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Accessibility Analysis towards Urban Ecoparks as a Measure of Integral Environmental Planning - Case Study: Manizales, Colombia

Diego Alexander Escobar[1], Jorge Alberto Montoya Gómez[1], and Carlos Alberto Moncada[2]

[1]Universidad Nacional de Colombia, Sede Manizales, Departamento de Ingeniería Civil, Colombia; daescobarga@unal.edu.co, joamontoyago@unal.edu.co
[2]Universidad Nacional de Colombia, Sede Bogotá, Departamento de Ingeniería Civil y Agrícola, Colombia; camoncadaa@unal.edu.co

Abstract

Objectives: Evaluate the territorial accessibility to the eco-parks of the city of Manizales, Colombia, in order to potentiate and promote their use, improving the interaction of the population with the environment. **Methods/Statistical Analysis:** The methodology addressed includes evaluation of territorial accessibility through geo-statistical analysis, using GIS tools, as well linking of socioeconomic variables for calculation of coverage. **Findings**: The average access level obtained for the eco-park system is close to 30 minutes of travel for coverage more than 80% in population and area, where the population belonging to the commune "Atardeceres" presents the greatest difficulty of access; On the other hand, the ecological center with the best evaluation obtained is the "Popular forest the meadow" eco-park. **Application/Improvements:** The methodological proposal is a support for environmental planning of a city and support for definition of future protection areas.

Keywords: Accessibility, Ecopark, Environment, Integral Development, Interaction, Society

1. Introduction

The "right to the city" does not necessarily imply the habitability of the citizen within the superficial limits that make it up; on the contrary, it focuses on the possibility of building spaces in which the social, economic and environmental components can fully develop, guaranteeing equal access to everything that transforms humans into citizens when shared in groups[1,2]. This phrase becomes a striking title for some book or political campaign, but does not look beyond what is legally defined. Why not complement this right to the city with a right to clean air? A right to the sea? A right to animals? Even a right to forests?[3]

Manizales, capital of the Department of Caldas and city belonging to the Colombian Coffee Region, is located at 5°3'58" North latitude and 75 29'05" West longitudes (Figure 1), on one side of the central mountain range on the 2150 a.m.s.l with a total extension of 572 km2[4]. Only 6.14% (35.11 km2) of the total area correspond to the urban area where 371.301 inhabitants live[5] and who must overcome the topographic characteristics of the city, where they find important limitations in the expansion processes and urbanization[6]. The characteristics of mobility of the city position the sustainable means of transport as the most used, with 71% of the trips generated daily, while the private means are limited to 29%[7]. However, the number of users in sustainable means presents downward trends, and there is no evidence of intervention by

*Author for correspondence

the municipal administration to re-empower them. As a particular case in the investigation, it is necessary to link the municipality of Villamaría in the calculation processes, fostered by the strong economic relationship and the interaction of the inhabited nuclei as a unified area[8]. The municipality of Villamaría is located, like Manizales (Figure 1), on the central mountain range at 5°02'44" North latitude and 75 ° 30'55" West longitude; it has a total extension of 462 km2[9] and has an estimated urban population of 48,636 inhabitants[4].

The urban link between the municipalities is facilitated by connecting a paved road with about 4 km in length[9], linked to the road network of the Manizales-Villamaría complex obtained from the Mobility Plan of the city of Manizales[10] in which the calculations are supported. The network of road infrastructure has a total of 749 kilometers strongly structured and intervened throughout its operation in order to mitigate and/or solve the mobility problems of citizens[10]. An important characteristic in the citizen's development lies in the possibility of the individual to interact with the surrounding environment, therefore, when understanding the connection between the municipalities, it is possible to examine the interaction of both populations with the different existing facilities, and among them, the Ecoparks play an important role as a tool for the social, cultural and environmental formation of citizens[11]. The Ecoparks are radiant and full of life spaces, between cement horizons, necessary for the individual's education and enjoyed as intangible assets of the citizenship[12]. They are also considered as an important strategy in the improvement of the quality of life of the increasingly urbanized and peripherally expanded societies[13,14].

In the case of Manizales, the definition of Ecoparks is addressed within the areas of urban environmental interest, established in the Territorial Ordinance Plan (2017-2031), as those areas of strategic importance and support that allow the preservation, restoration or sus-

