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TERRITORIAL ACCESSIBILITY ANALYSIS FOR URBAN INFRASTRUCTURE FACILITY LOCATION: A CASE STUDY IN VILLAVICENCIO, COLOMBIA

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Abstract: Territorial accessibility analysis is a crucial component of urban planning, enabling decision-makers to determine new locations for urban infrastructure facilities to enhance residents' quality of life. The objective of this paper is to propose a methodology for performing territorial accessibility analysis that integrates data analysis techniques, such as clustering, with tools like isochronous curves and percentage ogive graphs. This methodology is evaluated through a case study in Villavicencio, Colombia. Results indicate that the proposed methodology can accurately assess territorial accessibility and, in the case study, recommend investments in health and firefighting services.

Key words: territorial accessibility, isochronous curves, data analysis, clustering, transportation

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INTRODUCTION

Accessibility analyses are an important tool in urban planning, used, among other purposes, to shape public policies related to city infrastructure facilities (Geurs and van Wee, 2004). In essence, urban infrastructure projects and policies consider accessibility as a crucial factor in their formulation and evaluation. It is worth noting that decisions concerning urban infrastructure and transportation suppose substantial investments with short, medium, and long-term implications (Ortúzar and Willumsen, 2011), and they rely on this type of analysis as input. Through accessibility studies, it is possible to evaluate the ease (or difficulty) with which the population can reach a point of interest (e.g., healthcare centers), taking into account the available infrastructure and transportation means (Escobar et al., 2018; Gómez et al., 2018). Furthermore, this concept is related to a city's competitiveness, as cities with higher accessibility indicators tend to be more competitive (Martínez et al., 2021). Accessibility in a city can be evaluated in various ways, such as by exclusively considering access to a single service like educational institutions (Montoya et al., 2018), accessibility to food supply chains (Mejía et al., 2022), or accessibility to multiple services (Shen et al., 2020).

For this work, we employ integral accessibility and global accessibility as analytical methods. These methods are based on the city's infrastructure because they consider the city's road network, operational speeds, and transport infrastructure. Furthermore, integral accessibility introduces an additional perspective, focusing on facility-based accessibility by measuring access to specific points within the city. Additionally, this study assesses accessibility by considering the Primary Activity Nodes (PANs) included in the analysis of (Escobar et al., 2017) which are health, education, security and recreation as they represent the principal needs of the communities. Examples of such PANs are healthcare facilities such as hospitals or educational centers such as schools or universities.

To do so, this work proposes a three-phase methodology as follows. In the first phase, we gather data related to population, road infrastructure, and the location of the infrastructure facilities of the PANs that are included in the analysis. The second phase involves calculating travel times and distances for the population to access the infrastructure facilities. The third phase focuses on studying travel times and distances through isochronous curves and population ogive graphs. This analysis helps evaluate territorial accessibility and prioritize zones for new urban infrastructure development. To validate the performance and practicality of this approach, we utilize a case study inspired by data of Villavicencio City, Colombia.

Related works

Over the last decades, there has been interest from researchers in conducting studies on urban accessibility in various

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contexts. An example of this is (Gibbons and Vignoles, 2012), where the authors studied territorial accessibility in a community in England concerning educational facilities. In their study, the authors considered public transportation as the mode of transport for young people accessing educational opportunities in the city. They geographically referenced the residents and found, through the accessibility study, that distance to educational institutions significantly influences their selection. Another example of the applicability of territorial accessibility studies is (Mao and Nekorchuk, 2013).

In this work, the authors examined territorial accessibility, considering multiple modes of transportation for the population to access healthcare services. They proposed a variant of the Two-Step Floating Catchment Area Method and validated their approach using a case study inspired by the city of Florida in the United States. The authors found that considering multimodal transportation results in more realistic accessibility studies.

Other study on urban accessibility is (Wan et al., 2012). In this work, the authors investigated territorial accessibility, measured by how the population can reach healthcare services. They proposed a variation of the Two-Step Floating Catchment Area Method to plan healthcare network resources in cities. Their case study focused on the Austin-San Antonio corridor in central Texas, demonstrating that their methodology minimizes overestimation of healthcare demand by balancing spatial access to healthcare services. More recently, (Escobar et al., 2017) examined the territorial accessibility of the population in the city of Quibdó, Colombia, concerning primary services such as healthcare, education, and security. They employed the Mean Integrated Accessibility as a methodology to analyze the city's service infrastructure. The authors concluded that it is a priority for the city to invest in urban security facilities. Furthermore, in (Escobar et al., 2018), the authors studied territorial accessibility to security facilities was evaluated. The authors used geostatistical models to construct graphs and images that facilitate the interpretation of accessibility in cities. Their case study focused on the municipality of Pitalito in Colombia, a city which faced security challenges. Another related work on territorial accessibility is (Montoya et al., 2018). In this study, the authors analyzed the population's territorial accessibility to educational centers. They utilized geostatistical models supported by data from digital tools.

