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Evolution of Urban Accessibility in Manizales, Colombia, 2010 – 2017

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Abstract

Objetives: The main target of this research is to assess the evolution of urban accessibility offered by the transport infrastructure network of the city of Manizales, Colombia, between the years 2010 and 2017. **Methods/Statistical Analysis:** The research methodology addressed includes the development of 4 phases: i) updating of the transport infrastructure network, where two scenarios were analyzed, the transport network for years 2010 and 2017; ii) calculation of urban accessibility in average global terms, based on isochrone curves obtained from travel time analysis and ordinary Kriging model with linear semivariograma as geostatistical method; iii) calculation of the percentage savings in travel times; and iv) calculation of sociodemographic variables coverage. **Findings:** Accessibility results in scenario 1 (2010 year) evidences the intention of resolving mobility issues within the city without considering the different peripheral sectors; concluding that high economic income neigborhoods had better accessibility conditions. The infrastructure interventions made by the municipal administration in scenario 2 (2017 year) improve the connection between Central Business District with peripheral sectors. The travel time savings obtained for the peripheral sectors, evidence the inclusion of resident citizenship in the different activities that take place in the city, improving the quality of life. However, this improvement in accessibility is practically limited to the private transport mode, which is contrary to what is sought in terms of sustainability. A middle income neighborhood presents the greatest benefits with a travel time saving of up to 15% in more than 60% of its population. Finally, close to 50% of the population perceives savings of up to 15% relataed with travel times in 2010. **Application/Improvements:** The methodological approach is a support for urban planning, because it is technical supports that show the impact over population by transport network transformations in travel time terms.

Keywords: Accessibility, Coverage, Development, Mobility, Transport Infrastructure

1. Introduction

The models of development and growth of a city are closely linked to the capacity of implementing the infrastructure basic services require, taking into account water, electricity, sewage, roads, among others, with the purpose of increasing productivity and minimizing the economic gap between members of the same society.[1,2] In other words, an adequate investment in infrastructure facilitates and stimulates the economic growth of a society.[3,4] Considering the above, it can be assumed that road infrastructure networks are one of the fundamental pillars of development, therefore, the evaluation of the road system's coverage, as well as the definition of possible areas of intervention, are necessary. Manizales, capital of the Department of Caldas, is located under the central mountain range at 5°3'58" northern latitude and 75°29'05" western longitude within the Colombian coffee

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region (Figure 1). It rests on the 2150 a.s.m.l.[5] and presents an abrupt topography that is characteristic of the area, thus limiting its urbanizing and expansion processes,[6] in some cases forcing the development of informal housing in peripheral areas of the municipality.[7] The city has a total area of 572 square kilometers,[8] of which approximately 35.11 squere kilometers (6.14%) correspond to its urban area, occupied by 371,345 inhabitants.[9]. In relation to the mobility of the city, there is a high percentage of daily trips made in sustainable means of transport: 52% in public transport, 14% on foot and 1% by bicycle. On the other hand, 19% of trips are made by motorcycle and 10% by private car. Additionally, 31% of the populations perceive that their current trips take more time than in previous years.[10] Bearing in mind that this research focuses on the city of Manizales, it is important to clarify that within the calculation processes it is necessary to link the urban area of the municipality of Villamaría, considering its strong economic and geographical connection, as well as the interaction between their inhabited nuclei.[11] Like Manizales, the municipality of Villamaría rests on one side of the central mountain range at 5°02'44" northern latitude and 75°30'55" western longitude, with a total extension of 462 km2[12] and a population projection of 48,636 by 2017.[9]

The connection between the municipalities is based on a paved road of 4 kilometers in length, which is the only alternative linked to the road infrastructure network of Manizales, on which the calculations are made.[13] The road infrastructure network includes the 2010 and 2017 scenarios in which the interventions made by the municipal administration are considered, in order to lessen the mobility problems presented throughout the study period. Once the study sector is defined, the internalization of fundamental concepts for the analysis approach becomes important, among which accessibility is established as a strategic axis in the development of the research. The first technical definition of the term dates back to the 1950s, when Hansen in 1959 defined accessibility as "the potential for interaction opportunities"[14]; however, the concept has been used since the second decade of the 20th century.[15] Other definitions of the term suggest the interaction between basic forms of human activity, such as mobility, communication, understanding[16] from different approaches: infrastructure, land uses, location, among others.[18,19]. Some examples of accessibility in different fields of science consider studies of transport planning[16-20,21], sustainability[17-22], access to services or opportunities[22-23], trade[24-26] and others. Thus, considering the basic concepts of accessibility and its function within

