SOCIAL SCIENCES

TERRITORIAL ACCESSIBILITY AND PEACE PROMOTION: AN APPROACH THROUGH THE DEVELOPMENT OF THE ROAD INFRASTRUCTURE NETWORK.

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Abstract

The main objective of this research is to explore the connection between geographical accessibility and the presence of armed conflict in the department of Caldas. To conduct this analysis, a combination of layers and databases provided by Colombian government entities was used, along with the functionality of Google's DistanceMatrixApi, which allowed for the validation and adjustment of the road infrastructure network in the study area. Through the analysis of these data, it was possible to identify that rural areas, which have historically suffered the impacts of armed conflict, exhibit lower levels of accessibility compared to urban areas. This finding suggests that the presence and persistence of conflict have contributed to the limitation of efficient road connections in the department, which may have significant implications for socio-economic development and the quality of life of the local population.

Keywords: geographical accessibility, armed conflict, distancematrix api, peace.

INTRODUCTION

The armed conflict in Colombia has caused significant impacts on the population and the country's development, especially in remote rural areas, where state abandonment led guerrilla groups to settle during the more than six decades of the longest-lasting armed conflict in modern history worldwide [1]. With the signing of the peace treaty between the FARC-EP, the largest and most powerful guerrilla group, and the national government in 2016, a transition to the post-conflict era and peacebuilding is expected to begin. This transition entails increased investment and attention to the country's rural areas with the aim of closing the development gap exacerbated by the presence of armed conflict in these territories [2; 3].

A Brief History of the Armed Conflict and its Impact on the Territory

The impact of the armed conflict on territories varied in intensity over the years, driven by different political and economic motivations. The founding of guerrilla groups (FARC, ELN, EPL) occurred in the 1960s, following a period known as " The Violence," where the two traditional political parties (Liberals and Conservatives) engaged in a "civil war" that resulted in numerous casualties, mainly in the Andean region, and ended with the formation of the National Front (1958-1974), a 16-year period during which both parties alternated power every 4 years, sidelining alternative political participation (Grupo de Memoria Histórica, 2013). The exclusion of political participation and state abandonment of rural areas led to the formation of guerrilla groups in the 1960s, settled in remote rural areas and funded by local inhabitants, enjoying some acceptance in their early decades. Despite this, their territorial expansion was almost non-existent, which changed with the intrusion of the drug trade in the 1980s, leading to the expansion of coca cultivation and the emergence of paramilitary groups. Coca cultivation brought about changes in the social and economic dynamics of the armed conflict and the inhabitants of the remote rural areas where it was grown [4; 5]. By 1998, the armed conflict was located in specific areas of Colombian territory, a situation that changed drastically by 2002 when its geographical expansion was notable, driven mainly by the failed peace process of the government of Andrés Pastrana (1998-2002) with the guerrillas and the offensive of the paramilitaries seeking its failure [1; 6]. Then, with the implementation of Álvaro Uribe's democratic security policy (2002-2010), the armed conflict reached a peak of incidence in the national territory accompanied by the actions of the public force and the response of the guerrillas. The last stage of the armed conflict is framed by the peace talks between the FARC-EP and the national government (Juan Manuel Santos 2010-2018), a period where a few focal points of high conflict incidence still remained and culminated with the signing of the peace treaty in 2016 [3]. The end of the armed conflict paves the way for the beginning of the post-conflict period, where peace is expected to be consolidated and the signed agreements implemented.

Caldas and Post-Conflict

Caldas is a department located in the central-western region of Colombia (see Figure 1), with a population of 998,255 people and 27 municipalities. Its capital, Manizales, along with Villamaría, forms a conurbated area where 46.19% of the department's inhabitants reside [7]. The impact of the armed conflict in Caldas was accompanied by the replacement of traditional crops with coca cultivation in the early 1990s in the eastern area (Samaná, Norcasia, and Pensilvania), pressured by illegal armed groups from the Antioquia region [4; 5; 6]. At the beginning of the new millennium, the presence of paramilitary groups in the area increased, initiating a confrontation between guerrillas, paramilitaries, and the army that left indelible marks among the inhabitants of this region of the department through multiple selective killings, massacres, kidnappings, and takeovers of populated centers [1]. The armed conflict in Colombia has been measured through various indices. In 2014, the Center for the Analysis of Conflicts Resources (CERAC) categorized the municipalities of Colombia according to the presence and intensity of the armed conflict in the last 8 years, defining Samaná and Pensilvania as "strongly affected and interrupted" [8].