Additionally, in (Tahmasbi et al., 2019), a methodology is proposed to measure accessibility to public facilities while considering equity in terms of income. To do so, they employ concepts like the Gini coefficient and statistical indices. The authors test their approach using a case study in Isfahan, Iran, where the results demonstrate that low-income population groups benefit less from urban retail facilities. Another related work that studies accessibility is (Espejo-Díaz et al., 2023). This study focuses on urban accessibility to emergency medical services identifying hard-to-reach zones where there is an important delay in ambulance services. To improve the access to emergency services in hard-to-reach zones, the authors propose the location of vertiports to utilize electric vertical take-off and landing (eVTOL) vehicles for aeromedical transportation. The authors conclude that aeromedical transportation using eVTOL vehicles requires vehicles of minimum 120km of range. Another recent work on territorial accessibility is (Quijada-Alarcón et al., 2023). The authors evaluated the territorial accessibility and connectivity by proposing a three-stage methodology that includes spatial analysis. The authors tested the methodology in the province of Coclé in Panama, concluding that the improvements of the road network impact positively the access to health services and education. The aim of this paper is to propose a methodology for performing territorial accessibility analysis that integrates data analysis techniques, such as clustering, with tools like isochronous curves and percentage ogive graphs. Additionally, our methodology incorporates the use of data collected through digital devices and available in technological applications like Google Maps, which can provide a more accurate territorial analysis. The proposed methodology is validated using a case study addressing accessibility challenges in the city of Villavicencio.

Description of the case study

Villavicencio is located in the foothills of the Eastern Cordillera, in the northwest of the Meta department, on the left bank of the Guatiquía River, 82 km from the capital of the country, Bogotá (Alcaldía de Villavicencio, 2023). According to the latest political-administrative update of Villavicencio in 2021, the city now consists of 10 communes, as shown in Figure 1. The population of the municipality for the year 2018 (the latest census) was 531,275 inhabitants, with an estimated 90% of the population residing in the urban area (Departamento Administrativo Nacional de Estadística – DANE, 2018). It is noteworthy that half of the population is not originally from the municipality, as they come from other cities in the department, possibly emigrating from nearby cities and settling on the city's outskirts. These migrating individuals are generally from low-income backgrounds and often occupy illegal properties, resulting in disorderly and random growth of the city that does not align with the municipality's territorial planning.

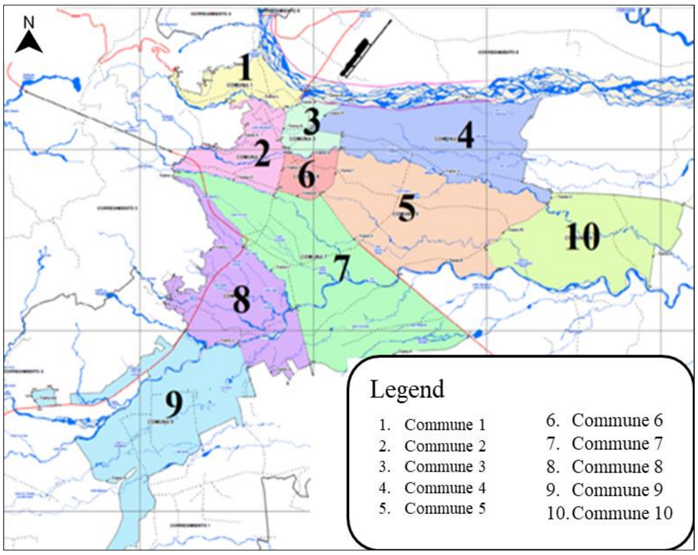


Figure 1. Administrative division of Villavicencio
(Source: Adapted from Alcaldía de Villavicencio, 2023)

A preliminary analysis of the location of urban infrastructure projects in the city reveals a concentration of Primary Activity Nodes (PANs) in the old town of the municipality, specifically in communes 2, 3, and 6. This centralization of

PANs hinders access to these services for the population living farther away, particularly on the outskirts of the city, where PAN coverage decreases. This, in turn, leads to a decreased quality of life for residents in these areas. For this reason, it becomes necessary to assess the coverage of different Primary Activity Nodes (health, security, education, and recreation) in the municipality of Villavicencio through an analysis of territorial accessibility.

This analysis aims to determine the areas of the city with the best coverage, as well as the population truly impacted by them. Furthermore, it allows for the identification of locations within the city where new infrastructure projects of various kinds can be situated, benefiting a larger number of residents.

METHODOLOGY

This section develops the three-phase methodology for conducting the territorial accessibility analysis and proposing new locations for urban infrastructure. Figure 2 presents the methodology which is divided into three phases that are detailed next.