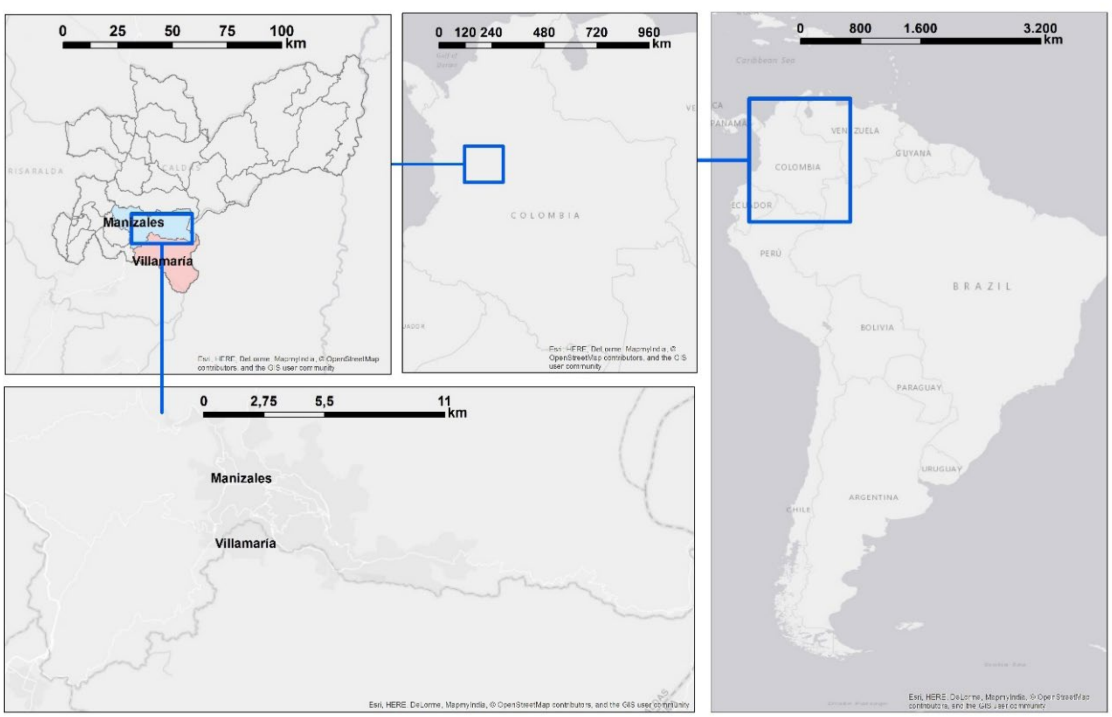

Figure 1. Geographical localization of study sector. Source: In.

our research, urban accessibility for the transport infrastructure network of Manizales and Villamaría is analysed and compared between the years 2010 and 2017, with the aim of evaluating the evolution of its coverage through socioeconomic variables after the interventions made by the municipal administration, as well as identifying sectors with access difficulties. After the brief introduction, the research methodology is presented; then, the results and discussion; and, finally, the main conclusions of the investigation are shown.

2. Methodology

The research methodology addressed includes the development of 4 main phases of a consecutive nature (Figure 2), which synthesize the calculation processes, as described.

2.1 Management and Updating of the Transport Infrastructure Network

Phase 1 includes the management and updating of the transport infrastructure network of the city of Manizales, obtained from the Mobility Plan[13] (Figure 3), composed of the system of nodes (intersections or points) and arcs (link or segment of track), in addition to the operating characteristics (speed, length, hierarchy, directionality, toponymy, typology). In order to evaluate the accessibility conditions between years 2010 and 2017, the network is refined for each scenario. Scenario 1 includes the state and functioning of the road network for the year 2010, which takes as reference the components established in the city's mobility plan to date; therefore, the refinement of the transport network is carried out without including additional modifications. Once the road network was revised and refined for 2010, it proceeded to define the interventions made by the municipal administration during the study period, which are subsequently linked to the study through the ArcMap tool, generating Scenario 2 (year 2017). In Figure 4, the location of the main interventions carried out during the period 2010 - 2017 is presented.

2.2 Calculation of Urban Accessibility

Once the two scenarios have been established, the urban accessibility based in the calculation of the isochrone curves is made from the travel time, which considers the

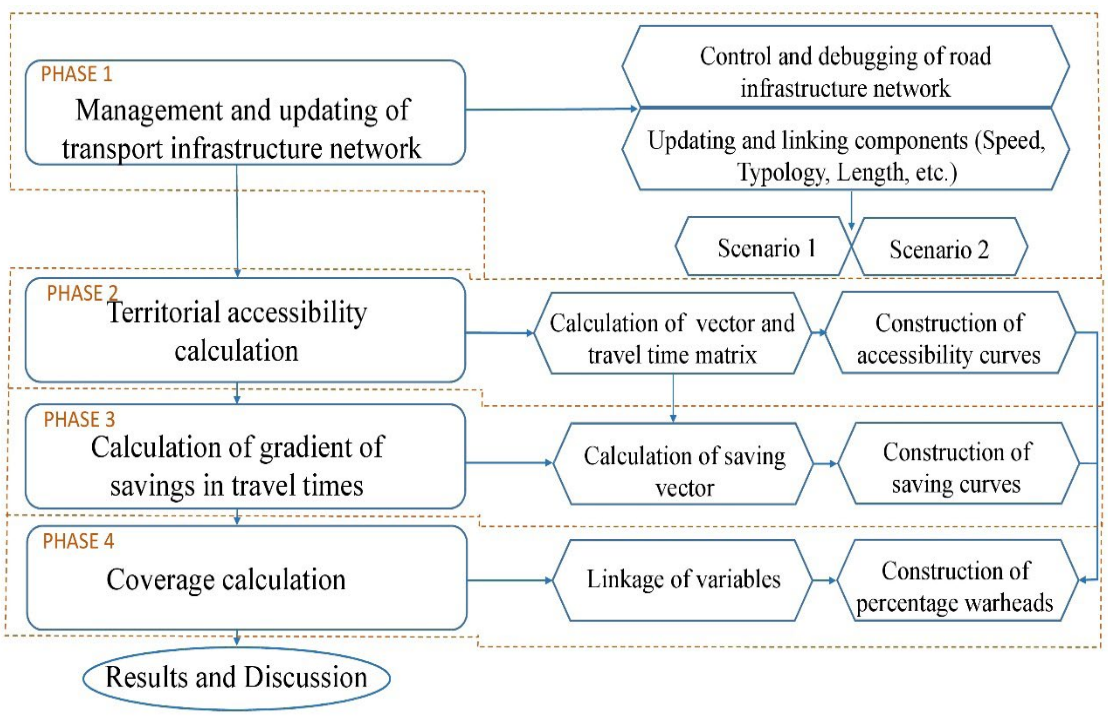

Figure 2. Research methodology. Source: In.

