Equity in cycle lane networks: examination of the distribution of the cycle lane network by socioeconomic index in Bogotá, Colombia

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ABSTRACT

The public network of bicycle lanes in Bogotá Colombia, known as ‘Ciclorutas’, is the largest in Latin America. Despite its success, disparities in regards to the distribution of routes by socioeconomic status (SES) of neighborhoods have not been examined. This exploratory analysis sought to assess the distribution and distance to the city network of bicycle lanes by neighborhood SES in urban blocks located in flat terrains. We conducted a spatial ecological analysis using secondary data obtained through geographic information systems from official databases. We calculated the shortest route from the centroid of each urban neighborhood block to the closest access point of the bicycle lane network. The median distance to the bicycle lane network from urban block centroids was 444m. This median distance ranged from 1,062m for the most disadvantaged areas to 315m for the wealthiest, showing a clear difference in the spatial distribution. Results show wide variation in the distribution of bicycle lanes by SES, but particularly for the most disadvantaged areas. Improving the conditions for cycling in a more equitable manner may involve expanding the network of bicycle lanes for populations living in less advantaged areas.

There is growing recognition about the relevance for promoting physical activity in urban settings, not only for its health benefits, but also for its contribution to sustainable urban development and environments (Kent and Thompson 2014). In this sense, active transportation such as walking and cycling for commuting purposes has ideal implications for human health, personal economy, and environmental reasons, including reduction of carbon emissions, one of the main causes of global warming (Bond and Sun 2005, Mosquera et al. 2012, Paez et al. 2014).

Several cities around the world have been promoting and encouraging the use of the bicycle for transportation purposes (Hirsch et al. 2017, Johansson et al. 2017). They have done so by investing in public infrastructure and implementing traffic laws and regulations that protect cyclists (Garrard et al. 2008, Gorobets 2016, Pedroso et al. 2016, Digiokia et al. 2017, Winters et al. 2018). Some cities such as Copenhagen and Amsterdam are world leaders in the promotion and use of the bicycle, with as much as 40% of their population using the bicycle for commuting purposes on a daily basis. This is a result of an excellent public infrastructure as well as the presence of a culture and well-rooted social norms around bicycle use. Research about inequalities in bicycling infrastructure is scarce, but there is some evidence showing that often times the populations in most need of alternative means of transportation are not benefiting from access to bicycle networks.

Bogota, the capital city of Colombia is one of the cities that has been recognized for increasing and encouraging the use of the bicycle as a means of transportation. Bogota has a population of approximately 8.2 million inhabitants. The city is located in a flat plateau (elevation: 2625m) with an average annual temperature of 14°C and an urban density of 177 inhabitants per hectare. Bogota’s urbanization process is similar to the one experienced by other major Latin American cities and is one characterized by unplanned growth and the existence of profound environmental inequalities. The city had a massive migration from rural to urban areas between 1950 and 1980 due to an intense civil war, this, coupled with the low economic development of the receiving cities, created among the immigrants an informal labor economy force and an illegal settling in shanty towns located in the hilly terrains of the outskirts of the city. As a result, these urban areas have important deficits in public transportation and recreational...
spaces, which include active transportation options such as bicycle paths. The social stratification system established in the city, which was created to alleviate the payment of public utilities among the poorest residents, might have exacerbated inequalities. Recent studies suggest that these regulations may adversely affect social mobility and perpetuate social stratification, since social segregation is increasingly not just a matter of household income, but also imbedded in a social collective mentality (Mallarino-Uribe 2008). Thus potential poor access to bicycle road infrastructure could be further magnified by the high degree of socio-spatial segregation documented in Bogota (Thibert and Osorio 2014, Czerny and Czerny 2017) and can increase health and environmental disparities.