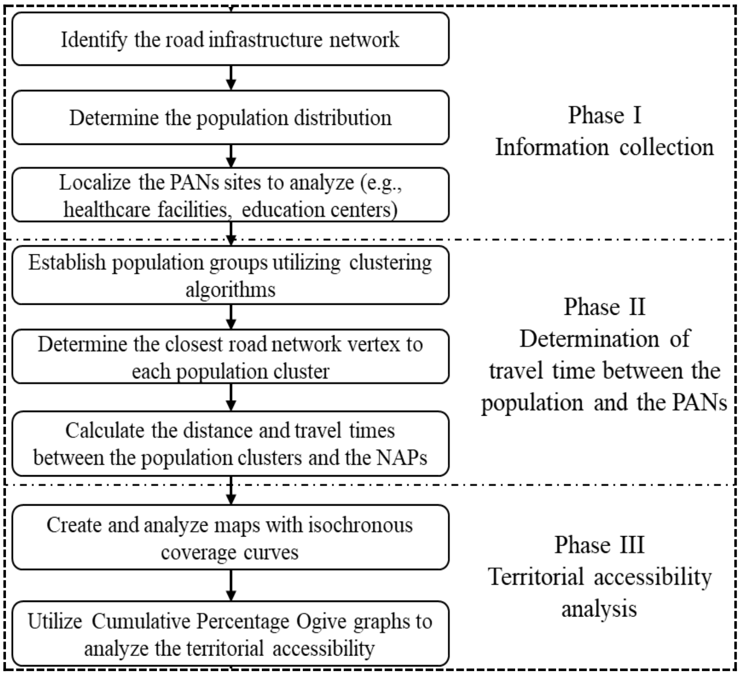


Figure 2. Proposed methodology for territorial accessibility assessment (Source: Authors)

1. Information collection

The first phase of the methodology involves collecting information related to the PANs, the population's location and distribution over the city, and the road infrastructure as follows:

Demand: The initial step involves locating and understanding the distribution of the city's residents. This necessitates geo-referencing the inhabitants, considering their concentration in various city areas. For example, in some Colombian municipalities, such georeferencing data is accessible through open data portals. Typically, this data is presented in the form of cartographic maps featuring layers representing city blocks or sectors. Each layer is equipped with attributes specifying the population count within its boundaries. By extracting the centroid of each layer and associating it with specific geographic coordinates, it becomes feasible to model the demand using coordinates, each with parameters indicating the number and demographic characteristics of the population in that location. Road Infrastructure: Information about the location of roads within the urban perimeter and in rural areas of the city should be collected. This information should cover roads, intersections, road directions, and other components of urban mobility.

PANs distribution: In addition to the previous information, the location of the infrastructure facilities of the principal activity nodes (PANs) is also needed. For instance, for studying the PAN of education services, the location of the schools must be collected. To do so, each PAN infrastructure facility should be represented by a pair of coordinates.

For this case study, population information for Villavicencio was extracted from the portal of the Instituto Geográfico Agustín Codazzi (IGAC), available in ESRI Shapefile format (*.shp) (IGAC, 2023). This data, apart from containing cartographic layers of the city blocks in Villavicencio, also includes information on the population residing in each city block. In total, 5441 city blocks were identified, representing the location of all urban residents in Villavicencio. To analyze and manipulate the shp files, we used the open-source software QGIS in its version 3.20.0-Odense.

Furthermore, with the assistance of the cartographic database of the municipality of Villavicencio available on the IGAC portal, information regarding the city's road network was extracted. Since the cartographic database from IGAC was found to be outdated, and in the last 5 years, the municipality of Villavicencio has made significant investments in its primary roads, including the opening of new corridors and the expansion of the urban area, the information was manually supplemented with cartography from technology providers, in this case, Google Maps. Finally, information regarding the Primary Activity Nodes (PANs) of the city was collected, either manually or with the assistance of the DANE portal (Departamento Administrativo Nacional de Estadística – DANE, 2023). In this study, we analyzed the following PANs:

Education: The analysis included 163 official primary and secondary education institutions.

Health: The analysis included 13 medical institutions, including health centers, clinics, and the departmental hospital located in the city.

Security: The security analysis was divided into two parts. The first sub-analysis pertains to police security forces, which are available in 13 facilities consisting of police stations and Immediate Response Commands (CAI). The other security sub-analysis was conducted concerning the fire department, with one station located in the city.

Recreation: This final analysis focused on parks, sports facilities, and courts available in the city for recreational activities for the public. In total, there are 315 facilities.

2. Determination of travel times between population and PANs

The second phase in the methodology involves determining the travel times and distances from the population to the

PANs. To do this, we first group the population based on their locations. This is necessary because the number of household or block locations in a city can be quite extensive, reaching thousands of locations. Therefore, to reduce dimensionality, a certain number of clusters are generated to represent groups of households or blocks. Multiple studies, such as (Espejo-Díaz et al., 2023; Wang et al., 2020) have utilized clustering algorithms to aggregate geographic coordinates. In this study, we implemented the k-means clustering algorithm presented in (Manning et al., 2009) as follows.