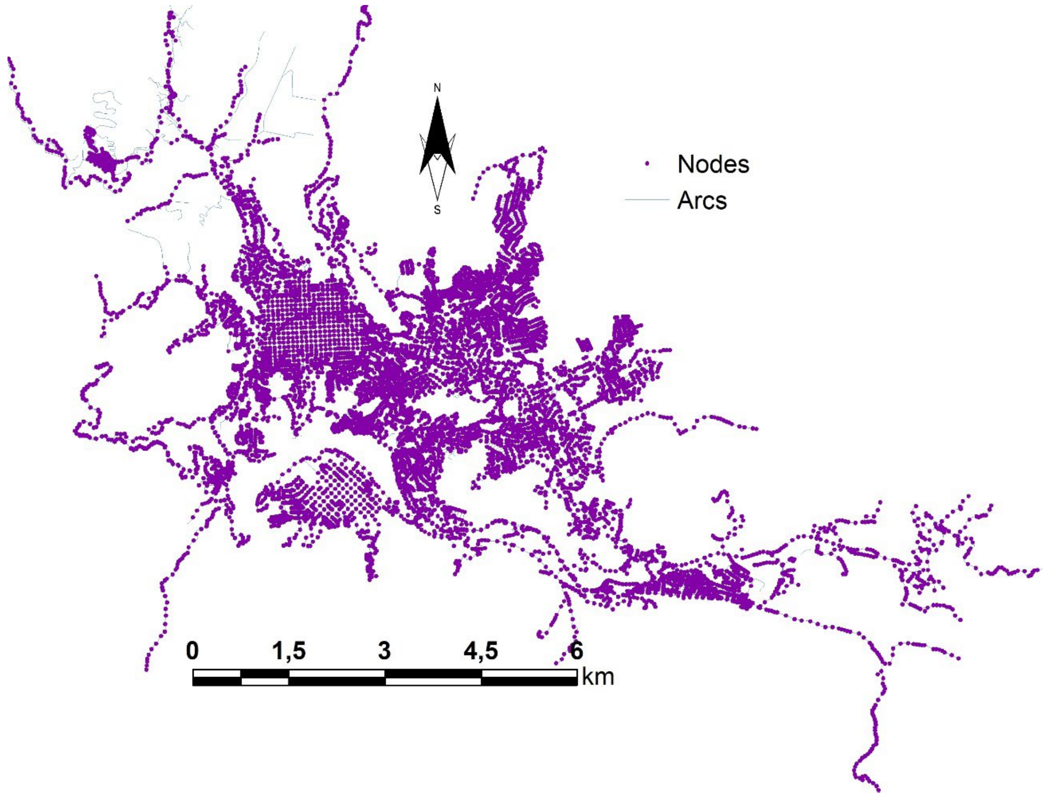

Figure 3. Road infrastructure network of Manizales (2010 year). Source: In.

