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Impact Assessment through Territorial Accessibility of the Set of Road Intervention Projects for the 2030 Skyline in the Municipality of Quibdo, Colombia

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Abstract

Objectives: To Minimize the cost in travel time for inhabitants, while maximizing the quality of life, guaranteeing social and economic growth of the municipality. **Methods/Analysis:** It is proposed to carry out evaluation of impact of road interventions based on territorial accessibility through geostatistical analysis, as well as the linkage of major socio-economic variables, using digital tools (ArcMap, Microsoft Excel, and TransCad). **Findings:** Applied mechanics allows efficient interpretation and replication of the impact assessment generated by road interventions, based on territorial accessibility, ensuring an effective decision making in the future, in order to generate a greater economic and social benefit for the city. **Application/Improvement:** The evaluation through accessibility facilitates the location of critical points in mobility, allowing focusing resources and improving the quality of life of the surrounding population.

Keywords: Accessibility, Development, Geostatistics, Mobility, Road Infrastructure

1. Introducción

The city of Quibdo, capital of the department of Choco, is located at 76°39'40 "east longitude and 5°41'13" north latitude, on one side of the Atrato River (Figure 1), on the Colombian pacific region[1]. The municipality has a total area of 3337.5 km2[1] and a total population of 115,711 inhabitants estimated at 2015[2]. Within the total area, only 0.59% (19.85 km2) represents its urban area, on which 93.02% of the population rests.

In terms of mobility, the largest proportion of vehicles in circulation on the city's roads are motorcycles, with percentages ranging between 80% and 88%, followed by light cars with between 8% and 10%, while the remaining percentage is distributed among freight vehicles and public transport[3]. Citizens' perception of travel time reveals that 45% of the population considers that time has not increased, followed by 43% who consider the journey requires a longer time while only 13% perceive a reduction in the travel cost[4]. The configuration or geographical distribution of the urban area of the city (Figure 2) shows limitations in the expansion processes in its road infrastructure network, which implies an increase in congestion and minimizes the possibility of interaction between traffic generators and attractors Taking into account the described, it is prudent to carry out the intervention of some road corridors in the municipality in order to determine impact on the territorial accessibility of the city.. The analysis for medium-term interventions will be carried out based on the projects proposed by the integral mobility plan for the city[5].

Prior to explaining the investigation, it is necessary to internalize the concept of accessibility mentioned above, which is its main tool and which evaluates the different interventions proposed.

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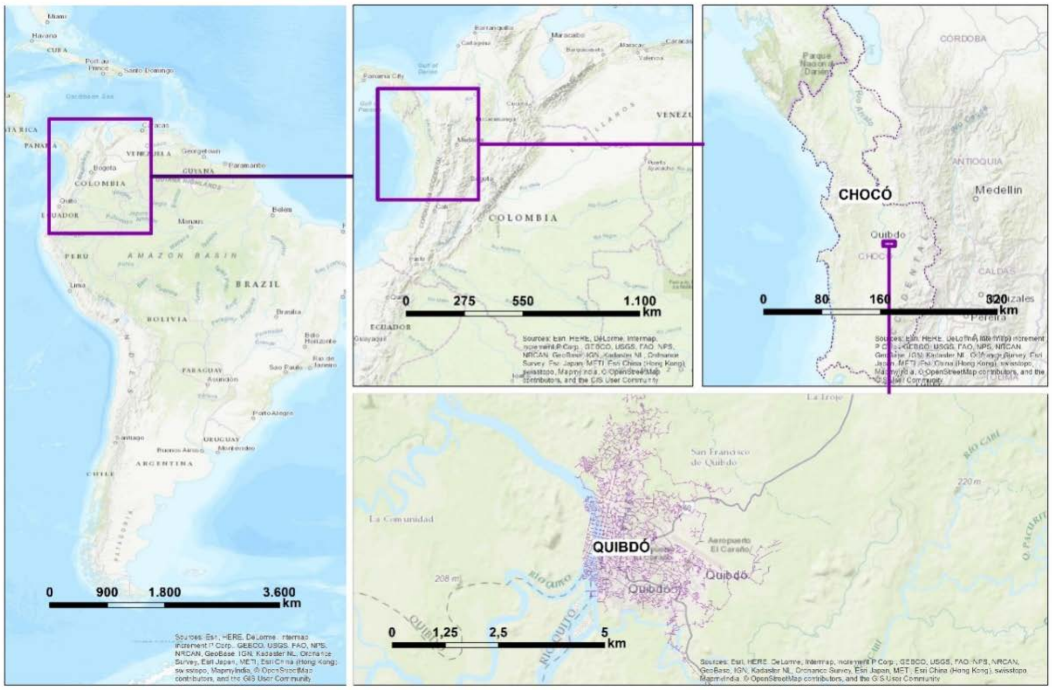

Figure 1. Geolocation of Quibdo.