Let $\mathbf{X_C}$ be the center of the potential cluster $\boldsymbol{c}$, then,

$$X_c = \frac{1}{|k|} \sum_{x \in k} \vec{x} \tag{1}$$

The purpose of the k-means algorithm is to minimize the average Euclidian distance between n groups or clusters and z data points. The squared Euclidian distance is given by the summation of the residual sum of squares as shown in Eq. (2).

$$RRS_k = \sum_{\vec{x} \in k} |\vec{x} - x_c|^2 \tag{2}$$

Finally, Eq. (3) minimizes the overall sum of squares of all data points.

$$Min\ RRS = \sum_{k=1}^{K} RRS_k \tag{3}$$

The next step in this phase is to determine the nearest road vertex to each population cluster. In this study, we assume that the population within each cluster starts its journey from this vertex. Once each cluster is associated with its corresponding nearest vertex, the next step is to determine the travel time from the vertex to or from the infrastructure facility locations of the PAN under study. In this work, we utilized the Google Maps Distance Matrix application programming interface (API) to determine the travel times and travel distances. This API provides travel times and distances for a matrix of origins and destinations, considering historical traffic condition data (Google Maps Plataform, 2023). Additionally, it allows for the utilization of new data sources, such as mobile phone geolocation or GPS data, which have the potential to enhance the accuracy of urban planning proposals (García-Albertos et al., 2019).

3. Analysis of territorial accessibility.

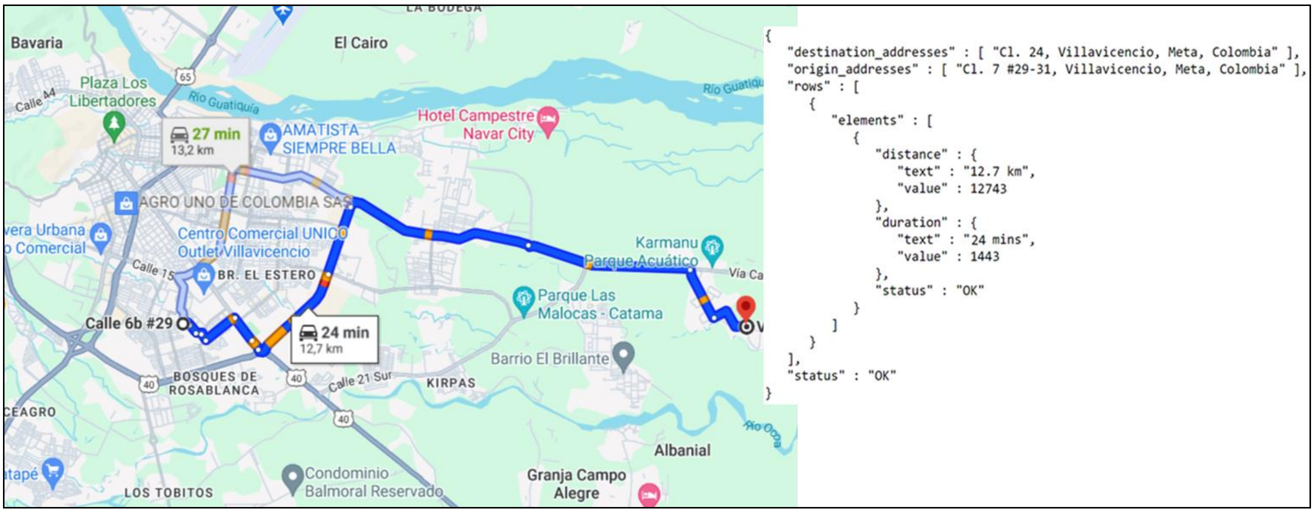
Once we have obtained the travel times of the population to the infrastructure facilities, the next phase of the methodology involves conducting a territorial accessibility analysis. This is done with the aim of identifying which areas of the city should be prioritized for investments in facilities to enhance territorial accessibility.

This analysis is carried out by generating isochronous curve maps. These are graphical representations that display the areas of the city that are within a specific time interval from a infrastructure facility. Each curve or zone on the map represents a time interval within which an infrastructure facility can be reached. For example, in an isochronous curve map used for analyzing security, if 5-minute intervals are considered, areas where a security infrastructure facility can be reached in 5 minutes or less will be identified with one color, areas within 5 to 10 minutes with another color, and so on.

It is worth noting that isochronous curve maps are valuable tools for decision-making not only in transportation infrastructure planning but also in the location of public services within cities. Finally, we conclude the territorial accessibility analysis by generating population coverage ogives. These graphs depict the distribution of the population in relation to travel distance coverage. The horizontal axis represents travel time intervals, while the vertical axis represents the accumulated population. These graphs are generated to assess the current state of territorial accessibility for the population and to compare them with similar graphs generated considering the proposed new facilities in the next subsection.