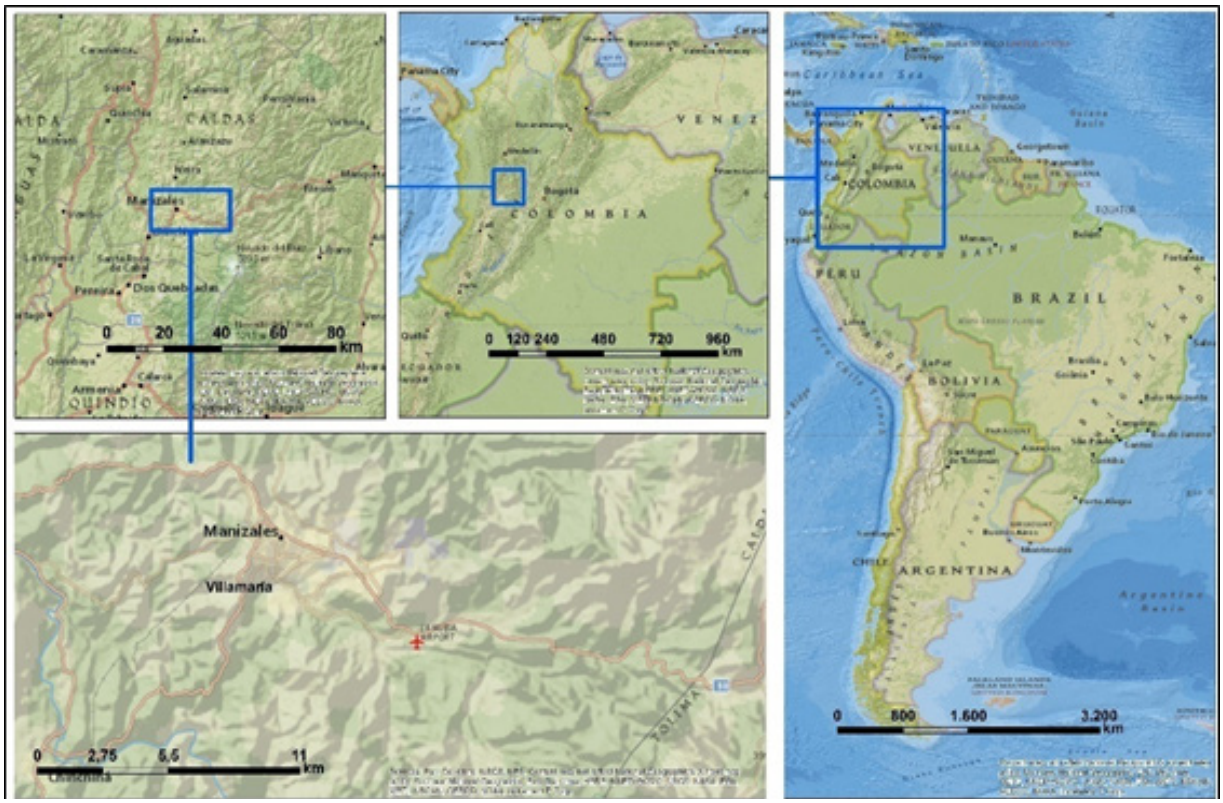

Figure 1. Geographic location of the municipalities Manizales and Villamaría.

tainable use of existing biodiversity, as well as ecosystem services, limited to conditions of use and management, promoting the potentialization of values from a public and/or private perspective[11].

Prior to the approach of the study, it is important to acquire the basic knowledge related accessibility, which starts the fundamental concept established by Hansen in 1959 as "the potential of opportunities for interaction"[15] despite the fact that the concept was approached from previous decades[16]. A more technical definition of the term, based on previous research concepts[17,18] is "the relationship between basic forms of human activity: mobility, understanding and communication; subject to reaching limitations given the existence of barriers"[19]. Consequently, it is possible to assume different components or variables immersed in accessibility within which there are origins and destinations[20] means of transportation, activity nodes, operating speeds and distance among others. With these components, studies and applications have been developed in various branches of science such as: sustainability[21], transport planning[20,22,23], and social exclusion[24,25], among others. Considering, then, the accessibility principles described, besides assuming the Ecoparks system as an element of integral development in a society, there is a need to evaluate the access level to each of said points in order to determine the population coverage and of the area offered, as well as the sectors of the city with deficiencies in their connection to the system. After the introduction, the research methodology is presented, the results and discussion are exposed later, and finally the main conclusions of the study are presented.

2. Methodology

The research methodology addressed consists of four main and consecutive stages, which are presented in Figure 2.

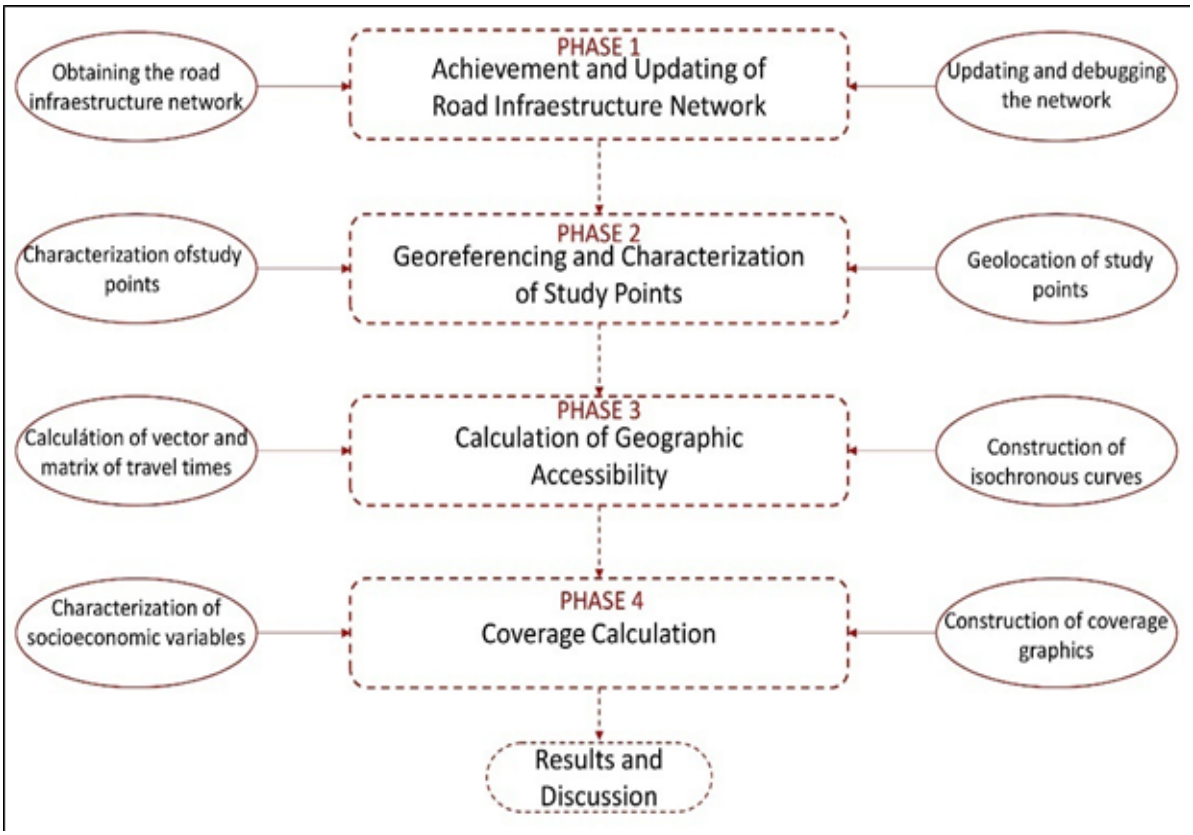

Figure 2. Research methodology.

2.1 Achievement and Updating of the Road Infrastructure Network

As an initial stage of the methodology, the updating and optimization of the road infrastructure network of the Manizales-Villamaría complex is addressed, which was obtained from the Mobility Plan of the City of Manizales[10], composed of a total of 11,374 links (arches or sections of track) and 8,580 nodes (intersections, origins and end of track), spatially distributed, in which the physical and functional characteristics of the system (directionality, speed, length, class, type of tread, etc.) are included.

