and theft, stemming from inadequate or nonexistent parking infrastructure, is among the factors influencing bicycle commuting decisions in this region (Castillo-Manzano et al., 2015; Chen et al., 2018; Marqués et al., 2015; Márquez and Soto, 2021).

Bogotá, the capital of Colombia, has earned acclaim for its substantial investment in bicycle infrastructure over the past decade, resulting in a doubling of the bicycle modal share within five years. This underscores the potential significance of BP facilities in users' bicycle choices, particularly for those relying solely on bicycles for transportation or unable to afford replacements in case of theft, which could impede their access to opportunities.

In this study, we evaluated the spatial distribution of BP facilities in Bogotá to gauge their efficacy in supporting the cycling network. Subsequently, we juxtaposed this assessment with origin-destination matrices of bicycle trips to ascertain alignment with riders' travel patterns. We hypothesize that there exists inequity in the BP distribution of the city. Our objective is to underscore the necessity of integrating BP facilities into comprehensive bicycle infrastructure planning while elucidating the adverse consequences of failing to do so for transportation equity.

This paper is structured as follows. Section 2 reviews the literature related to the problem under study. Section 3 presents a contextualization for the case study. Section 4 describes the methodology applied. Results and discussion are presented in Section 5. Finally, concluding remarks are presented in Section 6.

2. Literature review

2.1. Bike parking, cycling, and equity

Cycling facilities have been proven to have a relationship with promoting cycling behaviours (Félix et al., 2019; Yang et al., 2019). Cyclists who have access to parking facilities use their bicycles more frequently than those without (Codina et al., 2022; Hamre and Buehler, 2014). In terms of integration with public transportation and multi-stage trips including public transit services, users prefer bike parking facilities located near transit stations (Arbis et al., 2016). The closer the distance between the parking space and the station, the more desirable it is. Parking facilities are also a significant determinant of Bike-Shared Systems usage frequency (Du et al., 2019).

Furthermore, research has demonstrated that access to parking facilities at educational institutions significantly contributes to the likelihood of selecting cycling as a mode of transportation (Kamargianni, 2015). Additionally, such facilities have been shown to encourage modal shifts towards cycling when travelling to commercial or leisure destinations, such as shopping centres (Cui et al., 2014).

The availability of amenities, such as showers and lockers, and the security of parking lots can impact users' preferences for bicycle parking spaces (Buehler, 2012; Hamre and Buehler, 2014; Heinen et al., 2013). Additionally, the provision of complimentary car parking and the cost of parking can affect usage (Molin and Maat, 2015; Van der Spek and Scheltema, 2015). These factors, along with the nature of the parking space (e.g. outdoor or indoor) (Arbis et al., 2016), are important considerations for decision-makers aiming to promote bicycle usage. It is crucial to provide strategically located and well-equipped facilities, with a focus on equity, to encourage more people to choose bicycles as a mode of transportation (Nadimi et al., 2023).

However, a noticeable disparity exists between the allocation of resources for bicycle planning and policies in urban centres and the consideration of equity issues (Cunha et al., 2023; Cunha and Silva, 2022). According to several studies, there is a pattern worldwide suggesting the uneven investment in bicycle infrastructure, favouring high-income/wealthiest areas (Braun et al., 2019; Brezina et al., 2022; Cunha and Silva, 2023, 2022; Flanagan et al., 2016; Mora et al., 2021).

In communities that are disadvantaged and lack essential infrastructure, such as cycle lanes and parking facilities, the tendency for bicycle usage tends to decrease (Barajas and Braun, 2021; Tortosa et al., 2021). Infrastructure resource allocation is a planning concern with significant governance implications (Alm and Koglin, 2022) that, if mistaken, may promote social barriers.

The availability and accessibility of transportation infrastructure strongly impact mode choice in Bogotá's bustling metropolitan area, with a predominant reliance on public transportation for daily commuting. However, this reliance can exacerbate inequity, particularly among low-income individuals facing high mobility costs (Tiznado-Aitken et al., 2023), further heightened by the significant bicycle usage within the lowest Socio-Economic Strata (SES) (Teunissen et al., 2015).

The performance and structure of the transportation system can either promote or hinder social equity, contingent on the ease with which individuals can access opportunities (Wismadi et al., 2014). This accessibility ultimately shapes the capacity of citizens to unlock their potential and attain a state of well-being (Cohen, 1990). Therefore, well-planned and conveniently located bicycle parking facilities are crucial for promoting cycling as a viable transport option (Brezina et al., 2022) and ensuring equitable access to transportation for all users.

To the best of our knowledge, our study is the first to assess the distribution of bicycle parking racks and its implication on transport equity in the Colombian context, and the Global South.

3. Case study

Bogotá has labelled itself "the bicycle capital of the world" because of infrastructure investments and public policy implementation in the last decade. It currently has 630 km of bicycle lanes, making it the city with the largest cycling infrastructure in Latin America (Ríos Flores et al., 2015), and is one of the ten most cyclist-friendly cities in the world (Mobility Secretary, 2019). Moreover, the municipality plans to continue expanding the cycle network. According to the Urban Development Institute (IDU) there will be an investment worth 800 billion Colombian pesos (approximately $160,000,000 US dollars) in cycling infrastructure in the following years (Bogotá gov, 2020).

However, the security issues in the city put the use of bicycles in danger. An average of 21 bikes are stolen daily, with Suba, Engativa, and Kennedy (middle to low-income areas but also with industry and commercial land use) accounting for 43 % of all thefts. As a result, the satisfaction of cyclists has decreased, falling from 85 % in 2017 to 62 % in 2018 (Bogotá cómo vamos, 2019). Nevertheless, according to a survey on the quality of Bogotá's public transportation, 50 % of respondents stated to be willing to use a bicycle for their first/last mile if there were BPs (Cámara de Comercio de Bogotá, 2009).

Regarding social inequity, Bogotá ranked first in Colombia in 2012 (Valencia, 2016) and fifth in Latin America in 2012 (Cómo vamos, 2012). The city's wealthiest areas have lower population density than vulnerable (low-income) areas, mostly located in the periphery (Guzman et al., 2017; Skinner, 2004). Higher population density areas have higher transportation needs, demanding more mobility services and infrastructure. In this study, we assessed the current location of BP, keeping in mind the city's documented social disparity, and analysed whether their distribution make the bicycle a convenient mode for commuting.

In Colombia, residential properties are categorised according to SES into six groups or strata: low-low, low, medium-low, medium, medium-high, and high (DANE, 2021). This classification is not based on household incomes but rather on the house's physical characteristics and the quality of the services in the area. However, it can work as a proxy for household income (Cantillo-García et al., 2019).

4. Methodology

This study employed a geographic and machine learning approach, utilizing geographic files of cycling infrastructure (cycle lanes/path network and parking lots), and supplementary information, including an origin-destination matrix for bicycle journeys on a typical day. Geographic information was utilized to discern spatial patterns in BP distribution, socio-economic strata, and travel patterns. A machine learning model was then employed to identify patterns in this distribution, supported by a quantitative approach. Additionally, a perception survey (n = 397) covering various topics relevant to bicycle usage and bike parking preferences was conducted. The study considered all types of BPs with official records available.

4.1. Data and spatial analysis

For our study, we used socioeconomic information, the distribution of the bike lane network in the city obtained from "Datos Abiertos Bogotá" (https://datosabiertos.bogota.gov.co/dataset), the existing bicycle network, and the existing BP in the city (regardless of its public or private nature of the latter), as well as the matrices of trip generation and attraction by bike provided in the 2019 Mobility Survey. The trip data used is from open access and was taken from the official site SIMUR (https://www.simur.gov.co/encuestas-de-movilidad). It belongs to the most recent Mobility Survey from the city to which we have access. The data do not specify the motive of the trip, the duration, socioeconomic information of the users, nor the origin of the trip; it rather presents aggregated data on the number of trips with a duration larger than 15 minutes, made to each TAZ on a typical day. Although we do not have access to the specifications of the models used to get these results, we rely on the quality and veracity of the information provided by the district of Bogotá.

It is worth noting that, in this context, "public bike parking" means "on-street parking", with no usage fee. Meanwhile, "private bike parking" refers to covered locations with safety (e.g., guards) with usage fee.

The BP are parking lots equipped with infrastructure for temporary bicycle parking, which can be located in off-street parking lots, Transmilenio system stations, meeting points managed by the Institute for Social Economy (IPES), libraries, and shopping centres.

On the other hand, the mobility survey provides a total of trips generated and attracted per day for each Transportation Analysis Zone (TAZ). TAZs are zoning units typically used as part of the planning process in a classical transportation model, where the characteristics of a series of blocks are grouped or aggregated to simplify the analysis process. For our analysis, we used matrices of trip generation and attraction by bike for each TAZ. It is important to clarify that the 2019 Mobility Survey conducted a study that included zones "external" to the city; that is, neighbouring municipalities.

Furthermore, we integrated spatial information per block for Bogotá with the information for TAZ. Block information includes SES, which is not available for TAZ due to aggregation at the block level. We combined the available information for each block within each TAZ and determined the predominant SES in each TAZ based on the area of blocks belonging to each SES (the SES with the largest area in each TAZ). Subsequently, we assigned the dominant SES for each TAZ for use in our calculations. We followed a similar process to estimate the length of bicycle lanes per SES, by merging layers of the bicycle network and TAZ.