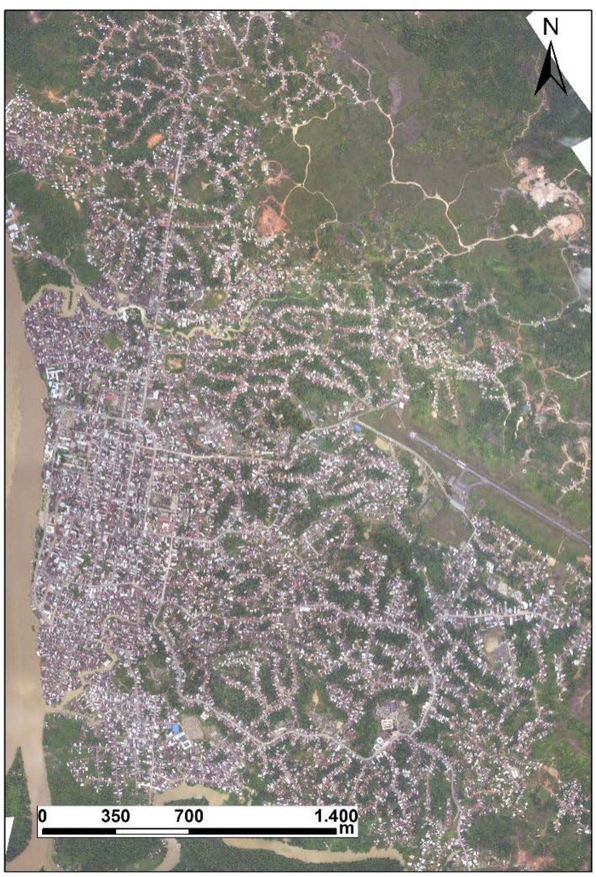

Figure 2. Aerial view of Quibdo.

The concept itself relates the ease of access between points of a system; however, in this field of application, this ease of access is conditioned to the existing transport infrastructure[6]. Taking this into account, different and very detailed definitions can be established, all starting from the same line established by Hansen (1959), "the potential of opportunities for interaction"[7], without limiting or losing enriching nuances present in classical definitions[8].

In this way, the term can be established as a set of interactions between basic forms of human activity, like the possibility of communication, mobility, understanding[9,10]; and observed or approached from different elements: land uses, infrastructure, location, among others[11,12].

Accessibility is evaluated from generating nodes or travel attractors, which consider the representation of potential users on a transport network (origin), motivated by an objective (destination) attractive enough, which generates the need to overcome the difficulty of tracing the trajectory[13].

Some applications of accessibility from different points of view can be observed in: public transport[6,14], transportation planning[9,13,15], social exclusion[12,16], trade[17,18], access to services[19,20], among others.

2. Materials and Methods

The methodology proposed for the approach to this investigation consists of 5 consecutive stages described and shown in Figure 3.

2.1 Characterization and Optimization of the Road iInfrastructure Network

As a first methodological component, the existing bibliographic and digital resources are intensively investigated for obtaining and characterizing the road infrastructure network of the city of Quibdo, originated on the present network from the diagnostic file of the integral mobility plan of the municipality (see Figure 4)[3]. The characterization and optimization is carried out through the use of the ArcMap tool, which facilitates the process and guarantees a better result.

The road infrastructure network consists of the set of nodes (space of convergence between transport networks) and arcs (continuous line joining two nodes together), spatially distributed, which contain the geometric and operational characteristics of the road system of the municipality. Speed, directionality, topology, typology, length, hierarchy, among others, are found within the components that make up the road network.