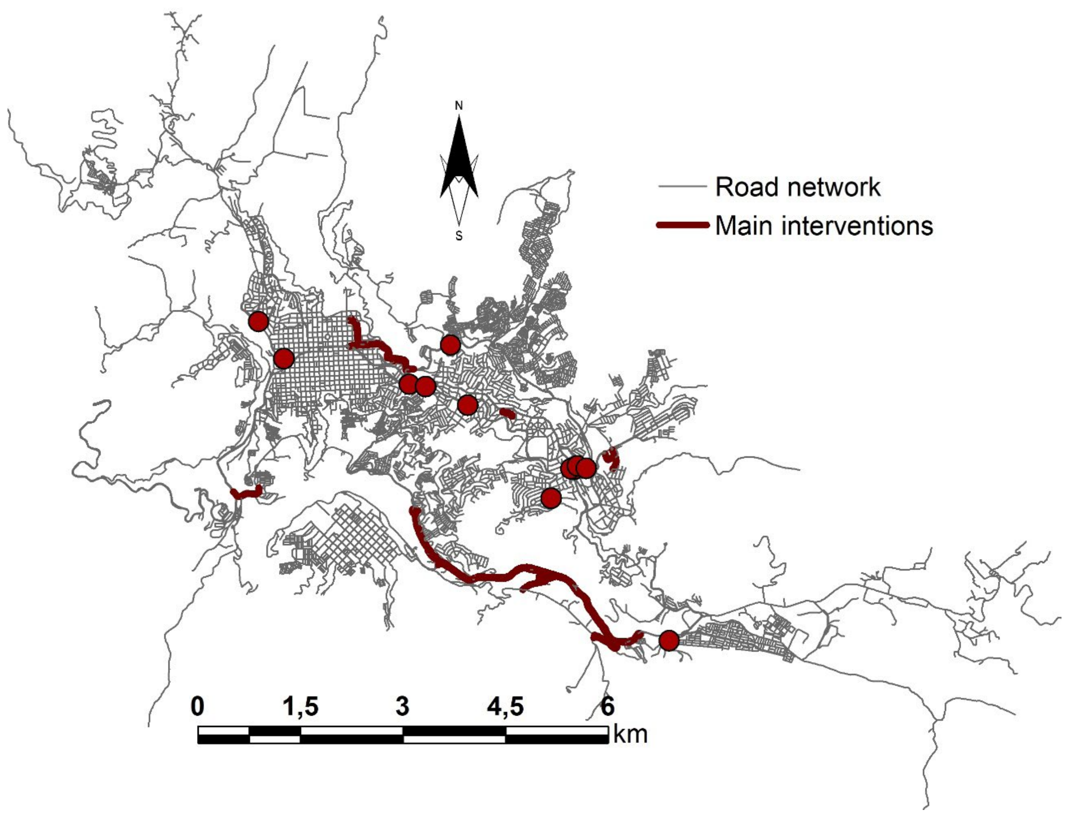

Figure 4. Main interventions on transport infrastructure network of Manizales (2017 year). Source: In.

cost of traveling over each arc by means of the speed and length relationship as shown in Equation (1), where: Tv_i = average travel time through the arch; L_i = Length of the arc; V_i = speed of the arc.

$$Tv_i = \frac{L_i}{V_i} \qquad i = 1,2,3,\ldots,n \tag{1}$$

After obtaining the cost of travel over each arc, the travel time matrix is calculated, where the minimum path is determined from a node of origin i one of destination j (Dkjistra Algorithm), to later determine the average travel time of each node through Equation (2)[27], where: tv_{ij} = Travel time from node to node; n = Total number of nodes analyzed.

$$\overline{Tv_i} = \frac{\sum_{j=1}^{n} tv_{ij}}{n-1} \quad i = 1,2,3,\ldots,n;\ j = 1,2,3,\ldots,n \tag{2}$$

Finally, the travels times are related to the geographical coordinates of each node and, through geostatistical calculations, the isochronous curves are constructed. The Geostatistical method used is the ordinary Kriging with linear semivariogram, where the semivariogram characterizes the dependency properties between nodes of the same field observed by Equation (3), where:[23] $Z_{(x)}$ = Value of the variable for a node with coordinates; $Z_{(x+h)}$ = Next sample value separated by a distance; n = Number of pairs separated by the distance.

$$\overline{\gamma_{(h)}} = \frac{(Z_{(x+h)} - Z_{(x)})^2}{2n}$$

2.3 Calculation of the Percentage of Savings in Travel Times

As a next methodological step, we proceed to construct the isochronous savings curves, by means of the relation of travel times between scenario 1 and 2 by means of Equation (4), where: $Saving_i$ = % of savings per node ; $Tv_{i(Sceanrio\_1)}$ = Travel time of node in the current scenario; $Tv_{i(Sceanrio\_2)}$ = Travel time of node in the future scenario.

$$Saving_i(\%) = \left(\frac{tv_{i(Scenario\_1)} - tv_{i(Scenario\_2)}}{tv_{i(Scenario\_1)}} \right) * 100$$

The relationship obtained from the travel time vectors is subjected to the Geostatistical treatment described in phase 2. A representative map of the variation in travel times generated by the implementation of transport interventions is obtained via ArcMap.

2.4 Coverage Calculation

As a final methodological phase, the socioeconomic variables to be related are researched, within which there is an area, population and socioeconomic stratification. This last variable includes the classification of the population according to socioeconomic status in a hierarchical manner[28]. In the case of Manizales, there is a total of 6 socioeconomic strata, 1 being the lowest economic capacity and 6, the highest economic capacity. Once the variables to be related have been selected, they cross over to the information obtained for each scenario, including the gradient, by means of the "Geoprocessing" extension of ArcMap; then, the data management is done through Microsoft Excel and with this build the cumulative percentage coverage curves.

3. Results and Discussion

3.1 Scenario 1

Figure 5 shows the variation in travel time for scenario 1, corresponding to the year 2010 at 5-minute intervals. It is observed that the shortest travel time is 25 minutes, located towards the center of the image on the corridor of Av. Santander. The characteristics of mobility for this year guaranteed a better displacement towards the nodes located in the Central Business District (CBD), leaving aside peripheral residential focus such as the "La Linda" (Sector North-West) and the Enea - Maltería (Sector South-East), which need up to 75 minutes of travel time.

Figure 6 shows the level of coverage accumulated by socio-economic stratum for scenario 1. For the curve from 30 to 35 minutes in travel time, stratum number 5 achieves a percentage of coverage greater than 90%, followed by stratum 6 with 65% and stratum 2 with 59%. On the other hand, strata 1 and 3 present the most unfavorable coverages for the same time interval with values of 33% and 40% respectively. After 35 minutes in travel time, there is a considerable separation by stratum number 3, finally needing 55 minutes to replace 90% of its population.