The operation of the road network within the calculations was subjected to the degree of detail that it presented, therefore, by investigating files, the different interventions made by the municipal administration throughout 2010-2017 (cierres de vía, construction of new infrastructure, improvement of the rolling surface, among others) were defined, which were linked through the ArcMap tool.

2.2 Geo-referencing and Characterization of Study Points

In the second stage, the study points are georeferenced using the ArcMap tool, in which the necessary spatial and functional properties (longitude and latitude, area, etc.) are loaded for the calculation of geographic accessibility. The ecotouristic points of interest of the city are in a total of 6 urban areas (Figure 3): Bosque Popular el Prado Ecopark, Cerro Sancancio Ecopark, Monteleón Forest Ecopark, Central University Ecopark, AlcázarEcopark, and YarumosEcopark. The functional areas of each of them are presented in Table 1[11].

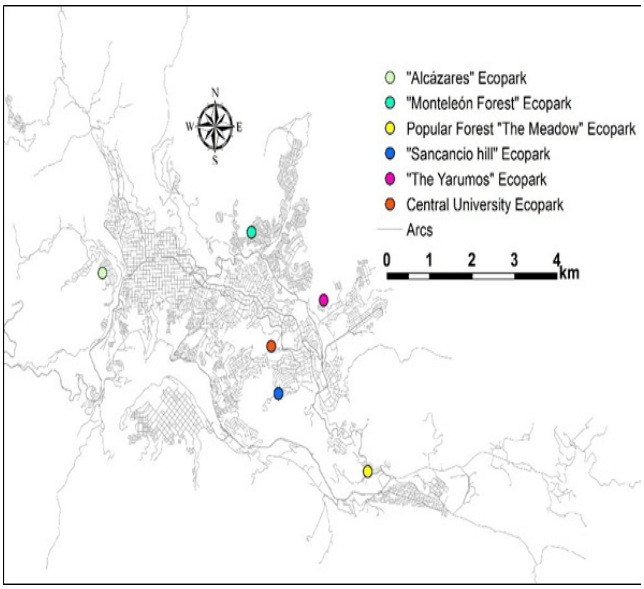

Figure 3. Location of urban Ecoparks.

2.4 Calculation of Geographic Accessibility

In the third stage, the fundamental elements for the construction of the isochronous curves are defined and their calculation is made from the travel time vector, by means of which the impedance (average time of travel) of travel-

Table 1. List of ecoparks and functional areas

Ecoparks of environmental interest	Area [ha]
Popular Forest The Meadow Ecopark	53,6
The Yarumos Ecopark	100,3
Alcazares Ecopark	40,2
Central University Ecopark	31,3
Cerro Sancancio Ecopark	77,2
Monteleón Forest Ecopark	70,2

ing on an arc is established by Eq. (1), where is the travel time of the are, the length and the speed.

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

The Dijkstra algorithm facilitates the procedure for calculating impedances in travel time from an origin node *O* to a destination node *F*, transiting over intermediate nodes; from mathematical logic of existence of connection. A d_{ij} value is then associated to each arc a_{ij}, defined infinite if a connection between the nodes i and j does not exist. Then, to the set of connected nodes in the running iteration (S) the vertex of origin *O* is incorporated. Consequently, labels (P) are designated with values of *O* for and of for. If i am different from the origin, additionally the variable t_i=*O* is generated. Then, the last node added to S is named as (y), so for every z node not added to S it calculates P_z=*min* ={P_z,P_y+ d_{yz}}. If P_y+ d_{yz}<P_z, it becomes t_z=*y* and, then, *z* is selected from all vertices z that complies with P_{z^*}=*min* {P_z}. If P_z=∞, the searches are completed and it is assumed that there is no connection between *O* and the vertices of the set S. However, if this connection exists, the process is continued and z* is incorporated into the set S, where P_{z^*} will be the value of the minimum distance between zy *O*. Finally, if *F*=*z** the iteration is completed, otherwise the process is repeated[26].

Once the calculation of the average travel time vector is completed, the geospatial data of each node is related to obtain the minimum travel time matrix, which is used in the construction of the accessibility curves, using the Kriging spatial interpolation model ordinary with linear semivariogram. This method of interpolation determines the properties of spatial dependence between points within a sample by means of Eq. (2), where $Z_{(x)}$ = value of the variable at a point with coordinates x, and; $Z_{(x+h)}$ = next sample value separated by a distance h; n = number of couples that are separated by the distance h.

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

2.4 Coverage Calculation

Stage 4 contemplates the incorporation of the socioeconomic variables to the study: area, communes, population and economic stratification. This last variable is defined by the National Administrative Department of States as an approximation to the hierarchical socioeconomic difference[27] interpreted as the existing economic gap between populations of the same locality. For this study, there is a total of 6 levels of strata and 12 communes, considering the municipality of Villamaría as a commune associated with the interpretation of the data. Stratum 1 is the one with lower economic capacity, while stratum 6 is the one with greater economic capacity. This is defined by the analysis of, not only the state and materials of the dwelling, but also the economic possibilities of the inhabitants of each dwelling. The correlation of the sociodemographic variables and the calculated isochronous curves are done by means of the "intersect" tool belonging to the ArcMap Geoprocessing extension, later treated in Microsoft Excel to generate the coverage give graphs, and give final input for the analysis of the level of impact generated by the Ecoparks.

3 Results and Discussion

3.1 Geographical Accessibility of the Ecoparks System

After establishing the necessary conditions for the analysis of geographic accessibility related to the road network and socioeconomic a variable, Figure 4 is constructed, in which the mean time of travel to the 6 ecoparks identified at 5 minute intervals is appreciated. It is observed that a large part of the city can access in an average travel time of less than 35 minutes to one of the recreational ecological centers indicated. However, isochronous curves with values reaching up to 65 minutes are identified towards the north-west sector. It is generally observed that given the geographical position of these ecotourism areas, it is the inhabitants of the eastern sector of the city who have more favorable access conditions.