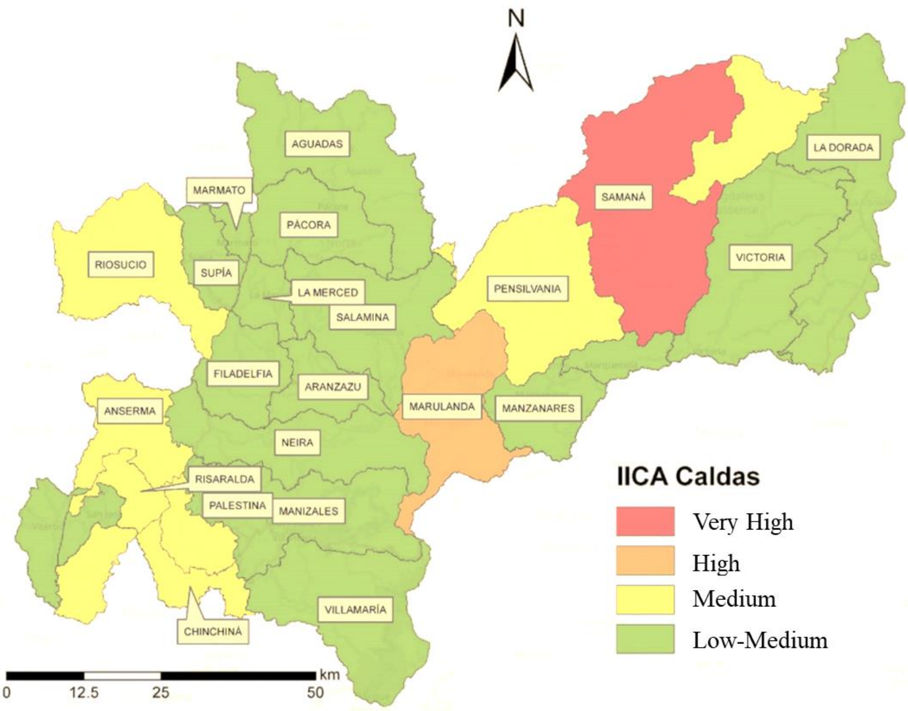

Figure 1 Caldas and IICA municiplaity. Source. Self made

Similarly, the National Planning Department (DNP) in 2016 defined the Armed Conflict Incidence Index (IICA) (from Low to Very High) per municipality based on data from six variables (Armed actions, homicides, kidnappings, landmines, coca crops, and forced displacement). According to this, Caldas as a department has a Medium-Low IICA; however, at the municipal level, Samaná and Marulanda register Very High and High IICA categories (see Figure 1) [9]. Finally, Salazar [6] analyzed georeferenced data from 1986 to 2015, defining Caldas as a region of recent high impact (2002-2012) due to the armed conflict. Despite the recent high incidence recorded in municipalities such as Samaná, Pensilvania, and Marulanda, no area of Caldas was prioritized in the Territorial Development Program with a Territorial Approach (PDET), which seeks the transformation of 170 municipalities in their historically rural areas affected by armed conflict, presence of illicit crops, poverty, and state abandonment in the framework of post-conflict [10]. For this reason, it is of utmost importance to define strategies with a territorial approach to prioritize government investment that will help close the gap in the rural areas of the department of Caldas most affected by armed conflict and state abandonment, thus consolidating peace in their territories. In this research, the geographical accessibility of the department of Caldas will be calculated through travel times defined in an origin-destination matrix fed with operational speeds extracted from the Google DistanceMatrix API [11].