4.2. K – Means algorithm

As part of our analysis, we applied an unsupervised Machine Learning algorithm known as the K - means. This is a clustering algorithm that groups the data according to the pattern recognition among the observations (Yu et al., 2018). The model aims to minimize the following objective function:

$$\min J = \sum_{j=1}^{k} \sum_{i \in C_j} ||x_i - c_j||^2$$

where J is the objective function, xi refers to the i-th observation, cj is the center of the j-th cluster, Cj is the set of objects in the j-th cluster, and k represents the number of clusters (Govender and Sivakumar, 2020).

It is a simple algorithm that adds a centroid to each cluster iteratively (Likas et al., 2003) with the objective of minimizing the sum of the square of the Euclidean distance between the points and the centre of the nearest cluster (centroid) (Nie et al., 2023). In our case, the attributes under which we decided to group the data were the coordinates of each point. That is, we grouped the centroids of each TAZ and each BP based on their geographic location.

There are several performance metrics to evaluate the optimal number of clusters in the K – means algorithm. One of them is the Davies-Bouldin index. This indicator allows us to determine the optimal number of clusters when running the algorithm (Maulik and Bandyopadhyay, 2002) by comparing the clusters' similarity using Euclidean distance between points. The lowest value of the index indicates the optimal number of clusters.

4.3. Survey

A survey was conducted to evaluate user perceptions of various aspects related to BP in Bogotá. The questionnaire had 34 questions that delved into subjects such as bicycle ownership, the willingness to use new bike parking facilities, experiences of being a victim of bicycle theft (including theft of parts), and opinions on diverse criteria pertaining to bicycle parking facilities—specifically, safety, ease of parking, space optimization, and appearance, among other factors. Additionally, we inquired about commuting preferences and the willingness to walk from a BP location to their destination to obtain an overview and provide a conceptual insight on the matter. The survey targeted bicycle users, irrespective of their daily riding habits. Applied between June and July 2021, the survey was exclusively administered online due to the pandemic restrictions in place during that period.

Our final sample comprised 397 valid responses of which 55.2 % were from women and 44.8 % were from men. Table 1 presents the fundamental socioeconomic characteristics of the respondents.

Table 1
Socioeconomic profile of surveyed people.

Socioeconomic Strata						
	1	2	3	4	5	6
	1.30 %	16.10 %	50.40 %	23.40 %	6.80 %	2 %
Occupation						
Student	Employee	Self-employed	Homemaker	Retired	Unemployed	Other
44.80 %	33 %	10.10 %	2 %	4.50 %	3.80 %	1.80 %
Age group (years old)						
14–24	25 – 34	35 – 44	45–54	55–64	65–74	75–76
50.6 %	15.1 %	10.6 %	14.6 %	8.6 %	0.3 %	0.3 %

Most respondents (approximately 68 %) belonged to medium to low socio-economic strata. Regarding age distribution, half of the respondents fell within the 14–24 years old bracket, while 15.1 % were between 25 and 34 years old. Despite capturing information from various age groups, the sample exhibits a notable skew towards young adults and youths. Occupation-wise, 44.8 % were students, 33 % were employed, and 10.1 % were self-employed, with homemakers, retirees, and unemployed individuals forming a minority.

5. Results and discussion

We analysed the spatial distribution of the BP and found that they are mainly located in the northeast zone of the city, where medium to high socioeconomic strata is predominant. Beside the residential area, there are mixed land uses in the zone, such as commercial, educational, and government buildings and facilities. In the following sections we present the results of our spatial analysis, the machine learning approach used, and the survey applied.

5.1. Spatial analysis

The distribution of SES in the city and the bicycle network is presented in Fig. 1. High strata (5 and 6) neighbourhoods are located towards the north-east of the city, while most of the lower strata (1 and 2) are located in the south, west, and on the periphery of the city as can be seen in Fig. 1; strata 3 (medium) is the most common, a high degree of segregation can be observed. Segregation is an issue that hinders accessibility of different population sectors, as those areas segregated by income are also segregated in terms of goods, public and health services (Andersson and Andersson, 2019; Jang and Yi, 2021; Zhang et al., 2021).

Table 2
Length of bicycle network per SES.

	Low SES	Medium SES	High SES
Length (km)	237.107	314.335	72.419
Area (km^2)	170.150	98.700	26.840
Lane (km)/Area (km^2)	1.394	3.185	2.698

Table 2 displays the aggregated length of bicycle networks (lanes) for each SES. The medium SES exhibits the highest value, approximately 314.335 kilometres (km) of cycling network, followed by the low SES with 237.107 km, and the high SES with 72.419 km. However, the table also showcases the area and the rate of cycling network per square kilometre in each SES in order to scale the information. Low SES have an area of approximately 170.150 square kilometres (km^2), leading to a rate of roughly 1.394 km of cycling lanes per each square kilometre. In contrast, Medium SES have a lower area (98.70 km^2) and yet a longer cycling network, leading to a rate of cycling lanes per each square kilometre of 3.185, significantly larger than Low SES. Finally, High SES have the lower area in the city (26.84 km^2) and a rate of roughly 2.698 kilometres of cycling lanes per square kilometre, almost twice as much as Low SES. This illustrates that the medium and low SES have significantly more extensive infrastructure available in terms of existing cycling network compared to the high SES, despite the smaller area the latter covers.

We illustrate the destination of bike trips and the location of BPs in Fig. 2. The city's south-western and north-western areas demonstrate a low density of BPs; paradoxically, both areas experience higher demand for bicycle trips. Conversely, the east side of the city exhibits low demand for bicycle trip and a high density of BP. Further, by comparing Fig. 1 and Fig. 2 an evident disparity in the distribution of BPs appears,

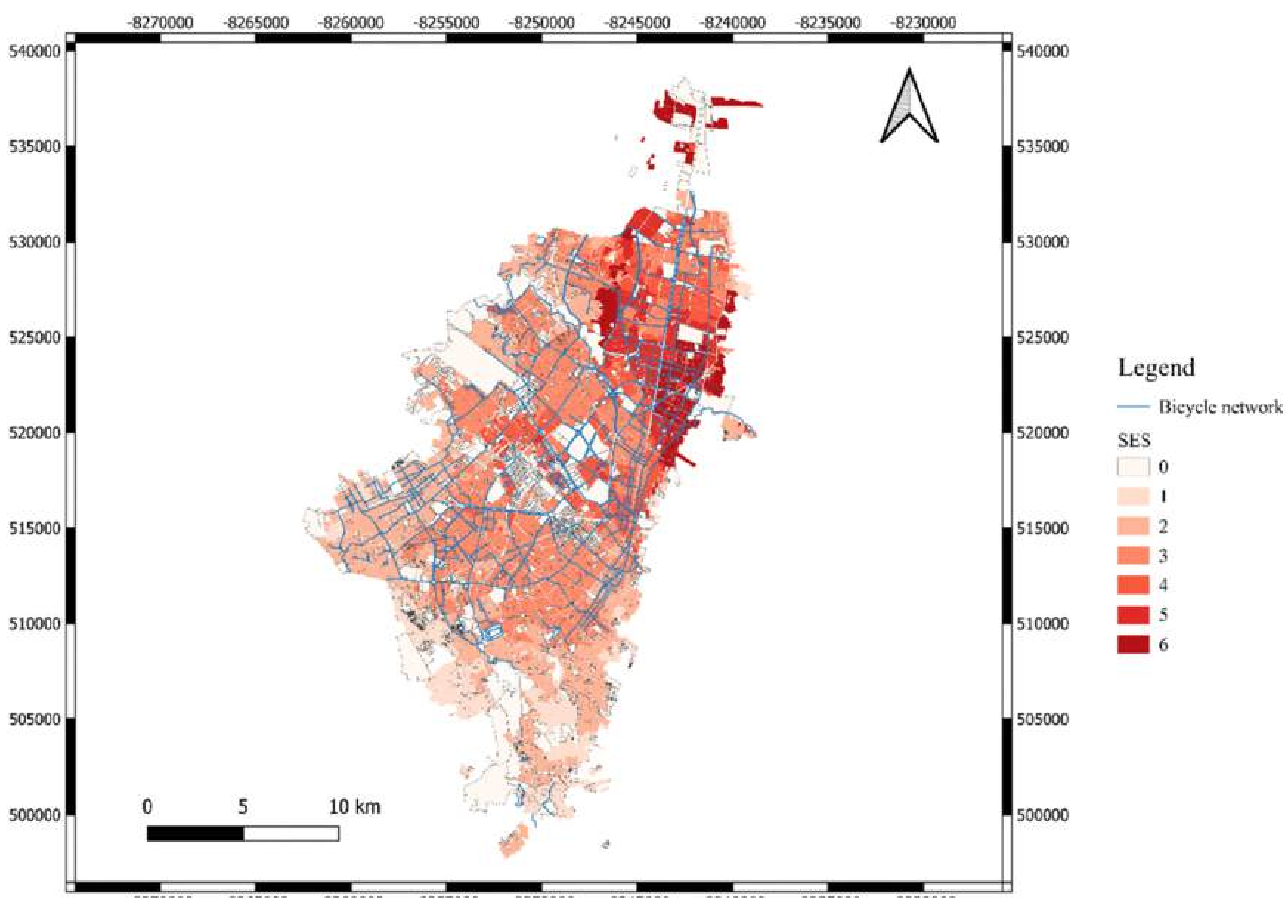

Fig. 1. Socioeconomic strata by block.