RESULTS AND DISCUSSION

The determination of distances and travel times was performed using the API Google Maps Distance Matrix. To do so, first a preprocessing of the information was conducted using the Python general programming software. Subsequently, the clustering step was performed using the K-means algorithm, generating **$k = 200$** clusters. This was done with the assistance of the Python sklearn library. As a result, 200 clusters were obtained, with an average distance of 164 meters from each block to the nearest cluster and a standard deviation of 8.3 meters. The next step in the methodology is to determine the nearest road vertex to each cluster. In this work, it is assumed that the population grouped in that cluster begins their journey from there. This is done using the municipal road network, which contains the georeferencing of 58,283 vertices in the city. Due to the large number of vertices, establishing the closest distance between each vertex and each cluster involves a significant number of calculations. To lower the computation time, the spatial. KDTree class from the Scipy library was used. Once the nearest vertex to each cluster is determined, the next step is to determine travel times using the Google Maps Distance Matrix API. To do this, an API key must be generated from the Google Developers platform. With the key, the coordinates of the origins and destination coordinates can be used to create a URL with which requests are made. The response to the request is a JSON-formatted dictionary containing the estimated travel time and distance between the origin and destination. The information provided corresponds to the estimated travel time by vehicle (car) at the time the query is made. This information is then decoded to obtain the distance and travel time. For further information, interested readers can refer to the documentation available at (Google Maps Plataform, 2023). Figure 3 presents an example of a manual request made on the Google Maps platform through a web browser and a request made to the Google Maps API. It can be observed that the time reported by the API is the same as the manual request. Using the API, thousands of queries can be performed in a short period of time.



```
{
   "destination_addresses" : [ "Cl. 24, Villavicencio, Meta, Colombia" ],
   "origin_addresses" : [ "Cl. 7 #29-31, Villavicencio, Meta, Colombia" ],
   "rows" : [
      {
         "elements" : [
            {
               "distance" : {
                  "text" : "12.7 km",
                  "value" : 12743
               },
               "duration" : {
                  "text" : "24 mins",
                  "value" : 1443
               },
               "status" : "OK"
            }
         ]
      }
   ],
   "status" : "OK"
}
```

Figure 3. Example of a request of travel times between two locations to Google Maps Distance Matrix API (Source: Authors)

The requests were made for the PANs under study as follows:

1. Education: A total of 32,600 requests were made, corresponding to the travel times and distances from each population cluster to the 163 educational institutions. These queries were conducted on a business day during the peak hours of the city, from 7:00 am to 8:00 am, to capture the city's rush hours.
2. Health: A total of 2,600 requests were made, corresponding to travel times and distances from each population cluster to the 13 healthcare facilities identified in the city. The queries were made during the peak hours of a business day in the city.
3. Security: First, 2,600 requests were made to determine travel times and distances from the 13 police force facilities to each population cluster. Next, 200 requests were made to determine travel times and distances from the fire station to the population clusters.
4. Recreation: For the analysis of this PAN, a total of 36,000 requests were made to determine the distance and travel time from each cluster to the 316 recreational facilities in the city. The above requests result in 5 distance and time matrices, each of size 200 (total clusters) by the number of facilities in each category or PAN. It is important to note that for the Security PAN, two matrices were generated because it includes analyses for both the police and firefighters. Finally, the nearest facility was determined for each population cluster, and with this information, the isochrone maps and population coverage ogives were created, which are presented in the following subsection.

Territorial accessibility analysis

To perform the territorial accessibility analysis, isochrone maps were constructed for each PAN. Figure 4 present the isochrone maps for the Education PAN, Health PAN, Security (Police) PAN, Security (Firefighters) PAN, and Recreation PAN, respectively. Additionally, in the territorial accessibility analysis, the cumulative percentage of population ogive was calculated for the PANs under study, which is depicted in Figure 5. Subsequently, an analysis of the individual results for each PAN and an integrated analysis are conducted. The objective of this analysis is to establish priorities for investments in the services under study. It is worth noting that, to calculate the isochrone map for recreation, the calculation matrix is in meters. In other words, for each population cluster, the distance to the nearest park in meters is requested to the API Google Maps Distance Matrix. Assuming an average walking speed of 4 km/h, the travel times between the households and the recreational nodes were obtained. The analysis of isochrone curve maps and cumulative percentage population ogive for each PAN category is presented below.

Education: From Figure 4 A), corresponding to the isochrone map for public education (official schools), it can be concluded that the city's infrastructure for schools is sufficient. The results indicate that 84.74% of the population is within a 5-minute drive of an official school. Regarding the cumulative percentage population ogive shown in Figure 5, it performed the best among the studied PANs. This curve exhibits significant growth in the first interval (0-5 minutes), while in the second interval (5-10 minutes), it covers over 98% of the population. If the city decides to invest in new public education facilities, it should review issues related to installed capacity, as territorial accessibility for the population is sufficient.