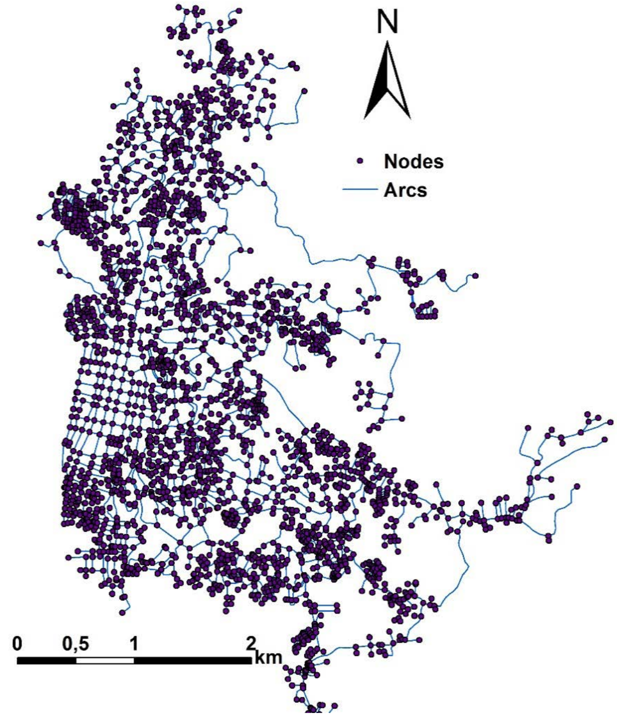

Figure 4. Road network for the city of Quibdo.

2.2 Formulation of Study Scenarios

As a next methodological phase, the necessary scenarios for the evaluation of the intervention were established.

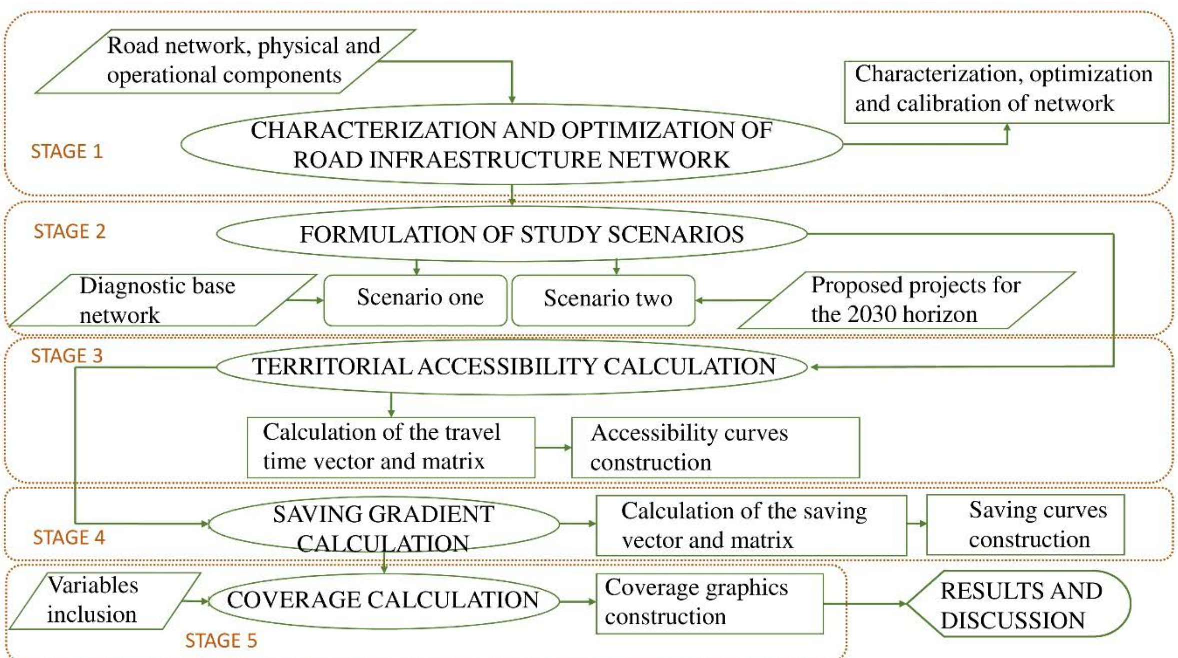

Figure 3. Aplicated methodology.

Scenario 1

In this first scenario, the calculation of territorial accessibility for road network in the current situation in the municipality is carried out. That is, the existing vehicular network is used, without making changes in its structures' background and form.