As a complement, Figure 7 is constructed, where the variation of accumulated coverage by population and area

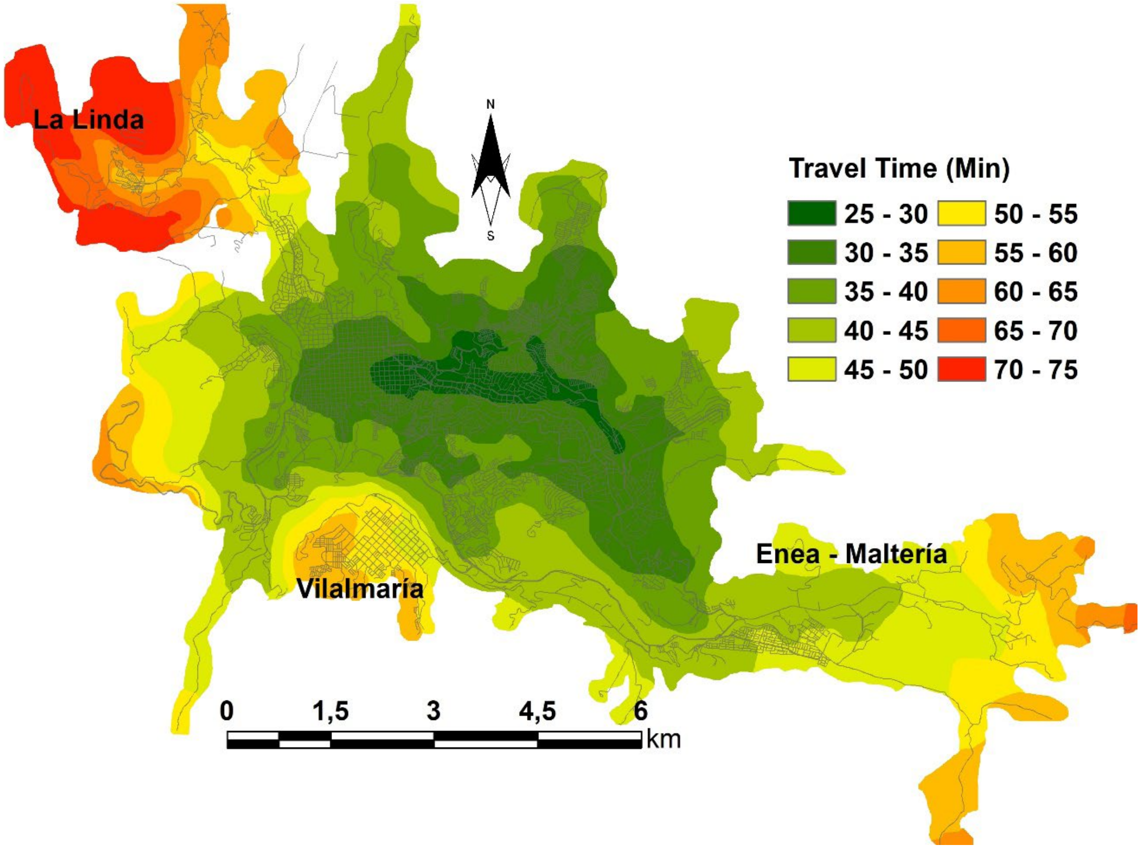

Figure 5. Urban accessibility curves for scenario 1 (2010). Source: In.

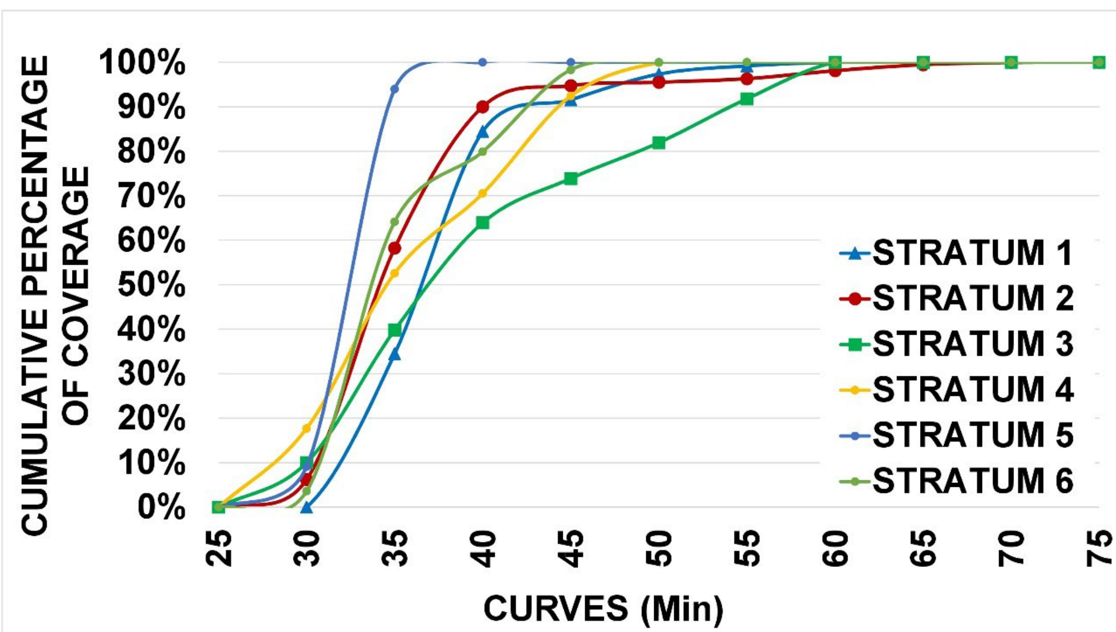

Figure 6. Accumulated percentage of coverage by socioeconomic stratum in scenario 1. Source: In.

is observed, with a separation between curves of up to 33%, generated by the high concentration of population towards the center of the city in relation to the surface that they occupy. Thus, for 50% of accumulated coverage for population and area, a travel time of 36 and 45 minutes respectively is required.