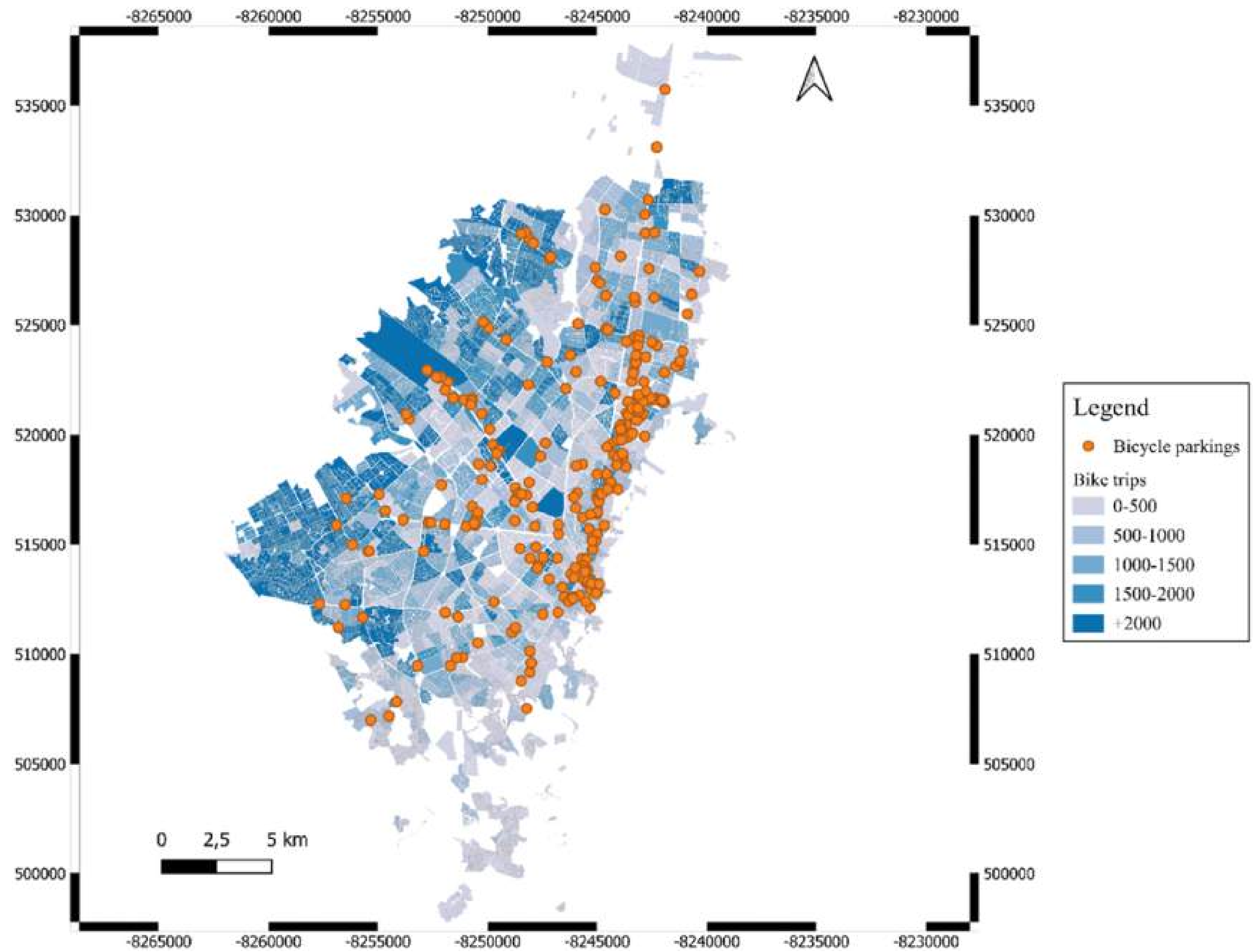

Fig. 2. Destination of bike-trips and BPs through the city.

they are mainly located in areas with high socio-economic strata and scarce in areas with low socio-economic strata.

In Bogotá it is normal for people to have their bikes at home. The origins are assumed to be the same as the residences, which is a customary practice due to security issues. Remarkably, the southern locality of Usme is devoid of BP and is home to 748012 people. In contrast, the area with higher BP density is located mainly in the middle to high areas with lower demand or attractor of bicycle trips. The spatial analysis shows that the current distribution of BP does not match the city's travel patterns.

The lack of BP in these areas could hinder the accessibility of its inhabitants and generate socio-territorial inequalities (Blanco and Apaolaza, 2018; Lucas, 2012). It also promotes segregation or social exclusion by jeopardizing access to the cycling network (Cornut and Madre, 2017; Dixit and Sivakumar, 2020; Lucas, 2012).

Fig. 3 illustrates an accessibility map of Bogotá, depicting the distance from each block to the closest BP facility. Distances are scaled in 150-meter intervals. The plot reveals a clear disparity between the periphery and inner-city areas. Notably, compared to Fig. 2, BPs are farther from blocks in the eastern city sector, which experiences a significant daily cycling volume. Interestingly, some peripheral areas, particularly in the east, have existing cycling infrastructure (lanes).

To analyse SES disparities, we calculated the mean distance and standard deviation of blocks to the closest BP for each SES level. We also plotted the distance distribution between blocks and the closest BP (presented in Fig. 4). Despite scaling limitations (high SES has fewer blocks and consequently less area than medium and low SES, see Table 2), the figure highlights a clear SES contrast. Low SES has a mean distance of 1870.766 m (standard deviation 1680.018 m) to the closest BP, more than double that of medium SES (mean 775.948 m, standard deviation 428.636 m) and nearly quadruple the distance of high SES (mean 493.371 m, standard deviation 357.966 m).

Fig. 4 presents the distribution of block distances to the closest BP for each SES level. All curves exhibit leftward skewness, resembling a Poisson distribution. Notably, high SES shows the lowest dispersion, with most blocks within 1000 m and a maximum distance of 2000 m from the closest BP (mean distance: 493.371 m). Conversely, medium SES has a considerably larger and more dispersed distribution due to a greater number of blocks, with most blocks situated within 2000 m of a BP, although some outliers reach up to 9500 m. Finally, low SES displays the most extensive distribution. While still left-skewed, the plot reveals a substantially higher number of blocks located at greater distances, with some exceeding 7000 m from the nearest BP.

5.2. K – means clustering

We applied the K – means algorithm in Python using the library scikit-learn (Pedregosa et al., 2011) using the coordinates of each point (TAZ and BP) as a reference for the clustering. The algorithm requires the number of clusters as an input. We defined 10 clusters as a starting point and then evaluated the Davies-Bouldin index versus the number of clusters, as can be seen in Fig. 5.

After executing the algorithm, the lowest value of the Davies-Bouldin index was found with six clusters; therefore, the optimal number of clusters was six. We rerun the algorithm using this number of clusters. The results are presented in Fig. 6.

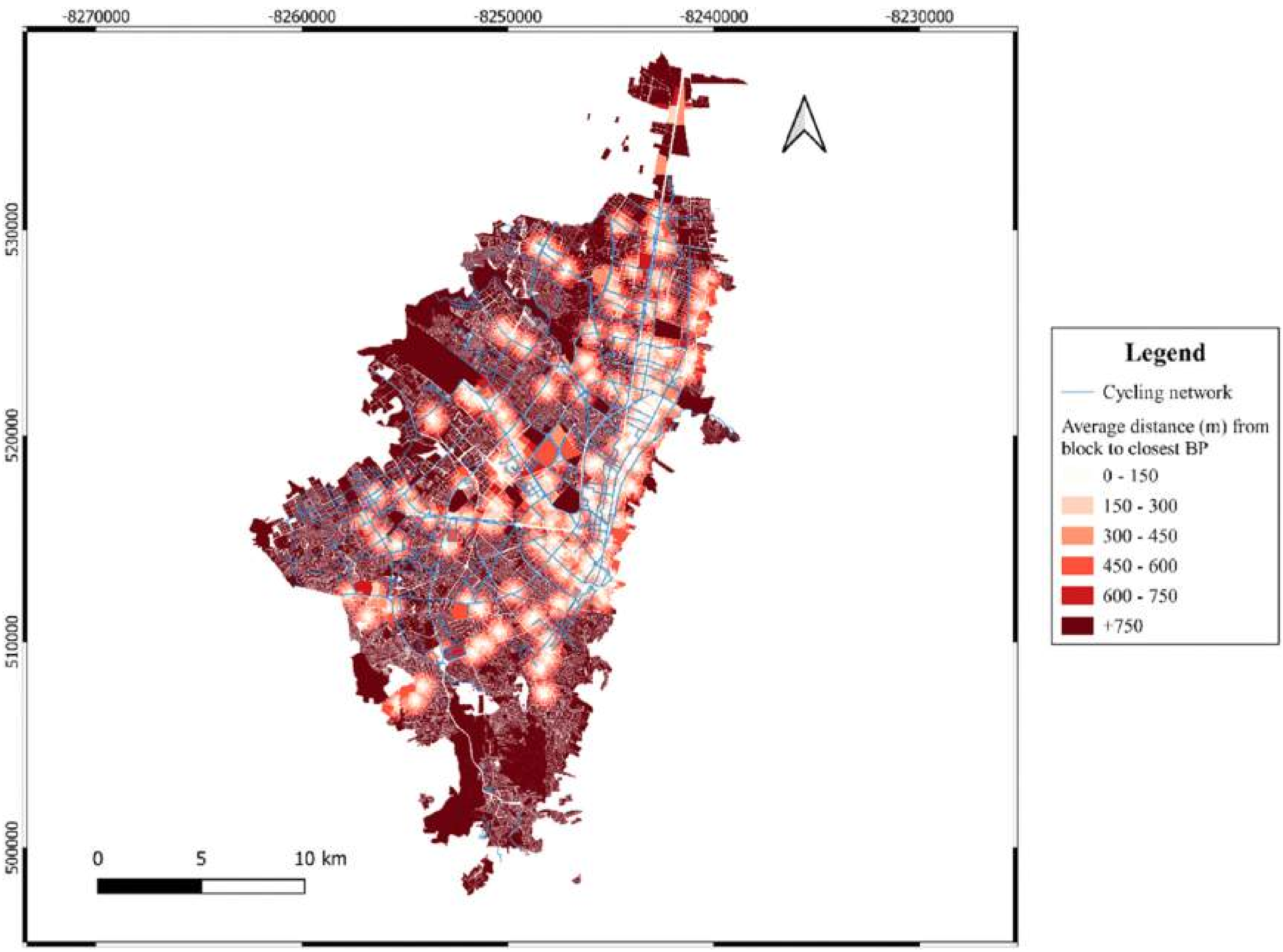

Fig. 3. Accessibility map of mean distance to BP at block level.