The level of accumulated percentage population coverage according to the isochronous curves is presented

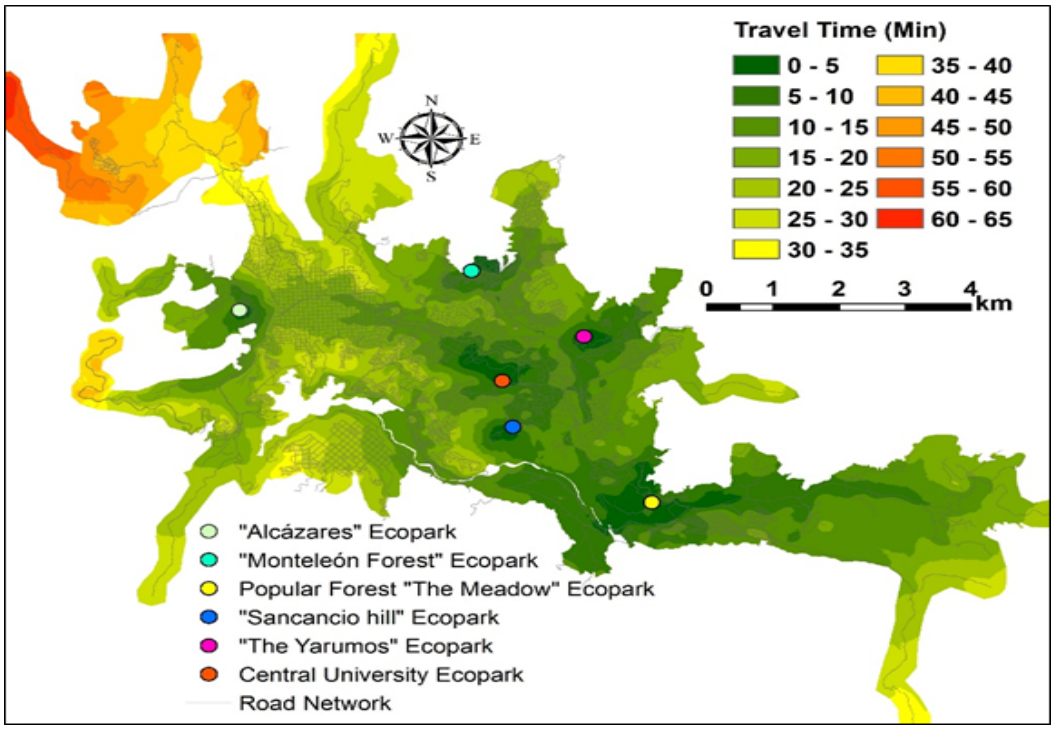

Figure 4. Geographical accessibility curves for the set of ecoparks in the city of Manizales.

in Figure 5a. Taking into account that the isochronous curves represent the possibility of access to the nearest Ecopark, it was obtained that given their location, it is possible to cover 70% of the city's surface in a travel time of less than 25 minutes, just as 90% of the population for the same time interval, in a travel time of less than 25 minutes, a user manages to travel to at least one of the Ecoparks. In addition, Figure 5b shows a discretization

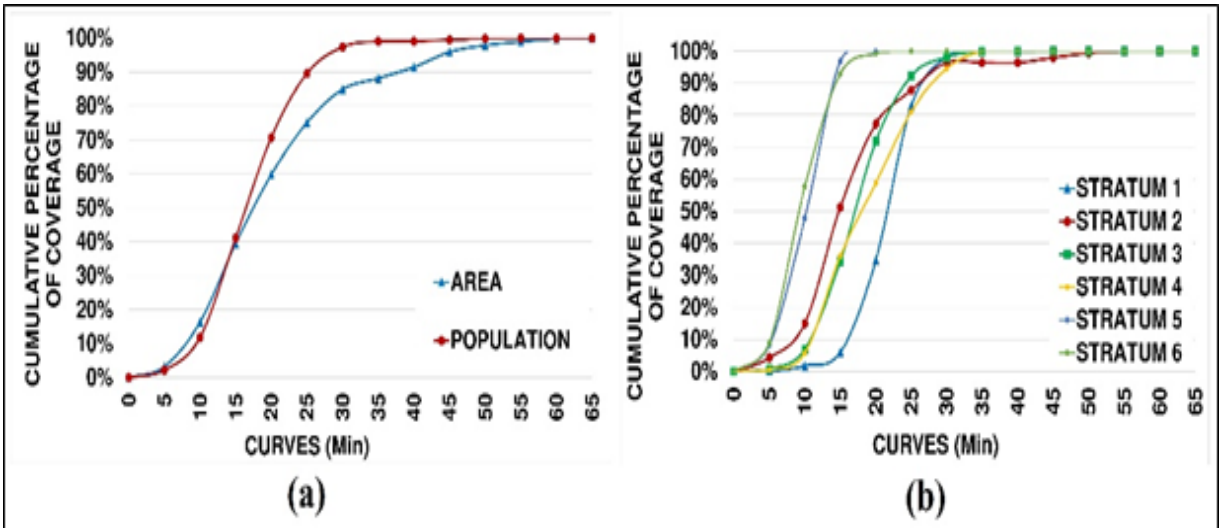

Figure 5. Accumulated percentage of coverage for the Ecoparks system: a) According to population and area; and b) According to socioeconomic status.

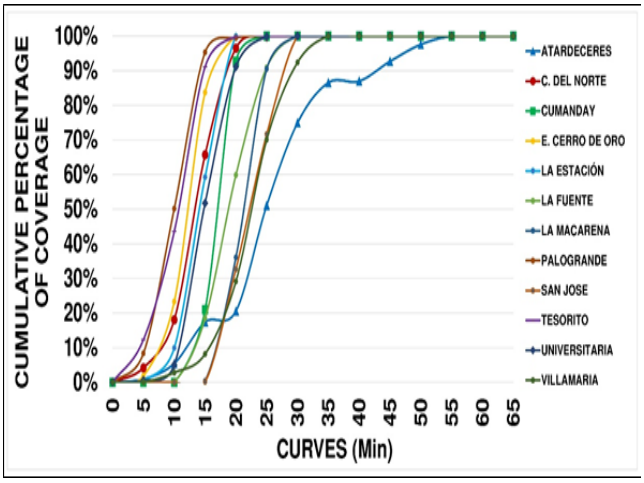

Figure 6. Accumulated percentage of coverage according to commune.

of the percentage coverage of the population according to the socioeconomic stratum.

It was obtained that the strata with greater accessibility are numbers 5 and 6 (high economic capacity), with a coverage percentage higher than 80% of the population in an average travel time of less than 15 minutes. The remaining strata have acceptable coverage levels with values higher than 50% of the population in travel times less than 25 minutes. Stratum 1 has the most unfavorable accessibility conditions.