3.1 Scenario 2

As a result of the interventions made by the municipal administration throughout the period between 2010 and 2017, Figure 8 was constructed. In it, the behavior of geographic accessibility at 5-minute intervals is appreciated, with a minimum value of 25 minutes and a maximum of 75 minutes. In relation to the current scenario, there is a strong expansion of coverage towards the eastern sector of the city, as well as in the south and northwestern sectors.

Figure 9 shows the structure of the cumulative coverage curves according to the socioeconomic stratum. A similar behavior between curves is identified for a travel time of less than 33 minutes. After this time, the warheads representative of strata 3, 4 and 5 are separated achieving values of 59%, 58% and 93%, respectively.

Additionally, Figure 10 is presented. It identifies the variation of accumulated coverage by population and

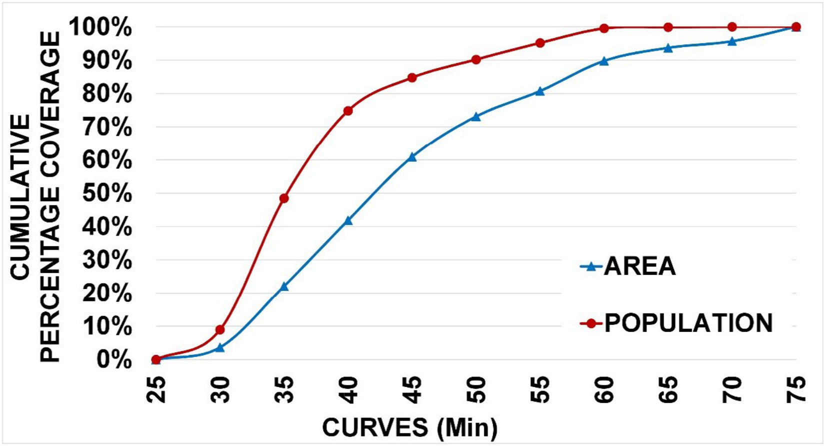

Figure 7. Accumulated percentage of coverage by population and area in scenario 1. Source: In.

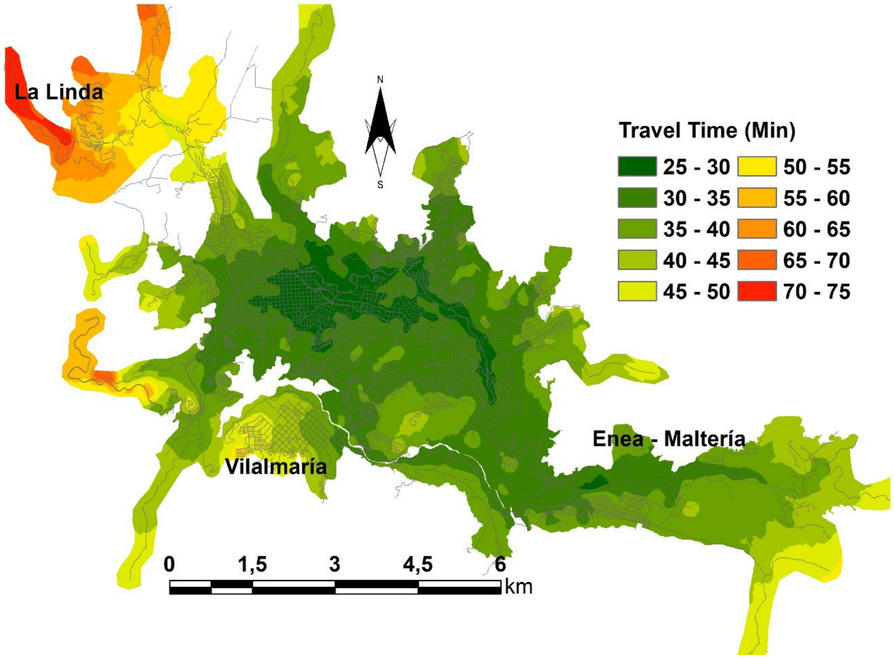

Figure 8. Urban accessibility curves for scenario 2 (2017). Source: In.

area, which requires a travel time of 35 and 38 minutes to supply 50% of its component, in addition to keeping the separation between ojives described in scenario 1.

3.3 Travel Time Savings Analysis

Taking into account the results presented in Figures 5 and 8, the calculation of the percentage of savings obtained by scenario 2 in relation to scenario 1 was made and, as a result, Figure 11 was obtained. It shows the variation of savings at 5% intervals, thus identifying the sectors of the city that benefit most from the interventions made. It is observed that the Middle East sector of the city contains the lowest savings, with a percentage lower than 5% in its great majority; as an opposite case, the greatest benefit is evidenced by the Enea – Malteria (southeast) share with values of up to 40% in savings, followed by Villamaría (south) and finally the area of La Linda (northwestern).