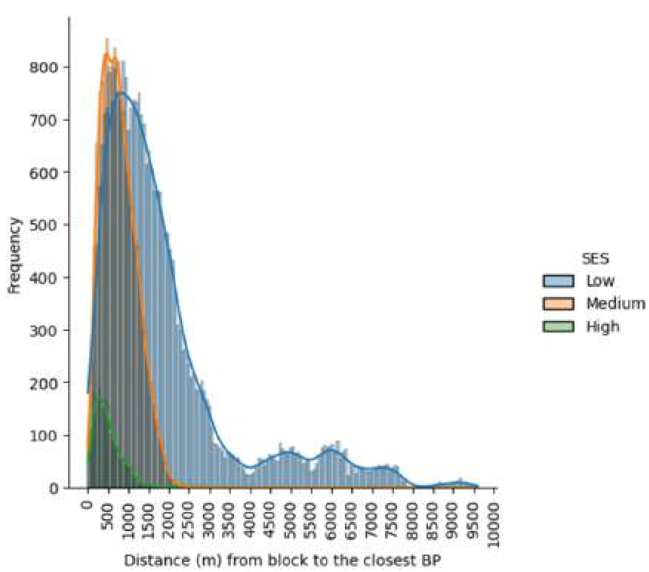

Fig. 4. Distribution of Block Proximity to Closest Bicycle Parking by Socioeconomic Strata.

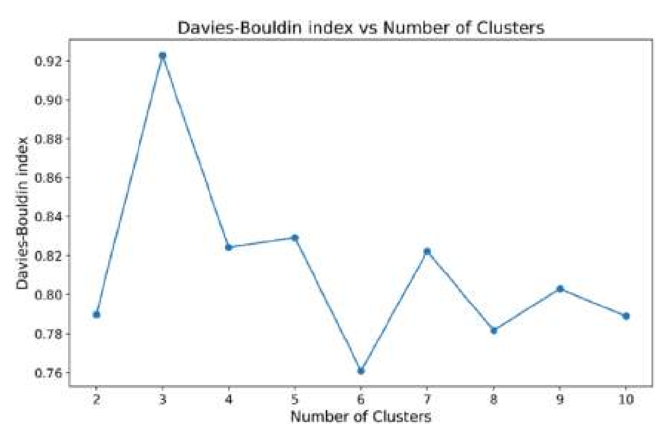

Fig. 5. Performance metric for the K – Means algorithm.

Visually, the clusters reveal an uneven distribution of BPs across the city, consistent with observations from Fig. 2. To provide a deeper analysis, we present numerical results of the clustering process in Table 3 and Table 4. These tables contain pertinent features including the number of BPs, number of TAZ (zones served), number of bike trips attracted (BTA) per day, BP capacity, BP per TAZ ratio (the ratio between total BPs available for a cluster and the number of TAZ for that cluster), and the proportion of TAZ per SES in each cluster. Clusters 1 and 6, representing higher and medium SES, boast the highest number of BPs (95 and 79 respectively), with the greatest BP capacity. However, these clusters do not attract the highest number of bike trips. Conversely, Clusters 3 and 4, dominated by TAZ with low and medium SES, attract the highest number of bike trips per day despite having a lower number of assigned BPs.

Furthermore, we computed the rate of BPs per TAZ for each cluster, emphasizing its significance. Cluster 1, situated in a high SES area, exhibited the highest rate (0.709), followed by Cluster 6 (0.405) in another high SES region. Conversely, Clusters 2 (0.060) and 4 (0.127)

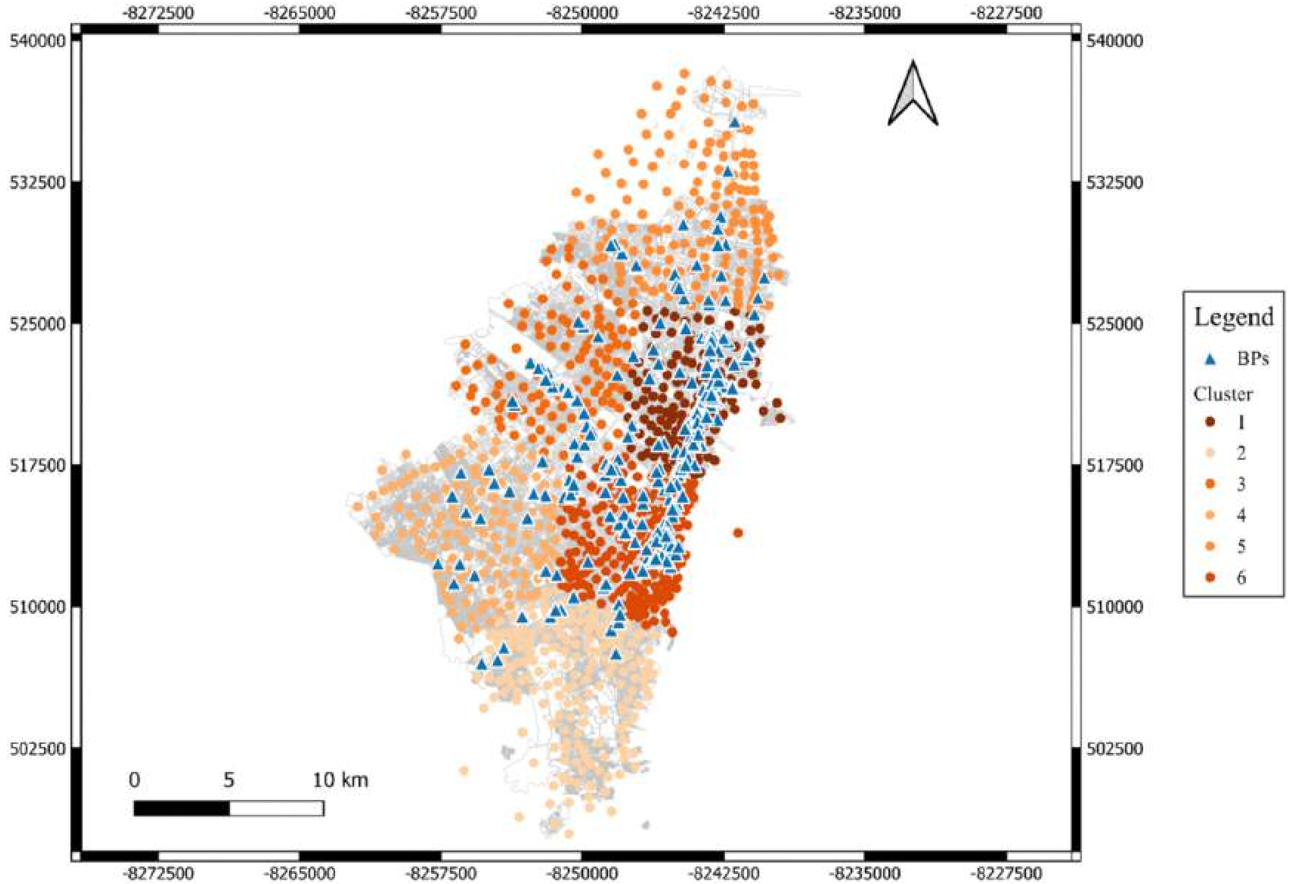

Fig. 6. Results of the K – means algorithm with six clusters.

Table 3
Results of the clustering process.

Cluster	Number of BPs	Number of TAZ	BTA	Capacity of BPs (number of bikes)	Rate BPs per TAZ	% of TAZ in Low SES	% of TAZ in Medium SES	% of TAZ in High SES
1	95	134	112440	6194	0.709	14.90 %	42.50 %	42.50 %
2	11	183	47793	1005	0.06	89.60 %	10.40 %	0.00 %
3	28	110	168624	3624	0.255	45.50 %	54.50 %	0.00 %
4	18	142	279545	2369	0.127	60.60 %	39.40 %	0.00 %
5	24	156	102796	3304	0.154	47.40 %	36.50 %	16.00 %
6	79	195	115837	7882	0.405	38.50 %	61.00 %	0.50 %

Table 4
Rates of BPs per number of TAZ according to SES.

		Low SES		Medium SES		High SES	
Cluster	Number of TAZ	Rate BPs per-TAZ	BTA	Rate BPs per-TAZ	BTA	Rate BPs per-TAZ	BTA
1	134	4.75	9220.5	1.67	51902.77	1.67	51317.11
2	183	0.07	36625.54	0.58	11167.42	-	0
3	110	0.56	83768.43	0.47	84855.54	-	0
4	142	0.21	216218.74	0.32	63326.31	-	0
5	156	0.32	28151.5	0.42	67208.31	0.96	7436.17
6	195	1.05	33011.46	0.66	82826	79	0
Average rate per SES		***1.16***	***67832.70***	***0.68***	***60214.39***	***27.21***	***9792.21***

had the lowest rates among all clusters, despite Cluster 4 attracting the highest number of bicycle trips per day. It is noteworthy that Clusters 2 and 4 are located in peripheral areas with low SES.