Health: Figure 4 B), corresponds to the health isochrone map. This figure confirms the preliminary analysis conducted earlier, which concluded that the PANs are centralized in the old urban area of the city, corresponding to communes 2, 3, and 6. Although 84.56% of the population is within the first two intervals (0-10 minutes), approximately 101,000 inhabitants need more than 10 minutes to reach a health center. This can have life-threatening consequences in the case of vital emergencies for that population. Additionally, from Figure 4 B), it can be concluded that health coverage in districts 5 and 7 is deficient.

Security: This PAN category analyzed both police security and firefighters. It is noteworthy that in these cases, travel times were calculated from the infrastructure facilities to the vertices representing the population's locations. This is because, unlike the PANs for education and health, in almost all cases, the police and firefighters are directed towards the population. Figure 4 C) presents the isochrone map for the police. According to this figure and the cumulative coverage ogive in Figure 5, it is observed that over 90% of the population is within 10 minutes, and in comparison, to the other categories, this represents good performance. Conversely, the results for firefighters are not as positive.

Figure 4 D) presents the isochrone map for fire services. From this map, communes 4, 5, 7, 8, 9, and 10 have areas where the isochrone curves extend beyond 10 minutes. This is confirmed by the population coverage ogive graph. This ogive performs the worst among those studied. Approximately 40% of the population is in the rightmost intervals, i.e., those over 15 minutes. There is even a small percentage of the studied population that is over 30 minutes away. These times can be very high in the case of fires and require action from the firefighters.

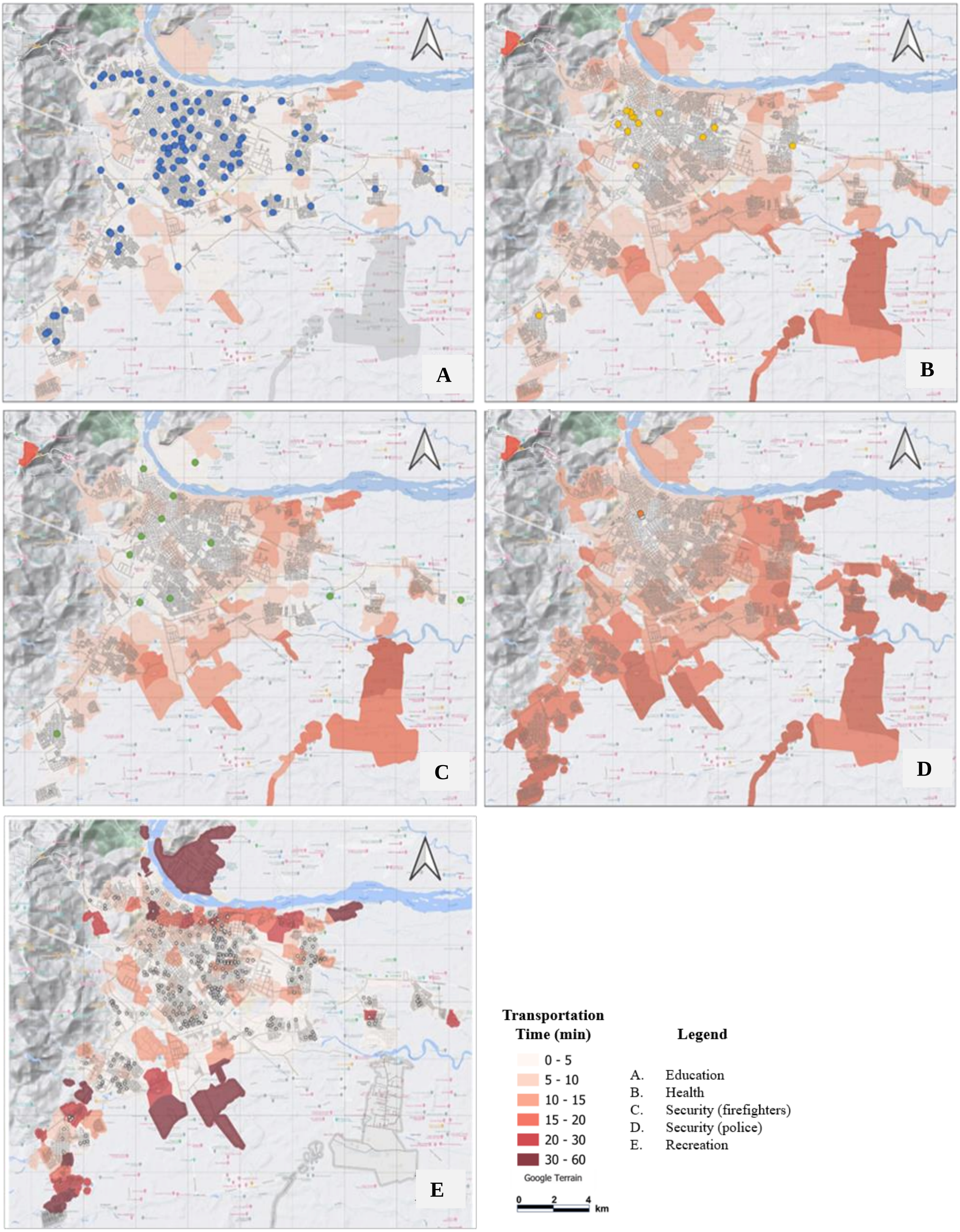


Figure 4. Isochrone maps for the PANs under study (Source: Authors)