Scenario 2

As a second scenario, it was proceeded to characterize and locate, on the current network, the interventions proposed in the formulation document of the integral plan of the municipality, for 2030. The interventions consider the construction of roads, maintenance and/or improvement, in addition to the construction of bridges and necessary structures[5].

2.3 Calculation of Territorial Accessibility

In this methodological phase, it was proceeded to construct territorial accessibility curves globally for each scenario. The structuring of curves focuses on the formulation of the travel time vector, which considers the displacement cost for each arc, considering speed and length, as observed in Equation 1, where Tv_i is the travel time in the arc i, L_i the length and V_i the speed[21].

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

After calculating the displacement cost for eacheach arc, we proceed to determine the minimum trajectory, when moving from a node of origin i and a destination node j, by using the Dkjistra algorithm, and thus assemble the matrix of average times displacement by Equation 2, where Tv_i is the average travel time of node i, tv_{ij} travel time from node i to node j and n the total number of nodes[21].

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

It is important to clarify that the Dkjistra algorithm determines the shortest path between a node of origin O and one of destination F. If there is a connection between these, it accumulates the cost of travel between the nodes, considering the displacement on the other points. In the absence of any connection, the process will be canceled and the route will be eliminated as it cannot reach its objective[22,23].

After obtaining the travel time values, the accessibility curves from geostatistical handles were constructed, using the ordinary Kriging projection method. This method characterizes the existing dependency between points of a same system observed by Equation 3[22].

$$\overline{\gamma_{(h)}} = \frac{\sum \left(Z_{(x+h)} - Z_{(x)} \right)^2}{2n} \tag{3}$$

$Z_{(x)}$ is the value for variable in node with x coordinates, $Z_{(x+h)}$ next value at a distance h and finally n, is the number of couples distanced by h.

2.4 Calculation of Saving Gradient

Obtained the accessibility curves, builds the savings gradient to determine the percentage of savings obtained from the proposed interventions in scenario 2 with respect to scenario 1. The construction of the curves is linked to the time relationship between the two scenarios and is obtained by equation 4.

$$Savings_i (\%) = \left(\frac{tv_{i(act)} - tv_{i(fut)}}{tv_{i(act)}} \right) * 100$$

In this equation, $Savings_i$ is the saving percentage for the node i, $tv_{i(act)}$ is the travel time in scenario 1 for the node I and $tv_{i(fut)}$ is the travel time in scenario 2 for node i. Subsequently, the Geostatistical model is executed in the same way as in the calculation of accessibility curves and thus the isochronous savings curves were obtained.

2.5 Coverage Analysis

Finally, in our last methodological item, an exhaustive review of the socioeconomic variables to be linked was carried out, within which there was population, area and dwellings. Once the variables were established, the results obtained from the accessibility and savings were interlinked using the ArcMap tool under its "Geoprocessing" extension, in order to later process the data in Microsoft Excel and thus construct the coverage graphs. It is important to clarify that the variables of population and housing are affected in scenario 2, due to the population growth established by the National Administrative Department of Statistics (DANE) for the year 2030, which directly influences the calculation of coverage. For scenario 1, there was a population of 107,634 inhabitants by 2015 and a total of 28,932 homes; while for 2030, the established population is 127,554 inhabitants and 33,287 homes[2].

3. Results and Discussion

3.1 Proposed Interventions

Within the framework of the integral mobility plan for the municipality of Quibdo, the sequence of interventions related to 2030 is established[5] (see Figure 5). Each intervention has a considerable impact on the mobility of the system; therefore, it is strictly necessary to incorporate each of the interventions on the current network, maximizing the benefits when moving in the sector. The proposed interventions are the following:

- Construction of 5.6 kilometers of roads that is currently underway.
- Rehabilitation of 96 meters of roads in bad condition.
- 907 meters of functional improvement of pavements.
- 4.3 kilometers of double carriageway distributed in several points of the city.
- Construction and opening of 200 meters of tracks.
- Construction of 2 bridges of great importance in the mobility to the north and southeast of the municipality.