Table 4 summarizes the rates of BPs and total BTA for each SES within each cluster. These rates were estimated as the division between the number of BPs for a cluster and the number of TAZ belonging to each SES in that cluster. Several key findings emerge both between and within clusters. Firstly, in Cluster 2, predominantly low SES (89 % of its area), the lowest rates of BPs per TAZ in this SES were observed (0.07). Despite a significantly higher indicator for medium SES in this cluster (0.58), there is a contrast in results: low SES attracts a significantly larger number of bike trips (36625.54 trips) than medium SES (11167.42 trips).

Similarly, in Cluster 4, dominated by low SES (60.6 % of its TAZ) and medium SES (39.4 % of its TAZ), these SES attract even more bike trips than Cluster 1 (216218.74 trips for low SES and 63326.31 trips for medium SES). Nonetheless, the rates remain relatively low, suggesting one BP available for every five TAZs (rate of 0.21) for low SES and one BP available for every three TAZs (rate of 0.32) for medium SES.

Clusters 3 and 5 exhibit similar BP rates for low and medium SES. However, Cluster 3 attracts more bike trips (over 80000 daily trips) for both low and medium SES compared to Cluster 5. Additionally, Cluster 5 includes high SES TAZ, absent in Cluster 3, where the BP rate is moderately higher (0.96). Interestingly, the high SES TAZ in Cluster 5 only attract 7436.17 daily trips, significantly lower than other clusters.

In Cluster 1, high BP rates are observed for low (4.75) and medium (1.67) SES. This cluster is characterized by a predominance of medium and high SES, with a high number of bike trips for these strata (over 50000 daily trips). Notably, there is an oversupply of BPs for low SES TAZ within this cluster, despite their lower number of attracted trips (9220.5).

Cluster 6 displays diverse patterns in BP distribution, dominated by medium SES TAZ (66 % of its area). The BP rate for this SES is 0.66, seemingly low considering the daily bike trips (82826) it attracts. Conversely, low SES TAZ exhibit a higher BP rate (1.05) despite attracting fewer bike trips (33011.46). The BP rates for high SES TAZ in this cluster are inflated due to the presence of only one high SES TAZ.

These results reveal an uneven allocation of facilities in the city, concentrating parking infrastructure according to SES patterns and not according to travel patterns (daily bike attracted trips).

5.3. Survey results

In this section, we present the survey results. We do not present the results for all the questions posed, but the more relevant for our analysis. The survey was applied online using the tool Google Forms. We aimed to capture responses from people using the bicycle for different purposes, such as commuting, recreation, work, and different usage frequencies.

Of the total sample size, 313 respondents (78 %) claimed to own a bicycle. When examining the reasons for bicycle usage, the majority cited recreational purposes (29 %), followed by 23 % who considered it their primary mode of transportation, 22 % who used it for occasional commuting, and 20 % who employed it for sports or training. A smaller percentage reported using bicycles for work-related activities such as food or mail delivery services. Surprisingly, 58.7 % of the respondents indicated unawareness of the BP network in the city.

5.3.1. Satisfaction and relevant criteria for parking facilities

We present the findings of a survey encompassing five questions that explore user preferences and perceptions regarding topics related to bicycle parking. The results, detailed in Table 5, reveal an uneven satisfaction level among users, with 46 % assigning a rating of "3" on a scale of 1–5, where 1 represents "Very Dissatisfied" and 5 corresponds to "Very Satisfied." In a system that exhibits optimal performance, one would anticipate a greater tendency towards higher satisfaction ratings. Regarding critical criteria for bicycle parking facilities, approximately 57 % of respondents attributed significance to safety. Notably, as the relevance indicator increased, there was a corresponding increase in the volume of responses, indicating a positive correlation between perceived relevance and the importance assigned by participants.

When it comes to ease of parking, there is a discernible proneness among users to regard this attribute as relevant.

5.3.2. Willingness to walk

We included two questions in our survey related to the willingness to walk: “How far away would you be willing to walk from a PUBLIC bicycle parking to your destination” and “How far away would you be willing to walk from a PRIVATE bicycle parking to your destination?”. We aimed to check whether there were any differences in the willingness to walk depending on the type of bicycle parking facility (either

Table 5
Responses to satisfaction and preference questions.

Question	1	2	3	4	5
How satisfied are you with the overall level of service provided by Bogotá's bicycle parking facilities? Please rate from 1 to 5, where 1 is Very Dissatisfied and 5 is Very Satisfied.	13 %	15 %	46 %	22 %	5 %
How important do you consider the following criteria for a bicycle parking facility in the city? Please rate from 1 to 5, where 1 is irrelevant and 5 is very relevant. [Safety]	7 %	11 %	26 %	14 %	43 %
How important do you consider the following criteria for a cycle park in the city? Please rate from 1 to 5, where 1 is irrelevant and 5 is very relevant. [Appearance]	10 %	20 %	35 %	20 %	14 %
How relevant do you rate the following criteria for a cycle parking facility in the city? Please rate from 1 to 5, where 1 is irrelevant and 5 is very relevant. [Space Optimisation]	9 %	14 %	30 %	20 %	27 %
How relevant do you consider the following criteria for a cycle parking facility in the city? Please rate from 1–5, where 1 is irrelevant and 5 is very relevant. [Ease of Parking]	7 %	13 %	29 %	17 %	34 %

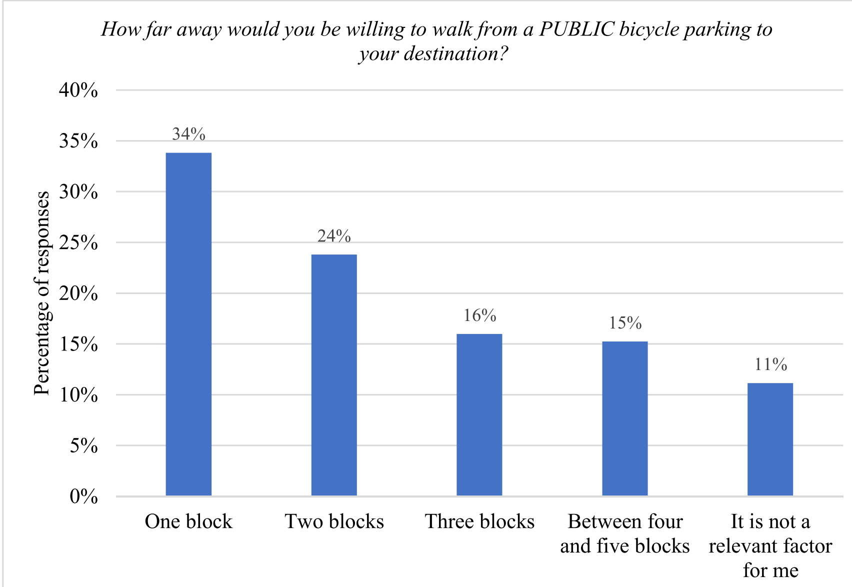

Fig. 7. Willingness to walk to public bicycle parks.

public or private) from the destinations of the respondents, irrespective this was their job, place to study, or anything else.

We faced a moderate disengagement in the responses for these questions. As a result, only 269 responses were included in this study for this question. Results are presented in Fig. 7 and Fig. 8. First, there is a trend regarding the number of blocks responders were willing to walk from their destination to a BP: the farther the facility, the lower the willingness to walk. This trend is emphasised in the case of public BPs.

In both cases (public or private), most respondents stated that they were willing to walk one block. However, in the case of private BP, the respondents seemed to be less sensitive to the distance between the parking facilities and their destination. The difference between being willing to walk three, and between four and five blocks is exiguous. Interestingly, 11 % of respondents replied that “the distance is not a relevant factor for them”.

This finding is consistent with other studies, such as that conducted in the Netherlands in 2010 (UE, 2010), where most people believed that 150 m is the absolute maximum acceptable (walking) distance to bicycle parking lots. Our results are also consistent with those in the Mobility Survey of Bogotá (Mobility Secretary, 2019), which indicates a mean distance of 57 m before “boarding” the bike, and 86 m after descending from it. However, it is important to mention that the Mobility Survey did not specifically ask about walking distance to and from bicycle parking facilities.

5.4. Discussion

Evidence from empirical studies and research supports the unequal distribution of space and services (concentrated in the wealthiest zones of the city, where a minority of the population lives) (Cunha and Silva, 2023; Guzman and Oviedo, 2018; Oviedo and Guzman, 2020; Vecchio et al., 2020) as well as the exclusion of captive and vulnerable users (such as cyclists) from planning decisions (Guzman et al., 2021). The district-level administrative structure in Bogotá (similar to other Latin American cities) impacts the uneven allocation of cycling infrastructure throughout the city (Tiznado-Aitken et al., 2022).