Carrying out an analysis by communes (political administrative division of the city), Figure 6 is constructed, in which those with greater accessibility to one of the Ecoparks are identified. The commune Palogrande (center south sector) is the best covered with a percentage of population over 90% in less than 15 minutes of average travel time, followed by the tesorito commune (eastern sector) with a similar behavior. On the other hand, the communes with the lowest level of coverage per population are the municipality of Villamaría with a population coverage percentage of 30% in less than 20 minutes and the municipality of Atardeceres with the lowest percentage, 20% for the same time interval, considering that this commune includes the farthest sector, the Linda (northwestern sector). The accumulated percentage population coverage for the other communes presents a similar

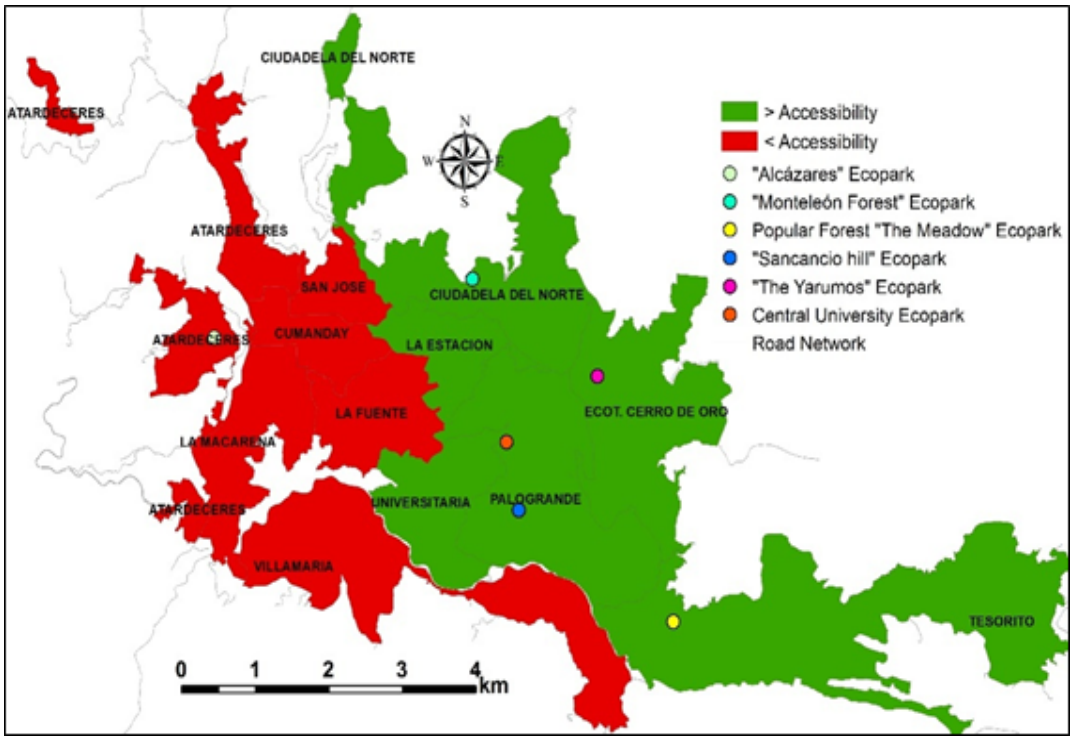

Figure 7. Schematization of the 6 communes with greater and less accessibility for Ecoparks.

trend, ranging between 40% and 70% for a time interval between 10 and 20 minutes.

Additionally, Figure 7 is presented, in which the geographic location of the 6 most accessible communes and the 6 communes with less accessibility conditions to the Ecoparks are shown. It is clearly identified that the greatest coverage occurs towards the eastern sector of the city, generated by the concentration of Ecoparks towards this part, which decreases the average travel time.

3.2 Individual and Comparative Analysis

In order to determine the coverage of socio-demographic variables for each Ecopark, the percentage ogives of accumulated coverage for the variables population, area and socioeconomic stratum, were constructed to perform a comparative analysis based on the unit percentage coverage of the 50% variables.

In Figure 8a, the level of percentage coverage of the population according to the isochronous curves for the Bosque Popular el Prado Ecopark is observed. It is identified that for a percentage of population and area of 50%, a travel time of 22 and 23 minutes of average travel time, respectively, is required with a cross behavior between both curves. The cross behavior of the curves of the area and population variables means that for lower average travel times, areas of low population density are covered,

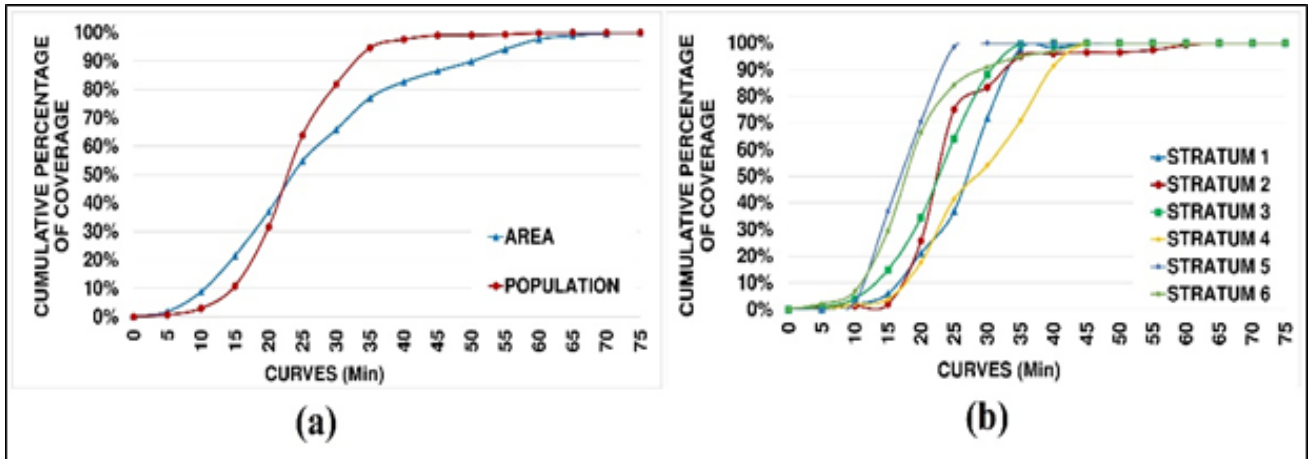

Figure 8. Cumulative percentage of coverage for the Bosque Popular el Prado Ecopark: a) According to population and area; and b) According to socioeconomic status.