3.2 Analysis of Territorial Accessibility at a Global Level

Scenario 1

Figure 6 shows the territorial accessibility curves for scenario 1 (current condition) which shows the behavior of urban mobility in the municipality of Quibdo. The variation between curves is presented every 0.5 minutes with its lowest point in the 12 minutes and the highest in 33 minutes towards the periphery. A great part of the municipality manages to be covered in a time of less than 30 minutes, largely due to the extension of the city. The maximum values are presented in the sectors of "El Futuro" and "Barrio Obapo", generated by their extreme condition and precariousness in some roads. It can be assumed then that mobility in scenario 1 allows the displacement of citizens in a relatively low time in relation to other cities of

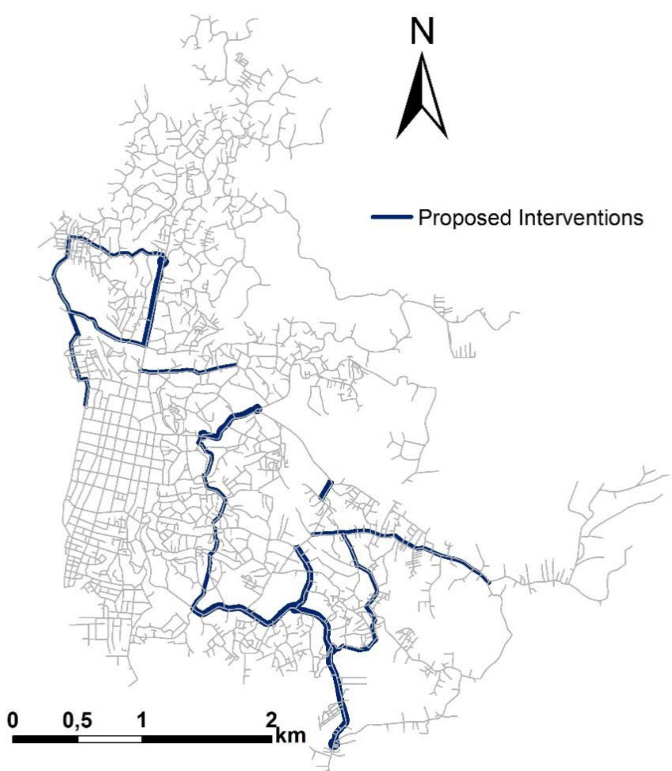

Figure 5. Proposed interventions for 2030.

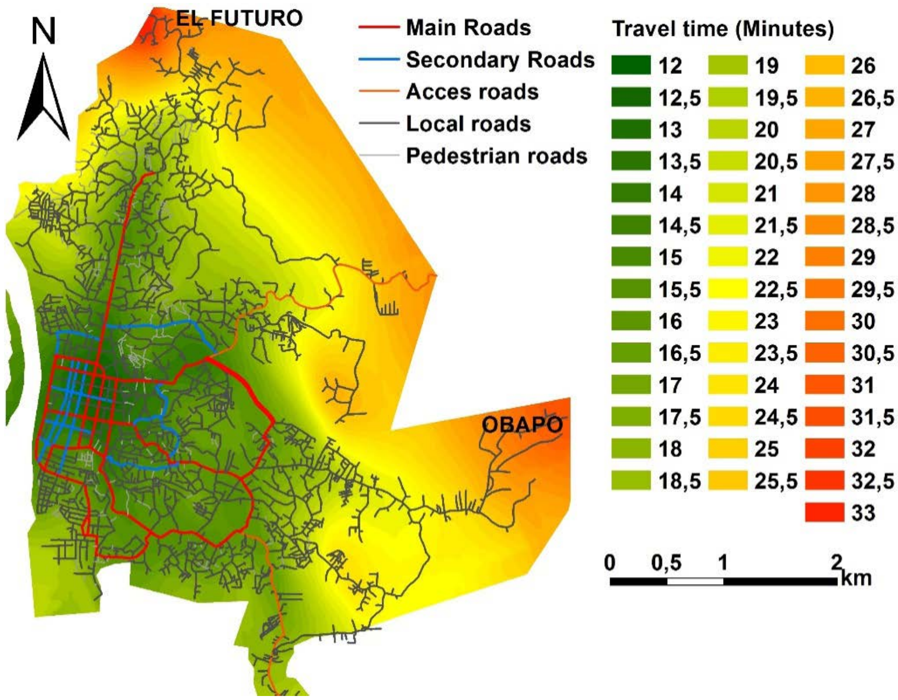

Figure 6. Isochronous curves for scenario 1.