The public network of bicycle lanes in Bogota Colombia, also known as ‘Cicloruta’ is the largest in Latin America, with approximately 344km of bicycle lanes distributed throughout the city (Gomez et al. 2015, IDU 2016). This program started between 1995 and 1998, when the first phase of the program was built, which encompassed 10km. In the period of 1998–2000 the ‘Cicloruta’ rapidly expanded to 300km. The following city administrations also invested in the constructions of more Ciclorutas but to a less extent (Parra et al. 2017). The objective behind the construction of the ‘Ciclorutas’ was to improve the mobility of the city by prompting an alternative means of transportation that would contribute to reduce the number of cars on the main roads and the amount of traffic jams, as well as reduce air pollution (Parra et al. 2017). To a certain extent, the initiative has contributed to meeting these objectives and has been successful in increasing the use of the bicycle for transportation purposes (Ramirez-Velez et al. 2016). On average, 5% of all trips in the city of Bogota are made by bicycle, making it the second highest use of the bicycle in Latin America, after Rosario Argentina where 5.3% of the trips are made on a bike. A recent report by the Inter-American Development Bank placed Bogota as the best city in Latin America for cyclists, despite shortcomings such as lack of bicycle parking spaces and a lack of connectivity and integration with other public transportation options. One of the areas and opportunities for growth identified in the report were the expansion of the system to places not currently reached, as well as increasing public lighting in many of the passages (2015a).

The availability of bicycle lanes by socioeconomic status (SES) is precisely the motivation behind the current analysis. There has been some prior research showing disparities in the design and distribution of parks and other leisure time and exercise opportunities in Bogota, with lower SES urban districts having fewer opportunities per inhabitant. In this regard, spatial and social disparities in terms of public space and physical activity infrastructure, is a commonly documented issue in research and practice.

To date, the distribution of the bicycle lanes of the ‘Ciclorutas’ has not been documented. In this study, we explore the spatial distribution of the lanes and document any differences according to the socioeconomic status of the neighborhood blocks in which they are located.

Methods

We conducted a spatial epidemiologic study using secondary data analysis obtained through Geographic Information Systems, using the official databases from Cadastre 2015, the institution in charge of the census of constructions and buildings for tax purposes (CATASTRO, 2018a). This contained information of both blocks and bicycle lanes. Blocks were defined as the urban space destined for residential building, usually in a square pattern and delimited by streets. Blocks are usually between 100 and 150m in length. The block includes two sidewalks facing each other (CATASTRO 2018b). Cycle lanes included different types of infrastructure: exclusive bicycle lanes, bike lanes on platforms, bike lanes demarcated on the road (bicycle lanes), and local vehicle lanes marked with priority for passing bicycles (IDU 2015). The 2015 bicycle lanes network included both separated and shared bike lanes, and the information was obtained from the Institute for Urban Development.

Network analyst (ArcGIS 10.3) was used to calculate the shortest route from the centroid of each of the residential blocks within the urban area of Bogota (33,405 blocks) to the closest access point to the Cicloruta. The ‘Make Closest Facility Layer’ tool within the Network Analyst extension calculates the distance between an origin, which in this case was the centroid of a block calculated in Cartesian coordinate space (X,Y) yielding a coverage of points, and a destination point, in this case the closest point of access to a Cicloruta. Following a structured network, the tool then seeks for the shortest route between these two points, for this we calculated the Manhattan distance, which considers road network to calculate the shortest distance between the origin and destination points. We used the street network grid data of Bogota from 2016, available from IDECA (Center for Spatial Data Infrastructure for Bogota) (CATASTRO 2018b), and the Cicloruta network’s official data from the Institute of Urban Development, where we converted a line data layer into a point data layer to estimate the closest access point to the Cicloruta. The result of the Make Closest Facility analysis produced a network of lines that connect each block’s centroid with the closest point of the
Cicloruta network based upon the shortest distance following the street network grid.

Figure 1 shows an example of how the shortest distance to the nearest bicycle lane crossing the street network was calculated. We did not include blocks located in terrain of slopes of 3% and more, because a previous study shows that persons who live in these urban areas are less likely to use the bicycle compared to those who live in a flat terrain (Cervero et al. 2009). For this reason, this study was restricted to 24,158 residential blocks located in flat terrain or with a slope less than 3%. We included a map of Bogota on Figure 2, showing the variation of the slopes of the terrain by SES.

SES of the block was defined on a numerical scale (1–6) as preestablished by Cadastre for determining the price of public utilities and taxes. (CONPES 1997). According to the most recent population census of Bogota, more than 50% of the population is classified as SES 1 (10.4%) and SES 2 (41.3%), 36.0% are from SES 3, with only 7.8% belonging to SES 4, 2.6% to SES 5, and 1.9% to SES 6.

Results

The overall median distance from block centroids to the bicycle lanes network was 444m. The median distance to the bicycle lane network according to SES ranges from 1,062m for SES 1 (most disadvantaged), 478m for SES 2, 438m for SES 3, 376m for SES 5, to 315m for SES 6 (wealthiest) (Table 1).