Subsequently, a geostatistical model will be applied to construct isochrone coverage curves and relate them to the population of each municipality to calculate weighted geographical accessibility according to urban and rural areas. This will be compared with the IICA of each municipality with the aim of seeking correlation between the variables [12]. Accessibility is a transportation model that measures the opportunities for interaction that individuals (work, education, health, recreation) have in a region through transportation supply (road infrastructure, transportation modes) [13]. Since its mathematical definition in 1959, researchers and city planners have developed various measures [14], among which are the gravity model [13; 15], the cumulative opportunities model [16], and geographical accessibility [12] as the most common due to their ease of interpretation.

Likewise, as computational capabilities grew alongside the use of Geographic Information Systems (GIS), more variables have been included in the measures, providing more perspectives on accessibility, such as the socio-economic income of inhabitants, laying the groundwork for equity analysis in access [17; 18] or transportation systems [19]. In this research, the differentiation between rural and urban areas will be taken into account as a variable in the analysis of geographical accessibility in Caldas, a study area where similar analyses have been conducted before without considering the aforementioned variables [20].

METODOLOGY

The research methodology employed is described below.

Data Collection

The first stage involved gathering input data for the research, entirely supported by primary information. Firstly, the geopolitical and administrative division of the department was downloaded using the National Geostatistical Framework (MDN) from the National Administrative Department of Statistics (DANE), which allows the download of georeferenced polygon layers of each municipality categorized by class (urban and rural) and detailed according to the census área. Secondly, the georeferenced departmental road network was obtained from the open data portal of the Cartography and Geography sub-directorate of the Agustín Codazzi Geographic Institute (IGAC) [21]. Thirdly, the Municipal Armed Conflict Incidence Index (IICA) was downloaded from the National Planning Department (DNP) in CSV format [9]. Finally, data from the 2018 National Population and Housing Census (CNPV2018) from DANE were downloaded in CSV format from the microdata area of the same entity [7].

Fine-tuning of Geographic Information Layers

During this stage, the necessary layers for calculating geographic accessibility were organized: the road infrastructure network and the political-administrative division of the department according to the census area.

For the fine-tuning of the road infrastructure network, two basic considerations were taken into account. The first is related to graph theory, which indicates that for transportation models, roads correspond to edges and intersections to nodes. Additionally, for geographic accessibility calculations and geostatistical models, it is necessary to maximize data in the spatial territory in order to increase its correlation and predictive accuracy. Therefore, the edges of the road infrastructure network were divided into segments of up to 300 meters using the Geopandas and Shapely libraries in Python 3.7. On the other hand, operating speeds were introduced into the network based on routes between cities calculated using the DistanceMatrix API from Google. This API was requested using geographic coordinates of two known points, providing distance and travel time, from which speeds were calculated and introduced as variables in the corresponding edges.

Additionally, fine-tuning of the political-administrative division of the department according to the census area was carried out by relating their unique codes to those of the CNPV2018, taking into account the rural and urban population and distributing them according to the polygon area. For this purpose, the Geopandas and Pandas libraries in Python 3.7 were used.

Geographic Accessibility

For the calculation of geographic accessibility (A) (equation 1), the travel impedance (Cij) is computed between all nodes of the road infrastructure network as origin (i) and destination (j) using the shortest path according to Dijkstra's algorithm [22], the road infrastructure network, and Transcad 8.0 software, following a validation process [14]

$$A = \frac{\sum_{i=1}^{J}\sum_{j=1}^{J} c_{ij}}{J-1} \quad (1)$$

After calculating geographic accessibility as the average travel time from each node of the road network to all others, isochrone curves were constructed using the ordinary Kriging geostatistical method with linear semivariogram as the structural equation. This method predicts travel times based on spatial correlation and distance between values, in this case, travel time. This model has proven to be the optimal interpolator, given its good results in various transportation-related studies [12; 23].