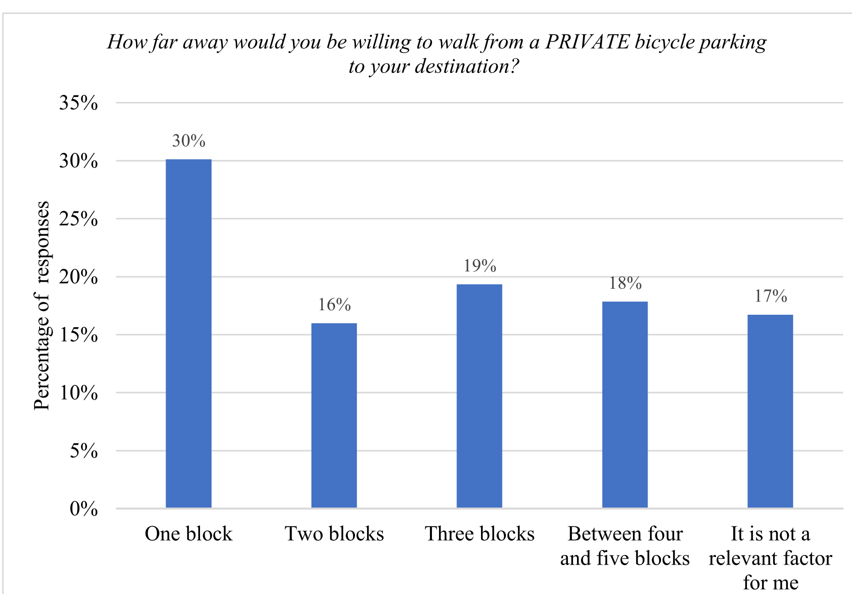

Fig. 8. Willingness to walk to private bicycle parks.

Our findings reveal a significant accessibility disparity regarding BP proximity across socioeconomic groups (SES). Low-SES residents experience lower BP accessibility (greater distances) compared to medium and high-SES residents. However, scaling and spatial distribution limitations may influence these results. Low-SES areas occupy a significantly larger peripheral zone, distant from the central business district (CBD) where jobs and universities concentrate (Guzman and Bocarejo, 2017). This inherent spatial arrangement inherently disadvantages low-SES residents in accessing BP infrastructure crucial for these activity zones, considering that BP placement appears to prioritize zones with high job and education density. While seemingly logical, this approach might be problematic. The Bogotá Mobility Survey suggests a higher frequency of cycling trips to peripheral areas compared to activity zones. Bogotá's high informality rate (33 %) (DANE, 2024) might also influence the results. Informal jobs, often located peripherally, could motivate cycling trips. Additionally, cycling trips may be driven by factors beyond work and education.

The city's cycling network predominantly extends through areas of low and medium SES. Given the higher rate of car ownership among individuals in high SES, it is logical for these areas to have a shorter length of available cycling network. However, the high concentration of BP in the wealthiest areas of the city at the expense of undersupplying the middle to low areas promotes social exclusion; moreover, if we consider that in these middle to high-income areas, the car ownership rates are higher (as is its usage) and are also well-served by public transport. In these same areas, more jobs and educational locations were within walking distance. Thus, we can say that most BPs are in areas that are not as needed as they are in the western zone of the city (as shown in Fig. 2 and Fig. 3), and this could endanger the freedom of mobility of low-income inhabitants who have limited transportation alternatives (e.g. no access to a car).

Our research findings align with prior studies conducted by Rosas-Satizábal et al. (2020), which highlight the disparity in access to opportunities, particularly in relation to job and education, among individuals from different socioeconomic backgrounds. Our results can assist municipalities in allocating public transport resources by utilizing origin-destination matrices and user preferences, while also considering other factors such as design and capacity, which have an impact on BP selection (Heinen and Buehler, 2019). Incorporating user perspectives into transportation planning can facilitate accessibility-focused procedures (Lucas, 2006; Wang et al., 2020).

Sound planning of the cyclists' infrastructure distribution in Bogotá should consider information that allows decision–makers to identify zones with exiguous (or none) coverage and establish priorities to make effective interventions, following a vertical equity approach. As stated before, the provision of a cycle network based on lanes alone is a myopic perspective to promote bicycles and encourage modal shifts if an essential trip-end infrastructure, such as parking lots, is not given.

We acknowledge that our work has several limitations; the main ones do not consider the BP characteristics (i.e. capacity, design, price, etc.) and that the methodology applied in the survey was not exhaustive, given that we did not account for factors affecting preferences, which will surely vary among age and socioeconomic groups, or that we did not provide a profound definition of topics susceptible to misunderstanding, such as the concepts of safety and innovation/technology (meaning cutting-edge parking facilities or app development for parking availability), however, the Mobility Secretary is currently working on the latter.

The information used regarding the total number of trips attracted in the city zones is limited in terms of its accuracy, as the Mobility Survey did not count the total bicycle trips made in Bogotá between each TAZ, but rather gathered information and made typical assumptions of large-scale planning studies. That is, a sample was taken, and generation and attraction models were created based on that sample. The validation of these models is beyond the scope of the present study.

Another limitation of our analysis lies in the lack of information on the BP occupancy rates (inventory studies). Additionally, information regarding the trips attracted is available per typical day and not at a granularity level that allows for a temporal analysis (for example, trips attracted per hour).

Regarding the survey, we acknowledge some limitations. First, the sample was slightly skewed to young adults, and we faced disengagement in the responses to key questions. Besides, because of the approach used to apply the survey (online), there is a possibility of statistical bias because of personality traits, sample selection (Greenacre, 2016; Valentino et al., 2020). Therefore, the insights from the responses may not be representative of the whole population.

Furthermore, one of the questions in our survey explicitly asked if respondents were willing to walk if they left their bicycle in a public or private parking lot. We acknowledge that this is a limitation of our study because determining willingness to walk (WTW) can be more accurately estimated through surveys of stated preferences as part of the choice experiments. These results can be used to propose discrete choice models that provide more robust estimates and avoid the potential ambiguities generated by the wording of the questions in our survey. The inclusion of these models was beyond the scope of this study.

6. Conclusions

We conducted a geospatial and machine learning analysis of BP locations in Bogotá, correlating them with bicycle travel patterns. Our findings indicate a mismatch between the current distribution and the city's demand for bicycle trip destinations, potentially impeding bicycle usage and exacerbating social exclusion. Similar to trends observed in other global cities, investment in sustainable transport infrastructure appears skewed towards middle-to-high-income areas, undermining transport equity. In our case study, the issue extended beyond location; it pertained to actual travel patterns. K – means algorithm proved to be a useful tool for this kind of analysis, being practical and providing stable results in short-time. We confirmed our hypothesis that there exists inequity in the BP distribution of the city.

Failure to provide or consider BP in cycling network planning could result in a perpetuation of inadequate infrastructure or compel users to resort to leaving their bikes in unsafe or restricted areas, discouraging bicycle usage due to perceived inaccessibility of destinations. Additionally, user awareness of BP locations is critical; our survey revealed that 57 % of respondents were unaware of the city's BP network or its whereabouts.

It is important to continue fostering integration of the cycle network with the public transportation system. According to Oviedo and Sabogal-Cardona (2022), there is room for growth in the city's cycling population, and new trends such as bike-sharing may significantly improve accessibility for low-income residents. In a situation where bicycles "operate together" with public transportation, the location of bicycle parking facilities is critical. If such integration is adequately achieved, bikes may become more attractive and competitive with cars (Fazio et al., 2021). We hope that our results will help decision-makers make informed decisions regarding investments, policies, and practices towards implementing bicycle parking facilities.

Future studies may assess BP characteristics depending on the type of user (Fazio et al., 2021), as well as user preferences for using bicycle parking, which may impact the predicted demand (La Paix et al., 2021). Assessing how different BP types could influence their choice may also be an interesting study that could help support the decision on which BP to implement depending on the environment, demand, type of user, and security of the area.

CRediT authorship contribution statement

Mauricio Orozco-Fontalvo: Writing – review & editing, Supervision, Investigation, Conceptualization. **Jorge Bolívar:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation. **Juliana Gómez:** Methodology, Investigation. **Armando Vélez:** Methodology, Investigation. **Filipe Moura:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used "ChatGPT" to check grammar and writing coherence of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

References

Alm, J., Koglin, T., 2022. In)capacity to implement measures for increased cycling? experiences and perspectives from cycling planners in Sweden. J. Urban Mobil. 2, 100029. https://doi.org/10.1016/j.urbmob.2022.100029

Andersson, D.E., Andersson, Å.E., 2019. Sustainability and the built environment: the role of durability. Sustainability 11, 4926. https://doi.org/10.3390/su11184926

Arbis, D., Rashidi, T.H., Dixit, V.V., Vandebona, U., 2016. Analysis and planning of bicycle parking for public transport stations. Int. J. Sustain. Transp. 10, 495–504. https://doi.org/10.1080/15568318.2015.1010668

Arellana, J., Saltarín, M., Larrañaga, A.M., González, V.I., Henao, C.A., 2020. Developing an urban bikeability index for different types of cyclists as a tool to prioritise bicycle infrastructure investments. Transp. Res. Part A: Policy Pract. 139, 310–334. https://doi.org/10.1016/J.TRA.2020.07.010

Barajas, J.M., Braun, L.M., 2021. Are cycling and walking good for all? Tracking differences in associations among active travel, socioeconomics, gentrification, and self-reported health. J. Transp. Health 23, 101246. https://doi.org/10.1016/j.jth.2021.101246

Blanco, J., Apaolaza, R., 2018. Socio-territorial inequality and differential mobility. Three key issues in the Buenos Aires Metropolitan Region. J. Transp. Geogr. 67, 76–84. https://doi.org/10.1016/j.jtrangeo.2017.07.008

Blanco, J., Bosoer, L., Apaolaza, R., 2014. Gentrificación, movilidad y transporte: aproximaciones conceptuales y ejes de indagación. Rev. De. Geogr. ía Norte Gd. 41–53. https://doi.org/10.4067/S0718-34022014000200003

Bogotá cómo vamos, 2019. Seguridad para los biciusuarios. Bogotá Cómo Vamos. https://bogotacomovamos.org/seguridad-para-los-biciusuarios/ (accessed 10.29.22).