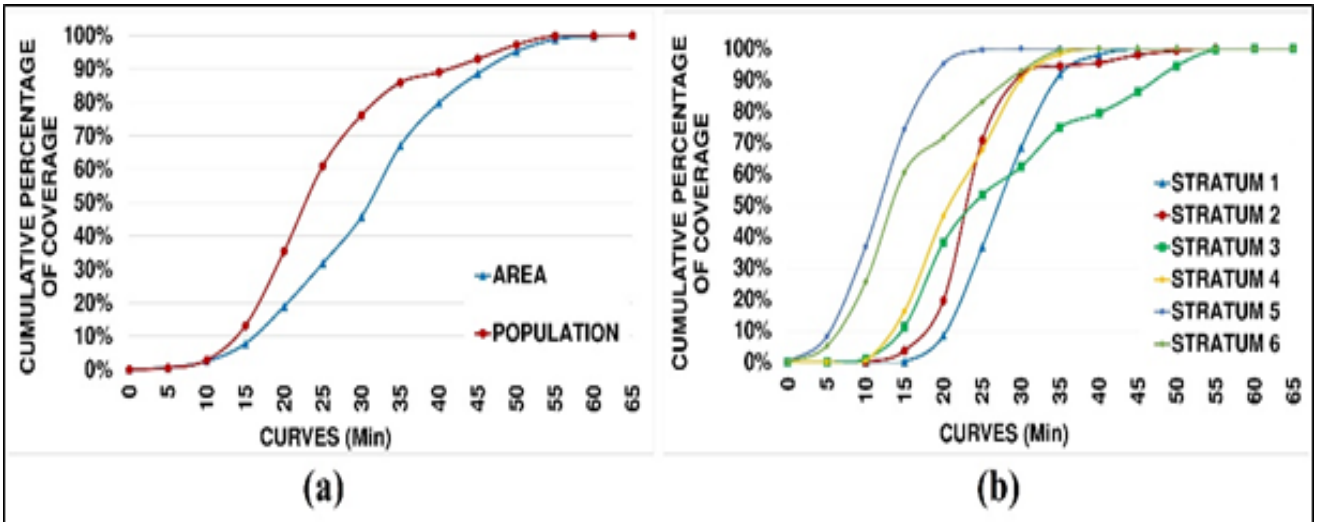

Figure 9. Accumulated percentage of coverage for the Central University Ecopark: a) According to population and area; and b) According to socioeconomic status.

and for larger average travel times, areas of high population density are covered. On the other hand, analyzing the percentage coverage of the population according to the socioeconomic stratum (Figure 8b), it is found that those that refer the best access conditions are the high strata (5 and 6), where 50% of the population invest 17 minutes of average travel time. Strata 1 and 4 are located in the furthest part of the graph, with a twisted behavior with each other and a travel time close to 30 minutes to cover 50% of its population.

As a result of the analysis for the Central University Ecopark (Figure 9a), it was obtained that for a population coverage of 50%, it is necessary to invest about 23 minutes in average time of travel; while for surface, it is necessary of about 35 minutes. This is due to the proximity of the Ecopark to sectors with high population density. The evaluation by socioeconomic strata (Figure 9b), allows to identify that the strata with greater accessibility to this Ecopark are the higher ones (5 and 6), which invest about 13 minutes of average time of travel to achieve 50% coverage. On the contrary, stratum 1 has the lowest coverage, and an average travel time of 25 minutes must be invested to cover 50% of the population. However, the configuration given of its curve, its percentage increases remarkably when exceeding 30 minutes of average travel time, thus displacing stratum number 3 to the last place in coverage.

Figure 10a shows the results obtained for the population and area analysis for the Cerro SancancioEcopark. The configuration of their percentage ogives shows that they overlap for a time less than 20 minutes of average time of travel. After this time a strong separation with amplitude between curves of almost 20% is presented, for which the coverage of 50% of population refers to the investment of approximately 31 minutes of average travel time, while for area, their requirement increases to 37 minutes.

In Figure 10b, the analysis of coverage according to socioeconomic stratum is observed, identifying a large separation between curves compared to the Ecoparks analyzed so far. However, strata 5 and 6 still the ones with the greatest coverage, since the population of stratum 5 is covered more quickly, although it begins its growth after 5 minutes and manages to cover 50% of its population in a shorter time. The time required to supply 50% of the population of stratum 5 is 19 minutes, while stratum 6 achieves it in 16 minutes. The remaining curves show similar early behaviors up to 20 minutes, from which the curve belonging to stratum 1 stands out for not presenting a significant coverage, positioning itself as the stratum with the lowest coverage.

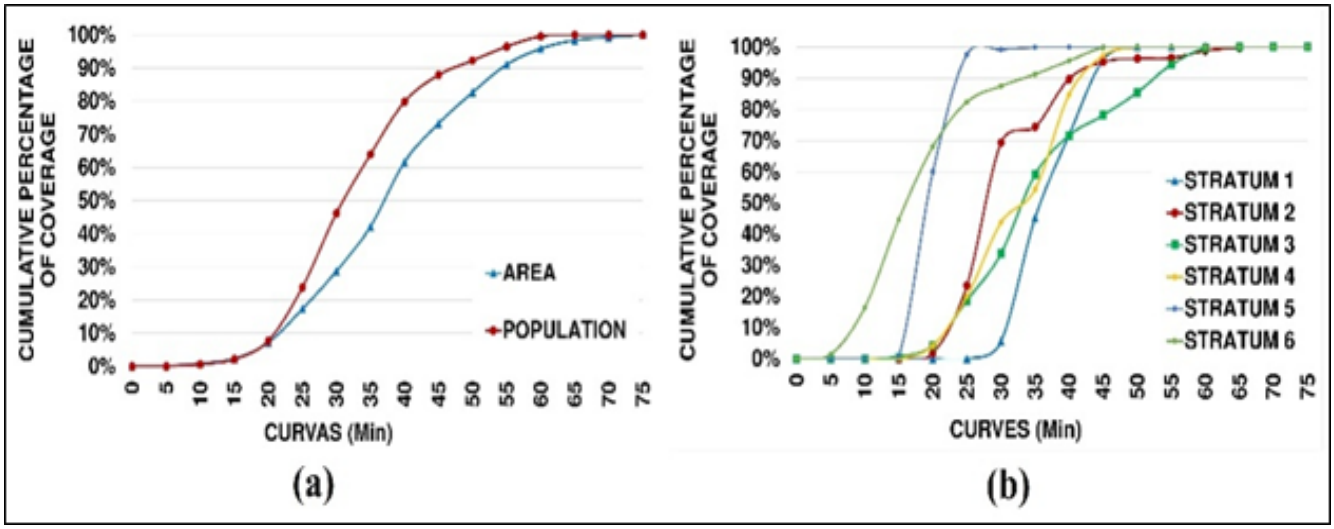

Figure 10. Accumulated percentage of coverage for the Cerro SancancioEcopark: a) According to population and area; and b) According to socioeconomic status.