Calibration and Validation

The calibration and validation process were conducted by comparing the minimum travel times between the population centers of the 27 municipalities in the department using the Google DistanceMatrixApi with the results provided by the shortest path algorithm of Transcad 8.0, using the road network adjusted in the second stage [11] In cases where the model results were lower than reality, penalties for turns were used as a calibration variable [24]. Finally, a linear regression was employed between the data as a validation method, aiming for a regression coefficient greater than 95% and a Pearson correlation close to 1.

Weighted Geographic Accessibility and Coverage Curves

In this stage, the accessibility isochrones were related to the political-administrative division of the department in its census area, calculating the coverage curves for total population and according to the category: urban and rural. Additionally, the weighted geographic accessibility was calculated per municipality ($\overline{A_m}$) based on the category of its territory (urban and rural) using equation (2) where C corresponds to the average travel time of the accessibility isochrone n and p represents the population within it [25]

$$\overline{A_m} = \frac{p_1 * \overline{C_1} + p_2 * \overline{C_2} + \cdots + p_n * \overline{C_n}}{p_1 + p_2 + \cdots + p_n} \quad (2)$$

RESULTS

Road Infrastructure and Census Division in the Department of Caldas

We begin by presenting the results of the adjustment of the road network and the polygon corresponding to the census area of Caldas, as shown in Figure 2. The departmental road network consists of 16,222 nodes, 16,274 arcs, and spans a length of 2,263 kilometers of roads. The most common speed range, between 20 and 30 km/h, accounts for 43.31% of the total length.

Additionally, the distribution of the census area is presented, where 74.35% of the population resides in urban areas, primarily in the conurbation between the capital Manizales and Villamaría.