Bogotá gov, 2020. Conoce la inversión que hará el IDU para red de ciclorrutas de Bogotá | Bogota.gov.co. https://bogota.gov.co/mi-ciudad/movilidad/conoce-la-inversion-que-hara-el-idu-para-red-de-ciclorrutas-de-bogota (accessed 10.26.22).

Braun, L.M., Rodriguez, D.A., Gordon-Larsen, P., 2019. Social (in)equity in access to cycling infrastructure: Cross-sectional associations between bike lanes and area-level sociodemographic characteristics in 22 large U.S. cities. J. Transp. Geogr. 80, 102544. https://doi.org/10.1016/j.jtrangeo.2019.102544

Brezina, T., Lemmerer, H., Leth, U., 2022. Mental barriers in planning for cycling along the urban–rural gradient. Transp. Res. Interdiscip. Perspect. 16, 100689. https://doi.org/10.1016/j.trip.2022.100689

Buehler, R., 2012. Determinants of bicycle commuting in the Washington, DC region: The role of bicycle parking, cyclist showers, and free car parking at work. Transp. Res. Part D: Transp. Environ. 17, 525–531. https://doi.org/10.1016/j.trd.2012.06.003

Buehler, R., Pucher, J., 2012. Cycling to work in 90 large American cities: new evidence on the role of bike paths and lanes. Transportation 39, 409–432. https://doi.org/10.1007/S11116-011-9355-8/

Cámara de Comercio de Bogotá, 2009. Movilidad en bicicleta en Bogotá.

Cantillo-García, V., Guzmán, L.A., Arellana, J., 2019. Socioeconomic strata as proxy variable for household income in transportation research. Evaluation for Bogotá, Medellín, Cali and Barranquilla. DYNA 86, 258–267. https://doi.org/10.15446/dyna.v86n211.81821

Castillo-Manzano, J.I., Castro-Nuño, M., López-Valpuesta, L., 2015. Analyzing the transition from a public bicycle system to bicycle ownership: a complex relationship. Transp. Res. Part D: Transp. Environ. 38, 15–26. https://doi.org/10.1016/j.trd.2015.04.004

Chen, P., Liu, Q., Sun, F., 2018. Bicycle parking security and built environments. Transp. Res. Part D: Transp. Environ. 62, 169–178. https://doi.org/10.1016/j.trd.2018.02.020

Codina, O., Maciejewska, M., Nadal, J., Marquet, O., 2022. Built environment bikeability as a predictor of cycling frequency: Lessons from Barcelona. Transp. Res. Interdiscip. Perspect. https://doi.org/10.1016/j.trip.2022.100725

Cohen, G.A., 1990. Equality of what? on welfare, goods and capabilities. Rech. écon. Louvain (Impr. é) 56, 357–382. https://doi.org/10.1017/S0770451800043943

Cómo vamos, B., 2012. Cómo vamos en desigualdad - Bogotá Cómo Vamos.

Cornut, B., Madre, J.L., 2017. A longitudinal perspective on car ownership and use in relation with income inequalities in the Paris metropolitan area. Transp. Rev. 37, 227–244. https://doi.org/10.1080/01441647.2016.1245218

Cui, Y., Mishra, S., Welch, T.F., 2014. Land use effects on bicycle ridership: a framework for state planning agencies. J. Transp. Geogr. 41, 220–228. https://doi.org/10.1016/j.jtrangeo.2014.10.004

Cunha, I., Silva, C., 2023. Assessing the equity impact of cycling infrastructure allocation: Implications for planning practice. Transp. Policy 133, 15–26. https://doi.org/10.1016/j.tranpol.2022.12.021

Cunha, I., Silva, C., 2022. Equity impacts of cycling: examining the spatial-social distribution of bicycle-related benefits. Int. J. Sustain. Transp. 1–19. https://doi.org/10.1080/15568318.2022.2082343

Cunha, I., Silva, C., Büttner, B., 2023. Practitioners' perspectives on cycling equity: Bridging the gap between planning priorities. Transp. Res. Part D: Transp. Environ. 123, 103902. https://doi.org/10.1016/j.trd.2023.103902

DANE, 2024. Empleo informal y seguridad social.

DANE, 2021. Estratificación socioeconómica.

Dill, J., Carr, T., 2003. Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them. Transp. Res. Rec. 116–123. https://doi.org/10.3141/1828-14

Dill, J., Gliebe, J., 2008. Understanding and measuring bicycling behavior: a focus on travel time and route coice. https://doi.org/10.15760/trec.151.

Dill, J., Voros, K., 2007. Factors affecting bicycling demand: Initial survey findings from the Portland, Oregon, region. Transp. Res. Rec. 9–17. https://doi.org/10.3141/2031-02

Dixit, M., Sivakumar, A., 2020. Capturing the impact of individual characteristics on transport accessibility and equity analysis. Transp. Res. Part D: Transp. Environ. 87, 102473. https://doi.org/10.1016/j.trd.2020.102473

Du, Y., Deng, F., Liao, F., 2019. A model framework for discovering the spatio-temporal usage patterns of public free-floating bike-sharing system. Transp. Res. Part C: Emerg. Technol. 103, 39–55. https://doi.org/10.1016/j.trc.2019.04.006

Epperson, B., 1994. EVALUATING SUITABILITY OF ROADWAYS FOR BICYCLE USE: TOWARD A CYCLING LEVEL-OF-SERVICE STANDARD.

Fazio, M., Giuffrida, N., Le Pira, M., Inturri, G., Ignaccolo, M., 2021. Bike oriented development: Selecting locations for cycle stations through a spatial approach. Res. Transp. Bus. Manag. 40, 100576. https://doi.org/10.1016/j.rtbm.2020.100576

Félix, R., Cambra, P., Moura, F., 2020. Build it and give 'em bikes, and they will come: the effects of cycling infrastructure and bike-sharing system in Lisbon. Case Stud. Transp. Policy 8, 672–682. https://doi.org/10.1016/j.cstp.2020.03.002

Félix, R., Moura, F., Clifton, K.J., 2019. Maturing urban cycling: Comparing barriers and motivators to bicycle of cyclists and non-cyclists in Lisbon, Portugal. J. Transp. Health 15, 100628. https://doi.org/10.1016/j.jth.2019.100628

Flanagan, E., Lachapelle, U., El-Geneidy, A., 2016. Riding tandem: Does cycling infrastructure investment mirror gentrification and privilege in Portland, OR and Chicago, IL? Res. Transp. Econ. 60, 14–24. https://doi.org/10.1016/j.retrec.2016.07.027

Gössling, S., 2016. Urban transport justice. J. Transp. Geogr. 54, 1–9. https://doi.org/10.1016/j.jtrangeo.2016.05.002

Govender, P., Sivakumar, V., 2020. Application of k-means and hierarchical clustering techniques for analysis of air pollution: A review (1980–2019). Atmos. Pollut. Res. 11, 40–56. https://doi.org/10.1016/j.apr.2019.09.009

Greenacre, Z.A., 2016. The Importance of Selection Bias in Internet Surveys. Open J. Stat. 6 397–404. https://doi.org/10.4236/ojs.2016.63035

Guzman, L.A., Bocarejo, J.P., 2017. Urban form and spatial urban equity in Bogota, Colombia. World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016. Transp. Res. Procedia 25, 4491–4506. https://doi.org/10.1016/j.trpro.2017.05.345

Guzman, L.A., Oviedo, D., 2018. Accessibility, affordability and equity: Assessing 'pro-poor' public transport subsidies in Bogotá. Transp. Policy 68, 37–51. https://doi.org/10.1016/j.tranpol.2018.04.012

Guzman, L.A., Oviedo, D., Arellana, J., Cantillo-García, V., 2021. Buying a car and the street: Transport justice and urban space distribution. Transp. Res. Part D: Transp. Environ. 95, 102860. https://doi.org/10.1016/j.trd.2021.102860

Guzman, L.A., Oviedo, D., Bocarejo, J.P., 2017. City profile: the bogotá metropolitan area that never was. Cities 60, 202–215. https://doi.org/10.1016/j.cities.2016.09.004

Hamre, A., Buehler, R., 2014. Commuter Mode choice and free car parking, public transportation benefits, showers/lockers, and bike parking at work: evidence from the Washington, DC Region. J. Public Transp. 17. https://doi.org/10.5038/2375-0901.17.2.4

Heinen, E., Buehler, R., 2019. Bicycle parking: a systematic review of scientific literature on parking behaviour, parking preferences, and their influence on cycling and travel behaviour. Transp. Rev. 39, 630–656. https://doi.org/10.1080/01441647.2019.1590477

Heinen, E., Maat, K., van Wee, B., 2013. The effect of work-related factors on the bicycle commute mode choice in the Netherlands. Transportation 40, 23–43. https://doi.org/10.1007/s11116-012-9399-4

Hull, A., O'Holleran, C., 2014. Bicycle infrastructure: can good design encourage cycling? Urban, Plan. Transp. Res. 2, 369–406. https://doi.org/10.1080/21650020.2014.955210

Hunt, J.D., Abraham, J.E., 2007. Influences on bicycle use. Transportation 34, 453–470. https://doi.org/10.1007/s11116-006-9109-1

Jang, S., Yi, C., 2021. Imbalance between local commuting accessibility and residential locations of households by income class in the Seoul Metropolitan Area. Cities 109, 103011. https://doi.org/10.1016/j.cities.2020.103011