Figure 12 shows the cumulative percentage of coverage according to socioeconomic stratum, for each saving value obtained. Strata 1 and 3 present the greatest benefits with a perceived travel time saving of up to 15% in more than 60% of its population, which reflects a better quality of life by requiring less time to travel. On the other side of the graph, strata 4, 5 and 6 show the lowest travel time savings. Number 5 corresponds to the lowest coverage with a value of up to 15% perceived by 12% of its population. The observed separation between curves, as well as the location of the savings in Figure 12, shows that the vast majority of the populations belonging to the lower

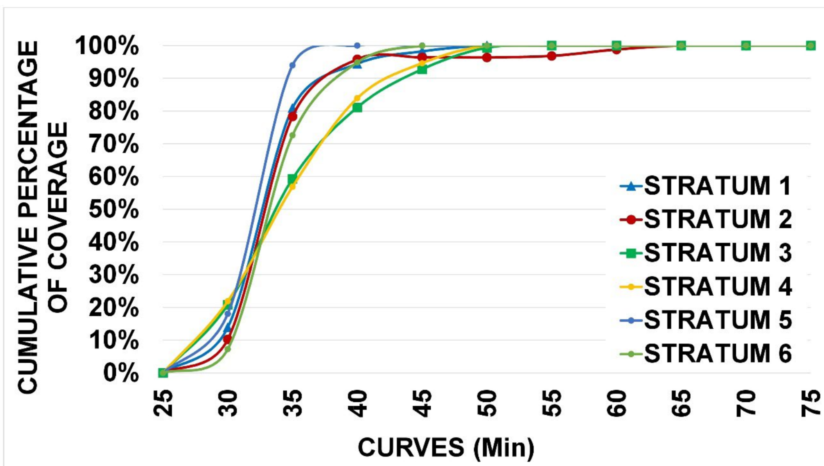

Figure 9. Accumulated percentage of coverage by socioeconomic stratum in scenario 2. Source: In.

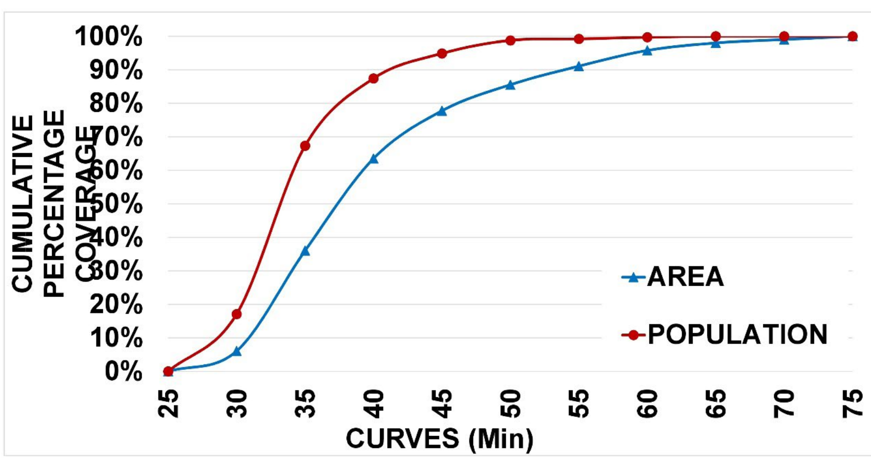

Figure 10. Accumulated percentage of coverage by population and area in scenario 2. Source: In.

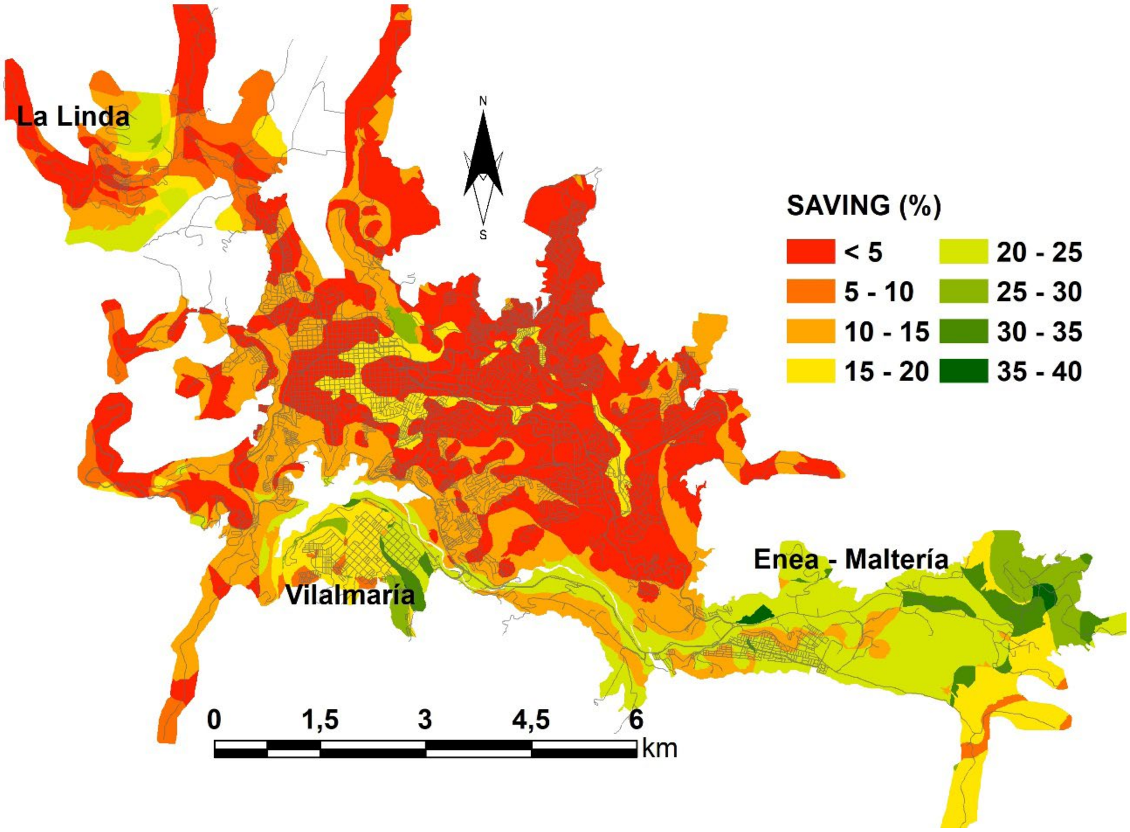

Figure 11. Savings percentage curves. Source: In.