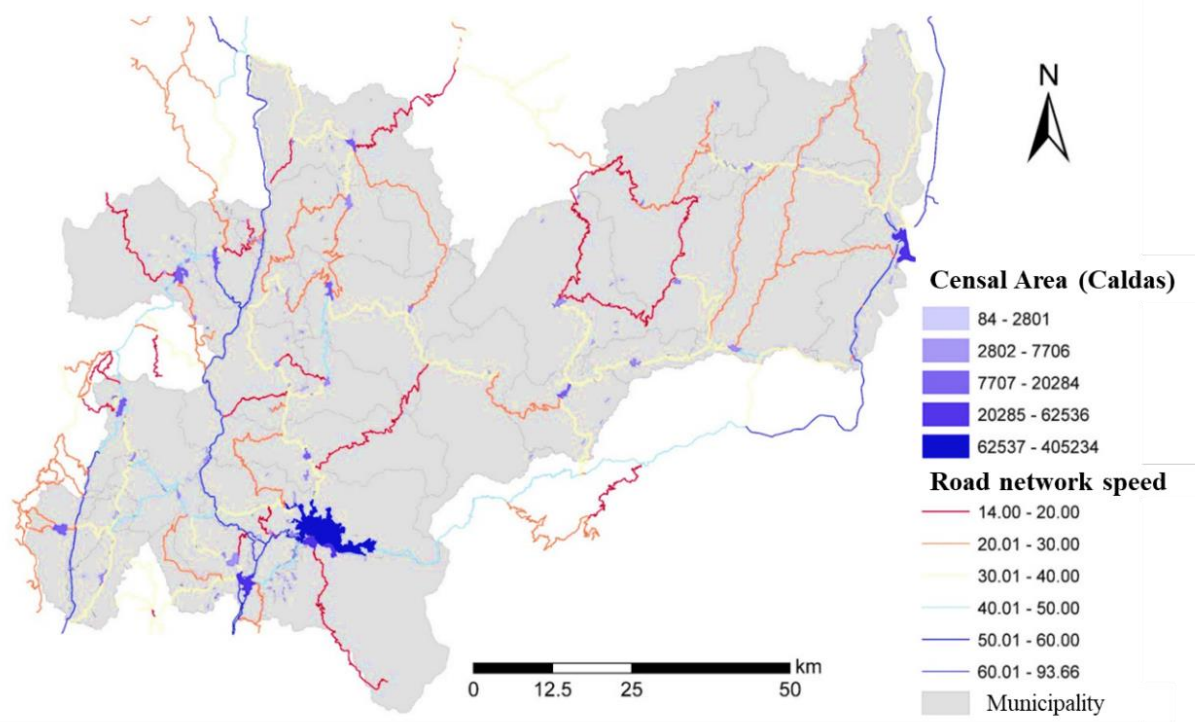

Figure 2 Censal Area and road network. Source. Self made

On the other hand, Figure 3 displays the validation of the geographical accessibility model for the Caldas department, comparing travel times between population centers calculated using the shortest path tool of Transcad 8.0 and the travel times obtained through the DistanceMatrix API from Google. In total, 749 routes covering the population centers of the 27 municipalities in the department were validated, considered both as origins and destinations of the trips. During the calibration and modeling process, turn penalties of 0.75 minutes to the left and 0.5 minutes to the right were established. Additionally, presents some indicators of model validation, including a Pearson coefficient close to 1 (0.9902), a regression coefficient of 97%, and a p-value less than 0.001, indicating that the road infrastructure network accurately represents the mobility of the department.

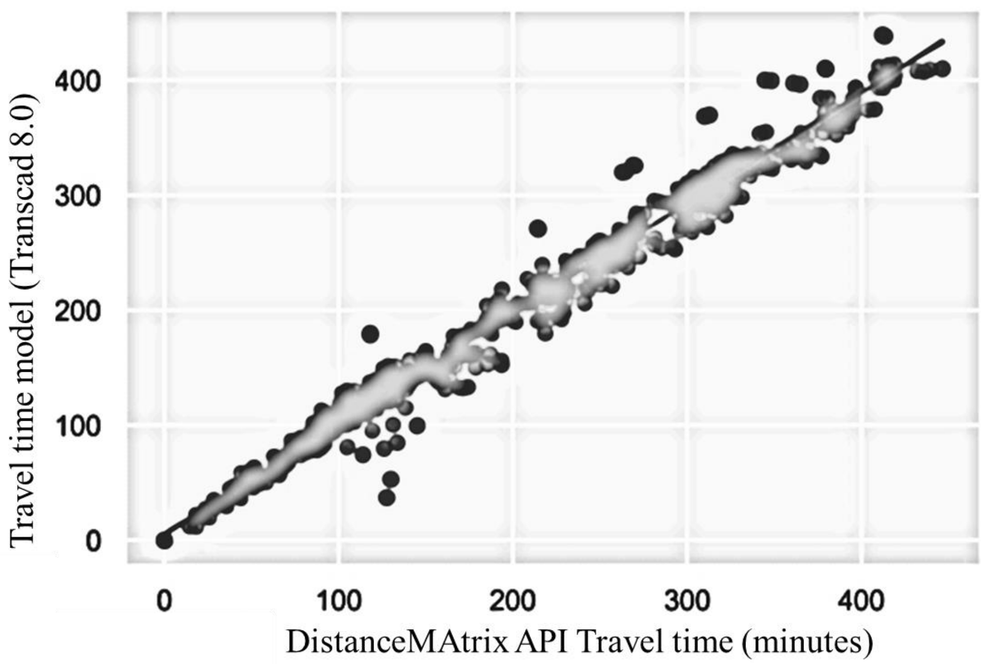

Figure 3 Travel time validation. Source. Self made

Geographic Accessibility

Figure 4 illustrates the geographic accessibility in the department of Caldas, with a minimum average travel time of 167 minutes in the area of Manizales, the capital, and a maximum of 343 minutes in areas to the northeast of the department, where municipalities like Norcasia and Samaná are located. The blue circles highlight areas in the department with better geographic accessibility, linked to the roads connecting the capital (Manizales) with the country's two main cities, Medellín to the north and Bogotá to the east.