Kamargianni, M., 2015. Investigating next generation's cycling ridership to promote sustainable mobility in different types of cities. Res. Transp. Econ. 53, 45–55. https://doi.org/10.1016/j.retrec.2015.10.018

Krizek, K.J., El-Geneidy, A., Thompson, K., 2007. A detailed analysis of how an urban trail system affects cyclists' travel. Transportation 34, 611–624. https://doi.org/10.1007/S11116-007-9130-Z/

La Paix, L., Cherchi, E., Geurs, K., 2021. Role of perception of bicycle infrastructure on the choice of the bicycle as a train feeder mode. Int. J. Sustain. Transp. 15, 486–499. https://doi.org/10.1080/15568318.2020.1765223

Likas, A., Vlassis, N., J. Verbeek, J., 2003. The global k-means clustering algorithm. Pattern Recognit. 36, 451–461. https://doi.org/10.1016/S0031-3203(02)00060-2

Lucas, K., 2012. Transport and social exclusion: Where are we now? Transp. Policy 20, 105–113. https://doi.org/10.1016/j.tranpol.2012.01.013

Lucas, K., 2006. Providing transport for social inclusion within a framework for environmental justice in the UK. Transp. Res. Part A: Policy Pract. 40, 801–809. https://doi.org/10.1016/j.tra.2005.12.005
Marqués, R., Hernández-Herrador, V., Calvo-Salazar, M., García-Cebrián, J.A., 2015. How infrastructure can promote cycling in cities: Lessons from Seville. Res. Transp. Econ., Bicycl. Cycle 53, 31–44. https://doi.org/10.1016/j.retrec.2015.10.017
Márquez, L., Soto, J.J., 2021. Integrating perceptions of safety and bicycle theft risk in the analysis of cycling infrastructure preferences. Transp. Res. Part A: Policy Pract. 150, 285–301. https://doi.org/10.1016/j.tra.2021.06.017
Maulik, U., Bandyopadhyay, S., 2002. Performance evaluation of some clustering algorithms and validity indices. IEEE Trans. Pattern Anal. Mach. Intell. 24, 1650–1654. https://doi.org/10.1109/TPAMI.2002.1114856
Mobility Secretary, 2019. Encuesta de Movilidad 2019.
Molin, E., Maat, K., 2015. Bicycle parking demand at railway stations: Capturing price-walking trade offs. Res. Transp. Econ. 53, 3–12. https://doi.org/10.1016/j.retrec.2015.10.014
Mora, R., Truffello, R., Oyarzún, G., 2021. Equity and accessibility of cycling infrastructure: An analysis of Santiago de Chile. J. Transp. Geogr. 91, 102964. https://doi.org/10.1016/j.jtrangeo.2021.102964
Moudon, A.V., Lee, C., Cheadle, A.D., Collier, C.W., Johnson, D., Schmid, T.L., Weather, R.D., 2005. Cycling and the built environment, a US perspective. Transp. Res. Part D: Transp. Environ. 10, 245–261. https://doi.org/10.1016/J.TRD.2005.04.001
Nadimi, N., Nordfjærn, T., Lori, H.S., Khalifeh, V., 2023. Improving Attitudes toward Cycling in a Middle East and North Africa Region City. J. Urban Plan. Dev. 149, 04022048. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000906
Nie, F., Li, Z., Wang, R., Li, X., 2023. An Effective and Efficient Algorithm for K-Means Clustering With New Formulation. IEEE Trans. Knowl. Data Eng. 35, 3433–3443. https://doi.org/10.1109/TKDE.2022.3155450
Noland, R.B., Kunreuther, H., 1995. Short-run and long-run policies for increasing bicycle transportation for daily commuter trips. Transp. Policy 2, 67–79. https://doi.org/10.1016/0967-070X(95)93248-W
Oviedo, D., Guzman, L.A., 2020. Revisiting Accessibility in a Context of Sustainable Transport: Capabilities and Inequalities in Bogotá. Sustainability 12, 4464. https://doi.org/10.3390/su12114464
Oviedo, D., Sabogal-Cardona, O., 2022. Arguments for cycling as a mechanism for sustainable modal shifts in Bogotá. J. Transp. Geogr. 99, 103291. https://doi.org/10.1016/j.jtrangeo.2022.103291
Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., Duchesnay, E., Louppe, G., 2011. Scikit-learn: Machine Learning in Python. J. Mach. Learn. Res. 12.
Pereira, R.H.M., Banister, D., Schwanen, T., Wessel, N., 2019. Distributional effects of transport policies on inequalities in access to opportunities in Rio de Janeiro. 12, 741–764. https://doi.org/10.5198/jtlu.2019.1523
Pucher, J., Buehler, R., 2008. Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany. Transp. Rev. 28, 495–528. https://doi.org/10.1080/01441640701806612
Ríos Flores, R.A., Taddia, A.P., Pardo, C.F., Lleras, N., 2015. Ciclo-inclusión en América Latina y el Caribe: Guía para impulsar el uso de la bicicleta.
Rosas-Satizábal, D., Guzman, L.A., Oviedo, D., 2020. Cycling diversity, accessibility, and equality: An analysis of cycling commuting in Bogotá. Transp. Res. Part D: Transp. Environ. 88, 102562. https://doi.org/10.1016/j.trd.2020.102562
Skinner, R., 2004. Bogotá. Cities 21, 73–81. https://doi.org/10.1016/j.cities.2003.10.003
Teunissen, T., Sarmiento, O., Zuidgeest, M., Brussel, M., 2015. Mapping Equality in Access: The Case of Bogotá's Sustainable Transportation Initiatives. Int. J. Sustain. Transp. 9, 457–467. https://doi.org/10.1080/15568318.2013.808388
Tiznado-Aitken, I., Mora, R., Oyarzún, G., Vergara, J., Vecchio, G., 2022. A bumpy ride: structural inequalities, quality standards, and institutional limitations affecting cycling infrastructure. Transp. Res. Part D: Transp. Environ. 110, 103434. https://doi.org/10.1016/j.trd.2022.103434
Tiznado-Aitken, I., Vecchio, G., Guzman, L.A., Arellana, J., Humberto, M., Vasconcellos, E., Muñoz, J.C., 2023. Unequal periurban mobility: Travel patterns, modal choices and urban core dependence in Latin America. Habitat Int. 133, 102752. https://doi.org/10.1016/j.habitatint.2023.102752
Tortosa, E.V., Lovelace, R., Heinen, E., Mann, R.P., 2021. Infrastructure is not enough: Interactions between the environment, socioeconomic disadvantage, and cycling participation in England. J. Transp. Land Use 14, 693–714. https://doi.org/10.5198/jtlu.2021.1781
UE, 2010. Give Cycling a Push Implementation Fact Sheet BICYCLE PARKING IN RESIDENTIAL AREAS Overview Background and Objectives.
Valencia, A., 2016. Bogotá fue la ciudad más desigual de Colombia en 2015 | Observatorio de Desarrollo Económico.
Valentino, N.A., Zhirkov, K., Hillygus, D.S., Guay, B., 2020. The Consequences of Personality Biases in Online Panels for Measuring Public Opinion. Public Opin. Q. 84, 446–468. https://doi.org/10.1093/poq/nfaa026
Van der Spek, S.C., Scheltema, N., 2015. The importance of bicycle parking management. Res. Transp. Bus. Manag. 15, 39–49. https://doi.org/10.1016/j.rtbm.2015.03.001
Vecchio, G., Tiznado-Aitken, I., Hurtubia, R., 2020. Transport and equity in Latin America: a critical review of socially oriented accessibility assessments. Transp. Rev. 40, 354–381. https://doi.org/10.1080/01441647.2020.1711828
Wang, Y., Cao, M., Liu, Y., Ye, R., Gao, X., Ma, L., 2020. Public transport equity in Shenyang: Using structural equation modelling. Res. Transp. Bus. Manag., 100555. https://doi.org/10.1016/j.rtbm.2020.100555
Wardman, M., Tight, M., Page, M., 2007. Factors influencing the propensity to cycle to work. Transp. Res. Part A: Policy Pract. 41, 339–350. https://doi.org/10.1016/j.tra.2006.09.011
Wismadi, A., Zuidgeest, M., Brussel, M., van Maarseveen, M., 2014. Spatial Preference Modelling for equitable infrastructure provision: An application of Sen's Capability Approach. J. Geogr. Syst. 16, 19–48. https://doi.org/10.1007/s10109-013-0185-4
Yang, Y., Wu, X., Zhou, P., Gou, Z., Lu, Y., 2019. Towards a cycling-friendly city: An updated review of the associations between built environment and cycling behaviors (2007–2017). J. Transp. Health 14, 100613. https://doi.org/10.1016/j.jth.2019.100613
Yu, S.-S., Chu, S.-W., Wang, C.-M., Chan, Y.-K., Chang, T.-C., 2018. Two improved k-means algorithms. Appl. Soft Comput. 68, 747–755. https://doi.org/10.1016/j.asoc.2017.08.032
Yuan, C., Sun, Y., Lv, J., Lusk, A., 2017. Cycle Tracks and Parking Environments in China: Learning from College Students at Peking University. IJERPH 14, 930. https://doi.org/10.3390/ijerph14080930
Zhang, T., Duan, X., Wong, D.W.S., Lu, Y., 2021. Discovering income-economic segregation patterns: A residential-mobility embedding approach. Comput., Environ. Urban Syst. 90, 101709. https://doi.org/10.1016/j.compenvurbsys.2021.101709