Recreation: The last PAN category addressed in this study is recreation. Figure 4 E) presents the isochrone map for recreation. From this Figure 4 E) and the cumulative percentage population ogive of Figure 5, it can be concluded that the city has good recreational facilities. Approximately 80% of the population is within a 10-minute walk of a park, and approximately 90% are within 15 minutes or less.

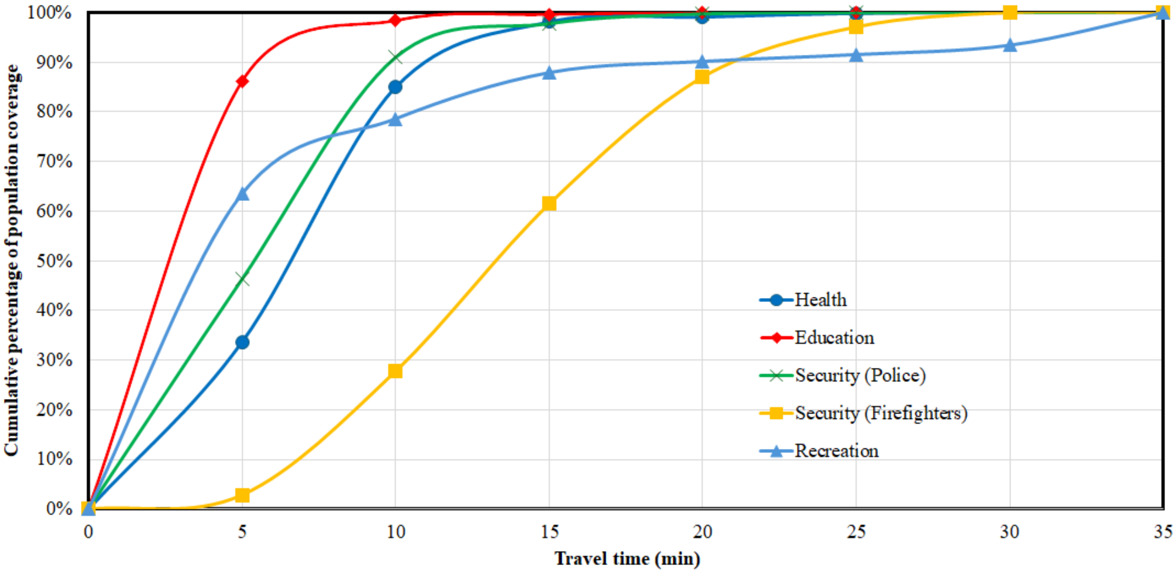


Figure 5. Cumulative percentage of population coverage for the PANs under study (Source: Authors)

CONCLUSIONS

From the analysis carried out, it is possible to conclude that the assessment of accessibility towards the PAN allows us to characterize the condition and coverage of the population with respect to the location of the facilities, thus allowing us to identify areas with access difficulties in search of possible solutions. It is possible to affirm that the current distribution of equipment in Villavicencio guarantees excellent access coverage to the population except for Health and Fire equipment, which due to their priority status should have significantly less time. Finally, it is possible to affirm that the proposed methodology allows for a concise approach to accessibility assessments, thus allowing users from other cities to make use of the methodology and replicate it for the benefit of the population.

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Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

Alcaldía de Villavicencio. (2023). [Villavicencio Major]. https://villavicencio.gov.co/

Departamento Administrativo Nacional de Estadística – DANE. (2018). Censo Nacional de Población y Vivienda 2018 Colombia [National Census of Population and Housing 2018 Colombia]. https://sitios.dane.gov.co/cnpv

Departamento Administrativo Nacional de Estadística – DANE. (2023). Estadísticas por tema [Statistics by Topic]. Retrieved from https://www.dane.gov.co/index.php/estadisticas-por-tema

Escobar, D.A., Montoya, J.A., & Galindo, J.A. (2018). Coverage evaluation for recreational and cultural facilities through accessibility in Pitalito, Colombia. *Contemporary Engineering Sciences*, *11*(84), 4147–4158. https://doi.org/10.12988/ces.2018.87334

Escobar, D.A., Montoya, J.A., & Moncada, C.A. (2018). Analysis of coverage for armed force land use in Pitalito (Colombia), through territorial accessibility. *Contemporary Engineering Sciences*, *11*(65), 3233–3244. https://doi.org/10.12988/ces.2018.87326