Table 1 also shows the number of blocks included in each SES, with 1,291 for SES 1, 9,158 for SES 2, 10,401 for SES 3, 1,966 for SES 4, 813 for SES 5, and 529 for SES 6, for a total of 24,158 blocks. Table 1, also includes a breakdown of the percentage of blocks that are located at less than 500m from the centroid of the block, between 500 and 999m, and 1000m away or more in each SES. For SES 1, 51.7% of the blocks were located more than 1000m away, versus 16.2% for SES 2, 7.2% for SES 3, 1.4% for SES 4, 7.9% for SES 5, and 11.7% for SES 6. In terms of blocks located less than 500m away, 36.5% of the blocks in SES 1 where in this category, versus 52% for SES 2, 57.3% for SES 3, 65.3% for SES 4, 71% for SES 5, and 73.2% for SES 6.

The average area of a block in the data used was 4,816.83m$^2$, ranging from 2,423.85m$^2$ for strata 1, 3,229.73m$^2$ for strata 2, 5,259.08m$^2$ for strata 3, 8,020.34m$^2$ for strata 4, 9,967.98m$^2$ for strata 5, and 17,663.06m$^2$ for strata 6 (Table 1). In terms of population density, blocks from SES 1 had an average population density of 67.8 inhabitants, SES 2 with 579.8 inhabitants, SES 3 with 431.3 inhabitants, SES 4 with 59 inhabitants, SES 5 with 14.6 inhabitants, and SES 6 with 5.2 inhabitants (Table 1).

Figure 2 shows the distribution of SES in the city against slope of the terrain, as it can be seen, areas of SES 1 and SES 6 are located in settings with the steepest inclinations of the terrain, compared to SES 2, 3, 4, and 5.
Figure 3 shows a graphic representation of the unequal distribution of bicycle lanes by neighborhood location and SES, the map shows a greater distribution of bicycle lanes in blocks of higher SES, those in blue, purple and green color, compared to the areas in orange and red.

We include five photos as illustrations of the differences in the types of Cicloruta infrastructure across all six SES types, SES 1 (Figure 4), SES 2 (Figure 5), SES 3–4 (Figure 6), SES 5 (Figure 7), and SES 6 (Figure 8). We selected Ciclorutas that were overall representative of the types of bicycle lanes that are found within each SES, for instance, exclusive bicycle lanes and bike lanes on platforms are more likely to be found on SES 4, 5 and 6, while bike lanes demarcated on the road (bicycle lanes), and shared road infrastructure marked with priority for passing bicyclist are more likely to be found in SES 1, 2 and 3.

Discussion

We found marked differences in the spatial distribution of bicycle lanes, particularly for SES 1, the most disadvantaged SES from the city. In terms of walking and cycling lanes it has been shown that, a distance of 500m is a walkable distance to reach a destination such as a walk or bike lane (Yang and Diez-Roux 2012, Watson et al. 2015). The median distance to a bicycle lane in the city of Bogota is 444m, which compared to many cities in the world is an excellent indicator of accessibility to alternative means of transportation. However, a closer look shows that for areas and neighborhoods in the city classified in the lowest SES (1), that distance is two times longer, with a mean of 1,237m. The distances for the remaining SES (2 to 6) are closer together with only small differences in distance, i.e. 478m for SES 2 compared to 315m for SES 6. The large gap that exists between

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**Table 1.** Number of blocks per SES, average size per block, population density, mean, median and range in meters of the shortest network route from the centroid of each of the blocks in Bogota (24,158 blocks) to the closest access point of the bicycle lane network, by neighborhood.