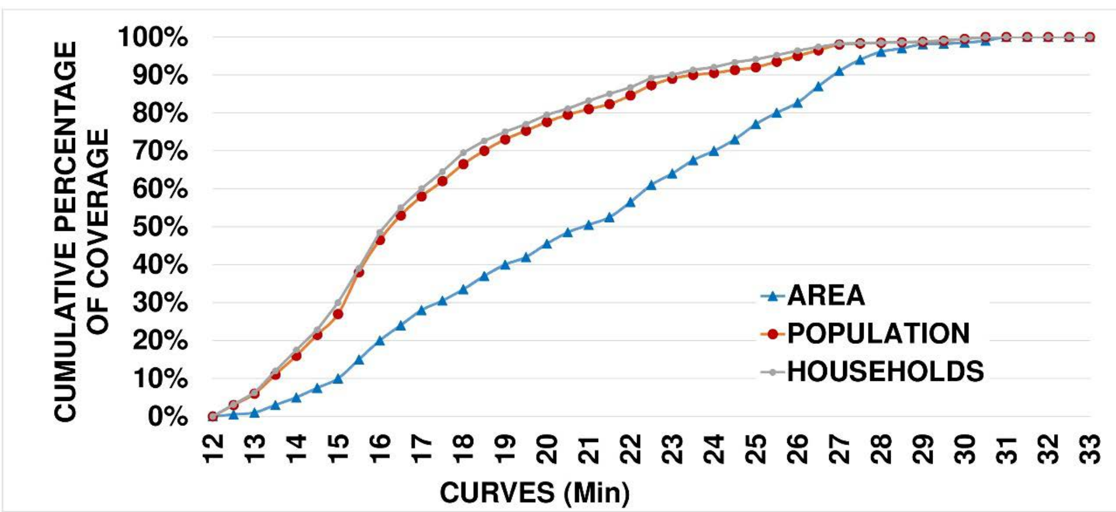

Figure 7. Accumulated percentage for variables in scenario 1.

the world[24,25]. However, the urban area of the municipality is not large enough to support travel times obtained, which is why future intervention is necessary to reduce the time, improve the rolling surface and minimize congestion.

Figure 7 shows coverage by area, housing and Population offered in scenario 1. It can be interpreted from the graph that the location of the population and its dwellings is given to and inside the urban area, thus managing to cover 70% in a displacement time less to 20 minutes, while for 50% of area, a displacement time less to 21 minutes.

Scenario 2

After carrying out the respective interventions on the initial network, Figure 8 was obtained, which shows the

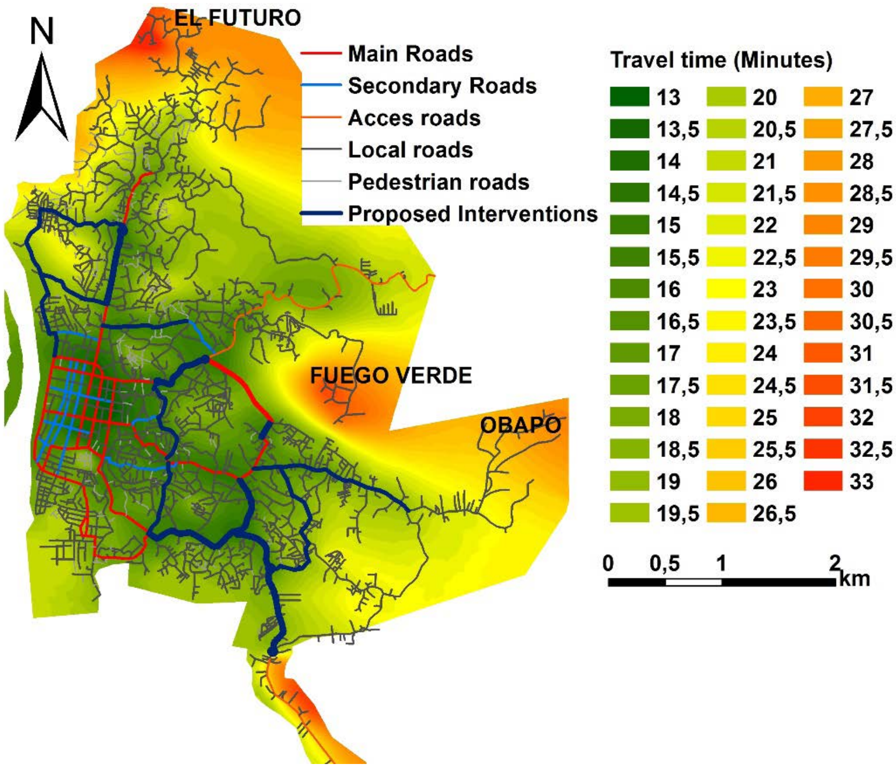

Figure 8. Isochronous curves for scenario 2.