Consequently, municipalities along these routes benefit from good geographic accessibility, thanks to the development of necessary infrastructure to connect the capital with key economic centers nationally [20]. On the other hand, the red circle marks areas with longer average travel times. These areas have been significantly affected by the armed conflict (Samaná, Pensilvania, and Norcasia), especially in the northern parts of Samaná and Norcasia, historically where coca cultivation has been concentrated [4; 5]

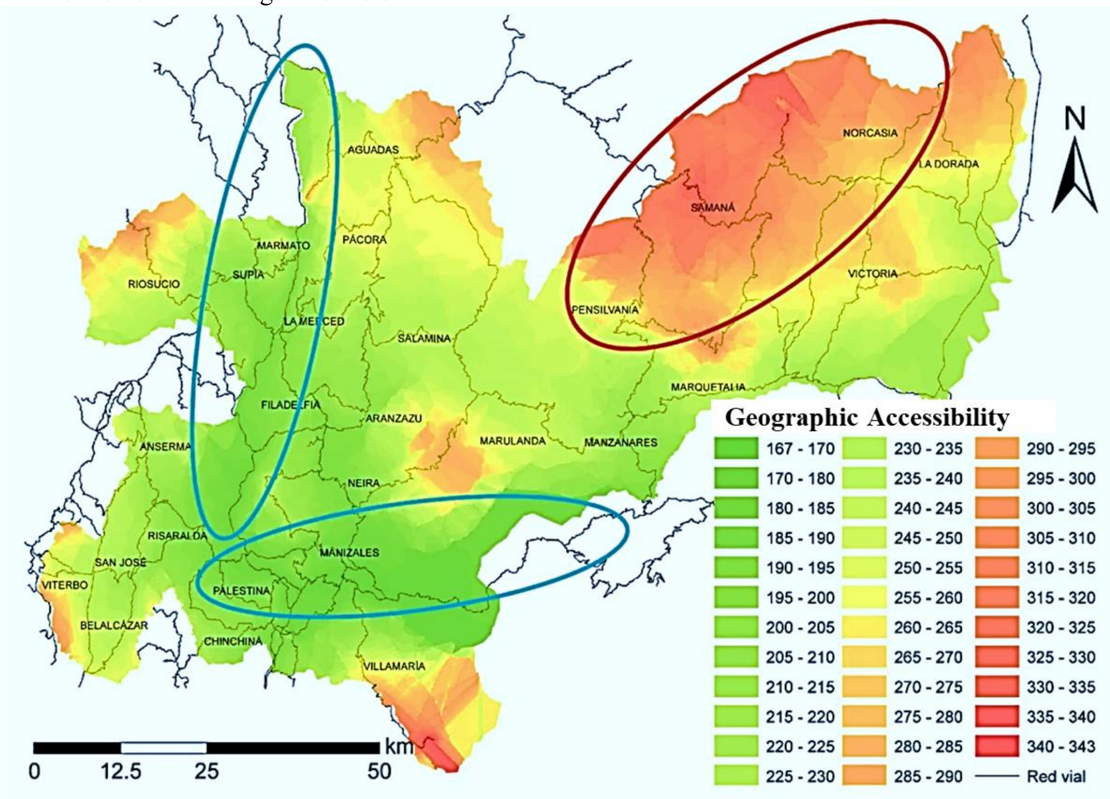

Figure 4. Geographical Accessibility. Source. Self made

In Figure 5, the cumulative curve of population percentage based on travel time is depicted, where 80% of the population of the department is covered in average travel times of 235 minutes or less. On the other hand, Figure 6 displays the cumulative curve of population percentage according to its classification, urban or rural. A marked disparity between the urban and rural areas is observed, as 80% of the population in the urban zone experiences average travel times of 230 minutes or less, while in the rural zone, the average travel time is 250 minutes. The access gap between rural and urban areas must be addressed by authorities, aiming to meet the basic needs of remote areas [26], especially to prevent a potential resurgence of armed conflict in these areas.

Therefore, population coverage through the road infrastructure network is crucial for increasing interaction opportunities in rural areas, addressing fundamental issues such as agricultural trade, healthcare, and higher education [27; 28].