Escobar, D.A., Urazán, C.F., & Moncada, C.A. (2017). Análisis de Cobertura Urbana de los Nodos de Actividad Primaria Mediante un Estudio de Accesibilidad Territorial en Quibdó (Colombia) [Analysis of Urban Coverage of Primary Activity Nodes Through a Territorial Accessibility Study in Quibdó (Colombia)]. Información Tecnológica, 28(5), 177–190. https://doi.org/10.4067/S0718-07642017000500018

Espejo-Díaz, J.A., Alfonso-Lizarazo, E., & Montoya-Torres, J.R. (2023). Improving access to emergency medical services using advanced air mobility vehicles. *Flexible Services and Manufacturing Journal*. https://doi.org/10.1007/s10696-023-09507-9

García-Albertos, P., Picornell, M., Salas-Olmedo, M.H., & Gutiérrez, J. (2019). Exploring the potential of mobile phone records and online route planners for dynamic accessibility analysis. *Transportation Research Part A: Policy and Practice*, *125*, 294–307. https://doi.org/10.1016/j.tra.2018.02.008

Geurs, K.T., & Van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, *12*(2), 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Gibbons, S., & Vignoles, A. (2012). Geography, choice and participation in higher education in England. *Regional Science and Urban Economics*, *42*(1–2), 98–113. https://doi.org/10.1016/j.regsciurbeco.2011.07.004

Gómez, J.N., Loures, L., Castanho, R., Cabezas, J., & Panagopoulos, T. (2018). Assessing the feasibility of GIS multimethod approach to ascertain territorial accessibility to hemodynamics rooms in Spain mainland. *Habitat International*, *71*, 22–28. https://doi.org/10.1016/j.habitatint.2017.11.001

Google Maps Platform. (2023). Distance Matrix API. https://developers.google.com/maps/documentation/distance-matrix

IGAC. (2023). Consulta Catastral [Cadastral Inquiry]. https://geoportal.igac.gov.co/contenido/consulta-catastral

Manning, C., Raghavan, P., & Schütze, H. (2009). *Introduction to Information Retrieval*. Cambridge University Press.

Mao, L., & Nekorchuk, D. (2013). Measuring spatial accessibility to healthcare for populations with multiple transportation modes. *Health & Place*, *24*, 115–122. https://doi.org/10.1016/j.healthplace.2013.08.008

Martínez, M., Rojas, C., Condeço-Melhorado, A., & Carrasco, J.A. (2021). Accessibility Indicators for the Geographical Assessment of Transport Planning in a Latin American Metropolitan Area. *Geographies*, *1*(2), 124–142. https://doi.org/10.3390/geographies1020008

Mejía, G., Aránguiz, R., Espejo-Díaz, J.A., Granados-Rivera, D., & Mejía-Argueta, C. (2022). Can street markets be a sustainable strategy to mitigate food insecurity in emerging countries? Insights from a competitive facility location model. *Socio-Economic Planning Sciences*, 101456. https://doi.org/10.1016/j.seps.2022.101456

Montoya, J.A., Escobar, D.A., & Younes, C. (2018). Coverage of educational centers from territorial accessibility in the municipality of Pitalito - Huila, Colombia. *Contemporary Engineering Sciences*, *11*(61), 3021–3033. https://doi.org/10.12988/ces.2018.87310

Ortúzar, J. de D., & Willumsen, L.G. (2011). *Modelling Transport*. Wiley. https://doi.org/10.1002/9781119993308

Quijada-Alarcón, J., Rodríguez-Rodríguez, R., González-Cancelas, N., & Bethancourt-Lasso, G. (2023). Spatial Analysis of Territorial Connectivity and Accessibility in the Province of Coclé in Panama. *Sustainability*, *15*(15), 11500. https://doi.org/10.3390/su151511500

Shen, G., Wang, Z., Zhou, L., Liu, Y., & Yan, X. (2020). Home-Based Locational Accessibility to Essential Urban Services: The Case of Wake County, North Carolina, USA. *Sustainability*, *12*(21), 9142. https://doi.org/10.3390/su12219142

Tahmasbi, B., Mansourianfar, M.H., Haghshenas, H., & Kim, I. (2019). Multimodal accessibility-based equity assessment of urban public facilities distribution. *Sustainable Cities and Society*, *49*, 101633. https://doi.org/10.1016/j.scs.2019.101633

Wan, N., Zou, B., & Sternberg, T. (2012). A three-step floating catchment area method for analyzing spatial access to health services. *International Journal of Geographical Information Science*, *26*(6), 1073–1089. https://doi.org/10.1080/13658816.2011.624987

Wang, Y., Deng, Y., Ren, F., Zhu, R., Wang, P., Du, T., & Du, Q. (2020). Analysing the spatial configuration of urban bus networks based on the geospatial network analysis method. *Cities*, *96*, 102406. https://doi.org/10.1016/j.cities.2019.102406

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