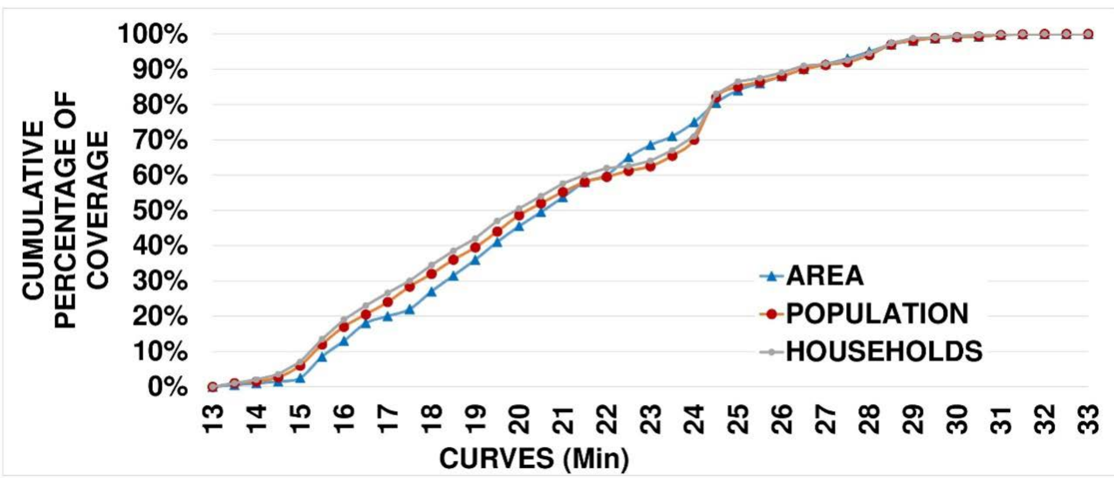

Figure 9. Accumulated percentage for variables in scenario 2.

territorial accessibility curves at the moment of operating the set of projects for 2030. The variation between curves, as in Scenario 1, is separated every 0.5 minutes, presenting their minimum value in 13 minutes and the maximum in 33 minutes. There is an expansion of the isochronous curves less than 20 minutes in travel time to the northeastern and eastern sectors of the city, which shows a significant contribution from road interventions in mobility.

In Figure 9, the results obtained for each socioeconomic variable considered are presented. A similar behavior between curves is observed with an overlap between 22 and 26 minutes of displacement time. In adition, for the housing and population considered in the horizon

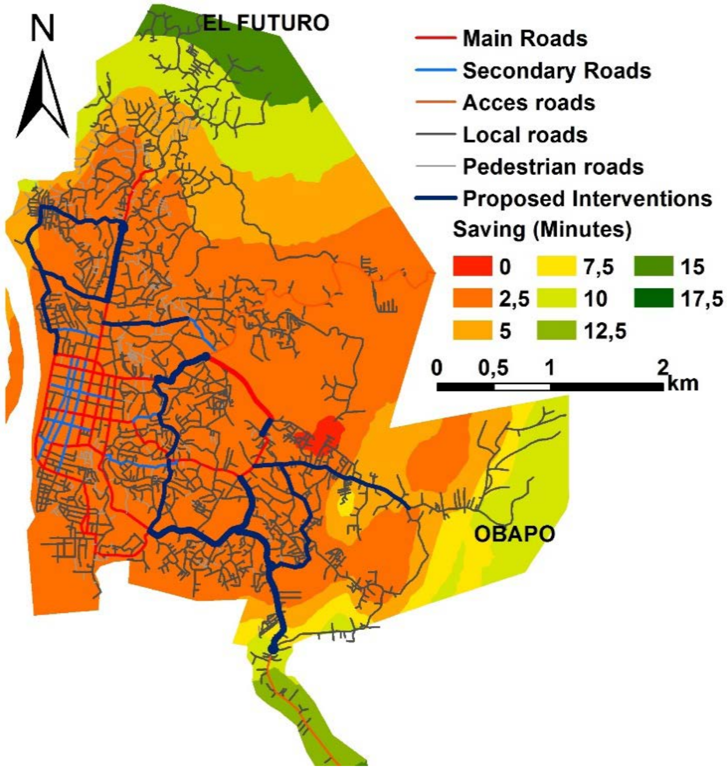

Figure 10. Savings curves for the proposed interventions for 2030.