The results of geographical accessibility weighted by municipality, classified according to urban and rural areas, are detailed in Table 1. It can be observed that Manizales presents the best indicator, with 178.30 minutes for the urban area and 183.06 minutes for the rural area. Conversely, Norcasia shows the worst indicator of weighted geographical accessibility in the urban area, with 281.29 minutes, while Samaná has the worst indicator in the rural area, with 309.40 minutes.

Furthermore, displays the IICA values for each municipality, which were assessed alongside urban and rural geographic accessibility, revealing a direct relationship (see Table 2).

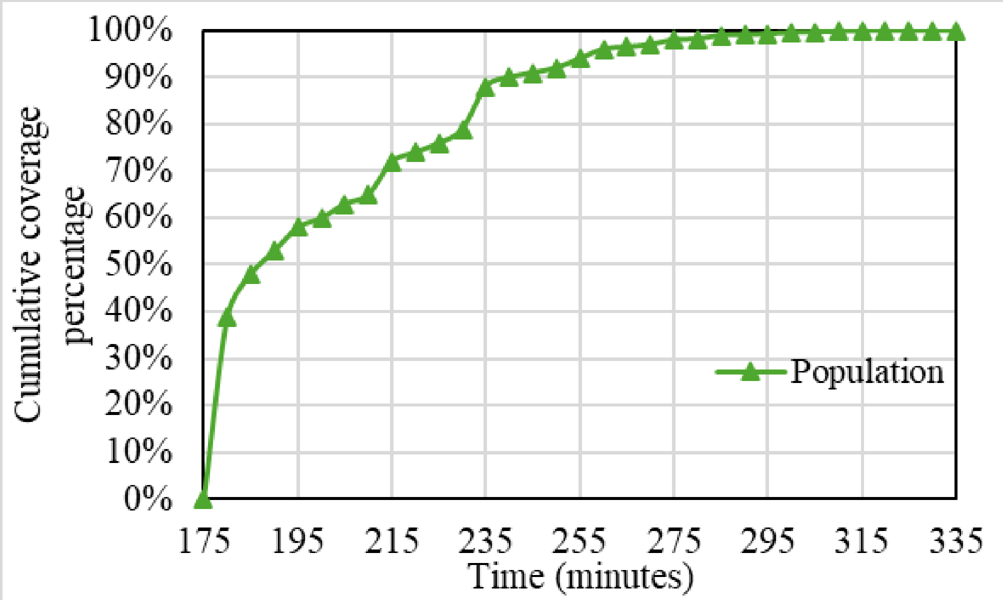

Figure 5 cumulative curve of population percentage. Source. Self made

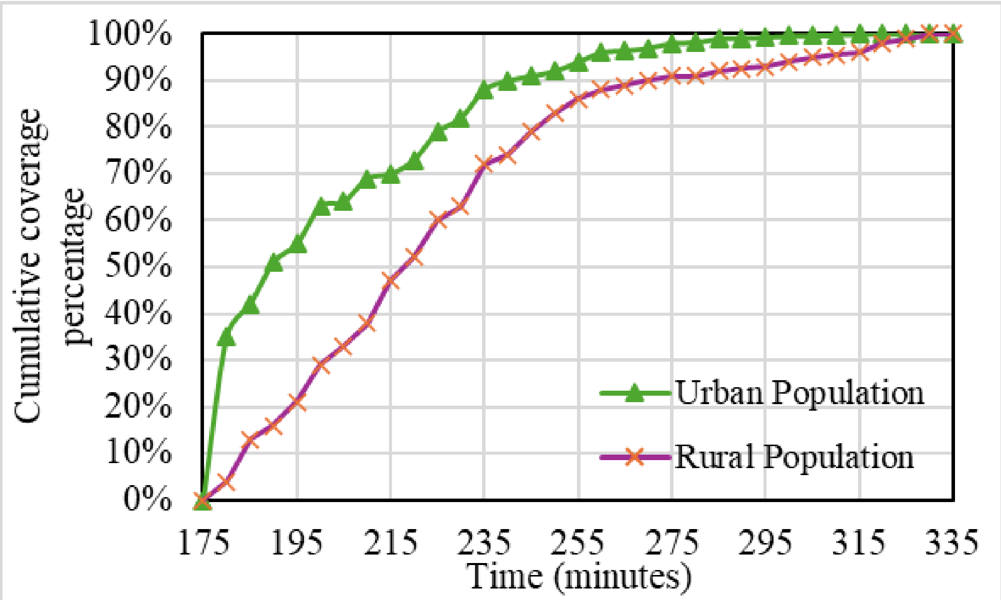

Figure 6 Cumulative curve of population percentage according to its classification, urban or rural. Source. Self made