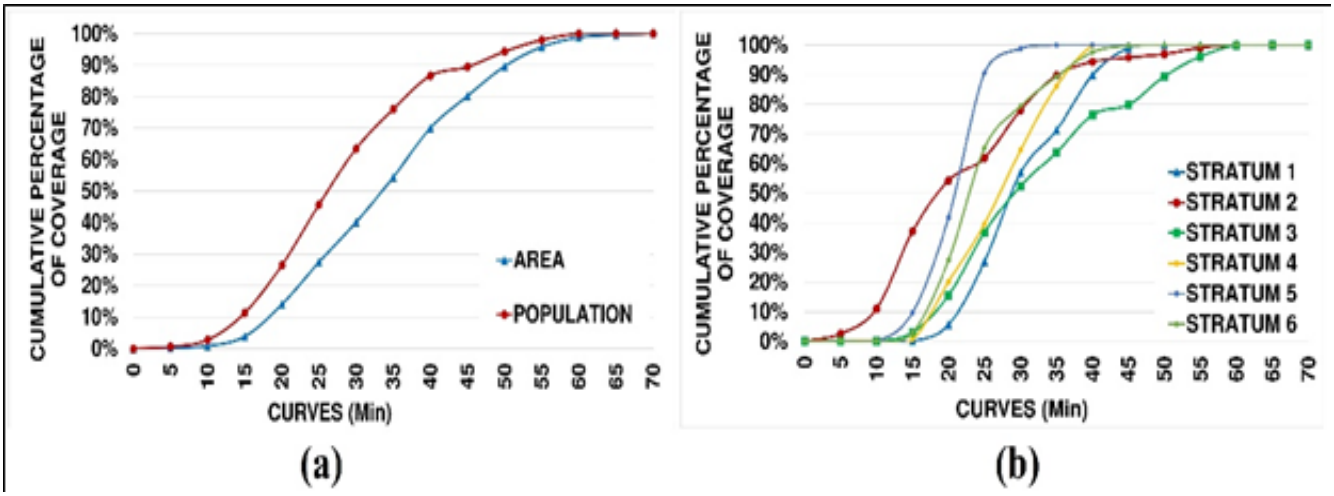

Figure 11. Accumulated percentage of coverage for the Bosque MonteleónEcopark: a) According to population and area; and b) According to socioeconomic status.

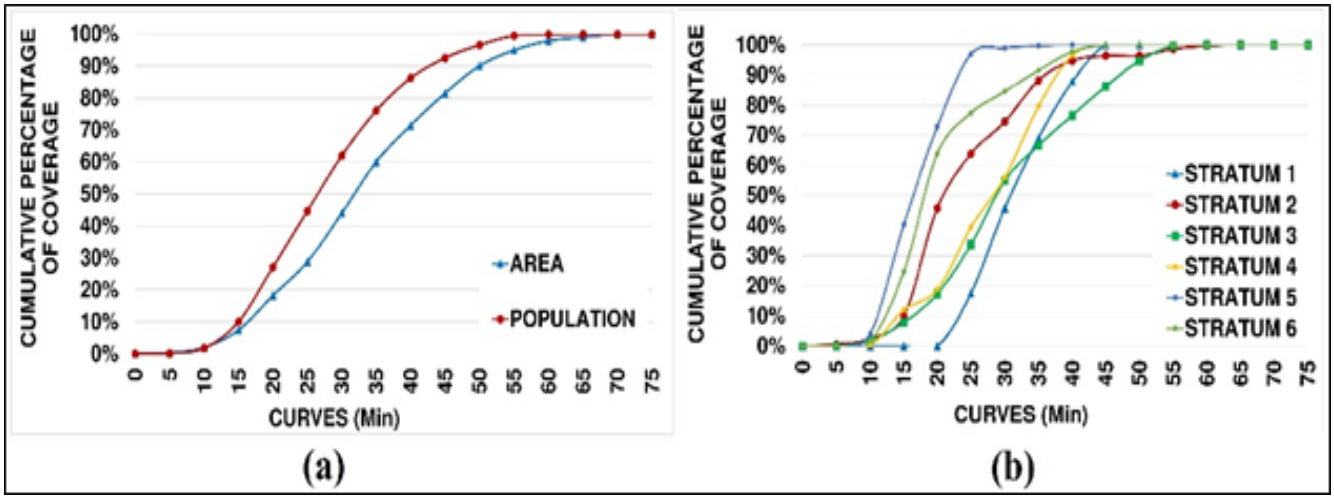

Figure 12. Accumulated percentage of coverage for the Los YarumosEcopark: a) According to population and area; and b) According to socioeconomic status.

Figure 11a shows the behavior of the cumulative percentage curves of population and area coverage for the Bosque MonteleónEcopark, in which the growth structure of the previous cases is preserved, with coverage of 50% of the variable population in a time of 27 minutes and 34 minutes for the variable area. In Figure 11b, there is great variation regarding the previous cases for the classification by socioeconomic stratum, in which stratum number 2 is located as the curve with the 50% coverage more quickly reached with 18 minutes. However, the citizens belonging to stratum 5 continue with the fastest coverage, needing close to 30 minutes to reach 100% of its population. Additionally, there is a variation in the lowest coverage: the curve of stratum 3 is the smaller scope, needing 30 minutes to achieve 50% of the population.