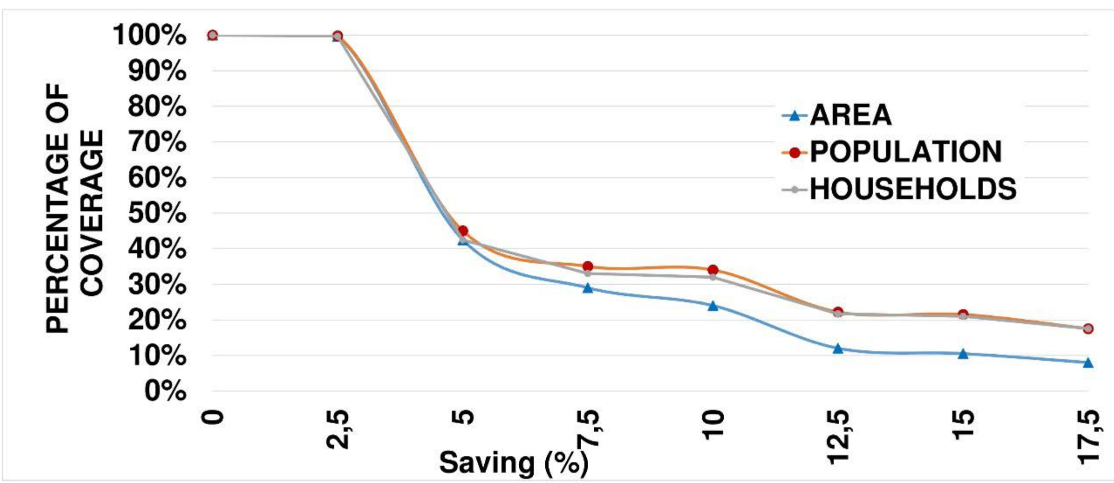

Figure 11. Savings percentage according to variables.

2030, a travel time of at least 22 minutes is required to cover 50% of these. In counterpart, the covered area presents a slight improvement in relation to scenario 1, by achieving over 50% in less than 21 minutes.

3.3 Savings Gradient

Once the accessibility curves for each scenario have been obtained, the savings curves observed in Figure 10 were constructed. In it, the variation is presented every 2.5%, identifying a maximum value of 17.5% of savings towards the peripheries of the municipality.

In more than 90% of the surface, savings are perceived, the vast majority of which are up to 2.5%. However, the greatest impact is on the Obapo and Futuro sectors, with percentages higher than 12.5%, thus guaranteeing a better connection in view of the social and productive inclusion of the population.

Finally, in Figure 11, the results of the perceived savings for each variable considered are presented, showing that 40% of the housing, area and population, perceives savings of up to 5%. After this mark, for population and area, around 20% perceives a saving of up to 15%, while the area perceives a saving of up to 10% in the same coverage limit. This variation between curves it's because incorporation of the projects focuses, mainly, on improving the conditions of displacement of the population, which implies an improvement in the quality of life.

4. Conclusion

The impact generated by the proposed interventions for 2030, evidence a considerable improvement in the mobility of the city. This is supported by the results obtained for the gradient of savings, where values are achieved in the majority of the surface of 2.5 Figure %, as well as a perceived maximum of 17.5% in the peripheries of the municipality.

In counterpart, the proposed interventions for 2030 can be assumed as elements of social and productive inclusion of the peripheral populations, guaranteeing a better displacement towards the interior of the city, in addition, it maximize the quality of life of the citizen, by decreasing the amount of time devoted to transport..

Additionally, it is required to carry out a transport demand analysis in order to evaluate the proposed interventions and complement the results obtained in the present investigation, considering models of public, private, autonomous transport, among others.

Finally, the analysis of territorial accessibility can be globally assumed as an efficient tool in the evaluation of interventions, guaranteeing logical and significant results, presented from easily interpretable graphic elements.

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