Municipality	IICA		Urban Accessibility	Rural Accessibility
Aguadas	0.01715	Low-Medium	253.25	252.47
Anserma	0.02233	Medium	226.81	227.35
Aranzazu	0.01073	Low-Medium	205.24	202.24
Belalcazar	0.01952	Medium	232.64	235.1
Chinchiná	0.02349	Medium	189.38	204.62
Filadelfia	0.01505	Low-Medium	202.5	205.98
La Dorada	0.01043	Low-Medium	232.55	251.14
La Merced	0.0117	Low-Medium	218.87	205.02
Manizales	0.00899	Low-Medium	178.3	183.06
Manzanares	0.01343	Low-Medium	212.5	211.93
Marmato	0.01199	Low-Medium	220	217.87
Marquetalia	0.01411	Low-Medium	235.69	242.5
Marulanda	0.05527	Hihg	242.5	182.5
Neira	0.0128	Low-Medium	192.37	188.72
Norcasia	0.02976	Medium	281.29	284.93
Pácora	0.0123	Low-Medium	252.71	250.66
Palestina	0.01951	Medium	197.15	194.07
Pensilvania	0.02522	Medium	250.93	279.53
Riosucio	0.02093	Medium	215.84	217.16
Risaralda	0.0199	Medium	212.52	202.66
Salamina	0.01494	Low-Medium	222.98	231.76
Samaná	0.08276	Very High	262.5	309.4
San José	0.01199	Low-Medium	222.43	237.23
Supía	0.01548	Low-Medium	202.55	206.03
Victoria	0.01226	Low-Medium	222.26	253.71
Villamaría	0.0065	Low-Medium	179.42	196.52
Viterbo	0.01887	Low-Medium	239.05	NaN

Table 1. Weighted geographic accessibility by municipality, urban and rural áreas. Source. Self made

	IICA	
	Pearson Correlation	p-value
Urban	0.5006	0.0091883
Rural	0.4178	0.0336726

Table 2 Relationship Accessibility vs IICA. Source. Self made

CONCLUSIONS

An important conclusion is that geographic accessibility plays a fundamental role in preventing and resolving armed conflicts. The lack of adequate road infrastructure in remote areas can contribute to the isolation of communities and hinder access to basic services and economic opportunities, which in turn can fuel tensions and conflicts. Improving geographic accessibility not only facilitates the socioeconomic development of a region but can also promote social integration and reduce disparities that are often a breeding ground for armed conflict.

Weighted geographic accessibility emerges as a crucial indicator of interaction opportunities in a region and the quality of its road infrastructure network. This indicator can be combined with others to assess road infrastructure projects and their impact on the region.

Considering the relationship between weighted geographic accessibility and the Index of Armed Conflict Incidence (IICA), the research highlights areas in the department where road infrastructure needs improvement to increase interaction potential among its inhabitants and prevent the resurgence of armed conflict. The need for special attention to the northern zone of Samaná and Norcasia in terms of road infrastructure investment to enhance connectivity with the rest of the department is evident. Additionally, the clear disparity between geographic accessibility indicators for residents of rural and urban areas underscores the widening inequality gaps.

Regarding armed conflict and the post-conflict stage in Colombia, Caldas should be included in the Prioritized Municipalities for Territorial Development (PDET), as areas like Samaná and Pensilvania have been significantly affected, according to various indices calculated by governmental and private institutions. This would enable them to create a Comprehensive Development Plan to prevent the return of conflict to the region.

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