| Socio-economic status of neighborhoods | Number of blocks | Average size per block in square meters | Average Population Density per block | Mean in meters (SD) | Median distance in meters in all blocks | Distance range in meters in all blocks | Percentage and number of blocks within less than 500m | Percentage and number of blocks between 500 and 999m | Percentage and number of blocks more than 1000m away |
|---------------------------------------|------------------|----------------------------------------|-------------------------------------|---------------------|----------------------------------------|------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| SES 1 (lowest)                       | 1291             | 2,423.85                               | 67.8                                | 1,237 (1044)        | 1062                                   | 80–5,666                                 | 36.5% (471)                                    | 11.8% (152)                                      | 51.7% (668)                                      |
| SES 2                                | 9158             | 3,229.73                               | 579.8                               | 611 (563)           | 478                                    | 67–6,672                                 | 52% (476)                                      | 31.8% (2912)                                    | 16.2% (1481)                                    |
| SES 3                                | 10,401           | 5,259.08                               | 431.3                               | 488 (318)           | 438                                    | 70–2,056                                 | 57.3% (5955)                                   | 35.5% (3696)                                    | 7.2% (750)                                       |
| SES 4                                | 1966             | 8,020.34                               | 59                                  | 407 (259)           | 376                                    | 49–2,009                                 | 65.3% (1283)                                   | 33.3% (654)                                      | 1.4% (29)                                        |
| SES 5                                | 813              | 9,967.98                               | 14.6                                | 414 (315)           | 325                                    | 65–1,536                                 | 71% (577)                                      | 21.1% (172)                                      | 7.9% (64)                                        |
| SES 6 (highest)                      | 529              | 17,663.06                              | 5.2                                 | 446 (419)           | 315                                    | 28–2,360                                 | 73.2% (387)                                    | 15.1% (80)                                      | 11.7% (62)                                       |
| Total                                | 24,158           | 4,816.83                               | 1,041.4                             | 565 (315)           | 444                                    | 28–6,672                                 | 55.6% (13,478)                                 | 31.7% (7666)                                    | 12.7% (3054)                                     |
SES 1 and SES 6, with a difference of 747m is worth highlighting in this study. Table 1 also shows that more than half of the blocks from SES 1 were located more than 1000m away, compared to only 16.2% for SES 2, 7.2% for SES 3, 1.4% for SES 4, 7.9% for SES 5, and 11.7% for SES 6. Thus showing a different view for the disparities found in this study. Since the majority of the blocks (52%) from SES 1 fall within a long range distance (more than 1000m) from the closest Cicloruta, compared to SES 6 where the

Figure 3. Map of Bogota distribution of bicycle lanes by SES. SES categories range from 1 – most disadvantaged, 2 – disadvantaged, 3 – middle, 4 – middle-high, 5 high, 6 – wealthiest.

Figure 4. Cicloruta planned but yet to be built in an SES 1 neighborhood. Photo taken by Jose David Pinzon.
majority of the blocks (57%) fall within a short range distance (less than 500m away to the closest bicycle lane), and given the limited transportation options from SES 1 versus SES 6 who would most likely have access to a car, investments in increasing the access of SES 1 to alternative means of transportation could be beneficial.

Many factors contribute to explain the low access of Cicloruta for SES 1. First, it is important to note that the majority of SES 1 in the city of Bogota were built in informal or unplanned development processes, which makes the public space in general and in particular the road infrastructure, insufficient, complex, and not fully developed (Thibert and Osorio 2014, Gomez et al. 2015). In addition, a map of the slope distribution of Bogota by SES, which can be seen on Figure 2, shows that neighborhoods located in the lowest (SES 1) as well as the highest SES (SES 6) are in hilly terrain with inclinations of more than 10% in some cases (Figure 2). However, it is important to note that this study excluded blocks that were located in terrain with slopes of more than 3%, thus the large gap between SES 1 and the remaining SES of the city found in this analysis, is still relevant. There is prior evidence showing that people from low SES, particularly 1, 2 and 3, use the bicycle as a means of transportation in Bogota with more frequency (2015b) mainly driven by an economic motivation, since riding a bicycle involves minimum monetary costs. A 2014 report by the Despacio Foundation, showed that 60% of bicycle trips in Bogota are made by people from SES 2, 28% by people from SES 3, and 7% by people from SES1 (Oliveros 2015). Time savings is another main cited benefit and reason for continued use of the bicycle as a means of transportation, an average bicycle trip in Bogota had a duration of 43 min compared to 97 min by car or public transportation in 2016. As a result, populations from low and middle SES are the ones that would likely benefit the most and have the greatest need for an appropriate bicycle network with higher accessibility and safety conditions.