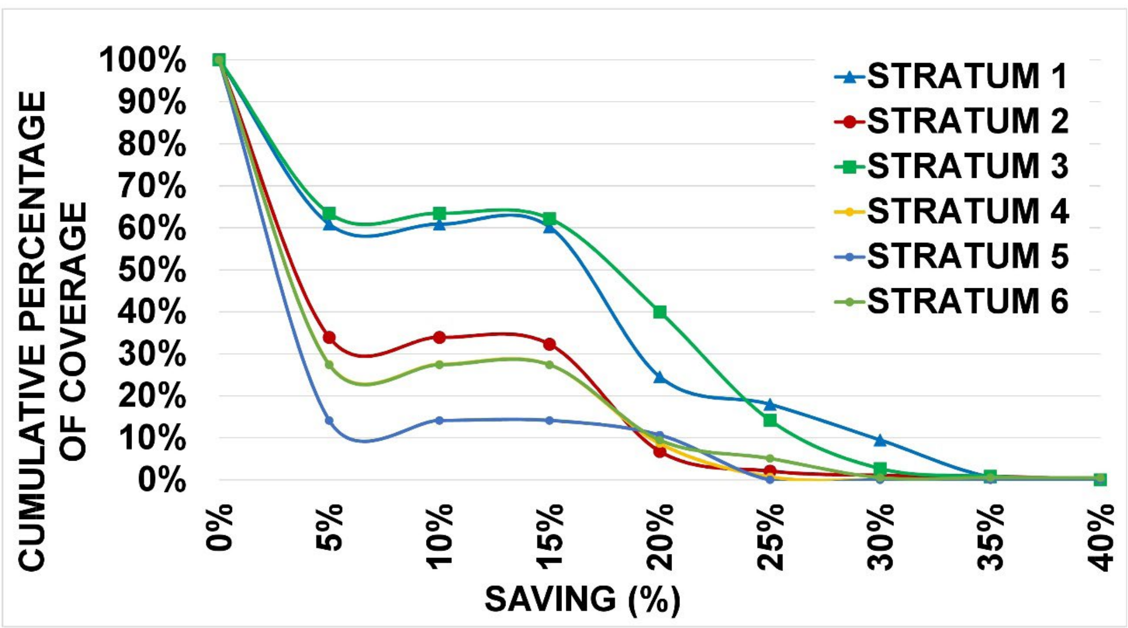

Figure 12. Accumulated percentage of coverage according to the perceived savings. Source: In.

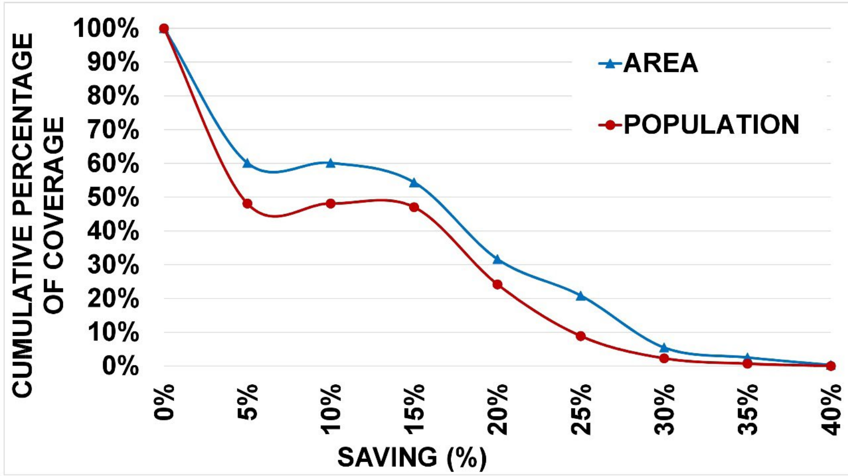

Figure 13. Accumulated percentage of coverage of population and area according to the perceived savings. Source: In.

socio-economic strata reside towards the peripheral areas of the city, which leads to possible social exclusion. However, once the interventions are made to the transport infrastructure network, access is guaranteed. Finally, in Figure 13, the cumulative percentages of coverage are taught according to the savings obtained by population and area. Close to 50% of the population perceives savings of up to 15%, while the area related to that same saving is around 54%.

4. Conclusion

The behavior of accessibility in scenario 1 evidences the intention of resolving mobility within the city without considering the different peripheral sectors in which a significant percentage of the population resides. The interventions made by the municipal administration in scenario 2 facilitate the connection of important population centers such as the Enea and Villamaría, thus ensuring an improvement in travel time for these sectors located in the periphery. The savings obtained for the peripheral sectors, evidence the inclusion of resident citizenship in the different activities that take place in the city, improving the quality of life, besides guaranteeing the right to the city. However, this improvement in accessibility is practically limited to the private transport mean, which is contrary to what is sought in terms of sustainability. Although the average travel time saved for the "La Linda" sector (northwestern) is significant, it is advisable to analyze alternative proposals in order to maximize the level of access in the sector, thus allowing efficient communication among the population of this area and the rest of the city.

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