Figure 12a shows the variation in coverage by population and area for the Los YarumosEcopark. For its base percentage of analysis (50%) a travel time of around 26

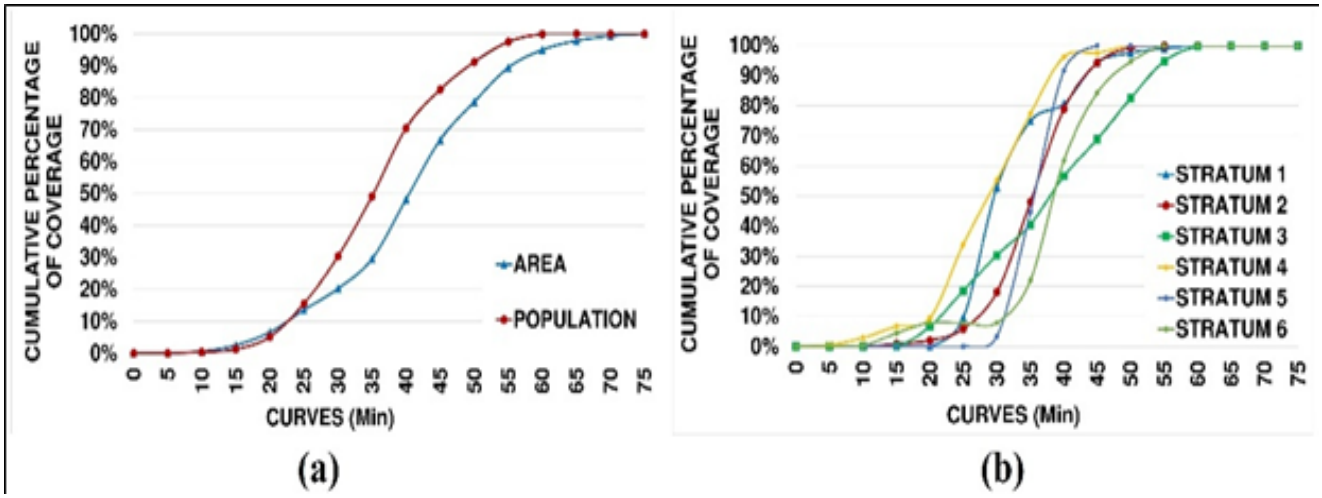

Figure 13. Accumulated percentage of coverage for the AlcázeresEcopark: a) According to population and area; and b) According to socioeconomic status.

minutes is required to supply the population, while for the variable area, an average of 32 minutes of travel time should be spent. The percentage coverage ogives according to the socioeconomic stratum (Figure 12b) do not show much variation as stratum 5 remains as the population with the best accessibility with an average travel time of 16 minutes to cover 50% of the population. Likewise, it was obtained that stratum number 1 requires the longest time to supply 50% of the population with 32 minutes.

Finally, Figure 13a shows the results obtained for the Los AlcázaresEcopark. The overlap of curves for population and area can be seen until 25 minutes later, achieving a separation of up to 22%. The travel time required to meet the 50% coverage base is 35 minutes in the population and 41 minutes for the area. The ogives by socioeconomic strata (Figure 13b) show a differentiated behavior to the other ecoparks, in which the total of the curves are located towards the center of the timeline (between 25 and 50 minutes), and in which stratum number 4 becomes the one with the greatest coverage with a time of 29 minutes for 50% of the population, followed by stratum 1 with 30 minutes. The behavior of the ogives for this particular case can be assumed by the location of the Ecopark, favoring to a large extent the citizenship of medium and low resources.

3.3 Comparative Analysis

Figure 14 shows the comparison of average travel times that must be invested to achieve coverage of 50% of the population and area variables. It is clearly identified that the Bosque Popular El Prado Ecopark has the highest valuation in each component, requiring the shortest time to supply 50% of population and area (22 and 23 minutes). It also presents the most complete ecotourism infrastructure compared with the other Ecoparks. The next place on the list is obtained by the Los Yarumos Ecopark, which despite requiring a little more travel time to supply the population (26 min) compared to the Central University Ecopark, has a better infrastructure rating, and a lower average time of travel for the variable area (32 min) of the ecoparks analyzed, the case of the Cerro Sancancio Ecopark stands out. Despite being located towards the center-east sector of the city, it has one of the lowest coverage, with 31 minutes in population and 37 minutes in area, as well as having a deficient ecotourism infrastructure. However, the lowest coverage was located in the Ecoparque los Alcázares, with times of 35 and 41 minutes for population and area respectively, clearly generated by its location towards the western sector of the city near the urban limits[28].

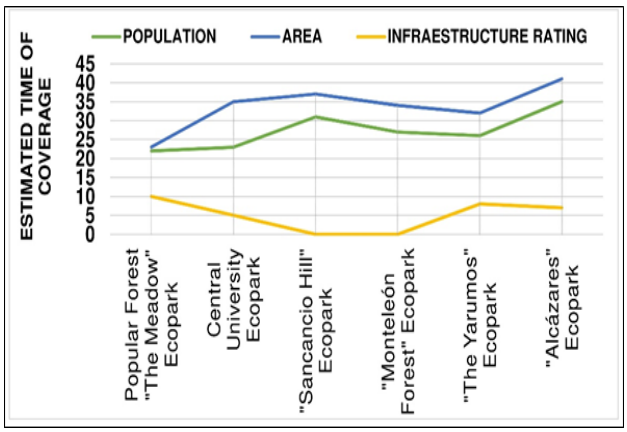

Figure 14. Comparison of coverage for the Ecoparks system.

4. Conclusions

The level of accessibility perceived by citizens is relatively good, considering that the average travel time spent in other Colombian cities exceeds 55 minutes[28,29], while in this case study the values obtained are minor. Clarifying that, for this analysis model, the average of the speeds of all modes of transport that circulate on the road infrastructure network of the city was considered. The level of access by socioeconomic stratum does not show deficiencies in relation to the total population. This is based on the level of access for the population of stratum 1 that, despite being the stratum with the greatest access difficulty, manages to cover more than 70% in a time less than 25 minutes. Nevertheless, it is observed that generally, the lower strata refer more unfavorable accessibility conditions than for the upper strata. It is evident that the western sector of the city has the lowest coverage regarding to the population by communes, generated by the low density of Ecoparks towards this sector of the city. Also, given the high urbanization towards this area, the possibility of expansion or construction of new Ecoparks is difficult.

5. Acknowledgments

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