The large difference observed in terms of block size and population density (Table 1) seen in this study is another factor that explains the differences
between SES 1 and the remaining SES classifications. The higher population densities are observed in SES 2 and 3, with 579.8 and 431.3 inhabitants respectively; whereas SES 5 (14.6 inhabitants) and SES 6 (5.2 inhabitants) have lower population densities. SES 1 and 4 are closer together with 67.8 and 59 inhabitants respectively. These differences are partly explained by the availability of land for public construction in Bogota, which is scarce and extremely pricy. In lower SES neighborhoods, blocks are smaller and denser, with fewer space for green zones and communal spaces as a way to maximize investment and return (Table 1). One of the results of this is that in many neighborhoods of lower SES, particularly 2 and 3, residents opt for vertical development, that is, building a second, third, or fourth floor in their dwellings, creating unequal urban design and in many cases violating density and public space norms, which can result in illegal and unsafe building constructions. On the contrary, higher SES neighborhoods have larger block areas and lower population density compared to lower SES neighborhoods (Table 1). They also have more public and private green areas and recreational zones, which were planned and abided by the normativity. In addition, although vertical development is present in higher SES, the constructions have larger spaces between them and are competitive in the market with higher construction quality and more amenities. Consequently, building of public infrastructure such as exclusive bike lanes is much more viable and easy in higher SES neighborhoods.

As seen earlier, more than 50% of the population in Bogota is from SES 1 and 2, and they are the ones more frequently using the bicycle for transportation, thus there is a need to improve multimodal mobility conditions for this population group. A study conducted by the secretary of transportation of Bogota shows as steady increase in bicycle use for population in SES 1 to 4 and a decline in SES 5 and 6. This suggests that infrastructure in these regions would be better used than additional infrastructure in areas of SES 6 which has not shown significant increase in bicycle use, possibly because of increased motorization and less population density. It is important to recognize that the majority of work places in Bogota are located in areas from SES 4 to 6, while SES 1 and 2 are in the city periphery with higher density and less financial resources for investment in infrastructure.

The current city administration of Bogota has pledged to improve cycling conditions in the city, including increasing the number of trips made by bike to 15% by 2020. However, no specific and measurable indicators are mentioned in the current administration plan, such as number of kilometers of expansion of the Ciclorutas and no mention of the spatial and socioeconomic inequities currently present in the city. In light of the current findings, more work and commitment is needed by the political administration of the city to continue making of Bogota a Bicycle friendly city and among the best and more recognized cities in the world for active transportation. Spatial and social inequities need to be acknowledged and recognized, and specific plans need to be develop to increase coverage in the areas of the city that are most in need of alternative means of transportation due to economic limitations of its population. Bogota is the city with the 4th highest most expensive public transportation. A secondary analysis of the present study (data not shown) revealed that populations in SES 1 and 2 are also significantly farther away from the network of BRT (Bus Rapid Transit System) also known as Transmilenio (mean distance of 4,025m for SES 1, and 2,185m for SES 2, compared to 1,223m for SES 6) and farther away from the network of feeder routes that reach the BRT (1,016m for SES 1 and 386.7m for SES 2 compared to 276 for SES 6).

In this sense, the population from SES 1, needs to overcome scarce and limited mobility options in order to move about in the city and reach destinations, this can have serious implications for work life, quality of life, and physical and mental health outcomes. In addition, only 20% of the population of Bogota uses a car as their primary means of transportation and they are overwhelmingly owned by people from SES 4, 5 or 6 (2015b). Moreover, due to the current exponential growth of the use of the motorcycle for transportation purposes and the implications that they have for worsening mobility in the city, increase rates of traffic injuries and fatalities, and increase air pollution (de Oliveira and de Sousa 2011, Chang et al. 2016, Pavanitto et al. 2018), the existence of alternative means of transportation such as the bicycle becomes even more relevant and needed. The competitive prices that companies are giving to motorcycles and the limited options for mobility among populations from SES 1 make of the motorcycle a very viable and likely option to improve their life conditions (Gomez et al. 2015, Parra et al. 2016). In conclusion, improving the conditions for cycling in Bogota, which include expanding the network of Ciclorutas to areas of low SES is something that the city can consider in order to address inequalities. If the goal is to address the needs of those highest dependent on bicycling, such as populations living in the most disadvantaged areas, then other cities could benefit from would benefit from the analytic approach used in this paper to assess access to cycle ways. Improving the conditions for cycling in a more equitable manner may involve expanding the network of bicycle lanes for populations living in less advantaged areas. However, it should be recognized that we
used secondary data for this analysis, and that this is a descriptive study rather than an inferential or predictive study. It is likely that more updated, direct and objective geographic data, as well as correlation analyses could change some results and, therefore, the conclusions of this study.

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